2007

Mouse device and method of support on muscular activity

Nahida Lebbos
San Jose State University

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MOUSE DEVICE AND METHOD OF SUPPORT ON MUSCULAR ACTIVITY

A Thesis

Presented to

The Faculty of the Program of Human Factors and Ergonomics

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Nahida Lebbos

August 2007

UMI Number: 1448867

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APPROVED FOR THE PROGRAM OF HUMAN FACTORS AND ERGONOMICS

Dr. Emily H. Wughalter, Ed.D., Committee Chair
Professor, Department of Kinesiology

Dr. Barbra Conry, Ph.D., Committee Member
Interim Dean, College of Applied Sciences and Arts

Dr. James Kao, Ph.D., Committee Member
Assistant Professor, Department of Kinesiology

APPROVED FOR THE UNIVERSITY

ABSTRACT

MOUSE DEVICE AND METHOD OF SUPPORT ON MUSCULAR ACTIVITY

by Nahida Lebbos

The aim of this study was to examine how the mouse device (3M mouse operated with a neutral handgrip vs. Kensington mouse operated with a pronated grip) and method of support (forearm support vs. no-forearm support) affect the muscular activity in the forearm, shoulder, and neck regions during computer mouse use. Thirty-six participants edited a text table in ten counterbalanced trials; five with each mouse device and method of support. Muscular activity was studied with electromyography in nine muscles of the upper extremity. Thumb force was also measured using a pinch grip dynamometer and participants rated the perceived comfort when using the different mouse device and method of support. Analysis of the EMG integrated values revealed less muscular activity in the forearm, shoulder, and neck regions with forearm support and greater muscular activity (with the exception of the anterior deltoid and extensor carpi radialis muscles) with 3M mouse use.

ACKNOWLEDGMENTS

I would like to express my appreciation to several individuals who made this thesis possible. These are people who provided guidance and support to complete this work. I would like to thank my thesis advisor, Dr. Emily Wughalter, for her continuous support and guidance throughout this process.

I am grateful to the following people for their generosity in letting me use their labs' resources at San Jose State University to conduct my experiment: Dr. Barbra Conry of the Stress Management Laboratory, Department of Kinesiology, Dr. James Kao of the Biomechanics Laboratory, Department of Kinesiology, Dr. Kevin Corker of the Human Automation Integration Laboratory (HAIL), Engineering Department, and the HAIL manager Sam Starr. Without their collective help, this work would never have been completed. My sincere thanks to: Dr. Barbra Conry, for arrangements to purchase the 10-channel biofeedback encoder (Flex Comp Infinity T7555M, Thought Technology, Ltd., Montreal, Quebec, Canada) and for allowing me to utilize the device for data collection during this study. Also, I thank Dr. James Kao, for his invaluable guidance and support in analyzing the Electromyography (EMG) data and providing the software to smooth the raw EMG data.

I am especially indebted to my friend Ray Oyung, for his continuous support, guidance, and encouragement. He was a pillar of strength during the long, hard road of overcoming obstacles while planning, running, and writing this thesis. His contribution was invaluable in customizing the workstation and editing every word in this thesis.

Finally, I would like to thank Vajira Nissanka, for creating the HTML prototype to carry the test protocol of editing the text table in the experiment, Laura Colletti for her statistical expertise and contribution to data analysis, and the personnel at 3M Corporate Customer Contact Center for providing two 3M computer mouse devices for the experiment.

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CHAPTER 1

Introduction

Worldwide, increased attention has been focused on work-related musculoskeletal disorders (Colombini & Occhipinti 2006; Punnett & Wegman, 2004). These disorders are a major cause of time lost from work and long-term disability (Bloemsaat, Ruijgrok & van Galen, 2004; Graves, Way, Riley, Lawton & Morris, 2004; Punnett & Wegman, 2004). Recently, in the United States, Europe, and other countries of the industrialized world, upper extremity work-related disorders became highly prevalent as the most common form of occupational illnesses (Colombini & Occhipinti 2006; Punnett & Wegman, 2004). These disorders, also referred to as repetitive stress injuries of the upper extremity, are defined as repeated activity-related musculoskeletal ailments of the upper extremity affecting muscles, tendons, ligaments, joints, peripheral nerves, and blood vessels, which result in pain, fatigue, stiffness, numbness, tingling, warm or cold feeling, and eventually impairing performance of daily work activities (van Galen, Liesker & Hann, 2007; Punnett & Wegman, 2004).

Epidemiologic Overview

In the United States, work-related upper extremity disorders accounted for approximately 66% of all work-related disorders in 1998, compared to 64% in 1996, and only 18% in 1982 (Bloemsaat et al., 2004; Mani & Gerr, 2000; Marcus, Gerr, Monteilh, Ortiz, Gentry, Cohen et al., 2002; U.S. Department of Labor, 1999). Tanaka, Petersen, and Cameron (2001) estimated that 40% of all diagnosed upper extremity musculoskeletal illnesses in the United States working population were determined to be

work-related, representing 500, 000 people or more affected yearly. This figure is consistent with the National Research Council and the Institute of Medicine estimation of upper extremity disorders associated with occupational risk factors (Punnett & Wegman, 2004). Worker's compensation claim costs for these disorders have increased dramatically over the past 20 years (Commission on Health and Safety and Worker's Compensation, 2000). In England, an estimated 4.2 million working days were lost in 1995 due to upper extremity work-related disorders (Graves et al., 2004).

In the United States, Northern Europe (Nordic region), and Japan, several surveys of working adults classified musculoskeletal disorders as the largest category of all occupational diseases, accounting for more than a third of all work-related illnesses and reported a prevalence of upper extremity musculoskeletal symptoms of 20 to 30 % or higher. These disorders resulted in more disability and time lost from work than any other groups of occupational diseases in the United States, Finland, Sweden, and England (Punnett & Wegman, 2004).

More recently, Colombini and Occhipinti (2006) stated that upper extremity work-related disorders represent the most common form of work-related illness in Europe and other countries of the industrialized world. They reported that in Europe, upper extremity disorders accounted for more than 45% of all occupational diseases, and the number of workers suffering some form of impairment or minor disability, as defined by the World Health Organization, secondary to these disorders, is on the rise. Further, it has been suggested that this increase in the rate of work-related upper extremity musculoskeletal disorders is underreported, which then would underestimate the actual

rate of these disorders and consequently the magnitude of the problem (Punnett & Wegman, 2004; Mani & Gerr, 2000).

Ergonomic Risk Factors

In an effort to prevent and reduce the occurrence of work-related upper extremity musculoskeletal disorders, researchers in the area of occupational disease prevention and physical ergonomics have been working worldwide to investigate the relationship between workplace factors and the development of work-related disorders of the upper extremity. However, controversy has developed largely within the United States (Punnett & Wegman, 2004) due to methodological limitations, inconsistent results, and gaps in interpreting the scientific literature which thus has created opportunities for disputing the importance of workplace factors and further research (Gerr et al., 1996; Punnett & Wegman, 2004; Stock, 1991). Regardless of this enduring controversy, sufficient evidence exists in the medical and scientific literature to identify ergonomic factors of excessive force, repetition, vibration, sustained awkward posture, extreme joint positions, and insufficient rest time (work/rest ratio) as risk factors for proximal and distal upper extremity disorders (e.g., trapezius myalgia, rotator cuff disorders, tendonitis, tenosynovitis, epicondylitis, bursitis, and carpal tunnel syndrome), (Babski-Reeves & Crumpton-Young, 2002; Bloemsaat et al., 2004; Flodgren, Heidena, Lyskova & Grenshawa, 2007; Gustafsson & Hagberg, 2003; Huang & Feuerstein, 2004; Mani & Gerr, 2000; Punnett & Wegman, 2004; van Galen, Liesker & Haan, 2007; Wells, Mathiassen, Medbo & Winkel, in press; Zennaro, Laubli, Krebs, Klipstein & Krueger, 2003).

In an attempt to prevent work-related upper extremity musculoskeletal disorders, ergonomists have developed, through the application of biomechanical principles and empirical testing, a large body of ergonomic recommendations for the modification of workstations, hand tools, tasks, and work organization (e.g., scheduling rest periods, alternating work tasks). Most recommendations emphasized that work using force-demanding hand tools above shoulder level should be avoided. The weight of hand tools should be kept as low as possible. The work site should provide the flexibility of working in different postures with proper body support and allow for the opportunity to take sufficient breaks (Cook & Burgess-Limerick, 2004; Galen, Liesker & Haan, 2007; Huang & Feuerstein, 2004; de Korte & van Lingen, 2006; Lee, Mcloone & Dennerlein, 2007).

Industrial Risk Factors

Work-related upper extremity musculoskeletal disorders are highly related to particular industries including clerical work, postal service, cleaning, industrial inspection, meat-packing, motor vehicle manufacturing, garment, and shoe manufacturing (Mani & Gerr, 2000; Punnett & Wegman, 2004). Alternatively, more recent concern has increased attention on the occurrence of work-related upper extremity musculoskeletal disorders related to video display terminal (VDT) or computer use (Aaras, Dainoff, Ro & Thoresen, 2001; Aaras & Ro, 1997; Bammer, 1987; Cook & Burgess-Limerick, 2004; Flodgren et al., 2007; Gerr, Marcus, Ensor, Kleinbaum, Cohen, Edwards et al., 2002 ; Gerr, Marcus, & Ortiz, 1996; Lintula et al., 2001; de Korte & van Lingen, 2006; Roman-Liu, Tokarski & Kaminska, 2001; Sillanpaa, Nyberg, Uitti, Takaia,

Kivi, Kilpikari et al., 2003; Wahlstrom, Svensson, Hagberg & Johnson, 2000). Computer use has increased from the 1970's, when visual displays started to appear in the office environment, through the last two decades to become an integral part of everyday office work (Dainoff, 1998). Gerr et al. (2002) examined the extent of computer use in 1997 and found that: (a) approximately 92 million U.S. adults used a computer, (b) 37% of all households had at least one computer, and (c) half of all employees utilized a computer on the job. During the same period, there were about 150 million computers in use worldwide (World Health Organization, 1998). Recent surveys from Japan showed that computers are being used in 93% of businesses and 47% of households (Straker, Pollock, Burgess-Limerick, Skoss & Coleman, in press).

A number of researchers have found that using a computer mouse, in particular, may increase the prevalence of work-related upper extremity musculoskeletal disorders (Armstrong, Martin, Franzblau, Rempel & Johnson, 1995; Cook & Burgess-Limerick, 2004; Dainoff, 1998; Fernstrom & Ericson, 1997; de Korte & van Lingen, 2006; Lintula et al., 2001; Flodgren et al., 2007; Straker et al., in press; Wahlstrom et al., 2000; Wells, Lee & Bao 1997). This may be related to: (a) extreme postures in ulnar deviation and extension of the wrist and external rotation of the shoulder associated with mouse use (Aaras & Ro, 1997; Dainoff, 1998; de Korte & van Lingen, 2006; Lee, Mcloone & Dennerlein 2007; van Galen et al., 2007, Wahlstrom et al., 2000); and (b) inadequate support of the upper extremity when operating a computer mouse (Cook & Burgess-Limerick, 2004; Feng, Grooten, Wretenberg, & Arborelius, 1997; Hasegawa &

Kumashiro, 1998; de Korte & van Lingen, 2006; Wells et al., 1997; Wahlstrom et al., 2000).

Depending on the type of work task and software used, computer mouse use constitutes two thirds of computer operation time (Johnson, Hewes, Dropkin, Rempel, 1993, Lee, Mcloone & Dennerlein, 2007). The extreme use of the graphic-user interface requiring the use of input devices such as computer mice will undoubtedly increase musculoskeletal injuries (Lee et al, 2007; Wells et al., 1997). Therefore, it has been proposed that work-related upper extremity musculoskeletal disorders associated with the use of a computer mouse will continue to rise (Flodgren et al., 2007; Sillanpaa et al., 2003). However, the exact pathophysiological mechanism behind upper extremity disorders related to using a computer mouse in general and more specifically forearm and wrist disorders related to mouse usage is still ambiguous (Lee et al., 2007). Thus, analysis of the effect of using a computer mouse on upper extremity muscular activity may shed some light on effective strategies for the prevention of upper extremity musculoskeletal disorders.

Significance of the Study

Practical Importance

The computer mouse is considered to be the standard input device (Perry & Voelcker, 1989) for the graphical user interface. As graphics become the center of many computer applications, the use of the computer mouse for object manipulation will increase (Gustafsson & Hagberg, 2003; Wahlstrom et al., 2000).

Over recent years, researchers have been investigating the relationship between computer mouse use and the prevalence of upper extremity musculoskeletal disorders (Aaras et al., 2001; Cook & Kothiyal, 1998; Lintula et al., 2001; Rukhamet & Nanthavanij, 2000; Sillanpaa et al., 2003; Wahlstrom et al., 2000). Understanding this relationship is essential for two reasons: (a) to reduce the occurrence of musculoskeletal disorders of the upper extremity, and (b) to generate ergonomic guidelines for mouse use. Consequently, the practical importance related to the use of a computer mouse in graphical user interface applications becomes an issue in safety. Therefore, studying the use of mouse devices becomes an ergonomic issue.

Scientific Importance

The high rate of musculoskeletal disorders among computer workers appears to be multifaceted and not completely understood (Aaras & Ro, 1997; Lee et al., 2007). Researchers suggested that musculoskeletal disorders are associated with awkward and extreme postures (Dainoff, 1998; Lintula et al., 2001; Marcus et al., 2002; Roman-Liu et al., 2001). Studies have also supported that different mouse positions on the workstation surface (Cook & Kothiyal, 1998; Harvey & Peper, 1997; Karlqvist et al., 1998; Rukhamet & Nanthavanij, 2000) and work with different methods of forearm support affect muscular activity (Aaras & Ro, 1997; Sillanpaa et al., 2003; Wells et al., 1997).

Despite the common knowledge about specific recommendations for proper postures during computer use (OSHA, 1997), "...associations between posture and musculoskeletal health among computer users are not well characterized" (Marcus et al., 2002, p. 237). Further, despite the knowledge about the high prevalence rate of upper

extremity musculoskeletal disorders associated with computer mouse use (Armstrong, Martin, Franzblau, Rempel & Johnson, 1995; Fogleman & Brogmus, 1995; Franzblau, Flachne, Albers, Blitz, Werner & Armstrong, 1993), the “differences between methods of using the computer mouse have not been well documented...” (Wahlstrom et al., 2000, p. 390). Thus, studying mouse usage is important.

Clinical Importance

Over the past two decades, studies have investigated, to a large extent, the effects of using the computer mouse on forearm and neck muscles to confirm the role of these muscles in increasing the muscle activity in the upper limb and the high prevalence of upper extremity musculoskeletal disorders. Conversely, few studies have tackled the problem of whether the activity of the hands may influence the muscular activity of the shoulder (Roman-Liu et al., 2001).

According to Laursen and Jenson (2000), computer mouse use entails high precision demands. High precision hand activity influences muscular activity in the shoulder muscles (Roman-Liu et al., 2001). In addition, the neuromuscular response of upper extremity musculature changes with handgrip position (Bressel, Bressel, Marquez & Heise, 2001). Thus, muscular activity in the shoulder may differ, for example, if the hand is oriented in a different position on the mouse. An examination of different mouse designs available in the market shows that the overall method of gripping a mouse is similar across manufacturers. Nearly all require a somewhat pronated grip (Gustafsson & Hagberg, 2003; Dainoff, 1998; Aaras & Ro, 1997). Pronation of the forearm is identified as a risk factor for musculoskeletal disorders in the elbow and forearm (Gustafsson &

Hagberg, 2003; Zipp, Haider, Halpern & Rohmert, 1983). This risk factor associated with forearm pronation is related to a sharp increase in activity of the pronator teres and pronator quadratus muscles in angles greater than 60 degrees of pronation (Zipp et al., 1983). Also, the muscular activity required to flex the elbow and maintain the forearm pronated is high because the biceps brachii is an elbow flexor and the major supinator of the forearm. Biarticular muscles require higher exertion to generate force (Aaras & Ro, 1997; Dainoff, 1998). Thus, avoiding forearm pronation may reduce static muscle activity in the elbow and forearm during computer mouse use.

A review of the current computer ergonomics market reveals that overall design is shifting toward allowing a neutral handgrip of the computer mouse. Only a few studies have specifically examined the prevalence of upper extremity musculoskeletal disorders associated with using a computer mouse in a neutral handgrip position (Aaras et al., 2001; Aaras & Ro, 1997; Gustafsson & Hagberg, 2003; Straker, Pollock, Frosh, Aaras & Dainoff, 2000). Of these studies, two (Aaras & Ro, 1997; Gustafsson & Hagberg, 2003) used electromyography (EMG) to assess the muscular activity in the forearm (extensors) and neck (trapezius) muscles.

Aaras and Ro (1997) compared a traditional mouse with an ergonomically designed vertical mouse (Anir mouse, Animax International ASA, Norway). The Anir mouse allows an operator to work in a more neutral forearm position while the traditional mouse design requires a pronated forearm position. Their results indicated decreased muscular activity in the forearm and neck muscles when using the Anir mouse. Forearm flexor muscles were not examined because Aaras and Ro referred to previous research

(Hagg & Milerad, 1996) that found static activity and muscular fatigue is larger in the extensor muscles when compared to the flexors muscles.

Gustafsson and Hagberg (2003) compared a traditional mouse (Microsoft 2.1 A) with a newly designed prototype mouse; they called the neutral mouse, designed to be held in a neutral hand grip position. Their results indicated decreased or unchanged muscular activity in the forearm extensor muscle. Trapezius muscle activity varied. It increased for some of the participants and decreased for others.

In both studies, (Aaras & Ro, 1997; Gustafsson & Hagberg, 2003), shoulder muscles were not examined. Aaras and Ro considered the activity of the trapezius muscle an indicator of postural activity of the neck-shoulder region. However, it has been suggested that EMG of the trapezius muscle may not represent the total muscular activity in the shoulder region (Palmerud & Kadefros, 1995). Therefore, it can be stated that shoulder muscle activity in relation to the use of a computer mouse in a neutral handgrip position is not well documented. Further investigation of this relationship may assist in reducing the risk of upper extremity musculoskeletal disorders associated with computer mouse use.

Alternatively, several studies found that using a traditional computer mouse, when supporting the whole forearm on the desktop in front of the worker, reduced the static muscular activity in the wrist-hand (Cook & Burgess-Limerick, 2004; Wahlstrom et al., 2000), forearm, and neck muscles (Aaras et al., 1998; Aaras & Ro, 1997; Cook & Burgess-Limerick, 2004; Lintula et al., 2001; Sillanpaa et al., 2003) whereas supporting only the wrist during mouse tasks increased muscular activity.

Conversely, Sillanpaa et al. (2003) found that forearm support increased the activity of the shoulder and forearm flexor muscles. Sillanpaa et al. (2003) related this finding to a possible increase of motion in the shoulder joint resulting from: (a) lack of wrist support to stabilize the arm during horizontal movements; and (b) participants attempting to avoid bending the wrist. In Sillanpaa et al. (2003) study participants used a traditional mouse (pronated grip) to complete the task. Thus, it would be of interest to determine whether the same results would occur if a different mouse design was compared. One may suggest that a neutral grip on the mouse may eliminate the need to fix the arm for horizontal movement as well as the need to actively keep the wrist joint in a neutral position.

Taking into account the prospect of reducing the development of chronic shoulder pain by avoiding shoulder muscle over activity (Aaras et al., 2001) and consequently the development of upper extremity musculoskeletal disorders, it is important to study whether using an alternative mouse device plays a role in the reduction of activity in the shoulder muscles and whether this reduction is affected by a specific method of support. The current proposed study could provide a contribution to the current literature and provide rehabilitation clinicians and ergonomists with some useful direction. The findings of this study may help standardize ergonomic guidelines, guide future mouse and workstation designs, and assist in reducing repetitive stress injuries.

Statement of the Purpose

The purpose of the current study was to determine how mouse device and method of support affect muscular activity during computer mouse use. The study compared the

muscular activity in the forearm, neck, and shoulder regions when using two different mouse devices (3M optical mouse operated with a neutral handgrip and Kensington optical mouse operated with a pronated handgrip) with two different methods of support (forearm support and no-forearm support). The Kensington optical mouse device will be referred to as the Standard mouse. The muscular activity was assessed by collecting EMG activity from the upper trapezius, anterior and middle deltoid, infraspinatus, biceps brachii, flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis, and extensor carpi ulnaris muscles.

Hypotheses

Null Hypotheses

1. Mouse device will not affect the muscular activity in the forearm, shoulder, and neck regions.
2. Method of support will not affect the muscular activity in the forearm, shoulder, and neck regions.

Delimitations

In the current study, the activity of interest (neuromuscular responses at different levels of the upper extremity) was limited to computer mousing because several ergonomic studies have related computer mouse use to work-related upper limb disorders. The outcome measures were limited to EMG analysis because many occupational studies have used surface EMG to evaluate muscular activity (Roman-Liu et al., 2001; O'Sullivan & Gallwey, 2002; Sundellin, 1992). Surface EMG was proposed as a suitable estimate of muscular activity because EMG activity increases with the level of

muscle activation (Hagg & Millard, 1996; Sundellin, 1992). Performance, measured as speed and time to complete a task, was delimited to the participants' individual preference as emphasis on speed during this experiment may not reflect real workplace constraints in which workers commonly perform tasks at their own preferred speed. The study was delimited to right-handed healthy adults who operate a computer mouse for at least 2 hours per day. The study protocol was delimited to a text editing task.

Throughout testing, a mouse pad was placed adjacent to right edge of the keyboard. The optical sensor of each mouse device was aligned to the middle point of the mouse pad.

Participants were delimited to maintain the mouse device on the mouse pad surface.

Participants were also delimited to start the task with the right shoulder in a neutral position, the right elbow in 90 degrees of flexion, and the wrist joint straight and aligned with the forearm.

Limitations

Results of this study were relevant to the task chosen (text editing using a computer mouse). This may limit the ability to generalize these results to other tasks as they may differ in the amount of muscular activity. The limitations also included the movement of EMG surface electrodes relative to the muscles due to changes in joint angles during activity. While it would have been more accurate to use indwelling electrodes, the invasive nature of such methods would have made its use prohibitive. Another limitation related to surface EMG electrodes was the possibility of signal cross talk between neighboring electrodes. It's possible that the results have been affected by individual differences among participants in terms of body posture, as people do not have

the same ergonomically correct posture when using a computer mouse. Also, another limitation may have been related to individual differences concerning grip intensity and hand position on a mouse. An additional source of error may have been related to participants exhibiting unfamiliar motion patterns when using a new mouse design in a neutral handgrip. However, training participants with the new mouse before data collection may control for this limitation.

Definitions

For clarification purposes, below is a list of terms that were used in this study:

Average EMG. Mean EMG amplitude recorded from a muscle during a given muscle contraction. The average EMG signal is reported in millivolts (mV).

Cross talk. Cross talk can be defined as an unwanted EMG signal that is detected by a surface electrode placed on a muscle through the activation of another nearby muscle (Bressel et al., 2001).

Forearm support. A forearm support provides full support in front of the operator on the work surface.

Healthy adults. Adults with no history of upper extremity disease or injury.

Integrated EMG. EMG amplitude recorded from a muscle during the entire time interval of this muscle activation. The integrated EMG signal is reported in millivolt-seconds (mV. s).

3M optical mouse. Shaped like a military fighter pilot flight stick controller, the 3M optical mouse is a computer mouse operated with a neutral handgrip. The 3M optical

mouse is distributed in the U.S. by 3M Company, St. Paul, Minnesota. For the purpose of this study the 3M optical mouse represented the neutral handgrip mouse.

Peak EMG. Maximum EMG amplitude recorded from a muscle during a given muscle contraction. The peak EMG signal is reported in millivolts (mV).

Standard mouse. A traditional computer mouse operated with a pronated grip. For the purpose of this study, the Kensington mouse was used to provide the standard mouse grip.

Surface electromyography (EMG). A method of collecting electrical signal activity (EMG signal) generated from a muscle using an instrument, called an electromyograph, and surface electrodes.

CHAPTER 2

Review of Literature

Work-related injuries of the upper extremity are a multifaceted ergonomic problem in modern society. Worldwide, researchers have increased awareness among occupational health professionals of the large burden of musculoskeletal disorders associated with repetitive stress disorders of the neck and upper limbs (Gerr et al., 1996; Graves et al., 2004; Punnett & Wegman, 2004; Stock, 1991). In recent years, studies have been conducted concerning work-related factors pertaining to the development of these disorders (Colombini & Occhipinti, 2006; Graves, et al., 2004; Huang & Feuerstein, 2004; Flodgren et al., 2007; Punnett & Wegman, 2004; Stracker et al., 2007; Wells et al., in press). Many studies have linked the risk of high activity in the shoulder muscles to: (a) work with the hands at or above shoulder level (Chaffin, 1973); (b) static muscle activity and added activity in the hand (Hagberg, 1981;); and (c) work with computers (Cook & Burgess-Limerick, 2004; Flodgren et al., 2007; de Korte & van Lingen, 2006; Lee et al., 2007; Marcus et al., 2002; Stracker et al., 2007; van Galen et al., 2007). The goal of this review of literature is to link hand activity with specific forearm rotation to upper extremity work-related disorders. The main idea of this review is that different hand grip positions result in specific neuromuscular responses in the upper extremity. In a sense, then, activity in the hand with specific forearm rotation may increase the muscular activity in the shoulder and forearm regions (van Galen et al., 2007). Increased muscular activity leads to muscle fatigue, inflammation, and pain which weaken the muscles and increase the prevalence of repetitive stress injuries (e.g.,

shoulder impingement syndrome). Inflamed muscles could also induce an increase in extraneural pressures, altering the blood flow to the peripheral nerves and consequently causing nerve dysfunction (e.g., carpal tunnel syndrome).

This review is organized in three sections. In the first section, upper extremity musculoskeletal disorders and their prevalence in relation to work with computers are discussed. In the second section the notion of upper extremity support and its ergonomic ramification in computer use is presented. Finally, in the third section the effect of handgrip position on upper extremity neuromuscular responses to work activity is discussed to shed light on the ergonomic importance of handgrip position in computer mouse use.

Upper Extremity Musculoskeletal Disorders

Overview

Upper extremity musculoskeletal disorders are painful illnesses involving tendons, tendon sheaths, muscle, nerves, bursa, and blood vessels of the upper extremity (Gerr et al., 1996; Flodgren et al., 2007; Punnett & Wegman, 2004). Upper extremity musculoskeletal disorders may be related to advances in technology (Hagberg, 1981; Hagberg, & Sundelin, 1986; Bammer, 1987; National Occupational Health and Safety commission, 1988; Straker et al., in press; Stock, 1991), which has assisted in minimizing work activity by creating less demand in heavy lifting occupations and more demand in occupations that entail rapid light work. The etiology of upper extremity musculoskeletal disorders is not completely known. Sillanpaa et al. (2003) stated that the biomechanical over activity resulting from increased muscular activity may have a significant role in the

development of upper extremity musculoskeletal disorders. Zennaro et al. (2003) explained that prolonged activities requiring low level muscle activation such in computer work increases the metabolic over activity in low threshold motor units causing muscle fiber injuries and increasing the prevalence of work-related upper extremity disorders. Johanssen et al. (2003) explained that impaired proprioception is a key risk factor for the development of musculoskeletal disorders. The author proposed that repeated activity and static muscle activity cause build-up of inflammatory substance in the muscle fiber, affecting muscle spindle physiological and motor control. Muscle spindle are responsible for movement and position awareness of the extremities (proprioception), when the muscle spindle afferent motor activity is altered secondary to inflammation, the proprioception accuracy decreases resulting in increased muscles co-activation leading to muscle over activity and pain if sustained for a long period of time. Aaras et al. (2001) explained that over activity in a single muscle fiber for a long period of time would result in pain due to muscle fiber damage. Light repetitive work over activity small muscle groups. Muscular over activity leads to muscle fatigue with ischemia and metabolic changes that impair small muscle enzyme functions and makes them prone to microscopic tears and inflammatory changes that causes muscle pain and dysfunction (Larsson, Bengtsson, Bodegard, Henriksson, & Larsson, 1988; Flodgren et al., 2007; Stock, 1991). Inflamed muscle tendons can compress neighboring peripheral nerves causing nerve dysfunction (Chaffin, 1973; Silverstein, Fine & Armstrong, 1986; Stock, 1991). Clinicians and ergonomists have identified upper extremity musculoskeletal disorders when they are associated with tasks requiring long lasting light

repetitive movements and awkward body postures as repetitive strain injuries, repetitive stress injuries, cumulative trauma disorders, cervicobrachial disorders, and/or overuse syndrome (Silverstein et al., 1986; Stock, 1991; van Galen et al., 2007).

Upper Extremity Musculoskeletal Disorders and Computer Use

Over the past decade, researchers have advised that working with computers increases the prevalence of upper extremity musculoskeletal disorders (Bloemsaat et al., 2004; Cook & Burgess-Limerick, 2004; Flodgren et al., 2007; de Korte & van Lingen, 2006; Laursen & Jensen, 2000; Lee et al., 2007; Marcus et al., 2002; Stracker et al., in press; van Galen et al., 2007; Zennaro et al, 2003). Consequently, a number of laboratory-based studies as well as epidemiological field studies have been conducted to determine the relationship between computer work and upper extremity musculoskeletal disorders.

Lassen et al. (2005) examined the association between computer work and disorders of the elbow and wrist/hand. The goal of the study was to determine if computer use constitutes an occupational hazard for developing upper extremity musculoskeletal disorder in general and more specifically to forearm and wrist/hand disorders. Six thousand nine hundred forty-three professional engineering technical assistants, performing various computer tasks, were examined. Participants completed a questionnaire at study baseline and one year after completing baseline as a follow-up. Using the questionnaire, participants reported: (a) pain in the neck and the right and left shoulder, elbow, forearm, and wrist/hand; (b) average hours per week working with a computer mouse and a keyboard during the past 4 weeks before completion of the

questionnaire; (c) psychosocial workplace factors such as job content, job demands, job control, and social support at work (this section was developed based on the Copenhagen Psychosocial Questionnaire developed by the Danish National Institute of Occupational Health); (d) demographic information about age, gender, height, and weight ; and (e) history of musculoskeletal conditions such as rheumatoid arthritis, neuritis, paralysis, cerebrovascular, accident sequelae, and fibromyalgia. Participants suffering from moderate pain in the shoulders, elbow, forearms, and wrist/hands during the week prior to the study were offered a clinical examination at study base line and one year after. Clinical cases were defined based on palpation tenderness in the muscles of the upper extremity. In general, the study findings confirmed a positive relationship between computer work and the prevalence of upper extremity musculoskeletal disorders. In particular, the authors found that excessive use of a computer mouse and to a certain extent keyboard use increased the risk of developing musculoskeletal disorders in the forearm, wrist, and hand regions.

In 2002, Gerr et al. conducted the first prospective study in North America to examine the prevalence of neck-shoulder and hand or arm musculoskeletal disorders associated with computer use. Over a three-year period, 632 newly hired workers were monitored and expected to use computers for 15 hours or more per week. Participants were asked to document the number of hours spent working with the computer, as well as any musculoskeletal symptoms (discomfort, pain, numbness, burning, tingling) they may have experienced throughout the three-year period of the study. These employees were tracked for a maximum of 38 months or until they showed musculoskeletal symptoms.

Participants who reported symptoms at entry level or during follow-up weeks underwent a physical exam to document and confirm changes associated with specific musculoskeletal disorders of the hand-arm and neck-shoulder regions.

At entry level of the study, Gerr et al. (2002) noted that in the week prior to the study, 10% of the 632 participants experienced neck-shoulder symptoms and 4% experienced hand or arm symptoms. After physical examination, 70% of the participants who reported neck-shoulder discomfort were found to have neck-shoulder disorders (mostly somatic pain syndrome), and 64% of the participants who reported hand or arm symptoms showed evidence for hand or arm tendon disorders (mostly DeQuervain's tendonitis). The occurrence of Carpal Tunnel Syndrome was minimal compared to other disorders. At the entry period of the study, three of the participants who reported hand or arm symptoms showed evidence for Carpal Tunnel Syndrome. During follow-up, 3 out of 120 participants who reported hand or arm symptoms showed evidence for Carpal Tunnel Syndrome. In addition, on entry to the study, eight participants reported a previous diagnosis of Carpal Tunnel Syndrome.

Overall, more than 50% of newly hired employees experienced hand or arm and neck-shoulder symptoms within the first year of work. The neck-shoulder symptom's annual prevalence was 58 cases out of 100 person-years. Within the first month of work 46% of the cases occurred. Somatic pain syndrome was the most diagnosed of the neck-shoulder disorders. In addition, the annual prevalence of hand or arm symptoms was 35 cases out of 100 person-years, where 32% of the cases occurred during the first month. DeQuervain's tendonitis was the most diagnosed among the employees who experienced

hand or arm symptoms. Within the first year of work, Carpal Tunnel Syndrome was observed in only 1% of newly hired employees. Gender, age, ethnicity, and past history of neck-shoulder pain also were found to contribute to neck-shoulder disorders. Gender, past history of hand or arm pain, prior computer use, and having children at home were found to contribute to hand-arm disorders. Women were more susceptible to disorders than men. Participants with two or more years of prior computer use exhibited a higher incidence of hand or arm symptoms. On the other hand no interaction was found between neck-shoulder symptoms and past computer use. Neck and shoulder disorders were more frequent than hand or arm symptoms. Thus, Gerr et al. (2002) suggested that the pathophysiology of hand or arm symptoms differ from that of the neck and shoulder regions due to differences in symptom prevalence, the pattern of work over time, and previous computer use.

Risk factors associated with computer use. The etiology of upper extremity occupational musculoskeletal problems is not fully known (Bloemsaat et al., 2004; Sillanpaa et al., 2003). Several studies suggested these problems may be the end result of specific ergonomic factors, individual characteristics, and psychosocial factors all together, and all of these factors should be addressed in order to prevent the occurrence of musculoskeletal disorders (Armstrong (1993; Bloemsaat et al., 2004; Huang & Feuerstein, 2004; Punnett & Wegman, 2004; van Galen et al., 2007). Despite the ambiguity of their etiology, researchers worldwide have cited forceful exertion, repetitive motions, vibration, and awkward postures as risk factors for hand, wrist, and forearm

disorders, and force exertion and posture as risk factors for neck and shoulder disorders (Mani & Gerr, 2000).

Thus, from the commonly identified work-related risk factors associated with computer use, posture was the most emphasized. Ergonomic guidelines recommend modifying these postures to reduce the risk of work-related upper extremity musculoskeletal disorders. Although, many clear guidelines have been established to adopt specific postures in computer use (OSHA, 1997; Punnett & Wegman, 2004), the relationship between specific posture and musculoskeletal well being is not clearly identified.

To better characterize this relationship, Marcus et al. (2002) conducted an epidemiological study with eight different companies in the Atlanta, Georgia area. Newly hired workers who were: (a) expected to work with a computer for more than 15 hours per work week; and (b) free of musculoskeletal symptoms in the week before starting the new job, were accepted into the study. Participants were asked to keep a weekly log of the time spent using the keyboard and performing other hand intensive tasks. They were also asked to report any workstation changes and the incidence of any musculoskeletal symptoms. Researchers examined several working postures to analyze the prevalence of hand/arm and neck/shoulder symptoms and disorders.

Marcus et al. (2002) found that specific seated postures could help minimize the occurrence of musculoskeletal disorders. Working with a keyboard with an inner elbow angle of more than 121 degrees, a more downward head tilt and using the chair armrests decrease the risk of developing neck and shoulder disorders. Alternatively, maintaining

elbow height below the keyboard “j” key and using a telephone shoulder support was found to increase the prevalence of neck-shoulder symptoms and disorders. On the other hand, using the keyboard with the “j” key located at more than 12 cm horizontally from the edge of the table decreased the likelihood of developing hand and arm symptoms and disorders. Also, keying with the “j” key at more than 3.5 cm above the desk surface, keying with a force greater than 48 grams, mousing with a wrist radial deviation of more than 15 degree and using a keyboard wrist rest increases the likelihood of developing hand and arm musculoskeletal symptoms. Finally, the length of time spent keying was found to influence the occurrence of hand and arm symptoms. The authors stated that an increase in weekly keying for about 20 hours, more than doubles the risk of developing hand and arm symptoms and disorders.

Further, van Galen et al. (2007) examined the effect of a newly designed vertical keyboard on muscle activity in the upper extremity. The new design was a mid-way split QWERTY-based keyboard with vertically sloped keyboard halves designed to provide forearm, wrist, and hand support. The new design allowed the user to type with a neutral forearm posture while facilitating full frontal view of the keys. One goal of the study was to determine whether the vertical keyboard reduces the muscle activity in the forearm and shoulder areas compared to a traditional keyboard during a prolonged typing session. Nine professional typist with a touch-type rate of over 300 keystrokes per minute participated in the study. EMG data were collected on the left side of the body from the upper trapezius, biceps, extensor carpi ulnaris, flexor carpi ulnaris, extensor carpi radialis

longus, flexor carpi radialis, extensor digitorum, and flexor digitorum superficial muscles.

Results showed that overall muscle activity was higher with the traditional keyboard compared to the vertical keyboard. More specifically, forearm extensor muscles activity was significantly higher with the traditional keyboard. These findings confirmed that forearm pronation and wrist ulnar deviation, when using a traditional horizontal keyboard, may increase pressure in the carpal tunnel and will overload the muscles in the forearm and hand, leading to repetitive strain injuries in these areas. The authors suggested that occupational preventive measures should focus on adopting alternative input devices that facilitate more neutral postures during computer use.

Juul, Sogaard, Stroyer & Jensen (2004) conducted a prospective study to identify risk factors linking musculoskeletal symptoms in the low back area and upper extremity, and more specifically in the shoulder and elbow areas, to computer use. Five thousand thirty-three office workers completed a questionnaire at study baseline and one year after baseline as follow-up.

Follow-up results showed that 10%, 18%, and 23% of total participants reported musculoskeletal symptoms more often in the elbow, shoulder, and low back areas, respectively, and 14%, 20%, and 22% reported more intense pain in the elbow, shoulder, and low back areas respectively. Women showed a higher prevalence of pain than men in all regions. The work/rest ratio and visual stress caused by glare or reflection were also significant risk factors for the prevalence of shoulder symptoms. The display height below eye level was a significant risk factor for elbow symptoms. The authors suggested

that future computer workstation designs should focus on minimizing glare, facilitating a proper display height set-up and also that work organization should consider work pauses between tasks.

Risk factors associated with non-keyboard input devices. Besides the traditional computer mouse design, the present computer market is filled with non-keyboard input devices (track ball, touch pad, track point, pen-tablet, and touch screen). The use of non-keyboard input devices is on the rise, and consequently, shoulder and arm musculoskeletal disorders are increasing (Frenstrom & Ericsson, 1997; Wahlstrom, 2000). Thus, the need for understanding the muscle strain associated with the use of an input device is essential. Operating a mouse requires excessive ulnar wrist deviation, wrist extension, and shoulder external rotation whereas non-mouse operation is performed with more neutral position and shoulder internal rotation. These extreme postures, associated with operating a mouse, lead to the development of musculoskeletal discomfort (Flodgren, et al., 2007; Karlqvist et al., 1994). Hagberg (1995) suggested that the reason why computer mouse work is associated with high risk of shoulder disorders is probably due to excessive working distance, and the association with forearm and hand disorders is probably due to extreme position of the wrist.

Frenstrom and Ericsson (1997) compared shoulder and forearm muscular activity when using four different input devices during computer work: (a) keyboard; (b) keyboard and a mouse; (c) keyboard, mouse and three dimensional arm support; and (d) keyboard with a track point located in the center of the keyboard and a handwriting task. They found that the handwriting task increased the muscular activity in the forearm. Use

of the track point alleviated the muscular activity in the shoulder muscles in comparison to mouse use without forearm support. Operating the keyboard alone was associated with high activity at the shoulder level, in comparison to the track point, and also increased the activity in the forearm muscles in comparison, to computer mouse use. Further, using a track point and a traditional mouse with movable arm support reduced shoulder muscle activity. Conversely, both the mouse and the track point increased the muscular activity in the hand and forearm muscles.

Sogaard, Sjogaard, Finsen, Olsen & Christensen (2001) suggested that the high prevalence of forearm and hand/wrist musculoskeletal symptoms associated with operating a two-button computer mouse may be related to high muscular activity in the finger extensor muscles. The authors related this high activity in the finger extensor muscles to users lifting or extending their fingers to prevent accidental button clicking and to the excessive wrist extension posture when users move the computer mouse.

Therefore, Lee et al. (2007) observed finger postural behavior, forearm/wrist, and handgrip behavior in 100 graduate students from the Harvard School of Public Health during specific computer mouse activities. A designated researcher, an occupational therapist by training, observed each participant for 5 minutes and recorded information about: (a) gender; (b) hand used during the tasks; (c) fingers used on each mouse button; (d) wrist extension levels; (e) level of wrist/forearm support on the workstation surface; (f) overall mouse grip; (g) finger support when using the mouse; and (h) finger postures across finger support during mouse use.

Results showed 48% of participants lifted their middle finger, 23% extended the middle finger, and 17% lifted and extended the middle finger while moving the mouse. Also, 77% supported their forearm and wrist on the workstation and 21% supported the wrist only during mouse use. Ninety-seven percent of the participants operated the mouse with an extended wrist posture. Lee et al. (2007) concluded that two-button mouse users may be at a high risk of developing musculoskeletal disorders of the forearm, wrist, and hand due to excessive finger and wrist extended postures during intensive mouse operation. Future preventive measures should focus on alternative input device designs to reduce finger lifting behavior and wrist extended posture in order to minimize the risk of developing hand and forearm musculoskeletal symptoms.

Kotani and Horii (2003) compared a traditional mouse and a pen-tablet system in order to evaluate the usability of the pen-tablet system as well as the muscular activity associated with its use over a 5-day protocol. In terms of usability, on the first day, the mouse performance (error rates and number of trials completed) was better than the pen-tablet system performance, but from day two to day five, the performance of the pen-tablet system improved to exceed the traditional mouse performance. To investigate muscular activity, the researchers collected EMG activity from the trapezius, biceps brachii, flexor digitorum superficialis, and the extensor digitorum muscles. In terms of muscular activity, the use of the pen-tablet system was associated with lower activity of the biceps brachii, digitorum superficialis, and extensor digitorum. Activity of the trapezius muscle was not significantly different between both devices. Among the muscles tested, the trapezius muscles showed the highest EMG activity. This high

activity may be related to the notion that the trapezius muscle becomes active to stabilize the arm and hand in a specific position when performing hand intensive tasks (Hasegawa & Kumashiro, 1996; Kotani & Horii, 2003). Thus, the use of a pen-tablet system cannot be considered one of the methods that can help alleviate the stress on shoulder muscles by decreasing the neuromuscular activity in the trapezius muscle (Kotani & Horii, 2003), unlike other methods such as forearm support (Aaras & Ro, 1997; Visser, 2000), input device position on the workstation (Harvey & Peper, 1997; Karlqvist et al., 1998), and proper display height (Villanueva, Jonai, Sotoyama, Hisanaga, Takcuchi & Saito et al., 1997). These methods all help lower the trapezius muscular activity during computer work. However, the pen-tablet system method is effective in alleviating the stress on the hand and finger muscles during computer work.

Laursen and Jensen (2001) conducted a study to compare shoulder muscle activity in young and older people while operating a computer mouse. They concluded that shoulder muscle activity was affected by age as muscular activity of the deltoid, neck extensors, and trapezius muscles was higher with older age. More importantly, they noted that proper forearm support at the working desk significantly lowers the muscular activity in the deltoid and trapezius muscles. Thus, it appears that efficient support of the upper limb is an important technique that is often emphasized when the aim is to promote shoulder musculoskeletal health.

Risk factors associated with mouse position. Karlqvist et al. (1998) stated that mouse position on the workstation may influence the upper extremity posture and muscular activity that an office worker may use to operate a computer mouse effectively.

Thus, mouse position can either facilitate an awkward posture or can induce a proper one while operating a computer mouse. According to Harvey and Pepper (1997), a computer worker typically operates a mouse located either to the right and above a keyboard or to the right next to an extended keyboard. In either position, the operator, unaware of body position, maintains an extended arm, and shoulder lifted upward and abducted for long periods of time. In 1994, Pepper and Tibbetts observed several office workers when performing computer mouse work for an extended period of time. Many of these employees reported symptoms in the shoulder and scapular regions secondary to using the computer mouse. The researchers related this to the layout of the workstation such that the tables and keyboard trays lacked a suitable ergonomic design for mouse placement.

Harvey and Pepper (1997) examined the effect of a trackball position (positioned centrally below the keyboard) and a mouse position (located to the right of the keyboard) on the activity of the neck-shoulder and back muscles (left sternocleidomastoid, right upper trapezius, right posterior deltoid, and right lower trapezius/rhomboids). They also evaluated subjective awareness of muscular discomfort. The researchers noted higher EMG activity from the upper trapezius, posterior deltoid, and lower trapezius/rhomboids muscles when operating a mouse to the right of the keyboard than when operating a centrally positioned trackball. A significant correlation between the results from the 5-point subjective awareness scale and the EMG activity of corresponding muscles was not found.

The authors concluded that this lack of accurate awareness in regards to increased muscle activity could lead to musculoskeletal discomfort and illnesses in various muscles of the upper extremity. Therefore, worker training and education may be essential in preventing occupational illnesses associated with computer work. Using the mouse to the right of a keyboard (or to the left for left-handed workers) significantly increases the muscular activity in the shoulder, neck, and back regions. Conversely, using a centrally positioned trackball decreased the muscular activity in the same regions. Thus, where possible, efforts should be made to position non-keyboard input devices more centrally in respect to the keyboard.

Rurkhamet and Nanthavanij (2000) conducted a field survey to investigate upper extremity discomfort related to the use of a keyboard and mouse and the position of these input devices on the work surface. Three common layout positions were examined including: (a) a bi-level computer desk with the monitor placed on the upper level and the mouse positioned adjacent to the keyboard on the retractable lower level of the desk; (b) an identical bi-level computer desk with the keyboard positioned on the lower level and the mouse positioned adjacent to the monitor on the top level of the desk; and (c) a standard writing desk with the computer monitor, keyboard and mouse positioned on the desk surface to the right or to the left of the workers. The sample included 150 Thai visual display operators classified in three groups (keyboard users, mouse users, and keyboard and mouse users). They completed questionnaires documenting personal information, work tasks, workstation layout descriptions, and upper extremity perceived discomfort levels. Rurkhamet and Nanthavanij (2000) found no significant discomfort

levels among keyboard users in any of the three workstation layouts. Higher levels of upper extremity discomfort were found among mouse users in the second layout position (mouse positioned far from the body requiring shoulder flexion and abduction for operation). High wrist and lower arm discomfort were noted among keyboard and mouse users in the third layout position. Rurkhamet and Nanthavanij (2000) concluded that the observed discomfort in the wrist and lower arm when working on a fixed writing surface is mostly due to mouse use. This discomfort did not result from extending the arm to reach the mouse because participants working on the fixed writing desk typically sit close to the work surface. The wrist and lower arm discomfort most likely resulted from the height of the work surface.

Cook and Kothiyal (1998) evaluated the effect of mouse position on the neck (middle trapezius) and shoulder (anterior and middle deltoid) muscular activity using surface EMG. The study involved 10 healthy keyboard and mouse users performing three, 20 minute mouse editing tasks. For each 20 minutes, the participants operated the mouse in one of three different positions with the center of the mouse pad serving as a reference point for mouse positioning. In the first position (normal position), the mouse was located immediately next to the right edge of a standard keyboard. In the second position (extreme position), the mouse was placed back and to the right of a standard keyboard forcing participants to assume a more flexed and abducted position to operate the mouse. In the last position (modified position), the mouse was positioned immediately next to a keyboard that did not have a numeric pad. Working in the modified position involved lower activity in the anterior and middle deltoid muscles

compared to the normal and extreme positions. There were no significant differences in trapezius muscle activity among the mouse positions. Cook and Kothiyal (1998) also employed the Rapid Upper Limb Assessment to compare working posture in the three different mouse positions. The Rapid Upper Limb Assessment measures upper extremity postures on a scale of 1 (*best*; i.e., neutral joint position) to 4 (*worst*; i.e., shoulder flexion 45° or above, and shoulder abduction). In terms of wrist posture, poor wrist working postures (wrist extension greater than 15°, ulnar deviation or radial deviation) were observed regardless of mouse position. In terms of upper arm postures, 80% of the participants had the best observed upper arm working postures in the modified mouse position, and 20% in the normal mouse position. Worst upper arm working postures (shoulder abduction, wrist extension or ulnar deviation), were associated with the extreme mouse position. Compared to the standard position, upper arm working posture was better in the modified position and worse in the extreme position. Cook and Kothiyal (1998) recommended that when it is possible, attempts should be made to use a keyboard without a numeric keypad. A keyboard shorter in length decreases the distance of the mouse from the body midline and therefore decreases shoulder abduction and flexion during mouse use. With this in mind, it seems appropriate that exploring innovative keyboard and mouse design solutions to improve upper extremity working postures in general and wrist posture in particular during mouse use should be a priority in future research.

Influence of Arm Support on Shoulder Muscle Activity

From the many suggested ergonomic interventions to decrease the risk of developing upper extremity musculoskeletal disorders, many researchers stated that proper arm support could reduce the muscular activity in the neck and shoulder regions, (Aaras, Horgen, Bjorest, Ro & Thoresen, 1998; Cook & Burgerss-Limerick, 2001; Marcus et al., 2002).

Hasegawa and Kumashiro (1998) proposed that in cases where the workstation cannot be adjusted to suit the operator height or lacks space for wrist support, a chair with height adjustable armrests should be used to allow for arm support and decrease the activity in the arm and shoulder muscles.

Moreover, Lintula, Nevala-Puranen & Louhevaara (2001) proposed the use of an ergonomic aid to facilitate bilateral arm support when the workstation does not allow proper support for both arms when working with a computer. The researchers examined the effect of an ergonomic support aid called the Ergorest toward reducing the muscle strain in the upper extremity. The Ergorest is an arm support device designed to decrease the muscular activity in the neck and shoulder regions. Lintula et al. (2001) measured the following variables during mouse and keyboard operation: (a) bilateral EMG activity from the upper trapezius and extensor digitorum muscles; (b) degree of wrist joint angle using goniometry; and (c) perceived muscle strain in the neck shoulder and arm area via visual analog scale. The study tested 21 healthy females. Participants were randomly assigned to work in one of three groups. The first group worked with a unilateral

Ergorest arm support on the mouse side. The second group worked with a bilateral Ergorest arm support. The third group (control) worked with no arm support.

Study findings confirmed the importance of bilateral arm support when operating a video display unit. In comparison with the unilateral arm support group and the control group, bilateral arm support was associated with significant lower activity of the trapezius muscle, less wrist extension by 10 degrees, and decreased subjective rating of muscle discomfort. The activity of the extensor digitorum muscle was not significantly influenced by the use of arm support, which is in line with other study results that evaluated arm support in hand intensive precision tasks (Milerad & Ericsson, 1994). Further, Lintula et al. (2001) stated that one arm support when operating a mouse may not be the best postural choice as it increases discomfort in the arm and shoulder due to the asymmetric body position that an operator takes when supporting that arm. The Ergorest may not only be a good assistive device for old workstations with no available space for bilateral arm support, but may be very useful in other hand intensive tasks such as assembly line, dentistry and laboratory type tasks where keeping the arms at a certain position for a certain period of time is necessary. Finally, Lintula suggested that there is a possibility that the Ergorest may be of some benefit to workers with physical limitations such as rheumatoid arthritis, however further research is needed to confirm its usefulness.

Erderly, Sihvonen, Helin, and Hanninen (1987) discussed the association of shoulder and neck problems with keyboard work. Using a computer does not only concentrate that activity in the small muscle groups of the forearm and hands, but it also increases the neuromuscular activity of the shoulder, neck, and trunk muscles as these

muscles work to maintain the head and the hands in the proper position. This static muscle work may be a factor in developing shoulder disorders. According to Erderly et al. (1987), supporting the arm when keying reduces EMG activity of the trapezius muscle. Also, the shoulder activity can be reduced when keying with an elbow angle of at least 100 degrees.

Feng, Grooten, Wretenberg, and Arborelius (1997) evaluated the effect of different methods of arm support (fixed arm support, horizontal movable arm support, and spring-loaded arm support) as well as no arm support on the activity of the shoulder (deltoid anterior, middle deltoid, and trapezius) and arm (extensor carpi radialis brevis) muscles during multiple work tasks (typing, pipetting, and unscrewing bolts). Results showed that EMG activity of the anterior and middle deltoid, and the trapezius muscles decreased when the arm was supported versus non-supported. There was no significant difference in the activity of the extensor carpi radialis brevis within the support and non-support conditions as well as between the support conditions. The horizontal movable support was the more effective in decreasing the activity in the shoulder muscle compared to the other methods of support.

In addition, Schuldt, Ekholm, Harms-Ringdahi, Nemeth, and Arborelius (1987) evaluated the effect of arm support (mounted horizontal padded plate for elbow support) and an arm suspension aid (elbow sling attached to an arm balancer) on neck (upper part of the trapezius/erector spinae, trapezius/anterior lateral margin, and sternocleidomastoid) and shoulder (middle part of the trapezius/supraspianus and dorsal erector spinae/rhomoids) muscle activity while using a pen to connect multiple dots on a card

placed on an attachment frame in front of the participants. This hand task was performed in three different work sitting postures: (a) total spine flexion with the attachment frame horizontal; (b) straight spine with the frame tilted 35 degrees from horizontal; and (c) straight cervical spine and slight backward tilt of the dorso-lumbar spine with frame angled 75 degrees from horizontal. The findings revealed that reduced activity at the neck-shoulder region was observed with both methods of support (arm suspension and arm support). Further, elbow support was proven to be a better method of support than the arm suspension aid when performing hand intensive tasks in a sitting workstation with the entire spine flexed whereas arm suspension was a better method to use when the work task required sitting with the spine tilted slightly backward.

Cook and Burgess-Limerick (2004) confirmed that forearm and hand support during computer work decreases the muscular activity in the neck and shoulder and minimizes awkward wrist postures during keyboard and mouse activities. However, they stated that despite this proven benefit, many computer users continue to use a “floating” posture when operating a keyboard and a mouse. In a floating posture, a neutral wrist position is maintained without supporting the arms. They also argued that the benefit of supporting the forearm on the work surface during keyboard and mouse use as reported in the literature has only been proven in a laboratory controlled environment. In addition, the fact that computer ergonomic aids and ergonomically designed concave workstations, that allow forearm support, are not as common in the workplace due to high cost, may be a factor why many computer workers still operate a computer with a floating posture of the upper extremity.

Therefore, Cook, and Brugress-Limerick (2004) sought to conduct a field study to determine the effect of adjusting a conventional workstation to allow forearm support during computer work on reducing neck, shoulder, wrist, and hand musculoskeletal complaints. Fifty-nine participants working in a newspaper call center participated in the study. Thirty participants were set-up to work with forearm support and 29 participants acted as a control group. Participants were followed for 12 weeks. At week 1, participants completed a questionnaire and answered questions about the number of computer work hours, work breaks, exercises, and discomfort that had developed based on the Nordic Questionnaire. They reported any history of musculoskeletal symptoms in the back and upper extremity in the past year or within a week prior to the study. Workstation measures before and after the adjustments were recorded. Keyboard and mouse placement on the work surface were also recorded. Wrist rest usage was also documented when applicable. At week 6, participants answered the discomfort questions again and the control group workstations were set-up to allow forearm support during computer activities. Participants were asked to report any increase in musculoskeletal discomfort. At week 12, all participants completed the same discomfort questionnaire and answered more questions about forearm support posture. The authors also used a goniometer to measure shoulder flexion during keyboarding activities.

Results showed that at week 6, the group working with forearm support reported significantly fewer cases of discomfort in the back and neck. At week 12, when comparing the data with the data collected from week 1 at study baseline, even fewer cases of musculoskeletal discomfort in the neck, back, and wrist were reported. The

researchers mainly related the decrease in discomfort to participant's forearm dynamic posture when using the keyboard. Participants in the forearm support condition pivoted their forearm to operate the keyboard instead of stabilizing the wrist and working in an ulnar deviation orientation typically associated with working in a floating posture. These findings were consistent with previous laboratory studies (Cook & Burgess-Limerick, 2001). Cook and Burgess-Limerick (2004) concluded that for most users, supporting the forearm during computer use reduced the risk of developing musculoskeletal disorders in the upper extremity, and forearm support should be facilitated in future workstation design.

Importance of Arm Support during Computer Mouse Use

As graphics become an essential part in many computer applications, the use of non-keyboard input devices (especially the use of computer mice) is increasing. The literature seems to indicate a clear relationship between operating a computer mouse and upper extremity musculoskeletal disorders (Armstrong et al., 1995; Flodgren et al., 2007; Kryger, Andersen, Lassen, Brandt, Overgaard, Thomsen, et al., 2003; Lassen, Mikkelsen, Kryger, Brandt, Overgaard, Thomsen, et al., 2004; Lee et al., 2007). It has been suggested that operating a computer mouse increases the risk of developing occupational musculoskeletal disorders (Fogelman et al., 1994; Hagberg, 1994; Karlqvist, 1994). Among computer workers, upper extremity musculoskeletal disorders are more likely to develop on the side that workers usually use to operate the mouse (52% yearly prevalence of shoulder musculoskeletal symptoms) than on the contralateral side (19% yearly prevalence of shoulder musculoskeletal symptoms) used to perform occasional keyboard

or paperwork tasks (Jensen, Finsen, Hansen & Christensen, 1999). More specifically, there is an increased risk for shoulder disorders on the mouse side due to the increase and continuous activity of the trapezius muscle noted on this side in comparison to the contralateral side (Jensen et al., 1999). This static overload of the trapezius muscle on the side of the mouse may be the result of maintaining the hand distant from the body in order to operate the mouse. This postural strain resulting in a low static activity of the trapezius muscle can overload Type I (slow twitch oxidative; Hamill & Knutzen, 1995) muscle fibers, which results in ischemia and metabolic changes that induce constant pain in the neck-shoulder region (Hagberg, 1995).

Many recommendations have been published regarding what methods to use when operating a computer mouse (Wells et al., 1997). Most of these recommendations have emphasized variation in work tasks, less strenuous posture and proper arm support when operating a computer mouse. In an attempt to set safe guidelines for mouse use, Wells examined several methods of upper extremity support when using a computer mouse: (a) elbow support at the chair armrest; (b) forearm support on the desk surface; (c) wrist support on the desk surface; and (d) no arm support. To test these methods, 20 participants were asked to perform a series of tasks (drawing, text editing, and playing a game for 3 hours). Surface EMG was recorded from the hand-forearm (first dorsal interosseous, fingers/wrist extensors, extensor carpi ulnaris, flexor superficialis, pronator teres, and combined flexor/extensor) and neck-shoulder (trapezius and infraspinatus) regions. Results showed lower EMG amplitude of the trapezius and shoulder muscles

when the elbow and forearm were supported. Thus, elbow and forearm support may be an appropriate and safe technique to use when operating a computer mouse.

Additionally, it was suggested that differences in muscular activity when using a computer mouse is not only associated with different methods of support but also with gender. Wahlstrom, Svensson, Hagberg, and Johnson (2000) examined the effect of three different methods of upper limb support and the effect of gender on the level of performance and muscular activity when operating a computer mouse. EMG activity was recorded from the right first dorsal interossei, right extensor digitorum, and right and left trapezius muscles. Wrist joint movements were recorded using an electrical goniometer. To measure the force exerted on the mouse, participants used a force-sensing mouse. Subjective ratings were also recorded to evaluate muscular activity. This study tested 15 men and 15 women. Participants performed a text editing tasks (highlighting and deleting) using the mouse in association with hitting the delete key on the keyboard in three different methods of support: (a) wrist-based method with forearm supported on the table surface and mouse operated from the wrist; (b) arm-based method with wrist supported on the table surface and mouse operated from the shoulder; and (c) an individually preferred method. The findings revealed significant differences in regard to gender. Women worked with a greater range of motion. They operated the mouse with the wrist more extended, with more ulnar deviation and with higher wrist velocity than men. Women showed higher EMG activity in the extensor digitorum and the first interossei muscles. They exerted greater forces (as a percentage of maximum voluntary contraction) when operating the mouse. Wahlstrom et al. (2000) associated these

findings with women having less muscular strength than men as well as with gender anthropometric differences, which affect biomechanical loads. In terms of support method, higher trapezius activity was noted when the wrist was only supported in comparison to the other two methods, and also greater wrist extension and subjective ratings of shoulder neck discomfort was associated with supporting the wrist only.

Alternatively, when the forearm was supported, higher forces were exerted at each side of the mouse, and higher ratings of perceived exertion in the wrist and hand-finger regions was noted in comparison to the other two methods. Wahlstrom, Svensson, Hagberg and Johnson (2002) stated that because there was a correlation between the subjective rating and the measured muscular activity, subjective ratings could be beneficial in assessing muscular activity. Finally, the authors suggested future research to replicate their study with a different type of mouse in order to determine whether similar results would be obtained.

Furthermore, Sillanpaa et al. (2003) compared the effect of supporting the forearm versus supporting the wrist on upper extremity muscular activity during computer mouse use. This study tested 14 women (35 to 50 years) that operated a computer for at least 4 hours per day and a computer mouse for at least 2 hours per day. The workstation was adjusted properly to each participant's height (feet comfortably on the floor and back well supported). The workstation consisted of an adjustable cutaway section that was opened or covered to allow forearm support or wrist support without a forward flexed posture. For the forearm support condition: (a) the cutaway section was opened toward the participant to allow full forearm rest; (b) the desk height was arranged

to be 1 cm above the participants elbow level; and (c) the mouse pad was positioned next to the keyboard at the rear end of the desk. For the wrist support condition: (a) the cutaway in the desk was covered and the height of the desk was set so the participant's wrist was 1 cm above elbow level; (b) the keyboard was repositioned on the desk front with the mouse pad next to it in a way that the participant's hand did not touch the desk; (c) the mouse pad was used but attached to a 20 mm thick wrist support; and (d) the monitor and the chair were pushed backwards about 20 cm to allow for the same erect and comfortable upper body posture and arm as in the forearm support condition.

Participants were asked to edit a text table. They performed 10 short trials (64 movements per trial, 75 seconds per trial, and 5 trials per support condition). Participants received training sessions three weeks prior to the test and 5 minutes before the test to get familiar with the trial tasks. After completing the trials, participants were asked to assess the activity and the usability of each method of support. Surface EMG was collected from the extensor carpi radialis, extensor carpi ulnaris, flexor carpi radialis, and flexor carpi ulnaris muscles at the forearm level, and anterior and middle deltoid, Infraspinatus, and descendent trapezius muscles at the shoulder-neck level. To analyze the difference in muscular activity between the two methods of support, Sillanpaa et al. (2003) used the 10th, 50th, and 90th percentiles of EMG amplitude. These percentages represent the static, medium, and peak muscular activity respectively (Jonsson, 1982), and according to Sillanpaa et al. (2003) this method called the amplitude probability distribution function became one of the most used measures in occupational studies to evaluate the difference in muscular activity after it was introduced by Jonsson in 1982. Further, researchers

collected video recordings of each trial after placing markers on the hand, wrist, and forearm to analyze wrist ulnar and radial deviations. EMG activity was normalized to each participant's average individual EMG amplitude mean and to the maximum EMG amplitude. Data were analyzed using a repeated measures analysis of variance.

EMG results showed increased activity of the forearm muscles for the 10th, 50th, and 90th percentiles in forearm support versus wrist support with the exception of the extensor carpi radialis, and the 10th percentile of the flexor carpi radialis. Conversely, the activity of the measured neck-shoulder muscles was less for the three different percentiles when the forearm was supported versus when the wrist was supported, with the exception of the infraspinatus muscle activity. Video motion analysis results showed greater wrist ulnar deviation (5.7 degrees) when the forearm was supported versus when the wrist was supported (2.9 degrees). Sillanpaa et al. (2003) stated that this finding clarifies the lower muscle activity in the forearm muscle (flexor carpi ulnaris and extensor carpi ulnaris) on the ulnar side when the wrist was supported versus when the forearm was supported. On the radial side, there was increased activity of the forearm muscle (extensor carpi radialis and flexor carpi radialis) when the wrist was supported in comparison to when the forearm was supported. Finally, a number of participants reported that supporting the forearm helped them perform the task easier, and work was lighter with forearm support than with wrist support.

Influence of Handgrip Position on Shoulder Muscle Activity

Bressel et al. (2001) investigated if handgrip position during an arm cranking exercise influenced the neuromuscular activity of muscles biceps brachii, lateral head of

triceps brachii, middle deltoid, infraspinatus, and brachioradialis . The motivation to conduct the study arose from the integration of two factors. First, little experimental research has been published on upper extremity neuromuscular responses for this activity. Second, knowledge of such information may benefit rehabilitation practitioners in general and more specifically rehabilitation clinicians who work with quadriplegic populations.

In this study 15 participants performed 360 degree rotations of an arm crank ergometer using three different handgrip positions (supinated, pronated, and neutral). EMG data were recorded from the muscles previously mentioned and relative duration of EMG activation and amplitude were quantified for the first and second 180 degrees of crank angle. The data showed significant findings that the infraspinatus muscle exhibited 36% less amplitude in the supinated grip versus the neutral handgrip position (second half-cycle), and the brachioradialis muscle displayed 63% greater amplitude across cycles in the neutral versus supinated and pronated handgrip positions.

Bressel et al. (2001) stated that the greater amplitude of the infraspinatus muscle in the neutral versus supinated grip may be related to the degree of shoulder abduction between handgrip positions. Participants who exhibited the least amount of shoulder EMG activity (infraspinatus muscle activity) during arm cranking exercises performed the task with the hand supinated and the shoulder adducted. The authors proposed that this observation of the infraspinatus muscle displaying less activity during the supinated grip position may be clinically relevant if it allows arm cranking to occur without subsequent shoulder pain, which is often the aim of shoulder rehabilitation. In other

words, during the early stages of shoulder rehabilitation, painful exercise of the involved tissues is contraindicated and the decreased activity of the infraspinatus muscle when the forearm is supinated may be helpful if it allows arm rotation to occur without subsequent shoulder pain.

Further, Bressel et al. (2001) related the greater brachioradialis activity observed in the neutral position to its anatomical advantage as an elbow flexor when the forearm is in a neutral position. They proposed that this observation could be relevant in the rehabilitation of a quadriplegic population. In other words, with the quadriplegic population having limited motor recruitment of selected upper extremity muscle groups, an outcome of increased motor activity of available muscles, such as from the elbow flexors, is desired if it improves motor performance. Because the brachioradialis muscle, an elbow flexor, exhibited an increase in activity during arm cranking in the neutral position, the authors suggested that quadriplegics may propel the cranks of an arm cranking apparatus more easily using the neutral handgrip position in comparison to the supinated and pronated position.

Handgrip Increases Shoulder Muscle Activity

Previous studies have revealed some risk factors for high activity and pain in the shoulder region. Among these risk factors were heavy industrial work (Herberts et al. 1976, 1984), elevated arm (Jarvholm, 1990), and increased hand activity (Sighom et al., 1984). However, no studies examined the association between hand muscle activity and shoulder muscle activity. Therefore, Sporrang et al. (1996) conducted a study to assess whether static hand activity affects the shoulder muscles, and if so, whether the

relationship varied among the tested shoulder muscles, as well as if the association depended on the degree of arm elevation.

This study included nine healthy participants. The supraspinatus, infraspinatus, middle deltoid, and upper trapezius were examined using EMG at eight different sites of the upper arm composed of flexion and abduction at four elevation angles. Flexion was performed in the sagittal plane and abduction in the scapular plane. The elevation was 30, 60, 90, and 120 degrees in each plane. In all arm positions, the elbow was flexed at 90 degrees and the upper arm was maintained in a neutral rotation. Each participant was asked to elevate the arm and keep it still for 10 seconds while holding a dynamometer (600g) in the hand. While maintaining the same arm position, the participant was asked to produce a static handgrip force of 30% and 50% of maximum voluntary contraction (MVC) for 10 seconds. This sequence was repeated for all arm positions and hand activities but separated by 2 minute rest periods.

An association between static handgrip and shoulder muscle activity was found. In relation to the degree of elevation in the two planes, the EMG activity increased in the supraspinatus muscle at and above 60 degrees of humeral flexion and in 120 degrees of humeral abduction. In the infraspinatus muscle, the changes were less. A significant increase was noted in flexion and a significant decrease was noted in abduction. In the deltoid muscle, there was increased activity in positions lower than 90 degrees, but the activity of the deltoid decreased in higher arm positions. There was no significant alteration in the activity of the trapezius.

In relation to the force of the handgrip exertion, the supraspinatus exhibited an increased activity with 50% of MVC at 90 degrees of elevation and with 30% of MVC at 120 degrees of elevation. The infraspinatus muscle responded with a decrease of muscle activity to handgrip exertion of 30% of MVC for all arm elevation angles except at the 120-degree position and the reduction was most prominent at 30 degrees of arm elevation. The middle deltoid muscle activity decreased significantly at the 120-degree position with 30% and 50% of handgrip force. There were no significant differences in the middle deltoid activity in the lower arm positions and the trapezius muscle showed insignificant alterations.

Sporrong et al. (1996) stated that high static handgrip force, particularly in elevated arm positions, increased the activity in the stabilizing muscles. The stabilizing muscles (supraspinatus, infraspinatus) were more influenced by hand activity than the motor muscles (deltoid and trapezius). The authors related this observation to the fact that stabilizing the shoulder joint is a major task for the supraspinatus and infraspinatus muscles. It could be possible that the need for stabilization increases with increasing hand activity. Moreover, the authors stated that when the rotator cuff muscles stabilize the shoulder joint, they also tend to abduct the upper arm. This may explain the decrease in deltoid muscle activity (the main function of the middle part of the deltoid muscle being abduction). This research led Sporrong et al. (1996) to conclude that the evaluation of handgrip activity is important when assessing the shoulder activity in manual work and in clinical evaluations of patients with shoulder pain.

Influence of Handgrip Position on Extraneural Pressures

Previous studies (Keir, 1998; Rempel, 1997) have examined the effect of wrist flexion/extension, ulnar/radial deviation, and fingertip loading on carpal tunnel pressure. However, the effect of forearm rotation (supination/pronation) on carpal tunnel pressure has not been examined. In addition, cadaver studies have shown that metacarpophalangeal joint flexion and the resulting incursion of the lumbricals into the carpal tunnel increased carpal tunnel pressure in cadaver hands. However, in vivo studies have not been conducted to confirm these findings. Therefore, Rempel et al. (1998) conducted a study to examine the effects of forearm rotation and metacarpophalangeal flexion on carpal tunnel pressure.

The effect of forearm rotation and metacarpophalangeal flexion on carpal tunnel pressure in 17 healthy adults was investigated. Pressure was continuously recorded with a saline-filled catheter inserted into the carpal tunnel and connected to a pressure transducer while participants slowly rotated the forearm from full pronation to full supination. Forearm rotation was repeated with metacarpophalangeal flexion of 0, 45, and 90 degrees. The results showed that minimum carpal tunnel pressure occurred at 45 degrees of pronation for all metacarpophalangeal angles (17 mmHg at 0 degrees metacarpophalangeal, 12 mmHg at 45 degrees, and 19 mmHg at 90 degrees). The maximum carpal tunnel pressure was observed at full supination for all metacarpophalangeal angles (54 mmHg at 0 degrees, 34 mmHg at 45 degrees, and 55 mmHg at 90 degrees). Further, carpal tunnel pressure increased significantly when the participants rotated the forearm from 0 to 45 degrees supination and from 45 degrees

supination to full supination across all metacarpophalangeal angles. When the forearm was in pronation, the pressure tended to be lowest at 45 degrees pronation, however, this difference was only statistically significant at 90 degrees of metacarpophalangeal flexion.

Rempel et al. (1998) stated that the study findings confirmed the strong interaction between finger postures, forearm postures, and carpal tunnel pressure. The authors suggested that the increase in carpal tunnel pressure observed when the forearm was rotated from 45 degrees of pronation (12 mmHg) to full supination (55 mmHg) may be related to two possibilities. First, pronation/supination changes the orientation of the tendons passing through the carpal tunnel and this change in orientation alters the volume and therefore the pressure in the carpal tunnel. Second, the proximal boundary of the effective carpal tunnel space, as defined by the flexor muscle bellies, changes shape with pronation/supination.

Further, the results showed that the pressure was the lowest at a metacarpophalangeal flexion of 45 degrees and increased with full metacarpophalangeal flexion (90 degrees) and metacarpophalangeal extension (0 degrees). The authors related the increase in carpal tunnel pressure as the fingers are flexed beyond 45 degrees to findings from a previous study of cadaver hands (Cobb et al., 1995). According to this study, lumbrical incursion into the distal end of the carpal tunnel leads to elevated pressure. Therefore, Rempel et al. (1998) concluded that this lumbrical incursion (e.g., the effect of skin folding in the palm) may explain the increase in pressure as the fingers are flexed beyond 45 degrees. To explain the increase in carpal tunnel pressure as the metacarpophalangeal joints are extended, the authors hypothesized that as the

metacarpophalangeal joints are extended relative to 45 degrees, the muscle bellies of the finger flexors, particularly the flexor digitorum superficial, move distally into the effective carpal tunnel space. These muscle bellies then act as a space occupying lesion, and results in elevated carpal tunnel pressure.

Finally, based on the current findings that the forearm rotation angle of 45 degrees pronation and the metacarpophalangeal flexion angle of 45 degrees were associated with the lowest carpal tunnel pressure, Rempel et al. (1998) proposed that these postures should be considered in designing ergonomic hand tools and modifying work tasks for workers with carpal tunnel syndrome. The authors suggested that these postures could help rehabilitation clinicians in treating patients with carpal tunnel syndrome. In addition, these postures could assist orthotists in designing more efficient splints that would provide maximal blood flow to the tissues in the carpal tunnel.

Influence of Handgrip Position on Shoulder Muscle Activity during Mouse Use

A causal relationship exists between awkward and extreme postures and shoulder, elbow, and wrist musculoskeletal symptoms among computer mouse users (Aaras & Ro, 1997; Flodgren et al., 2007)). Maintaining the forearm in pronation requires high force exertion and therefore, forearm pronation is a risk factor for elbow and forearm occupational disorders. This potential prevalence is due to increased activity of the pronator teres and pronator quadratus in angles greater than 60 degrees of pronation (Zipp et al., 1983). It is also very demanding to bend the elbow and maintain a pronated forearm because the biceps brachii is a forearm supinator (Dainoff, 1998). Further, operating a mouse is typically associated with outward rotation of the shoulder, which

may increase the risk of developing neck-shoulder discomfort (Wahlstrom, Svensson, Hagberg & Johnson, 2002). In order to minimize awkward postures, a number of researchers evaluated alternative mouse designs that allow for a more neutral grip in comparison to the traditional pronated grip needed to operate a standard mouse design.

Gustafsson and Hagberg (2003) examined the effect of using a neutral handgrip compared to a pronated handgrip on exposure, comfort, exertion, and productivity when operating a computer mouse. The authors compared a traditional mouse (Microsoft 2.1 A), operated using a pronated handgrip with a newly designed prototype mouse that was labeled the neutral mouse, designed to be operated with a neutral hand grip. Nineteen (nine males and ten females) experienced Visual Display Unit (VDU) workers who used a computer mouse in their daily computer work activities participated in the study. All participants normally used their right hand to move the computer mouse. A week prior to the study, participants practiced using the neutral mouse for one half of the workday. Prior to the practice period, participants were instructed to use the whole arm to move the neutral mouse on the work surface. EMG data were collected on the right side of the body from the upper trapezius muscle, extensor carpi radialis and extensor carpi ulnaris muscles, and from the first interossei dorsal muscle (responsible for finger abduction movement). Right wrist joint position and range of motion were measured using an electrogoniometer. Participants were asked to complete a text editing task for 15 minutes with each handgrip position using their normal speed when using a computer mouse. Text editing task consisted of selecting highlighted characters (random location) with the mouse and then deleting the characters using the delete key on the keyboard with the

same hand operating the mouse. Number of pages edited and number of errors were recorded. Participant preference data were also collected after completing the text editing task with both handgrip positions. Before and after work with both mouse hand grip positions, participants rated their perceived exertion in the neck, shoulders, arms, wrists, and hands using a 10-point Borg's scale.

The results showed decreased wrist extension and ulnar deviation with the neutral mouse handgrip position compared to the mouse pronated handgrip position. EMG data showed decreased or unchanged muscular activity in the forearm extensor muscles and the first dorsal interossei muscle with the neutral mouse grip compared to the traditional mouse grip. Trapezius muscle EMG activity varied. This activity increased for some of the participants and decreased for others when using the neutral mouse. Only three participants reported overall better body comfort when using the neutral mouse compared to the traditional mouse. Most participants reported high perceived exertion in the right shoulder and wrist with the pronated mouse hand grip position compared to the neutral position. A median of one or more errors were observed when working with the neutral mouse compared to the traditional mouse. A 24% decrease in productivity was observed with the neutral mouse. All participants edited more pages using the traditional mouse. This finding is consistent with previous research by Straker et al., (2000) who found an 11% decrease in performance even after 2 weeks of training with a mouse operated with a neutral hand grip position. Fifty percent of the participants stated that compared to the traditional mouse, the neutral mouse had low precision and was difficult to move. There was no significant difference between females or males, order of the two mouse hand

positions, or time of the day in any of the measurements collected. All participants reported that using a neutral hand grip to operate the mouse was more restful and convenient for the hand and the wrist. However, participants still preferred using the traditional mouse over the newly designed neutral mouse. Gustafsson and Hagberg (2003) suggested that this finding can be explained by participant familiarity with using a traditional mouse.

Finally, Gustafsson and Hagberg (2003) concluded that hand grip position is an important factor when working with a computer mouse. Operating a mouse with a neutral hand grip position decreased the muscle activity in the forearm and wrist areas and minimized wrist deviation movements. However, working with a neutral grip may reduce productivity and result in a low subjective comfort level. The authors advised that future research should focus on studying health effect when operating a mouse with a neutral handgrip position in healthy working populations based on previous findings by Aaras et al. (1998) and Aaras et al. (2001) that showed decreased pain among VDU operators when using more neutral handgrip position,.

Dainoff (1998) evaluated the performance of an ergonomically designed mouse (Anir mouse, Animax International, ASA, Norway). What distinguished the Anir mouse from any other traditional mouse was the ability to provide a neutral handgrip? The mouse is shaped like a military fighter pilot's flight stick control and allows the user to rest the ulnar side of the hand on the mouse with the thumb on a rocker switch (for right and left mouse clicks) located on top of the stick. Also, a scrolling feature can be activated with the middle finger during mouse use.

Dainoff demonstrated that the forces needed to operate an Anir mouse with a neutral handgrip position originated in the larger muscles of the arm in comparison to the small muscles of the hand and wrist that would control a traditional mouse (operated with a pronated hand grip). Thus, Dainoff suggested that lower performance in terms of speed of use and error rate may be observed when using an Anir mouse in comparison to a traditional Microsoft mouse. Using two types of application (point/click and drag) he evaluated the performance of the Anir mouse in comparison to a Microsoft mouse in terms of speed and accuracy. Performance assessment was based on Fitt's Law as an assessment measure in human computer interaction (Mackenzie, 1992). The Fitts' Law formula is as follows: $MT = B + m (\log_2 (2A/W))$. Motion speed and accuracy are measured from the originating point to the target (these values may vary with width (w) and amplitude (A) or distance. The $\log_2 (2A/W)$ is a theoretical measure (i.e., index of difficulty). The constant (m) represents the slope, which is also represented as the inverse of information transfer in bits per second ($1/b$). Dainoff (1992) suggested that this formula could be utilized to determine if the slope would differ for the Anir mouse in comparison to the traditional mouse. According to Langolf, Chaffin, and Foulke (1978) the slope of Fitt's Law is steeper for arm motions in comparison to finger motions. For a specific index of difficulty (size and location of target), more time is needed to accomplish a goal when using the arm than when using the fingers. With this in mind, Dainoff (1998) investigated the following questions with 10 undergraduate students:

- (a) is there a performance difference between the two different types of computer mice;
- and (b) how large is the learning curve when using a non-traditional mouse.

Mousing tasks were performed over 16 sessions in a two-day period in a counter-balanced fashion between the two mouse types. The results revealed that although statistically significant, the performance between the two mouse types had little practical difference in accuracy and speed and the time needed to learn how to operate the Anir mouse most likely occurred within the first session.

Stracker, Pollock, Frosh, Aaras, and Dainoff (2000) compared the Anir mouse to a traditional computer mouse with a focus on usability, performance, and discomfort level. Participants were non-injured office workers and assigned to one of two groups: (a) a control group using a traditional mouse for a 3 week period; and (b) an intervention group using the Anir mouse for a 2 week period followed by a third and final week using a traditional mouse. Usability, performance and discomfort levels were assessed at the beginning and end of each week. Usability was measured with a questionnaire that covered perceived ease of use. Performance was evaluated using a word processing task with the time to finish the task as compared to zero error rate as outcome measures. Discomfort level was assessed using body map and visual analog discomfort scales. Overall, the Anir mouse was less easy to use and participants took about 11 % longer to complete the word processing task. However, performance trends indicated a learning curve. There was a tendency for performance levels to improve with experience, which is in concurrence with a study conducted by Dainoff (1998). For some participants, the use of the Anir mouse somewhat decreased discomfort levels. However, even though most participants reported positive short-term effect of Anir mouse use, the ability of the Anir mouse to decrease upper extremity discomfort was not statistically significant.

Straker et al. (2000) related this non significant finding to individual differences, and suggested that future research should analyze findings at the individual level rather than the group level.

Aaras, Dainoff, Ro & Thoresen (2001) investigated whether workers suffering from musculoskeletal pain had less pain when operating a mouse that facilitates a more neutral grip position (using the Anir mouse) in comparison to the pain level when using a traditional mouse that usually requires a pronated grip. Using a visual analog scale, participants were asked to rank their average level of pain throughout the testing period. The results indicated that working with a neutral handgrip (Anir mouse) decreased pain level in the neck, shoulder, forearm, wrist, and hand for participants who suffered discomfort at these levels. Further, the pain reduction effect lasted for approximately one year. The authors suggested that this finding could be important to consider because it may provide a method for early prevention of the development of potentially serious musculoskeletal pain.

Furthermore, Aaras and Ro (1997) conducted an EMG study to investigate the effect of a neutral handgrip when operating a computer mouse on musculoskeletal health. They stated that a more neutral grip of the mouse may help minimize the activity in the forearm muscles. To test their hypothesis, they compared the EMG activity of the extensor digitorum communis, extensor carpi ulnaris, and trapezius muscles when operating two different types of mice (Standard Microsoft mouse versus the Anir mouse) with two conditions of support (forearm support versus no-forearm support).

For this study, 13 healthy computer workers participated. They received a 2-day training session, before running the study to become familiar with the handling and use of the Anir mouse. The study was divided into two 30 minute sections, separated with a 10 minute break. In the first 30 minutes, seven participants performed painting tasks with the Anir mouse and six participants performed the same tasks with the Microsoft mouse. After the 10 minute break, participants worked for another 30 minutes but with the other type of mouse in order to counterbalance the study groups. All participants worked in a seated position with the forearm fully supported on the table surface in the first part of the study and then repeated the same protocol without support of the forearm in the second part of the study. Findings were as follows: (a) when the forearm was supported, there was less activity in the extensor communis muscle when using the Anir mouse than when using the Microsoft mouse; (b) the extensor carpi ulnaris showed less activity when operating the Anir mouse; and (c) no significant difference in the static activity in the trapezius muscle between the two types of mice was present.

When the forearm was not supported, there was significantly lower activity in the two extensors muscles when using the Anir mouse than when using the Microsoft mouse. Similar to the support condition, the trapezius muscle activity did not differ when using the Anir mouse in comparison to the Microsoft mouse. In addition, the researchers stated that even though they did not conduct a statistical analysis to compare the muscular activity on the trapezius muscle in the two different support conditions, the results indicated that supporting the forearm resulted in lower muscle activity in the trapezius muscle.

Finally, taking into consideration the facts that no statistical analyses were conducted to compare the effect of the two methods of support and only the forearm extensors and the trapezius muscles were tested in this study, it would be of interest to conduct an EMG study to determine whether the same results would occur with other upper extremity muscle groups and whether there is an interaction between the method of support and the type of mouse use.

Summary

Computer users are at risk of developing upper extremity musculoskeletal disorders (Colombini & Occhipinti, 2007; Marcus et al., 2002; Sillanpaa et al., 2003; Cook & Burgess-Limerick, 2004; Flodgren et al., 2007; Punnett & Wegman, 2004). Mouse users, in particular, have a greater prevalence to upper extremity musculoskeletal disorders as a consequence of awkward working postures (wrist extension, wrist ulnar deviation, and shoulder abduction) and inadequate upper arm support during mouse operation (Wahlstrom et al., 2000; Kryger et al., 2003, Lee et al., 2007).

Operating a computer mouse involves a pronated grip. Pronation of the forearm is identified as a risk factor for musculoskeletal disorders in the elbow and forearm (Dainoff, 1998; Aaras et al., 1997; van Galen et al., 2007; Gustaffson & Hagberg, 2003). Thus, avoiding forearm pronation may reduce static muscle activity in the elbow and forearm during computer mouse use. Also, computer mouse use entails high precision demands. High precision hand activity affects the muscular activity in the shoulder muscles (Roman-Liu et al., 2001). The neuromuscular responses of the upper extremity changes with handgrip position (Bressel et al., 2001). Thus, muscular activity in the

shoulder may differ, for example, if the handgrip on the mouse is oriented in a different position than pronation. Contemporary computer mouse designs are shifting toward a more neutral handgrip of the computer mouse (e.g., Anir vertical mouse, 3M optical mouse). The main goal of the Anir mouse and the 3M optical mouse design is to decrease the activity in the hand and forearm by allowing the user to operate the mouse with a whole arm movement instead of a wrist movement (wrist ulnar and radial deviation) typically associated with operating a traditionally designed mouse.

Four studies examined the effect of neutral handgrip of the computer mouse on musculoskeletal health (Aaras & Ro, 1997; Aaras et al., 2001; Gustafsson & Hagberg, 2003; Stracker et al., 2000). One study compared a newly designed prototype of a mouse, called the neutral mouse to a traditional mouse (Microsoft 2.1 A) and the other three studies compared the Anir mouse to a traditional mouse (Microsoft, Redmond, WA). However, only two studies (Aaras & Ro, 1997; Gustafsson & Hagberg, 2003) used EMG to assess neuromuscular activity in the forearm extensors and trapezius muscles. In both studies, forearm flexor muscles and shoulder muscles were not examined. Aaras and Ro (1997) explained that forearm flexors were not examined because the static activity and muscular fatigue is larger on the forearm extensors when compared to forearm flexors. Also, the shoulder muscles were not considered because the researchers considered the activity of the trapezius muscle an indicator of postural activity of the neck-shoulder region. However, according to Palmerud and Kadefors (1995) EMG activity of the trapezius muscle does not represent the total activity in the shoulder region. With this in mind, one may conclude that shoulder muscle activity in relation to

neutral handgrip position when using a computer mouse is not well documented.

Investigating this relationship may influence the desired outcome of the task to reduce the risk of upper extremity musculoskeletal disorders.

Alternatively, Sillanpaa et al. (2003) found that supporting the forearm when operating a computer mouse reduces the static activity in the neck (trapezius muscle), shoulder (anterior deltoid), and forearm extensor muscles (extensor carpi radialis) and increases the activity on the infraspinatus and forearm flexor muscles. Sillanpaa et al. (2003) suggested that this increased activity may be related to increased motion in the shoulder joint resulting from participant attempts to avoid bending their wrist joint when operating the mouse and from lack of wrist support to stabilize the arm during horizontal movements. Participants in this study used a traditional mouse (pronated grip) to complete the task. It would be of interest to investigate whether the same results would occur with a different mouse design. One may hypothesize that a neutral grip on the mouse may eliminate the need to fix the arm for horizontal movement as well as the need to actively avoid bending the wrist joint thus reducing shoulder muscle (infraspinatus in particular) overload.

When considering the prospect of reducing shoulder muscle overload, it is important to study whether neutral handgrip of the mouse plays a role in the reduction of muscular activity in the shoulder region and whether this reduction is affected by specific forearm support. Therefore, the purpose of this study was to determine how mouse device and method of support affect the muscular activity in the upper extremity. The study used electromyography to compare the muscular activity in the forearm, shoulder,

and neck regions when using two different mouse devices (3M optical mouse operated with a neutral handgrip and Standard optical mouse operated with a pronated handgrip) with two different methods of support (forearm support and no-forearm support).

CHAPTER 3

Method

The purpose of the present study was to determine how mouse device and method of support affect the muscular activity in the forearm, shoulder, and neck regions when mouse device varies (i.e., 3M optical mouse as compared to a Standard optical mouse) and when the method of support varies (i.e., with forearm support and with no-forearm support). This chapter presents the methodology considered to fulfill the objective of the study.

Participants

After obtaining permission from San Jose State University Human Subjects-Institutional Review Board (see Appendix A), thirty-six volunteers with no history of upper extremity disease or injury, who use a computer mouse at least 2 hours per day, were recruited from the San Jose State University community to participate in the study. The limitation of computer mouse use of 2 hours per day was based on a study conducted by Sillanpaa et al. (2003). They examined upper limb support in relation to the development of musculoskeletal ailments among participants who operated a computer mouse for 2 hours or more per day. To be considered for the present study, participants were required to be right-hand dominant mouse users. This requirement was necessary because the 3M ergonomic optical mouse was designed to be operated with the right hand only. All participants completed a Background Questionnaire documenting demographic, occupational, and personal health information related to musculoskeletal symptoms of the upper extremity (see Appendix B). A portion of this questionnaire was

based on the Standardized Nordic Questionnaire for the analysis of musculoskeletal symptoms (Kuorinka, Jonsson, Kilborn, Vinerberg, Biering-Soresnsen, Andersson & Jorgensen, 1987). Eligible participants signed an informed consent that outlined the purpose, methods, and risks associated with the outcome measures (see Appendix C).

Instrumentation

Computer

Computer equipment consisted of a Personal Computer (PC), Intel Pentium 4 processor, with a standard 105-key keyboard, and a 1024 x 768 resolution monitor at 85 Hz.

Mouse Device

Two types of computer mouse input devices were used in this study.

1. The 3M optical mouse (EM500GP-AM, 3M, St. Paul, MN), identified as 3M mouse. The 3M mouse (see Appendix D) is an identical version of the Anir mouse (Animax International ASA, Norway) operated with a neutral handgrip position. Its vertical shape allows the user to rest the ulnar side of the hand on the mouse base and the thumb on the rocker switch (for right and left mouse clicks) located on top of the vertical stick. It is designed for use with the right hand only. The 3M mouse was available in two sizes: (a) small-medium for palm widths between 2.75-3.50 in; and (b) large for palm widths between 3.50-4.0 in (see Appendix E). For the purpose of this study, each participant was fitted to the mouse size that most accurately fits his or her hand.
2. The Kensington optical mouse identified as the Standard mouse (see Appendix F), a traditional mouse operated with a pronated grip.

Work Seat

The work seat consisted of a standard ergonomic office chair with height and tilt adjustments and no arm rests (see Appendix G).

Workstation

The workstation consisted of an adjustable table with two customized external extensions (265 x 530 mm). The two extensions were attached via clamps to the front edge of the table to form a U-shape extension. This U-shape allowed the seated participant to have a full support of the forearm without creating a forward posture. The two extensions were removed from the edge of the table to allow the seated participant to support only the wrist for the no-forearm support condition. A 4 mm thick fabric-top mouse pad with a silicon rubber base (190 x 195 mm) was used in every condition. The keyboard was placed on the table surface and the monitor was kept at the same level for both methods of support.

In the forearm support condition (the forearm fully supported in front of the operator on the work surface), the workstation height was adjusted to 1 cm above the participant's elbow level (Sillanpaa et al., 2003). The computer monitor was positioned directly in front of the participant at a 50 cm distance from the participant's eyes (Kroemer, Kroemer & Kroemer-Elbert, 2000) and was set so the center of the screen was at the participant's eye level (Cook et al., 1998). The chair was positioned in relation to the monitor and to the participant to maintain the 50 cm distance between the participant's eyes and the monitor. The chair stability was maintained by the U-shaped design of the work station for the forearm support condition and enforced by instructing

participants to refrain from changing the chair's position during trials. The keyboard was positioned at the front end of the table. The left edge of the "h" key was aligned with the participant's body midline. The mouse pad was positioned adjacent to the right edge of the keyboard. The center point of the mouse pad served as a reference guide for mouse placement. The optical sensor of the mouse was aligned with the middle of the mouse pad. For consistency purposes, markers were used to indicate keyboard and mouse placement in each support condition for each participant (see Appendix H).

In the no-forearm support condition (the wrist only is supported in front of the operator on the work surface), the two extensions were removed from the front edge of the table so the forearm did not touch the table surface (Sillanpaa et. al, 2003) and the workstation height was adjusted so the height of the participant wrist was 1 cm above his or her elbow level. The computer monitor and the chair were kept at the same distance (50 cm) in relation to the participant and the same upper body posture as the forearm support condition (see Appendix I). The chair stability was maintained by instructing participants to refrain from changing chair's position during trials and by close monitoring from researcher to ensure chair stability throughout testing.

Electromyography

Surface electromyography (EMG) was used to record muscular activity from the upper trapezius, infraspinatus, anterior and middle deltoid, biceps brachii, extensor carpi radialis, extensor carpi ulnaris, flexors carpi radialis, and flexor carpi ulnaris muscles of the right upper extremity.

Thought Technology adhesive electrodes (Thought Technology, Ltd., Montreal, Quebec, Canada) were used. The electrodes were placed on the skin over the midline of the muscle belly (Deluca, 1997) and aligned parallel to the muscle fibers (see Appendix H and Appendix I). More specifically, electrodes were placed 6 mm apart over the belly of each muscle being examined (Cook et al., 1998). The skin was cleaned with alcohol wipes prior to electrode placement to reduce electrical impedance (Bressel et al., 2001).

EMG data were collected with a 10-channel biofeedback encoder (Flex Comp Infinity T7555M, Thought Technology, Ltd., Montreal, Quebec, Canada), and Thought Technology MyoScan sensors (see Appendix J). The EMG signals were amplified, bandwidth filtered, and sampled at 400 Hz. In a typical surface EMG spectrum, according to Winter (1990), most of the signal is concentrated in a band between 20 and 200 Hz, with less signal extending up to 100Hz. The raw EMG data sampled at 400 Hz were processed using the following methods (Winter, 1990) of online processing:

- (a) removed DC bias to align the raw EMG data equally above and below the zero line;
- (b) full wave rectification to generate the absolute value of the EMG data with positive polarity (the rectified signal is reported in millivolts [mV]); (c) obtained a linear envelope by filtering the full-wave rectified EMG signal using a 4th order Butterworth filter with a 6 Hz cutoff frequency (the linear envelope, reported in millivolts [mV], follows the trend of the EMG and resembles a curve); and (d) obtained an integrated EMG for the entire time interval of the muscle contraction (the integrated EMG, reported in millivolt-seconds [mV.s] combines the amplitude and the duration of the muscle contraction).

The EMG activity of each muscle was normalized to the individual's isometric maximal voluntary contraction. Maximum voluntary contraction for each muscle was determined using manual muscle testing in the sitting position (Daniel & Worthingham, 1995). In the seated antigravity position each participants were asked to move their upper extremity to a specific position in space. Then, participants were asked to hold the position against strong pressure.

To evaluate the differences between the two independent variables (mouse device and method of support), the following dependent variables; normalized average, peak, and integrated EMG values were calculated for each trial. However, only integrated EMG values were used for the analysis because it reflects the activity of a specific muscle throughout the total duration of the muscle activity.

Study Design

Upper extremity neuromuscular responses to computer mouse use were measured using surface EMG. Seating position in relation to the workstation was standardized for each participant based on ergonomic and anthropometric guidelines. The two mouse devices (3M mouse operated with a neutral grip and a Standard mouse operated with a pronated grip) with the two methods of support (forearm support and no-forearm support) were examined during computer mousing tasks.

Selected Muscles

Electromyography signals were recorded from several upper extremity muscles. The muscles were selected based on evidence in the literature that the excessive use of these muscles may result in musculoskeletal disorders of the upper extremity, and that

certain muscles may be overstressed when operating a computer mouse. These muscles were: (a) at neck level: the right upper trapezius usually associated with somatic pain syndrome (Gerr et al., 2002); (b) at shoulder level: the right infraspinatus muscle typically associated with impingement syndrome and rotator cuff muscle tendonitis (Bressel et al., 2001); the right middle deltoid muscle, which was selected to reflect the supraspinatus muscle activity (Kronberg, Nemeth, & Brostrom, 1990) also associated with impingement syndrome and rotator cuff tendonitis (Bressel et al., 2001); and the right anterior deltoid selected for its high activity associated with computer mouse (Cook & Kothiyal, 1998); (c) at arm level: the biceps brachii muscle which is associated with bicipital tendonitis (Gerr et al., 2002). The biceps brachii muscle was selected because of its biomechanical function. This muscle is a shoulder flexor, a major supinator of the forearm and an elbow flexor. As a biarticular muscle, the biceps brachii requires higher exertion to generate a given force, therefore high demand is placed on this muscle to flex the elbow joint and maintain the forearm pronated to operate a traditional computer mouse (Aaras & Ro, 1997; Dainoff, 1998); and (d) at forearm level; extensor carpi radialis and extensor carpi ulnaris associated with extensor tendonitis or lateral epicondylitis (Gerr et al., 2002). These forearm extensors act as stabilizers during computer mouse use and therefore they are at higher risk for fatigue and injuries (Aaras & Ro, 1997); the flexor carpi radialis and the flexor carpi ulnaris associated with flexor tendonitis (Gerr et al., 2002).

Testing Protocol

Testing protocol consisted of a symbol manipulation task (see Appendix K). The task was built in Hyper-Text Markup Language (HTML) with color-coded mouse symbols and squares. The construction of the task was based on the test protocol employed by Sillanpää et al. (2003). The task consisted of a grid eight rows by six columns. A total of 16 blue mouse symbols were coded with letters and numbers (A1 through A4, B1 through B4, C1 through C4, and D1 through D4). These were placed in the center of the grid across 16 white squares formed between the 3rd and 6th row and between the 2nd and 5th column. Each corner of the grid consisted of a different color coded and numbered cluster of four squares (A1 to A4 is represented in red, B1 to B4 in green, C1 to C4 in pink, and D1 to D4 in yellow) matching the coded mouse symbols in the center of the grid . To perform the task, participants used the mouse to execute point, click, cut, and paste functions to move the 16 mouse symbols in a fixed order from the center of the grid to the matching squares in the four corners of the table. Participants initiated the task by moving mouse symbols A1 through A4 to the corresponding squares in red (A1 to A4) located in the lower right-hand corner of the grid. The same procedure was performed to move the remaining mouse symbols (group B, C, and D respectively) to their corresponding squares.

Trials

To complete one trial, participants moved all mouse symbols to their respective color-coded squares within the grid. In total, each participant completed 20 trials as follows. In each of the two methods of support (forearm support and no-forearm

support), each participant completed one set of 10 trials. After completing one set of 10 trials with one method of support, participants received a 12 minute rest period before repeating a second set of 10 trials with the second method of support. Each of the two sets of 10 trials was subdivided into two sets of five trials. The first subset of five trials was completed using one of two mouse devices (3M mouse or Standard mouse) and the second subset of five trials was completed using the second mouse device. Participants rested for 6 minutes between the first subset of five trials and the second subset of five trials. Within each subset of five trials, participants rested for 3 minutes between each trial.

The order of the trials for the two independent variables (method of support and mouse device) was counterbalanced (see Appendix L). Four groups (nine participants each) were formed after counterbalancing the mouse device and the method of support. The groups performed the counterbalanced trials as follows.

1. Group 1 began the protocol with forearm support and used the 3M mouse first and the Standard mouse second. This group finished with no-forearm support and performed the task with the 3M mouse first and the Standard mouse second.
2. Group 2 followed the same order for the method of support as Group 1, but used the Standard mouse first and the 3M mouse second.
3. Group 3 initiated the protocol with no-forearm support and used the 3M mouse first and the Standard mouse second. Then, Group 3 finished with forearm support and used the 3M mouse first and the Standard mouse second.

4. Group 4 followed the same order as Group 3 for the method of support, but used the Standard mouse first and the 3M mouse second.

Procedure

Participants completed the protocol in one test session at the Human Automation Integration Laboratory (HAIL), in the Department of Engineering at San Jose State University. The session was conducted in a 4 hour period including rest periods. Participants completed each trial in a fixed order. Symbols were selected using the mouse, cut and pasted to corresponding color-coded squares in a self-paced manner requiring a total of 64 actions.

Participants performed 20 trials counterbalanced across mouse devices and tasks. The 20 trials were divided into two sets of 10 trials. Participants completed one set of 10 trials with forearm support and one set of 10 trials with no-forearm support. Participants rested for 12 minutes between the two sets of 10 trials. The two sets of 10 trials in each of the two methods of support were divided into two subsets of five trials each. Participants completed one subset of five trials with the 3M mouse and one subset of five trials with the Standard mouse. Participants rested for 6 minutes between the two subsets of five trials. Within each subset of five trials, participants rested for 3 minutes between each trial. During each rest period, participants were encouraged to get up, move around, and focus their eyes on objects at far distances. Participants were instructed to keep each of the trials very short (not to exceed 2 minutes to avoid fatigue that may alter posture). They were also instructed to avoid excessive bending of the wrist and to slide their wrist on the table surface. On the test date, and prior to testing, each participant received 25

minutes of training with the 3M mouse and 5 minutes of training with the symbol manipulation task.

Electromyography signals were recorded from the upper trapezius, anterior and middle deltoid, infraspinatus, biceps brachii, flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis, and extensor carpi ulnaris muscles. Thumb force was measured for each participant using a pinch grip dynamometer before and after completing each trial with the 3M mouse. Participants were instructed to place the dynamometer on the palm of the left hand and were asked to apply a pincer grip with the right hand (i.e., grip the non-supported end of the pinch dynamometer between right thumb and index finger). Thumb force was reported in Libra (see Appendix M). After completing the protocol, participants were given a post-test Preference Questionnaire (see Appendix N) in order to collect information on each participant's subjective preferences in regards to the mouse devices and methods of support used in the study.

Data Analysis

Electromyography data were analyzed using quantitative methods to determine any differences present in EMG values between mouse type and method of support. A two-factor within subjects analysis of variance (ANOVA) was conducted to compare integrated EMG values (dependent variable) to mouse device type and method of support (independent variables). The probability associated with Type I error was set at $\alpha = .05$ for all observations. Type II error (power) was set at .70 with a medium effect as a minimum acceptable level of power. The estimated sample size (36 participants) was calculated with the following equation by Keppel, Saufley, and Tokunaga (1992):

$n' = \phi^2(1 - \omega^2/\omega^2)$. Omega squared (ω^2) was used to estimate the sample size (n') by employing ϕ (phi) as the statistic for the value of power that was determined to be 1.5 (representing a power of .70) and a medium treatment effect size was estimated (.06). This required 36 participants in this repeated measures design.

A supplemental analysis of data collected from the post-test Preference Questionnaire was conducted. These data were coded and scored. Data are presented as percentages to report subjective preferences in regards to the mouse device and method of support used.

Finally an ANOVA was conducted using thumb force data to test for differences before and after using the 3M mouse in all trials. The goal was to assess the muscular activity in the thumb experienced with 3M mouse use.

Chapter 4

RESULTS

Surface electromyography (EMG) data from the right upper extremity muscles (upper trapezius, infraspinatus, anterior and middle deltoid, biceps brachii, extensor carpi radialis, extensor carpi ulnaris, flexors carpi radialis, and flexor carpi ulnaris) for the two methods of support (forearm support and no-forearm support) and the two mouse devices (Standard mouse and 3M mouse) were collected from 36 participants.

All participants were current San Jose State University students from the Department of Kinesiology. Participants were 22 males and 14 females. Participants' ages ranged between 18 and 48 yrs with an average age of 24.7 yrs. As shown in Figure 1, participants reported most frequently used input devices as follows in descending order from most commonly used to least commonly used: (a) traditional mouse (Standard mouse); (b) touchpad; (c) trackball; and (d) a ballpoint pen-type mouse. Participants reported average computer mouse use in hours per day as 2.47 hours (range = 0.35-8.00).

Figure 1. Mouse type frequently used by test participants.

Analysis of Variance of Integrated EMG Data

A randomized block factorial design with two repeated measures was used to analyze the data using SPSS 14.0 general linear model (GLM) to compare integrated EMG between method of support (forearm support and no-forearm support) and mouse type (Standard mouse and 3M mouse). Integrated EMG values were only included in the analysis. Average and peak EMG values were excluded from the analysis because integrated EMG was considered to be most representative of muscle activity during the entire time interval of this muscle activation. All analyses initially included a between-subjects ANOVA to test for order effects which may have occurred due to inadequate counterbalancing of conditions (Group 1: no-forearm support/3M mouse, no-forearm support /Standard mouse, forearm support/3M mouse, forearm support/Standard mouse; Group 2: no-forearm support/Standard mouse , no-forearm support/3M mouse, forearm support/Standard mouse, forearm support/3M mouse; Group 3: forearm support/3M mouse, forearm support/Standard mouse, no-forearm support/3M mouse, no-forearm support /Standard mouse; Group 4: forearm support /Standard mouse, forearm support/3M mouse, no-forearm support/Standard mouse, no-forearm support/3M mouse). Pairwise comparisons were used to evaluate significant interactions. Integrated EMG values were transformed using either a log, or square root transformation to correct for substantial or moderate positive skewness.

Upper Trapezius Muscle

One participant was removed from the analysis after determining that the data set represented an extreme outlier. This result remained after the data were transformed.

A trend was observed between mouse type and sequence of mouse device use, $F(3, 31) = 2.76, p = .059$. Upper trapezius muscle activity increased for all groups when using the 3M mouse (see Figure 2). A significant interaction between method of support and mouse type was found, $F(1, 34) = 7.21, p < .05$, (see Table 1).

Figure 2. Trend for significance of mouse type by sequence interaction for integrated EMG of the upper trapezius muscle.

Note. Error bars denote standard error.

Pairwise comparisons revealed a significant difference between mouse type for each method of support ($p < .001$). The overall muscle activity associated with the use of the 3M mouse ($M = 4.14$, $SD = .371$) was greater than the muscle activity associated with the use of the Standard mouse ($M = 3.84$, $SD = .48$; see Figure 3). The interaction was due to the lack of a significant difference between the two methods of support with the use of the 3M mouse compared to the significant improvement when using the Standard mouse with forearm support. Overall, forearm support reduced upper trapezius muscle activity ($M = 3.92$, $SD = 0.50$) compared to no-forearm support ($M = 4.06$, $SD = 0.39$).

Table 1.

Analysis of variance for method of support, mouse type and sequence of the upper trapezius muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>
Support	1	0.679	9.36**
Support x sequence	3	0.115	1.58
Error(support)	31	0.073	
Mouse	1	3.209	63.91***
Mouse x sequence	3	0.139	2.76
Error(mouse)	31	0.05	
Support x Mouse	1	0.280	7.21*
Support x Mouse x Sequence	3	0.048	1.25
Error (support x mouse)	31	0.039	

Note. *** $p < .001$, ** $p < .01$, * $p < .05$.

Figure 3. Significantly greater upper trapezius muscle activity with 3M mouse than with Standard mouse.

Note. Error bars denote standard error.

Infraspinatus Muscle

A significant interaction was found between mouse type and the sequence of conditions administered $F(3, 32) = 3.76, p < .05$. Pairwise comparisons revealed that infraspinatus integrated EMG values for the Standard mouse and 3M mouse were significantly different for all conditions ($p < .05$). Thus, the interaction seemed to be due to larger differences between mouse conditions (see Figure 4). Overall, infraspinatus muscle activity associated with the 3M mouse ($M = 4.18, SD = 0.44$) was greater than the activity with the Standard mouse ($M = 3.80, SD = 0.53$). As shown in Table 2, significant main effect of support type $F(1, 32) = 41.73, p < .001$ was also found. As shown in Figure 5, infraspinatus muscle activity with no-forearm support ($M = 4.13, SD = 0.47$) was greater than with forearm support ($M = 3.85, SD = 0.55$).

Figure 4. Significantly higher infraspinus muscle activity with 3M mouse than with Standard mouse for all sequences.

Note. Error bars denote standard error.

Table 2

Analysis of variance for method of support and mouse type as within-factors and for sequence of the conditions as between-factor of the infraspinus muscle

Source	df	MS	F
Support	1	2.811	41.73***
Support x sequence	3	0.074	1.10
Error(support)	32	0.067	
Mouse	1	5.075	72.48***
Mouse x sequence	3	0.264	3.764*
Error(mouse)	32	0.070	
Support x Mouse	1	0.045	1.34
Support x Mouse x Sequence	3	0.002	.068
Error (support x mouse)	32	0.033	

Note. ***p < .001, *p < .05.

Figure 5. Significantly greater infrapinatus activity with no-forearm support than with forearm support.

Note. Error bars denote standard error.

Middle Deltoid Muscle

A significant interaction was found between mouse type and the sequence of conditions administered $F(3, 32) = 9.57, p < .001$. A pairwise comparison of mouse types revealed significant differences at each sequence level ($p < .01$). As shown in Figure 6, the interaction seemed to be due to the larger increase in middle deltoid activity from using the Standard mouse as compared to using the 3M mouse for the participants that received no-forearm support and the Standard mouse condition first (no-forearm support/Standard mouse, no-forearm support/3M mouse, forearm support/Standard mouse, forearm support/3M mouse).

A significant interaction was found between method of support and mouse type, $F(1, 32) = 7.46, p = .01$, (see Table 3). Pairwise comparisons revealed significant effects

of mouse type at each support level ($p < .001$). As shown in Figure 7, the middle deltoid muscle activity using the 3M mouse ($M = 4.15$, $SD = 0.41$) was greater than the muscle activity using the Standard mouse ($M = 3.63$, $SD = 0.59$), and muscle activity decreased with forearm support ($M = 3.75$, $SD = 0.60$) compared to no-forearm support ($M = 4.02$, $SD = 0.50$).

Figure 6. Significant interaction of mouse type by sequence conditions for integrated EMG of the middle deltoid.

Table 3

Analysis of variance for method of support and mouse type of the middle deltoid muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Support	1	2.562	52.15***	.000
Support x sequence	3	0.021	0.42	.740
Error(support)	32	0.049		
Mouse	1	9.747	161.68***	.000
Mouse x sequence	3	0.577	9.57***	.000
Error(mouse)	32	0.060		
Support x Mouse	1	0.195	7.46**	.010
Support x Mouse x Sequence	3	0.038	1.47	.242
Error(support x mouse)	32	0.026		

Note. *** $p < .001$, ** $p < .01$.

Figure 7. Significantly increased middle deltoid activity with 3M mouse and decreased activity with forearm support.

Note. Error bars denote standard error.

Anterior Deltoid Muscle

The sequence factor was removed from the analysis because there was no significant interaction with mouse type or method of support. There was no significant main effect of type of support or interaction (see Table 4). A significant main effect of mouse type was found, $F(1, 35) = 34.08, p < .001$. As shown in Figure 8, the anterior deltoid muscle activity with the 3M mouse ($M = 3.52, SD = 0.39$) was less than the muscle activity with the Standard mouse ($M = 3.77, SD = 0.38$).

Table 4

Analysis of variance for method of support and mouse type of the anterior deltoid muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>
Support	1	0.069	2.62
Error(support)	35	0.026	
Mouse	1	2.347	34.08***
Error(mouse)	35	0.069	
Support x Mouse	1	0.002	0.163
Error	35	0.012	

Note. *** $p < .001$.

Figure 8. Significantly lower anterior deltoid muscle activity with 3M mouse than with Standard mouse.

Note. Error bars denote standard error.

Biceps Brachii Muscle

No significant main effects of mouse type or method of support or interaction effects of the biceps brachii muscle were found. Table 5 displays only the 2x2 ANOVA because there were no significant interactions with the sequence factor.

Table 5

Analysis of variance for method of support and mouse type of the biceps brachii muscle

Source	df	MS	F
Support	1	0.001	0.042
Error(support)	35	0.018	
Mouse	1	0.109	1.859
Error(mouse)	35	0.059	
Support x Mouse	1	0.005	0.433
Error(support x mouse)	35	0.011	

Extensor Carpi Radialis Muscle

There were no interaction effects of sequence with method of support or mouse type and therefore the sequence factor was removed from the analysis. A significant main effect of mouse type was found, $F(1, 35) = 66.79, p < .001$. As shown in Figure 9, the extensor carpi radialis muscle activity with the 3M mouse ($M = 4.19, SD = 0.26$) was less than with the Standard mouse ($M = 4.44, SD = 0.22$). There was no main effect of method of support or interaction (see Table 6).

Figure 9. Significantly lower extensor carpi radialis muscle activity with 3M mouse than with Standard mouse.

Note. Error bars denote standard error.

Table 6

Analysis of variance for method of support and mouse type of the extensor carpi radialis muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Support	1	.000	0.04	.851
Error(support)	35	0.009		
Mouse	1	2.271	66.79***	.000
Error(mouse)	35	0.034		
Support x Mouse	1	0.015	3.76	.061
Error(support x mouse)	35	0.004		

Note. *** $p < .001$.

Extensor Carpi Ulnaris Muscle

Integrated EMG values for the extensor carpi ulnaris were square root transformed to correct for non-normality. The sequence factor was removed because there was no significant interaction with method of support and mouse type. A significant main effect of mouse type was found, $F(1, 35) = 4.72, p < .05$. As shown in Figure 10, the extensor carpi ulnaris muscle activity when using the 3M mouse ($M = 156.09, SD = 60.34$) was less than the muscle activity when using the Standard mouse ($M = 147.08, SD = 54.48$). There was no main effect of method of support or interaction (see Table 7).

Figure 10. Significantly greater extensor carpi ulnaris muscle activity with 3M mouse than with Standard mouse.

Note. Error bars denote standard error.

Table 7

Analysis of variance for method of support and mouse type of the extensor carpi ulnaris muscle

Source	df	MS	F
Support	1	1087.636	0.715
Error(support)	35	1520.865	
Mouse	1	2921.731	4.718*
Error(mouse)	35	619.272	
Support x Mouse	1	139.235	.377
Error(support x mouse)	35	139.235	

Note. *p < .05.

Flexor Carpi Radialis Muscle

One participant was removed from the analysis because the dataset remained an outlier even after transformation. The sequence factor was removed because there was no significant interaction with method of support and mouse type. Significant main effects were found for method of support ($F(1, 34) = 27.21, p < .001$) and mouse type ($F(1, 34) = 112.26, p < .001$) (see Table 8). As shown in Figure 11, the flexor carpi radialis muscle activity was greater with no-forearm support ($M = 3.64, SD = 0.48$) as compared to forearm support ($M = 3.50, SD = 0.48$). In addition, as shown in Figure 12, the flexor carpi radialis muscle activity was greater with the 3M mouse ($M = 3.82, SD = 0.43$) than with the Standard mouse ($M = 3.32, SD = 0.40$).

Table 8

Analysis of variance for method of support and mouse type of the flexor carpi radialis muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Support	1	0.726	27.21***	.000
Error(support)	34	0.027		
Mouse	1	8.746	112.26***	.000
Error(mouse)	34	0.078		
Support x Mouse	1	0.035	1.67	.205
Error(support x mouse)	34	0.021		

Note. *** $p < .001$.

Figure 11. Significantly higher flexor carpi radialis muscle activity with no-forearm support than with forearm support.

Note. Error bars denote standard error.

Figure 12. Significantly higher flexor carpi radialis muscle activity with 3M mouse than with Standard mouse.

Note. Error bars denote standard error.

Flexor Carpi Ulnaris Muscle

The sequence factor was removed from the analysis because there was no significant interaction with method of support and mouse type. A significant main effect of method of support was found, $F(1, 35) = 10.05, p < .01$. As shown in Figure 13, there was a decrease in flexor carpi ulnaris muscle activity with forearm support ($M = 3.58, SD = 0.29$) compared to no-forearm support ($M = 3.68, SD = 0.27$). The flexor carpi ulnaris muscle activity was greater with the 3M mouse ($M = 3.66, SD = 0.28$) than with the Standard mouse ($M = 3.60, SD = 0.28$); however, the main effect of mouse type was not significant $F(1, 35) = 3.73, p = .06$ (see Table 9).

Figure 13. Significantly greater flexor carpi ulnaris muscle activity with no-forearm support than with forearm support.

Note. Error bars denote standard error.

Table 9

Analysis of variance for method of support and mouse type of the flexor carpi ulnaris muscle

Source	<i>df</i>	<i>MS</i>	<i>F</i>
Support	1	0.327	10.05**
Error(support)	353	0.033	
Mouse	1	0.110	3.73
Error(mouse)	35	0.030	
Support x Mouse	1	0.013	0.71
Error(support x mouse)	35	0.019	

Note. ** $p < .01$.

Analysis of Variance for Thumb Force

Thumb force data collected using a pinch grip dynamometer before and after performing tasks with the 3M mouse for the two methods of support (forearm support and no-forearm support) was compared using a repeated-measure ANOVA with one between factor to test for sequence (group) effects, which may have occurred due to the counterbalancing of conditions. There was a significant interaction between the sequence factor and the method of support $F(3, 32) = 5.26$, $p < .01$ (see Figure 14). Forearm support significantly improved thumb force when using the 3M mouse when participants received the no-forearm support condition first $t(8) = 2.6$, $t(8) = 2.5$, $p < .05$, for both sequences (Group 1: no-forearm support/3M mouse, no-forearm support /Standard mouse, forearm support/3M mouse, forearm support/Standard mouse; Group 2: no-forearm support/Standard mouse, no-forearm support/3M mouse, forearm support/Standard mouse, forearm support/3M mouse). However, if the 3M mouse with forearm support was performed first (Group 3: forearm support/3M mouse, forearm

support/Standard mouse, no-forearm support/3M mouse, no-forearm support /Standard mouse), thumb force improved with no-forearm support $t(8) = -2.052, p = .074$. If the Standard mouse with forearm support was performed first (Group 4: forearm support /Standard mouse, forearm support/3M mouse, no-forearm support/Standard mouse, no-forearm support/3M mouse), then thumb force remained the same after using the 3M mouse for both support types $t(8) = 0.00, n.s.$

Figure 14. Depicted is the significant interaction of method of support by sequence for thumb force. The sequence in which participants received the method of support affected the change in thumb force with 3M mouse use.

Note. Error bars denote standard error.

Post-Test Individual Preference Questionnaire Analysis

Data collected from the post-test Preference Questionnaire were analyzed for all 36 participants. Results were as follows.

All participants (N = 36) found the shape and buttons of the 3M mouse suitable. However, two participants (5.5%) found the mouse size unsuitable. One reason reported by one participant was that the hand grip on the 3M mouse was too long.

Of the 35 participants 26 (74.3%) preferred the forearm support and nine participants (25.7%) preferred no-forearm support. One participant's preference was reported separately because the response was based on mouse type. This participant preferred forearm support with the 3M mouse and no-forearm support with the Standard mouse.

Of 35 participants, 33 (91.7%) reported the 3M optical mouse comfortable and three participants (8.3%) reported the 3M optical mouse uncomfortable. All participants reported the Standard mouse comfortable (see Figure 15).

Figure 15. Perceived comfort level of mouse type.

Most participants ($n = 34$, 94.4%) found the forearm support comfortable, however, two participants (5.6%) reported the forearm support was not comfortable. Participant comfort level varied with no-forearm support in which twenty-five participants (69.4%) reported no-forearm support comfortable while eleven participants (30.6%) reported no-forearm support uncomfortable (see Figure 16).

Figure 16. Perceived comfort level for method of support.

Of the participants 75 percent ($n = 27$) preferred forearm support over participants who preferred no-forearm support ($n = 9$; 25%; see Figure 17). Participants were evenly divided on their preference of mouse type (see Figure 18).

Figure 17. Subjective preference for forearm support over no-forearm support.

Figure 18. Subjective preference for mouse type between 3M mouse and Standard mouse.

Preferences for different combinations of method of support and mouse type are shown in Figure 19. Overall, participants preferred forearm support and preferences for mouse type were evenly divided under methods of support.

Figure 19. Preferred combination of mouse type and method of support.

Chapter 5

DISCUSSION

The aim of this study was to determine how mouse device and method of support affected the muscular activity in the forearm, shoulder and neck regions when mouse device type varies (i.e., when using a 3M optical mouse and a Standard mouse) and when the method of support varies (i.e., with forearm support and with no-forearm support). In this chapter the findings, suggestions and recommendations for future research are discussed.

EMG data showed that the muscle activity clearly shifted across different muscles of the upper extremity when mouse device and method of support varied.

The reason for examining two mouse types operated with two different handgrip postures (3M mouse: neutral grip and Standard mouse: pronated grip) was that wrist posture has been described as extreme in computer mouse work. Several researchers revealed that individuals operate a computer mouse in extreme wrist ulnar deviation (Flodgren et al, 2007; Gustafsson & Hagberg, 2003; Karlqvist et al., 1994; Keir et al., 1998; Zipp et al., 1983) and external rotation of the shoulder (Karlqvist et al., 1994) increasing the risk of repetitive stress injuries in the upper extremity. Non-mouse operators (e.g., keyboard users) work with the wrist in more of a neutral wrist position with a slight internal rotation of the shoulder, thus decreasing the risk of repetitive stress injuries in the upper extremity (Marcus et al., 2002). It was anticipated that the 3M mouse might facilitate a neutral grip during mouse work which should avoid the mouse work postures described

above, and as a consequence, decrease the muscular activity in the neck, shoulder and forearm regions.

The reason for examining the two methods of support (forearm support and no-forearm support) was that varying upper extremity support has been shown to affect the muscular activity in the forearm and neck-shoulder regions. According to Sillanpaa et al. (2003) and Cook and Burgess-Limerick (2004), supporting the forearm when using a computer mouse decreases the muscular activity in the neck region. It was anticipated that forearm support would decrease the muscular activity in the neck-shoulder region which should decrease the risk of upper extremity musculoskeletal injuries.

Overall, the null hypothesis that mouse device type would not affect the muscular activity of the forearm, shoulder, and neck muscles was rejected. It was revealed that the 3M optical mouse resulted in higher activity in the shoulder muscles with the exception of the anterior deltoid. Increased muscle activity in the forearm flexor muscles and decreased muscle activity in the forearm extensor muscles with the exception of extensor carpi ulnaris were also observed when using the 3M mouse. Contrary to what was expected based on previous research (Aaras & Ro., 1997; Gustafsson & Hagberg, 2003), there was a difference in the upper trapezius muscle activity between the 3M optical mouse and the Standard mouse. Analyses revealed that using the 3M mouse resulted in higher activity of the upper trapezius muscle.

Overall, the null hypothesis that method of support would not affect the muscular activity of the forearm, shoulder, and neck muscles was rejected. Forearm support resulted in lower activity in the forearm and neck muscles as compared to muscle activity

with no-forearm support. There was an interaction effect between mouse device and method of support. Working with the 3M mouse combined with forearm support resulted in higher activity in the shoulder muscles than working with the Standard mouse and no-forearm support. There was a significant decrease in muscular activity when using the Standard mouse with forearm support. This may indicate the difficulty that computer operators have in adopting an ergonomically combined handgrip and upper arm dynamic posture for computer mouse operations.

Neck Muscle Activity

Contrary to what Aaras and Ro (1997) found, analyses revealed significant differences in upper trapezius activity when comparing the 3M mouse to the Standard mouse). Upper trapezius EMG activity was higher with 3M mouse use compared to Standard mouse use. This finding is partially supported by Gustafsson and Hagberg (2003) who reported an increase in the muscular activity of the right upper trapezius for some of their participants and a decrease for others when operating a computer mouse with a neutral handgrip position. There was no decrease in the upper trapezius activity with the 3M mouse when method of support varied. Participants were instructed not to bend their wrist laterally when using the 3M mouse but to move the 3M mouse using the whole arm. Participants were also instructed to keep their elbow rested on the table surface when working with the 3M mouse and forearm support condition. According to observations, a set of participants did not fully comply with the instructions provided to them. In the no-forearm support condition, they spontaneously pushed down on the base of the 3M mouse in an attempt to stabilize the wrist, consequently shrugging the shoulder

slightly (main function of the upper trapezius muscle). In the forearm support condition and in an attempt to stabilize the wrist, participants pushed down on the base of the 3M mouse lifting the elbow slightly off the table to move the 3M mouse that consequently elevated the shoulder slightly. These observations may explain the higher upper trapezius activity associated with the use of the 3M mouse. Instructing participants to move the 3M mouse without bending the wrist made operating the 3M mouse more difficult, thus increasing the muscular activity in the neck area especially with forearm support.

On the other hand, when comparing the no-forearm support to forearm support, upper trapezius muscle activity decreased with forearm support. This result showed that the arm was unloaded by using the forearm support, as found in previous research studies (Aaras et al., 1995; Sillanpaa et al., 2003). All of these factors suggest that the type of device and method of support used during mouse device operation might be important for the neck muscular activity and confirms the challenge to find an ergonomically correct wrist and arm posture to operate a computer mouse (Sillanpaa et al., 2003).

Shoulder Muscle Activity

There was greater activity in the middle deltoid muscle and infraspinatus muscle with the 3M mouse as compared to the Standard mouse. Also, the muscle activity in the middle deltoid muscle and infraspinatus muscle was significantly higher with no-forearm support than with forearm support. An interesting interaction effect between sequence and mouse device was observed in the middle deltoid muscle EMG data. A significant increase of middle deltoid EMG activity was noted when participants progressed from

using the Standard mouse with no-forearm support to using the 3M mouse with both method of support. On the other hand, the muscular activity in the anterior deltoid muscle decreased with 3M mouse use compared to Standard mouse use. An explanation based on observations is that most participants spontaneously kept the upper arm closer to their body when using the 3M mouse (i.e., using the 3M mouse with limited forward movement of the shoulder) compared to participants moving the arm more forward and away from their body (main function of the anterior deltoid muscle) when using the Standard mouse resulting in higher activity in the anterior deltoid muscle. There was no significant difference in anterior deltoid activity with no-forearm support compared to forearm support.

Forearm Muscle Activity

Forearm Extensor Activity

There was less activity in the extensor carpi radialis muscle when working with the 3M mouse compared to working with the Standard mouse. This decrease in muscular activity most likely resulted from operating the 3M mouse with a neutral handgrip compared to using a pronated grip to operate the Standard mouse. However, there was higher activity in the extensor carpi ulnaris muscle when working with the 3M mouse compared to working with the Standard mouse. The reason for this high muscular activity most likely resulted from participants pushing the ulnar side of the hand downward against the base of the 3M mouse in a slight ulnar deviation and extension to anchor the wrist and move the 3M mouse. These results partially agree with the findings from Aaras and Ro (1997) who reported decreased muscular activity in the forearm

extensor muscles when operating a computer mouse with a neutral handgrip and Gustafsson and Hagberg (2003) who reported decreased or unchanged muscular activity in the forearm extensor muscles when operating a computer mouse with a neutral handgrip. Consequently, this difference in the findings supports the need for further research to examine more closely the muscular activity of the forearm extensors muscles when working with a computer mouse coupled with a detailed biomechanical analysis of the wrist range of motion to examine the effect of the above observed changes in wrist dynamic posture when operating a computer mouse with a neutral handgrip.

According to Hagg and Millard (1966) and Aaras and Ro (1997) on computer mouse use, the muscular activity in the forearm extensors muscles is greater than on the forearm flexors muscles because they work as stabilizers of the wrist during mouse use. Consequently, it was assumed that supporting the arm while operating a computer mouse may decrease the activity in the forearm extensor muscles. In the present study, there was no significant difference in the muscular activity in the forearm extensors between no-forearm support and forearm support condition. Forearm support did not decrease the muscular activity of the forearm extensors. This result does not agree with Sillanpaa et al. (2003) findings that forearm support decreased the activity in the extensor carpi radialis muscle. As mentioned previously, participants were instructed to avoid bending the wrist with 3M mouse use and were asked to move the 3M mouse using whole arm movements. An explanation for the non significant effect of forearm support on the forearm extensors muscles, specifically the extensor carpi radialis muscle, may be that participants did not follow the instructions. Most likely participants elevated the shoulder

slightly and pushed the ulnar side of the hand downward in a slight ulnar deviation and extension to anchor the wrist and move the 3M mouse, which consequently forced them to slightly bend the wrist in a radial deviation to facilitate using the thumb for 3M mouse button control. Wrist extension and radial deviation constitute the main function of the extensor carpi radialis muscle. This may explain why the activity in this muscle was not minimized with forearm support.

Forearm Flexor Activity

The activity of the flexors carpi radialis was significantly higher with the 3M mouse than with the Standard mouse. This significant increase may be explained from observations by participants moving the wrist from slight extension and ulnar deviation to stabilize the wrist for moving the 3 M mouse to slight flexion with radial deviation to use the thumb for left and right mouse clicking. There was no statistical significance of mouse device effect on the flexor carpi ulnaris muscle, however EMG activity of the flexor carpi ulnaris was higher when working with the 3M mouse than when working with the Standard mouse.

The flexor carpi radialis muscle and flexor carpi ulnaris muscle were significantly less active with forearm support than with no-forearm support. This finding seems to suggest that supporting the forearm allowed the participants to control the mouse movement with the wrist in a more relaxed posture than with no-forearm support, which resulted in less activity in the forearm flexors. However, further research to uncover these relationships are needed especially because it was also found that there was no

difference in the muscular activity in the forearm extensor muscles between forearm support and no-forearm support.

Thumb Muscle Activity

The current design of the 3M mouse requires the use of the thumb for left and right clicks. One may argue that this design puts the thumb at a biomechanical disadvantage (full extension and abduction), increasing the static activity in the thumb muscles and the risk of musculoskeletal injuries. If this were true, increased fatigue should be observed in the thumb after using the 3M mouse. In the present study, EMG data were not collected from the thumb muscles. However, thumb force was measured using a pinch grip dynamometer to evaluate whether the thumb force decreased following 3M mouse use, which may indicate increased fatigue of the thumb muscles.

Analyses revealed that the order of using mouse device and method of support significantly affected the thumb force. Forearm support improved thumb force if participants performed the condition with no-forearm support first in combination with either the 3M mouse or the Standard mouse. Alternatively, if forearm support was used first with the 3M mouse, thumb force still improved with no-forearm support. There was no statistically significant difference in thumb force after using the 3M mouse for both method of support if participants performed the condition with the Standard mouse and forearm support first. This interesting interaction between the thumb force and sequence of conditions should be examined further. On the other hand, it may not be accurate to predict effects of using the thumb for 3M mouse control from the relatively short term exposure provided by the protocol. This suggests further investigation of the muscular

activity in the thumb with 3M mouse use preferably using EMG measures. Using surface EMG to assess the muscular activity at the thumb level may be challenging because of the small size of the thumb muscles. However, with the advance in technology, small EMG sensors are now available and they can be used to assess the activity of the thumb muscles. An example of these sensors is the SX230 active EMG sensors (Biometrics, Ltd.). In practice, these sensors require only one active sensor to be placed on the body of the muscle and independent of the number of active EMG sensors being used at any one time, only one reference ground cable is required.

Perceived Comfort and Subjective Preference

Overall, working with the 3M mouse was considered to be non strenuous. The majority of participants did not report any discomfort during or after performing the task with the 3M mouse. Most participants were satisfied with the 3M mouse shape and button design.

When asked about their preferred method of support, the majority of participants preferred forearm support over no-forearm support, which most likely seems to be due to the fact that the arm was unloaded by the forearm support as expected.

The result from the “comfort level” questions after experiencing the different modes of interaction (mouse type; method of forearm support) does not agree with the EMG activities concerning the 3M mouse. Nearly all participants found using the 3M mouse comfortable to use, however, the EMG analyses revealed high muscular activity with 3M mouse use. This indicates that it may not be accurate to predict the perceived comfort level when using the 3 M mouse from the relatively short term exposure

provided by the study protocol (4 hour session) and further investigation is needed using longer exposure time to computer mousing task to understand the correlation between EMG activity of the upper extremity muscles and the subjective perceived comfort level when using the 3M mouse. Understanding this correlation will help improve existing ergonomic guidelines on rest periods, exposure time and computer mouse design.

In contrast, perceived comfort level with the Standard mouse and forearm support agrees with the EMG findings. All participants were comfortable working with the Standard mouse and almost all of them found working with forearm support comfortable. More variation was reported in the perceived comfort level associated with no-forearm support. In addition, more participants found no-forearm support comfortable than uncomfortable.

When queried about which of the interaction modes participants would prefer to use, most participants reported their preferences towards forearm support over no-forearm support. Participants were evenly divided in their preference for mouse device type. Preferred mouse device and method of support combinations were rank ordered, and the data revealed the highest preference for forearm support and use of the Standard mouse. Forearm support and 3M mouse use was next, followed by no-forearm support with 3M mouse. The least preferred combination was no-forearm support and use of the Standard mouse. These results indicate that participants preferred to keep the forearm supported as a method to unload the arm (i.e., decrease the muscle activity). As long as the forearm was supported, participants were almost evenly split in their preference for mouse device type.

Conclusion

The present study revealed that muscular activity shifted across different muscles of the upper extremity when mouse device and method of support varied. In contradiction to what was expected, using the 3M mouse increased shoulder and neck muscular activity (with the exception of the anterior deltoid muscle) thus increasing the risk of repetitive stress injuries in these areas. A possible explanation for this increased activity in the neck and shoulder regions with the use of the 3M mouse may be related to increased movement in the shoulder joint as a result of participant attempts to avoid controlling the mouse movement with the wrist. This confirms that wrist postures (radial/ulnar deviation; flexion/extension; pronation/supination) have serious implications on the motor control and coordination of the upper extremity. It highlights the fact that changing wrist orientation on the computer mouse from pronated grip to neutral grip and constraining wrist movements by attempting to operate the 3M mouse using the whole arm, caused higher activity in the shoulder and neck region validating the complex interaction between the muscular activities at different level of the upper extremity and wrist posture during computer mouse use and raising the need for further research to examine this interaction.

As anticipated, the use of the 3M mouse decreased the activity in the forearm extensor muscles with the exception of the extensor carpi ulnaris. Aaras and Ro (1997) and Gustafsson and Hagberg (2003) obtained partially similar results and in line with their research recommendations, the present study supports the need for reducing the pronation of the forearm when working with a computer mouse. On the other hand, the

use of the 3M mouse increased the activity in the forearm flexor muscles. This increased activity with 3M mouse use may be related to participant tendencies to bend the wrist in a slight flexion with radial deviation to use the thumb for left and right clicking. A possible explanation, for the above results may be the design of the 3M mouse. While the shaft of the 3M mouse design succeeded in facilitating a neutral grip and therefore partially decreasing the activity in the forearm extensors muscles, the base of the 3M mouse failed in providing sufficient support for the wrist during mouse movement. The relatively small base of the 3M mouse may have contributed to the small dynamic range of motion observed at the wrist level as participants tried to anchor the wrist down in an attempt to stabilize it to move the 3M mouse on the table surface. Further, the placement of the left and right mouse buttons on top of the shaft increased the need for lateral wrist movement (radial deviation) with thumb abduction/adduction to perform right and left mouse clicking. This suggests the need for further research examining in depth wrist dynamic range of motion during computer mouse activity using electrical goniometry coupled with electromyography. Biomechanical analysis of wrist range of motion with EMG assessment of the upper extremity muscles may help clarify the relationship between wrist dynamic postures and upper extremity muscular activity.

Overall, working with the 3M mouse was perceived as comfortable by the majority of participants and half of the participants preferred working with the 3M mouse over the Standard mouse.

As anticipated, the use of forearm support decreased neck, shoulder and forearm muscular activity with the exception of the extensor carpi radialis muscle. Observations

revealed that the increased activity in the extensor carpi radialis with forearm support may be related to participant tendencies to push the ulnar side of the hand downward in a slight extension with radial deviation in an attempt to stabilize the wrist while moving the 3M mouse using the arm as instructed by the researcher. All participants preferred working with forearm support over no-forearm support. Results from the present study correlate with other studies, which conclude that a need to support the forearm during computer work would be beneficial. Opposite to expectations, using the Standard mouse combined with forearm support decreased the activity in the neck and shoulder muscles. Perhaps once the arm was unloaded with arm support, moving the mouse with the pronated grip did not cause significant muscular activity increase in the upper extremity. For preferred mouse device and method of support combinations, participants preferred mostly forearm support and Standard mouse use followed by forearm support and 3M mouse use.

Finally, forearm support improved thumb force if participants worked initially with no-forearm support in combination with either the 3 M mouse or the Standard mouse. Alternatively, if forearm support was used initially with the 3M mouse, thumb force still improved with no-forearm support. Thumb force remained constant after using the 3M mouse if the participants used the Standard mouse with forearm support first.

The results of this study confirm the complexity of the interaction between handgrip position and muscular activity on the upper extremity. The findings suggest that mouse use may be a risk factor for musculoskeletal repetitive stress injuries, particularly related to arm posture adopted. Results also suggest that mouse device type

may contribute to shoulder and neck discomfort and that further investigation of preventive measures is needed.

In conclusion, there are several suggestions for items requiring further investigation. The results of the current study were delimited to the text editing task chosen and most likely to the relatively short term exposure provided by the study protocol. Foldgren et al. (2007) found that painting rectangles on a computer screen involves the same level of precision and repetitive movements observed during mouse design task. They stated that this painting task is suitable for studying upper extremity musculoskeletal risk factors associated with computer mouse use. Prolong exposure to high precision mousing task increases muscular activity in the upper extremity and therefore the risk of developing musculoskeletal injuries (Roman-Liu et al., 2001). A study could follow the current study design but modify the test protocol to include painting task in which participant can use a painting brush to fill the inside of squares with different colors. Participants can perform this painting task for 2 full working days, eight hours per day. Further, the current study outcome measures were limited to EMG analysis. An objective biomechanical analysis of the wrist movement is missing. Therefore, to better understand how handgrip position affects the neuromuscular responses in the upper extremity, the study can use in addition to electromyography measures, electrical goniometry to measure wrist dynamic range of motion when using the computer mouse in both neutral and pronated grip position.

Further, in the current study observations of participants revealed that most participants, in order to avoid moving the 3M mouse with the wrist in the forearm support

condition, pushed the wrist downward on the table surface and cleared the elbow off the table surface by slightly shrugging the shoulder to move the 3M mouse with the whole arm, instead of simply using the arm and sliding the forearm on the table surface as instructed. This significantly increased the muscular activity in the neck and shoulder regions. Therefore, the activity in the neck and shoulder muscles should be compared with both handgrip positions (pronated and neutral grip), but with control of wrist lateral bending to provide more support for the wrist (especially when controlling the mouse in a neutral hand grip) and with more freedom of elbow movement on the table surface to control shoulder elevation and facilitate sliding the forearm on the table surface. A study could be designed to examine the effect of wrist support pad in combination with the 3M mouse and the Standard mouse in both methods of support, but modify the forearm support condition to drop the elbow off the table surface to minimize the need to clear the elbow by shrugging the shoulder to move the 3M mouse.

Another suggestion would be to compare the activity in the forearm muscles while operating a computer mouse with both handgrip positions, but with control of the thumb and wrist postures in the neutral handgrip condition to provide more biomechanical alignment at the wrist and limit the tendency for radial deviation and wrist extension that was observed with 3M mouse use. This suggests a need to design an alternative mouse device structure to facilitate neutral handgrip, but with button placement and control similar to Standard mouse button design and a wider base to provide more support for the wrist.

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Appendix A

Human Subjects-Institutional Review Board Approval

San José State
UNIVERSITY

**Office of the Academic
Vice President**
Academic Vice President
Graduate Studies and Research
One Washington Square
San José, CA 95192-0025
Voice: 408-283-7500
Fax: 408-924-2477
E-mail: gradstudies@sjsu.edu
http://www.sjsu.edu

To: Nahida Lebbos
4 Bayside Village Place, #303
San Francisco, CA 94107

From: Pam Stacks,
Interim AVP, Graduate Studies & Research

Date: July 13, 2004

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

“Mouse Device and Method of Support on Muscular Activation.”

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Pam Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subjects portion of your project is in effect for one year, and data collection beyond July 13, 2005 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

cc: Dr. Emily Wughalter

The California State University:
Chancellor's Office
Bakersfield, Channel Islands, Chico,
Dominguez Hills, Fresno, Fullerton,
Hayward, Humboldt, Long Beach,
Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San Jose, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

Appendix B

Background Questionnaire

Date ____/____/____

Cipher ____

A. Please answer all questions.**B. Please mark boxes and lines as follows:**Small boxes ☐ should get a checkmark “√” or an “x”

Lines should get numbers or text: _____

C. Watch for special instructions relating to a question or set of questions.

1. What is your gender?
 - a. ☐ Female
 - b. ☐ Male
2. What is your occupation?
 - a. ☐ Student
 - b. ☐ Office worker
 - c. ☐ Other _____
3. How old are you? _____ years old
4. How tall are you? _____ ft _____ In.
5. How much do you weight? _____ lbs
6. Are you right or left handed?
 - a. ☐ Right
 - b. ☐ Left
7. On average, how many hours per day do you use a computer mouse?
_____ hours

8. Rank order the type of mouse design you use from most to least
(1=most; 4=least)
- a. ___ Traditional
 - b. ___ Track ball
 - c. ___ Touch pad
 - d. ___ Other _____
9. What is the total length of time that you can spend using a computer mouse without any signs of discomfort or fatigue?
_____ hours
10. Have you ever had shoulder problems (aches, pain/discomfort, or injury)?
- a. ☐ Yes in my right shoulder
 - b. ☐ Yes in my left shoulder
 - c. ☐ No
11. Have you ever had other upper extremity, neck, elbow, wrist, and/or finger problems (aches, pain/discomfort, or injury)?
- a. ☐ Yes in my neck
 - b. ☐ Yes in my right elbow
 - c. ☐ Yes in my left elbow
 - d. ☐ Yes in my right wrist
 - e. ☐ Yes in my left wrist
 - f. ☐ Yes in my right index
 - g. ☐ Yes in my left index
 - h. ☐ Yes in my right thumb
 - i. ☐ Yes in my left thumb
 - j. ☐ No
12. Have you experienced any shoulder or upper extremity discomfort in the last 7 days?
- a. ☐ Yes
 - b. ☐ No

San José State
UNIVERSITY

**Department of Industrial
& Systems Engineering**

Room 283, Engineering Building
One Washington Square
San José, CA 95192-0085
Voice: 408-924-3301
Fax: 408-924-4040
E-mail: isengr@email.sjsu.edu
<http://www.engr.sjsu.edu/ise>

The California State University:
Chancellor's Office
Bakersfield, Channel Islands, Chico,
Dominguez Hills, Fresno, Fullerton,
Hayward, Humboldt, Long Beach,
Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San José, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

Appendix C

Agreement to Participate in Research

Responsible Investigator: Nahida Lebbos

Title of Protocol: Mouse Device and Method of Support
on Muscular Activity

1. I have been asked to participate in a research study investigating the electromyographical activity of the following upper extremity muscles: upper trapezius, anterior and middle deltoid, infraspinatus, biceps brachii, flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis and extensor carpi ulnaris muscles during computer mouse use. The purpose of this research study is to determine how mouse device and method of support affect the muscular activity in the forearm, shoulder and neck regions.
2. I will be asked to participate in a 4 hour test session including orientation, completion of pre-test and post-test questionnaires, electromyographic surface electrodes set-up, and performance of mouse tasks (editing and painting) with an HTML software interface at the Human Automation Integration Laboratory in the Engineering Department at San Jose State University.

Participant's Initials _____

3. The risks associated with this study are negligible, but may include skin irritation from preparing the skin for electrode placement, muscle fatigue and soreness from performing 20 trials of editing a text table and painting a table of four squares using a computer mouse.
4. The potential benefit of my participation in this research study is to help reduce the risk of upper extremity disorders associated with computer mouse use.
5. The results of this research study may be published; however my name will be kept confidential. To maintain my anonymity, the Responsible Investigator will code my name with a specific cipher and this cipher will be used on all test data sheets and only she will have access to the confidential coded participants list, which will be destroyed after the end of data collection.
6. I understand that I am volunteering to participate in this research study and I will not receive any compensation for my participation.
7. Questions that I may have regarding this research study will be answered by Nahida Lebbos at (415) 310-0271. Complaints about any aspect of this research may be presented to Dr. Emily H. Wughalter, Ed.D. (Thesis Chair) at (408) 924-3043. Questions about research participants' rights or research-related injury may be presented to Pamela stacks, Ph.D., Interim, Associate Vice President, Graduate Studies and Research, at (408) 924-2480.
8. No service of any kind, to which I am otherwise entitled, will be lost or jeopardized if I choose not to participate in the study.
9. My consent is being given voluntarily. I may refuse to participate in this entire study or in any part of the study. If I decide to participate in this study, I am free to withdraw at any time without any negative effect on my relations with San Jose State University.

Participant's Initials _____

10. At the time that I sign this consent form, I will receive a copy for my records that is signed and dated by the Responsible Investigator.

11. My signature on this consent form indicates my agreement to participate in this research study.

Participant's signature

Date

12. As the Responsible Investigator, I certify that I have informed the participant about the purpose, methods, and risks associated with participating in this research study. I have answered the participant's questions that were raised and have witnessed the participant's signature.

Investigator signature

Date

Participant's Initials _____

Appendix D

3M Optical Mouse

Appendix F

Kensington Three-Button Optical Mouse (Standard Mouse)

Appendix G

Work Seat

Appendix H

Workstation for Forearm Support Condition

Forearm Support with
Standard Mouse

Forearm Support with
3M Mouse

Appendix I

Workstation for No-forearm Support Condition

No-forearm Support with
Standard Mouse No-forearm Support with
3M Mouse

Appendix J

Thought Technology 10-Channel Biofeedback Encoder

Thought Technology, Ltd., Montreal, Quebec, Canada

Thought Technology MyoScan Sensor with adhesive electrodes

Appendix K

Symbol Manipulation Task with Colored Squares and Mouse Symbols

D1	D2			C1	C2
D3	D4			C3	C4
	A1	A2	B1	B2
	A3	A4	B3	B4
	C1	C2	D1	D2
	C3	C4	D3	D4

Appendix L

Mouse Device and Method of Support Counterbalance Diagram

In the following diagram the independent variables are represented as follows:

Method of support:

FS: forearm support

NFS: no-forearm support

Mouse device:

3M: 3M mouse

SM: Standard mouse

Appendix M

Pinch Grip Dynamometer

Measuring thumb force with a pincer grip using a pinch grip dynamometer

Appendix N

Individual Preference Questionnaire

Cipher ---

A. Please answer all of the following questions.**B. Mark boxes and lines as follows:**Small boxes ☐ should get a checkmark "√" or an "x":

Lines should get text: -----

C. Please watch for special instructions relating to a question or set of questions.

1. Did you experience any discomfort during or after using the 3M optical mouse?

a. ☐ Yesb. ☐ No

If yes, please answer question 2, if no, please skip to question number 3

2. Please indicate the type of discomfort, location and time of occurrence?

Type of discomfort	Location (Fingers, wrist, forearm, arm, shoulder and neck)	During use	After use
a. ☐ Pressure points	-----	-----	-----
b. ☐ Fatigue	-----	-----	-----
c. ☐ Tightness	-----	-----	-----
d. ☐ Cramp	-----	-----	-----
e. ☐ Stiffness	-----	-----	-----
f. ☐ Pain	-----	-----	-----
g. ☐ Others	-----	-----	-----

3. Do you consider the design of the 3m optical mouse (in terms of size, shape and buttons location) suitable for your right hand?

Size

☐ Yes ☐ No

Shape

☐ Yes ☐ No

Buttons location

☐ Yes ☐ No

4. Which method of support do you prefer the most?

a. ☐ Forearm support

b. ☐ No-forearm support

5. Please circle your comfort level when using the following:

	VU	U	SU	N	SC	C	VC
3 M optical mouse	1	2	3	4	5	6	7
Kensington mouse	1	2	3	4	5	6	7
Forearm support	1	2	3	4	5	6	7
No-forearm support	1	2	3	4	5	6	7

*VU: very uncomfortable; U: uncomfortable; N: neutral; SC: somewhat comfortable; C: comfortable; VC: very comfortable

6. If you had a choice, which of the following would you prefer to work with? (Choose 1 from each column):

Combined

Mouse device

Method of support

a. ☐ Forearm support & 3M mouse

a. ☐ 3M mouse

a. ☐ Forearm support

b. ☐ Forearm support & Kensington mouse

b. ☐ Kensington mouse

b. ☐ No-forearm support

c. ☐ No-forearm support & 3M mouse

d. ☐ No-forearm support & Kensington mouse