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EMG activity of the upper trapezius during computer mouse use in three locations

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EMG ACTIVITY OF THE UPPER TRAPEZIUS
DURING COMPUTER MOUSE USE IN THREE LOCATIONS

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ABSTRACT

EMG ACTIVITY OF THE UPPER TRAPEZIUS
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In a laboratory-based mouse placement comparison study, 18 college students performed mouse-intensive computer tasks in 3 mouse placement conditions (short, standard, and keypad cover). Surface electromyography (EMG) measured left and right upper trapezius (UT) muscle activity. Higher muscular load was identified in the right UT when inputting with the mouse in the keypad cover condition using a within-subjects one-way analysis of variance design. Baseline pre- and post-EMG activity showed no fatigue effect. Data were also collected for operator technique; preference of mouse placement conditions; and comfort and discomfort. Subjective findings were not in agreement with direct measurements. The EMG results do not support using the keypad cover as an ergonomic accessory. Further studies on the effects of ergonomic accessories on pointing device positioning, posture, and performance are needed to identify optimal human-computer interaction.

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INTRODUCTION

Upper extremity musculoskeletal disorder (UEMSD) cases have steadily increased nationwide since 1983 in the worker's compensation system (Brogmus, Sorock, & Webster, 1996; CTDNEWS, 1997a). UEMSDs stemming from the advent and widespread use of computers only recently have led to studies on the effects of keyboarding on the upper extremities (Faucett & Rempel, 1996); however, alternative input devices are also suspected to contribute to UEMSDs (Hagberg, 1995).

The most common alternative input device, the computer mouse, is being used more since the emergence of graphical software programs, internet communication, and an increasingly computer-oriented world-society (CTDNews, 1997b; Fogleman & Brogmus, 1995). Many employees have reported UEMSDs related to using the mouse (CTDNews, 1997b; Hagberg 1995). One study has shown that the mouse is used 31% of the time during word processing activity, 42% of the time during spreadsheet/database activity, and 65% of the time during graphics/drawing activity (Johnson, Hewes, Dropkin, & Rempel, 1993). During the last decade, a continuous stream of studies was published related to the physical detriments of using a computer mouse (e.g., Armstrong, Martin, Franzblau, Rempel, & Johnson, 1995; Damann & Kroemer, 1995; Dowell & Gscheldle, 1997; Fogelman & Brogmus, 1995; Franco, Castelli, & Gatti, 1992; Hagberg, 1995; Johnson, et al., 1993; Johnson, Tal, Smutz, & Rempel, 1994; Karlqvist et al., 1998; Karlqvist, Hagberg, & Selin, 1994; Paul & Nair, 1996; Wells, Lee, & Bao, 1997). These studies address problems related to the arms, wrists, and hands, but seldom refer to shoulder problems.

Sommerich, McGlothlin, and Marras (1993) reported that shoulder region pain ranks second only to neck and lower back pain in clinical frequency, and that occupational shoulder illnesses are on the rise. Shoulder disorders are common to employees who spend much of the workday alternating between using the keyboard and the mouse (Hagberg, 1994). A limited number of research studies have investigated the shoulder in relation to mouse use (Karlqvist et al., 1994; Karlqvist et al., 1998; Paul, Lueder, Selner, & Limaye, 1996; Paul & Nair, 1996).

Symptoms in the shoulder frequently occur during prolonged, repetitive activity involving a forward flexed cervical spine and elevated arms with high workload, precise physical performance, and cognitive demands (Kilbom & Persson, 1987; Kroemer, 1989). Several studies have investigated muscle activity in the shoulder during keyboarding as measured by electromyography (EMG) (Aaras, Veierod, Larsen, Ortengren, & Ro, 1996; Aborg, Fernstrom, & Ericson, 1995; Fernstrom, Ericson, & Malker, 1994; Hermans & Spaepen; Waested & Westgaard, 1996); however, only three EMG studies were found concerning the shoulder during mouse operations (Karlqvist et al., 1998; Paul, et al., 1996; Wells, et al., 1997).

<u>Problem Statement</u>

The purpose of this study was to determine the effects of computer mouse placement on muscle activity in the right and left upper trapezius.

<u>Research Hypothesis</u>

The following research hypothesis was made for the purpose of the study:

1. The placement of the computer mouse will affect muscle activity of the right and left upper trapezius. The keypad condition was expected to register higher right upper trapezius muscle activity than the short keyboard condition due to increased shoulder elevation. It was anticipated that the standard keyboard condition will register higher right upper trapezius muscle activity than the short keyboard condition but lower than the keypad condition since the electrodes could register some muscle activity related to shoulder abduction. It was expected that there would be no difference in muscle activity in the left upper trapezius between treatment conditions.

Limitations

This study was limited by the following:

1. Individual differences among participants, such as, (a) body structure (for example, some may have broader shoulders or wider waistlines than others which would change the approach angle to the mouse and possibly result in awkward postures for some, such as external elbow rotation when using a mouse with standard keyboard arrangement, (b) mouse input style (for example, some participants may use the dragging feature, anchor their volar wrist (anterior surface at carpal tunnel region) and move the mouse with their hand rather than the entire arm, apply more force with the arm than the shoulder when moving the mouse, or lift the mouse up off of the mouse pad surface), (c) visual ability (for example, some participants may have unidentified or uncorrectable visual problems), and (d) posture (for example, leaning to one side or a forward flexed rather than an erect sitting posture will change body mechanics when using the computer

mouse).

2. Test conditions that do not measure the exact speed of performance, only the relative type of tasks completed within the time allotted.

3. The number keypad cover prevents use of the number keypad, which is preferred by many computer users who alternate between inputting data with the number keys on the keypad and the mouse.

Delimitations

The study was delimited to:

1. Student participants at San Jose State University between the ages of 18 and 65 years who were willing to be evaluated in a computer laboratory setting.

2. Participants who had more than 10 hours of experience using Windows 98 and Microsoft Office 97 software interfaces, a standard mouse with the right hand, and a PC computer.

3. Participants who reported being free from shoulder disorders/pain.

4. The Adaptables, Inc. non-adjustable number keypad cover, the Great Quality, Inc. Mini-Keyboard, the Dell, Inc. standard keyboard, the Microsoft, Inc. two-button mouse, and the Humanscale, Inc. thin keyboard tray with pull-out lily pad mouse trays were used in this study. The lily pad mouse trays were positioned at a height 0.50 in. (1.27 cm) below the keyboard tray, and articulated out from both sides of the keyboard tray. Only the lily pad on the right side was used during this study for the standard keyboard and mouse condition.

5. The same neoprene mouse pad surface for all mouse locations. (Specifically, the neoprene pad was placed over the top of the smooth hard plastic Adaptables, Inc. non-adjustable number keypad cover or positioned on the mouse tray with the standard keyboard arrangement and positioned on the keyboard tray with the short keyboard arrangement.)

6. The Thought Technology, Ltd. Biograph® Version 2.0 with the EMG modalities.

7. Pregelled and preset interelectrode distances on Thought Technology's tripolar Triode™ active surface electrodes because of conductivity, ease of application, minimal discomfort, and standardization of procedures.

Assumptions

The researcher assumed that:

1. Participants responded honestly and accurately about having no recent history of shoulder disorders (as measured by the modified Standardized Nordic Questionnaire).

2. Standard ruler and goniometer measurements were accurate and reliable.

3. The researcher was accurate and reliable in visually locating and palpating the upper trapezius for electrode placements.

4. The researcher vigorously cleaned the shoulder points of contact for electrode placement and the electrode points of contact provided ample conductivity.

Definition of Terms

The following terms are defined in reference to their use in this study:

Computer Mouse. An electronic device that acts as an adjunct to a keyboard by allowing quick movement of a cursor across the screen and selection of an item without having to use slower cursor movement functions of the keyboard (Davie, Katifi, Ridley, & Swash, 1991).

Motor Unit. A motor unit consists of one motoneuron, its axon branches, and all of the muscle fibers that they innervate. It is the smallest functional part of the neuromuscular system. In each muscle, motor units vary in size within a characteristic range. The mean size may comprise as few as three or as many as 2000. Mean motor unit size is relative to the function of the muscle (Loeb & Gans, 1986; U.S. Department of Health and Human Services, 1992).

Motor Unit Action Potential. The motor unit action potential is the waveform consisting of the spatio-temporal summation of individual muscle fiber action potentials originating from muscle fibers in the vicinity of a given electrode or electrode pair (Loeb & Gans, 1986; U.S. Department of Health and Human Services, 1992).

Mousetrapper. A bimanually-operated and centrally-located pointing device that allows the computer operator to keep the numeric keypad while avoiding reaching to the sides of the keyboard to operate the computer mouse.

Number Keypad Cover. Also known as Mouse Bridge, Mouse Caddy, and Mouse Stage. Generally, a thin, plastic sheet that fits over (horizontally) and conceals the number keypad portion of the keyboard. The number keypad cover provides a flat surface close to the standard keys of the keyboard for mouse placement and use. There are several different brands and types of number keypad covers sold to consumers.

Shoulder Abduction. The scapula slides laterally and forward along the surface of the ribs (Rasch & Burke, 1978).

Shoulder Adduction. Movement of the scapula medially toward the spinal column (Rasch & Burke, 1978).

Shoulder Circumduction. A combination of movements that cause the elbow to describe a circle (Rasch & Burke, 1978).

Shoulder Extension. Backward elevation of the arm (Rasch & Burke, 1978).

Shoulder External Rotation. Transverse rotation of the humerus (around its long axis clockwise) toward the front of the body (Rasch & Burke, 1978).

Shoulder Flexion. Forward elevation of the arm (Rasch & Burke, 1978).

Shoulder Internal Rotation. Transverse rotation of the humerus (around its long axis counterclockwise) toward the back of the body (Rasch & Burke, 1978).

Surface Electrodes. When attached to the skin above the muscle segment under study, surface electrodes can gather EMG signals. They are used to study an entire muscle group. Silver-silver chloride electrode disks are placed on the skin's surface. Commercially available electrodes range in diameter from 1 to 5 mm for the active part of the electrode that is usually assembled with a plastic surround to enable adhesion to the skin. Generally, bipolar or tripolar ones are used so that there is an additional ground connection being made between the participant and the electronic amplifier (Loeb & Gans, 1986; U.S. Department of Health and Human Services, 1992).

Surface Electromyography (EMG). A technique whereby voltage-measuring electrodes are attached to the skin's surface and used to detect and/or infer various events, such as force, fatigue, and usage of muscles, relating to muscular contractions. The potential difference (voltage) of electrical activity produced between charged objects moving free electrons between the inside and outside of a cell is measured by the electrodes. At rest, the polarized muscle fiber remains in equilibrium until upset by a stimulus. When a muscle cell is stimulated by the arrival of a nerve impulse, the membrane potential is reduced, the muscle cell becomes depolarized, and ions move across the membrane. The ionic migration to extracellular regions produces a motor unit action potential, which is detected and recorded by EMG electrodes. The EMG electrodes are connected to an amplifier and a display or an output system to read the EMG signal data (Loeb & Gans, 1986; U.S. Department of Health and Human Services, 1992).

Upper Extremity Musculoskeletal Disorder (UEMSD). An UEMSD is an abnormal physical condition that occurs when force is applied repeatedly over a prolonged period to the same muscle group, joint, or tendon to the extent that it causes soft tissue micro-tears and trauma. Key risk factors include repetition, high force, awkward joint posture, direct pressure, vibration, and prolonged constrained posture. The disorders can involve nerves, blood vessels, or tendons, which connect muscles to bones. UEMSDs are often complex, multi-factorial interactions between exposure, dose, response, and capacity (Armstrong, et al., 1993; Rempel, Harrison, & Barnhart, 1992).

Importance of the Study

Human-computer interaction programs have made the mouse a dominant input device and in some instances, mouse use is greater than keyboard use (CTDNews, 1997b). Recently, the literature has identified the computer mouse as a source of UEMSDs (Hagberg, 1995). The placement of the mouse to the right of the keyboard results in awkward posturing of the right shoulder (Hagberg, 1995; Karlqvist et al., 1994; Karlqvist et al., 1998). When the mouse is placed to the far right of the computer monitor, far forward from the user's torso, and on the table top above the keyboard tray height, the user must extend and elevate the arms, thereby raising, outwardly rotating, and abducting the shoulder (Bass, 1993; CTDNews, 1997b; Karlqvist et al., 1998).

To improve positioning of the right shoulder some vendors of office products (e.g., Alimed®, Source One®, and Keyboard Alternatives & Vision Solutions) are recommending various prefabricated number keypad covers that fit over and conceal the number keypad portion of the keyboard (refer to Appendix A). People who frequently use their numeric keypad rarely use this keyboard accessory. Still, some will switch to using the number keys on the keyboard that appear on the upper row or embedded number keys (when available) so they can reduce the lateral or forward reach to the mouse. Since the keypad covers (also known as mouse bridges) are positioned higher when compared to the mouse placement with a standard keyboard, the keypad cover might raise the shoulder and create more strain on the shoulder and neck muscles. The physical effects of using ergonomic aids, such as number keypad covers, are unknown since a limited number of studies have been conducted to determine their effectiveness (Morse, 1995; Paul & Nair, 1996).

The effect of a combined numeric keypad cover and keyboard set-up on shoulder/scapula muscle activity has not been evaluated. The purpose of this study is to evaluate the effects of the placement of a mouse on right and left shoulder muscles when computer operators maintain the elbow at a 90° angle to the keyboard height and use a mouse on a numeric keypad cover, a mouse tray surface next to and slightly below the standard-size qwerty nonadjustable keyboard, and a keyboard tray surface next to the short qwerty nonadjustable keyboard. Comparing the physical requirements and subjective ratings of the three computer keyboard-mouse arrangements can assist ergonomists in making appropriate recommendations for optimal placement of the computer mouse. Perhaps the results will allow designers to envision an input/keyboard configuration that will reduce the amount of UEMSDs associated with computer mouse usage.

REVIEW OF LITERATURE

The review of literature chapter is divided according to the following subheadings: shoulder kinesiology; shoulder region MSDs (musculoskeletal disorders) associated with computer use; UEMSDs associated with the computer mouse; frequency, duration, force, and speed of input on a computer; EMG (electromyography) and shoulder pain; and shoulder posture during mouse use.

Shoulder Kinesiology

The shoulder girdle is made up of four bones: the scapula (shoulder blade), the humerus (upper arm bone), the clavicle (collarbone), and the sternum (breastbone). Movement of the shoulder occurs at four joints articulating these four bones. Two primary joints of the shoulder girdle are the glenohumeral joint and the scapulothoracic joint. The glenohumeral joint is a ball-and-socket joint that allows movement of the upper arm in many planes. These include flexion and extension, abduction and adduction, external and internal rotation, and circumduction (refer to Definition of Terms). The scapulothoracic joint involves scapula movement on the thorax. The scapula has no joint articulation with the main skeleton and is held to the thorax by muscles and articulations with the clavicle and the acromioclavicular and sternoclavicular joints. The acromioclavicular joint connects the acromion process of the scapula to the clavicle. The acromion makes up the roof of the shoulder and is commonly used as a marker for measuring anthropometrics. It can be palpated on the outer tip of the shoulder joint. The sternoclavicular joint connects the sternum to the clavicle. The planes of motion of the scapula on the thorax include upward rotation and downward rotation, elevation and depression, protraction and retraction, anterior tipping (rounding), posterior tipping, and winging (Perry, Rohe, & Garcia, 1992). Full motion of the shoulder requires synchronous motion of these joints moved by muscles attached to the shoulder girdle. Smooth, synchronous motion is determined by the scapulohumeral rhythm. After 30° of shoulder motion, there is a 2:1 ratio of movement of the shoulder (humerus) to the scapula; for example, for every 20° of shoulder motion there is 10° of scapular motion (Rasch & Burke, 1978). Restriction or lack of synchronous motion at any of the joints of the shoulder girdle will restrict mobility and fluidity of shoulder motion.

Muscles connect the bones of the shoulder girdle with the main skeleton and produce movement at the shoulder. Posterior muscles are the levator scapulae, trapezius, rhomboid, and latissimus dorsi (with an anterior insertion). The levator scapulae and trapezius are the prime movers for elevation of the shoulder girdle. The levator scapulae are small muscles on the back and sides of the neck beneath the upper portion of the trapezius. The trapezius muscle is a triangular sheet of fibers located on the posterior surface of the neck and shoulder, which lies immediately beneath the skin. It is flat and thin, except in the upper thoracic and low cervical regions where it is thick and diamond-shaped. The upper fibers of the trapezius either draw the head back or to one side if the scapula is fixed. When the scapula is not fixed, the upper fibers elevate and upwardly rotate the scapula as when shrugging or hiking the shoulder. The upper trapezius works in concert with the levator scapulae and upper digits of the serratus anterior to passively support, elevate, and upwardly rotate the scapula. The middle fibers of the trapezius are a prime mover for retraction of the scapula, and the lower trapezius depresses and rotates the scapula downward, and assists with retraction (Netter, Mitchell, & Woodburne, 1987; Thomas, 1993).

Anterior shoulder muscles are the subclavius, pectoralis major, pectoralis minor, serratus anterior (lateral), and coracobrachialis. One part of the deltoid muscle is located on the anterior side. The deltoid surrounds the superior portion of the shoulder joint and is divided into the anterior, middle and posterior deltoid. The anterior deltoid flexes and horizontally adducts the shoulder; the middle deltoid abducts the shoulder, and the posterior deltoid extends and horizontally abducts the shoulder joint. Four muscles contribute to the rotator cuff including the supraspinatus, infraspinatus, teres minor, and subscapularis. The tendons form a cuff on the humeral head and help raise and rotate the arm by keeping the humerus tightly in the socket (glenoid fossa) of the scapula during shoulder motion. Shoulder muscles rarely act independently of one another, and the ultimate purpose of all shoulder motion is to increase the area through which the hand may move. In every arm movement there is an associated movement of the shoulder girdle. Shoulder stabilization is required for the arm to remain in a static position (Rasch & Burke, 1978). In this capacity, it is not surprising to find shoulder MSDs associated with computer input activity (Hagberg, 1995).

Shoulder Region MSDs Associated with Computer Use

Shoulder region MSDs are painful conditions affecting muscles, nerves, bursae, tendons, tendon sheaths, and blood vessels (Gerr, Marcus, & Ortiz, 1996). Examples of shoulder region MSDs frequently considered to be work-related include neck torsion syndrome, neck tension syndrome, thoracic outlet syndrome, myofascial syndrome, cervobrachial disorder, tendinitis, shoulder impingement, and bursitis (Armstrong et al., 1993, 1995; Hagberg, 1995; Johnson et al., 1993; Keyserling, Stetson, Silverstein, & Brouwer, 1993; Rempel et al., 1992; Sauter, Schleifer, & Knutson, 1991; Sommerich et al., 1993).

A population-based survey (Pope, Croft, Pritchard, Macfarlane, & Silman, 1996) suggested that shoulder pain is very common, occurring in 7 - 20% of the adult population. Sommerich et al. (1993) reported that shoulder region pain ranks second only to neck and low back pain in clinical frequency, and that occupational shoulder illness is on the rise. Also, a survey of health problems of 3,819 computer workers showed that second only to eyestrain (70.3%), pain and stiffness in the neck or shoulders were reported by 52.4% of the respondents (Evans, 1985). Tension neck syndrome appears to have the highest rate of occurrence (Hagberg & Wegman, 1987). Constant fatigue and/or tenderness and stiffness, particularly in the upper trapezius region, characterize this syndrome (Hermans & Spaepen, 1995).

Shoulder girdle discomfort in computer use stems mainly from static loads on shoulder muscles. Static muscle loading occurs when a muscle is contracted at a heightened state of tension over a prolonged interval (Sauter et al., 1991). Several studies (Aborg et al., 1995; Faucett & Rempel, 1994; Hagberg & Sundelin, 1986; Sommerich et al., 1993) have shown a relationship between upper-arm elevation and shoulder muscle load, or that working with raised arms increases the risk of neck and shoulder MSDs. Keyboards and mice situated above elbow height induce UEMSD symptoms (Faucett & Rempel, 1994; Sauter et al., 1991). Shoulder girdle injuries are of special concern because options for their prevention may be limited. The addition of the mouse to the computer workstation has not reduced the frequency of UEMSD occurrences (Fogelman & Brogmus, 1995). Incorporating mouse technique into computer operations changes working posture and movements compared to keyboard use without the mouse (Karlqvist et al., 1994). The risk of injury to the shoulder girdle during mouse use has not been fully examined; further research would provide useful information for computer operators, computer device manufacturers, and ergonomic specialists (Hagberg, 1995).

<u>UEMSDs Associated with the Computer Mouse</u>

A growing number of computer users appear to be developing shoulder injuries related to mouse use (Armstrong et al., 1995; Hagberg, 1995; Johnson et al., 1993). Fogelman and Brogmus (1995) performed a computer search involving data from nearly two million claimants of the Liberty Mutual Insurance Company. The researchers matched verbal strings of computer letters and words related to UEMSDs (also termed cumulative trauma disorders of the upper extremity) and computer mouse use to identify computer mouse-related claims. They discovered that computer mouse MSDs accounted for only .04% of all claims, 1.05% of UEMSDs, and 6.1% of computer UEMSDs in 1993. These statistical findings, particularly associated to computer mouse use, may be underestimated since the method used in the study was based on a brief narrative description of each accident, and identified only if the claim description had a string matching those chosen by the authors. Also, there is a general awareness of computer-related MSDs, but not of the computer mouse as a causal factor. In the Fogelman and Brogmus (1995) study, data analysis revealed that computer mouse users experienced more injuries related to shoulder strain than carpal tunnel syndrome, and that computer mouse injury claims were more likely to involve the hand, lower arm, upper arm, clavicle and scapula than all UEMSDs or ones which were computer-related.

According to Fogelman and Brogmus (1995), computer mouse UEMSD worker's compensation claims are increasing rapidly, and since using a mouse is a fairly new trend, there is a potential for persistent growth of work injury claims related to mouse use in the future. In 1994, Webster and Snook also used Liberty Mutual's computer database and found that the mean cost per case of UEMSDs was nearly twice the amount for the average workers' compensation claim, and the median cost per UEMSD case was five times the amount for the median of all compensable claims. Johnson et al. (1993) stated that people most prone to problems from using the computer mouse are: 1) intensive mouse users where use constitutes nearly 100% of the job, or 2) unconditioned mouse users who are periodically required to use the mouse full-time.

One survey study of 475 male and 67 female computer-assisted design (CAD) operators with identical work tasks showed that the CAD operators who used the mouse at least 5.6 hours per week reported more arm discomfort than did the CAD operators who performed fewer hours of mouse-based work (Karlqvist, Hagberg, Koster, Wenemark, & Anell, 1996). Additionally, CAD operators using a nonoptimal mouse location reported more symptoms from shoulder joints, shoulders, elbows, and wrists than those using an optimal mouse location. The optimal and nonoptimal mouse locations were formulated based on studies of biomechanical torque and musculoskeletal loads in the neck and shoulders. Intra- and intermethod reliability tests were completed prior to the study with engineers, epidemiologists, and secretaries who use mouse-based software programs to research data and compose, copy, and edit text. The reliability tests with a test-retest method revealed high intramethod reliability on questions concerning weekly computer input duration and mouse use duration, and the locations of the keyboard and the mouse on the working table. Elbow angle during computer work and time spent in meetings and discussions had low reliability.

Hagberg (1995) disputed the belief that there is a mouse-arm syndrome after sending questionnaires to 751 computer operators who were using a computer mouse 2 - 10 hours per week. Hagberg required participants to mark the location of their symptoms on a mannequin drawing and the intensity of symptoms on a digital visual analogue scale (VAS). The findings support the idea that computer mouse use may cause symptoms not only in one part of the body, but in several regions in specific combinations. Hagberg concluded from the responses that three different morbid processes may cause the symptoms related to mouse use, including shoulder-scapular pain, wrist pain, and hand-finger symptoms; therefore, the term syndrome does not apply. Furthermore, the author speculated that postural strain related to low level static loading on the upper part of the trapezius muscle is recruited by having to reach out away from the body to use the mouse as opposed to keeping the arm closer to the torso.

Elevating and flexing the shoulders for prolonged periods can shorten the musculature of the levator scapula and upper trapezius (Hagberg, 1995). Moreover, blood flow and oxygen to the muscle are reduced. The result is increased fatigue and muscle pain. Awkward postures can compound this process by elevating the degree of static muscle loading. Over time, these ergonomic risk factors can lead to UEMSDs.

The firing behavior of motor units during low-level static loading of muscle fibers is not well understood. Hagberg (1995) hypothesized that the shoulder-scapular region experiences low level static loading as a result of overuse of the Type I (slow twitch, oxidative) muscle fibers that may cause ischemia and metabolic damage with release of metabolites. The idea was that these metabolites might sensitize pain receptors and produce persistent pain. Two possible ways to prevent the overuse of Type I muscle fibers were discussed: (a) Making sure that work tasks involve different contraction levels, so that different fiber types are used, and (b) increasing the work effort so that Type IIA and Type IIB (fast twitch, oxidative and fast twitch, glycolytic) muscle fibers are also used. An operational method to accomplish this might be to perform tasks that are comprised of a variety of physical movements and force demands rather than tasks involving repetitive fine motor movements with low-level force exertion. The operator technique for mouse use involving more dynamic shoulder movement rather than statically holding the shoulder to move the mouse with the smaller muscles of the arm, wrist, and hand would appear to be beneficial in preventing the negative effects of low static loading of the shoulder.

Frequency, Duration, Force, and Speed of Input on a Computer

Even though muscle activity is low during computer use (Chaffin & Andersson, 1984), many computer users report fatigue, stiffness, and soreness in the shoulder-neck region when working for several hours at their computers (Hagberg & Sundelin, 1986; Kilbom & Persson, 1987; Kroemer, 1989; Rose, 1991). Some studies show a relationship between time spent on computer work and the occurrence of musculoskeletal symptoms (Hermans & Spaepen, 1995). Wells et al. (1997) strictly controlled postures during their research of upper limb supports during mouse input. However, they predicted that mouse users would change postures and vary the use of arm/wrist supports with the progression of the workday rather than remaining in the same posture and support conditions. This might lead to poorer postures with the onset of fatigue. However, Wells et al. felt that fatigue and discomfort would decrease over a workday as a result of increased variety of postures, supports, and movement patterns. Using combined EMG and subjective discomfort data, they were able to show that elbow and forearm supports during mouse use minimized the static load on the shoulder and forearm muscles.

Repetitiveness is based on the number of exertions needed to perform a task and the time allocated to complete the task. The number of exertions is related to the quantity of data or the number of commands that must be inputted into the computer within a specific time frame (Armstrong et al., 1995). Fast and repetitive keying rates have been associated with a higher likelihood of incurring UEMSDs. While mouse usage may not involve as much repetition or as many exertions as are found in data entry with a keyboard, it often involves fast-paced work over prolonged intervals and minimal recovery time between exertions (Armstrong et al., 1995). An increasing number of software programs require primarily mouse use. Johnson et al. (1993) demonstrated that intensive mouse users are often found in graphical arts, engineering design, programming and accounting occupations. In addition, the researchers applied video analysis to discover that mouse usage accounted for 65% of the time spent performing graphics/drawing tasks, 40% of the time on database/spreadsheet tasks, and 30% of the time on word processing tasks.

The force of exertion is associated with inertia, reactions of work tools/objects, and gravitational force. Pushing and pulling the mouse across a mouse pad, pushing buttons on the mouse, holding down buttons on the mouse (often in conjunction with sliding the mouse across the pad), and occasionally lifting up the mouse to reposition it on the mouse pad may affect reaching distance and result in excessive fatigue or chronic UEMSD in the shoulder region (Armstrong et al., 1995; Hagberg, 1995). Limited knowledge of postural compensations occurring during mouse use makes it difficult to improve upper extremity posture and movements to reduce risk of injury.

<u>EMG and Shoulder Pain</u>

Muscle activity can only be measured through indirect means. The most common and least invasive method is to perform surface EMG testing. The electrical activity in the trapezius muscle is often chosen to represent the workload of the neck and shoulder region. The scapula is stabilized by the trapezius, and the trapezius is then loaded during arm activity (Aaras et al., 1996). Netter, et al. (1987) reported that the upper trapezius and levator scapulae are primarily responsible for shoulder elevation. Contrarily, Johnson, Spalding, Nowitzke, and Bogduk (1996) reported that the upper trapezius is not responsible for shoulder elevation because it attaches to the clavicle, not to the scapula, and the strongest fibers are transversely orientated so they cannot support the shoulder girdle by direct suspension. Johnson et al. stated that the upper trapezius indirectly supports the shoulder girdle by a mechanism involving the clavicle and the sternoclavicular joint. However, the authors concluded that the levator scapulae, the rhomboids, and possibly to a lesser extent, the upper fibers of the serratus anterior, are the only suspensory muscles of the scapula. Surface EMG cannot detect muscle activity of the rhomboids, the levator scapulae, and the serratus anterior since these muscles are too deeply situated (Basmajian & De Luca, 1985).

Some EMG methods that evaluate muscle activity are used to infer static muscle loading by measuring the firing behavior of motor units in different muscle types. The resulting muscle load in practical workplace situations or in intervention studies requires several recordings in sequence at intervals. Under these circumstances, the validity and reliability of EMG test methods and equipment used are of crucial importance (Aaras et al., 1996).

Locating the muscle under study for optimal electrode placement is difficult since individuals' muscular structure can vary significantly. For example, autopsies have shown that some of the muscles attaching to the scapula have single fascicles or multiple fascicles with parallel or similar orientations, while others have multiple fascicles with widely dissimilar orientations (Johnson et al, 1996). Also, there is greater variation in EMG signal output when making comparisons across subjects than when comparing subjects to themselves (U. S. Department of Health and Human Services, 1992). Therefore, comparisons made on the same subject are more valid.

Electromyographic signals are normalized between participants, portions of muscles (to avoid confounding factors such as the length-tension relationship), and test sessions to circumvent problems with comparison. Normalization of EMG signals involves the conversion of absolute EMG values to relative values on the basis of reference electrical activity. Muscle activity during a specified task is compared to a reference value from that muscle and is expressed as a percentage of that reference value. Maximal voluntary contraction (MVC) of a predetermined, isometric movement as the reference electromyographic signal is the most common normalization technique (Kelly, Kadrmas, Kirkendall, & Speer, 1996). In this technique, generally one to three trials of 100% voluntary muscle contraction are measured and then used as a reference point for comparison to the working percent of MVC. Musculoskeletal disorders can occur if an isometric movement is greater than 5% to 8% MVC for a prolonged interval (Chaffin & Andersson, 1984; Grandjean, 1987; Hagberg & Sundelin, 1986). Another normalization technique involves measuring the shift in frequency of EMG signals to detect muscle fatigue. Muscle fibers activate slowly when fatiguing which is seen by a lower frequency emission of EMG signal (Paul et al., 1996).

Shoulder muscle activity was measured with surface EMG from the trapezius during computer work as part of a longitudinal study in Sweden (Aborg et al., 1995). Sixteen data-entry operators who complained of severe neck and shoulder pain wore lightweight data-collecting units in a girdle belt for two 8-hour workdays (including break and lunch periods). After the first day of data collection, ergonomists restructured the data entry work in hopes of reducing the risk of pain and injury resulting from the prolonged static work. The data entry-processing department was closed down and the employees transferred to several other departments and began to perform more varied tasks. Data entry was still the main task for these workers, although the time spent performing other types of office work increased. Eighteen months later, data were collected over the second workday to observe any differences. Mean muscle activity throughout the entire workday was analyzed for both the right and left trapezius. Results of the Aborg et al. (1995) experiment revealed high static muscle loading both before and after the reorganization. The average left shoulder muscle activity was 7.7% MVC in 1991 and 8.8% MVC in 1992 ($N = 15$). For the right shoulder, the mean muscle activity was 7.3% MVC in 1991 and 6.8% MVC in 1992 ($N = 16$). No statistical significance was found for the differences between the two test periods. These levels of muscle activity have been shown to contribute to MSDs (Chaffin & Andersson, 1984; Grandjean, 1987; Hagberg & Sundelin, 1986). Both before and after the reorganization, most participants reported repetitive strain and constrained work postures, and their subjective complaints did not differ in severity or frequency of pain. All but one participant's work content remained the same throughout the study. Fernstrom and Ericson (1996) performed a similar study ($\underline{N}$ = 16) looking at upper arm elevation during office work using an electrogoniometer (Abduflex). They found no differences in arm elevation despite new alternative tasks over an 18-month period.

The study by Aborg et al. (1995) may have been poorly controlled since it failed to mention if data entry employees were set-up properly at their new workstations or if they received training in proper body mechanics, relaxation techniques, or stretches for computer work. Since these employees were already having neck and shoulder pain before the study began, their pain could have influenced their EMG readings. Severe neck and shoulder problems may have increased the muscle activity in the trapezius or caused abnormal EMG patterns because of the presence of inflamed fascia or other disorders in the shoulder region. In support of this hypothesis, Hermans and Spaepen (1995) demonstrated that the activity of the trapezius could increase more significantly for injured workers than for healthy workers when performing computer work over the course of a working day.

In Hermans and Spaepen's (1995) experiment, the main objective was to compare self-perceived fatigue to EMG findings over an 8-hour workday between 5 female VDU workers with previous pain complaints in the shoulder-neck region and 5 female VDU workers who had no pain symptoms. Participants' reports of upper trapezius muscle fatigue were compiled, and EMG recordings of the upper right and left trapezius muscles were measured. The workers used the keyboard and the mouse. Participants were studied for 3 hours in the morning and 3 hours in the afternoon. The results showed that the complaining group reported higher discomfort than the healthy group. The healthy group did not report any discomfort until the afternoon, when they reported only slight discomfort. The complaining group began to express discomfort after only an hour of work. By late morning, the complaining group reported moderate discomfort, and at the end of the day they indicated moderate to heavy discomfort. Immediately following the lunch break, both scores decreased and were not different. Also, following the lunch period, lower activity of the muscles was observed. These findings support the importance of taking rest breaks, although several short pauses are recommended over one long break to alleviate discomfort and lower muscle activity (State of California, 1992).

One current debate among ergonomists is whether to recommend armrests when using the mouse. Paul et al. (1996) studied that question. The research team attached surface EMGs to the forearm flexors and extensors, and trapezius muscles on both the left and the right sides of 11 office workers during 90 minutes of mouse use under three conditions. The conditions were (a) height and rotation adjustable armrests (5 in. or 12.70 cm height range and 360° rotation range around a vertical axis), (b) height adjustable armrests (2 in. or 5.08 cm) without any rotation feature, and (c) unsupported arms. Increased fatigue was shown in the right trapezius and left and right flexor muscles with use of height adjustable armrests as compared to height and rotation adjustable armrests ($p < .05$).

Electromyography signals consist of a series of action potentials firing at certain frequencies. These frequencies can be captured through a series of electronic filters that provide useful data for studying local muscle fatigue. As a muscle is contracted for a prolonged period, the high frequency components of the signal decrease, and the low frequency components gradually increase. This change causes a shift in the power spectrum (V^2/Hz) toward the lower frequencies (U. S. Department of Health and Human Services, 1992). According to Paul et al. (1996), when participants worked with their arms unsupported EMG data showed more fatigue in the upper extremities than when resting the forearms on height and rotation adjustable armrests. Also, participants reported significantly lower discomfort in their upper back, neck, and shoulder when using the height and rotation adjustable armrests during mouse use than the height-only adjustable armrests and no armrests. No significant changes in discomfort were reported for lower back, upper arms, elbows, hands, and wrists between the three conditions.

A study by Wells et al. (1997) favored the use of elbow and forearm support over unsupported arms and the use of wrist support during computer mouse activity. Their investigation involved four different types of mouse activities using a Windows 95 software program: (a) drawing, (b) text editing, (c) tapping, and (d) extended game playing. Participants practiced using the mouse in the support conditions with different tasks for a total of 2 hours over an interval of 2 to 4 days. Electromyographic surface electrodes collected data from eight muscles of the right (dominant) upper extremity and shoulder when using the mouse to perform drawing, text editing, and tapping for 3-minute periods per activity. The team of researchers also examined wrist posture and performance. Twenty participants served in the experiment; 10 performed the tapping task, and another 10 performed the drawing and editing tasks. Fifteen of these participants were assigned to all four-wrist support conditions. Five of the 20 participants were randomly assigned to one of the four support conditions. EMG was not used in the game-playing task, but researchers recorded performance and musculoskeletal discomfort over the 3-hour testing period.

In this study, the no support condition showed the most shoulder muscle activation, while the wrist support condition showed the most muscle activity in the arms. The elbow support condition had the lowest muscle activity overall, but moderate activity in the trapezius. The difference between the conditions was largest for the shoulder girdle. Wells et al. stated that the static muscle activation in the unsupported arm condition might have contributed to shoulder disorders. Interestingly, no pattern of regional discomfort appeared for participants in any particular arm support condition during the 3 hours of game playing. Participants felt slightly more discomfort in their shoulder and wrist regions than their forearm and elbow regions. However, an increasing trend of discomfort was reported for all of the above areas. The discomfort data correlated to the EMG findings.

Hagberg and Sundelin (1986) investigated discomfort and load on the right and left upper trapezius muscle when operating a word processor by placing EMG surface electrodes on the descending part of the trapezius muscle of six female secretaries over 3- to 5-hour work periods. A static local muscular load of 3.2% MVC was found on the trapezius. While most leading researchers report 5% to 8% MVC as the low range indicator for ergonomic risk, Hagberg and Sundelin (1986) reported that the acceptable ceiling limit was only 2% MVC. However, only 44% of the variance was explained, possibly due to individual differences related to the small sample size and minimal management over the type of work performed (e.g., keyboarding, mouse input, peripheral tasks).

Aaras et al. (1996) completed a field EMG study of the trapezius muscle among computer workers. The researchers found that even a small variation in work position changed the absolute value of static trapezius load by up to 100% or more since the muscle activity was very low during data entry work. The results were inconclusive because the type and pace of work were poorly controlled. A closer analysis of shoulder positioning and arm movement through combined EMG and visual observation might have added more value to the results of the Aaras et al. (1996) study. Observing shoulder posture and movement patterns during performance of computer tasks, while simultaneously recording ongoing EMG activity from multiple sites, would be invaluable for determining ergonomic efficiency and preventing repetitive strain injuries.

Shoulder Posture during Mouse Use

Sustained, nonneutral postures during mouse use can create potential isometric muscle contraction problems in the affected muscles (Rose, 1991). Commonly observed harmful postures include overly elevated forearms caused by the elbows resting below the height of the mouse, overly extended arms caused by sitting too far back from the mouse, fully pronated forearms (palm down), rounded shoulders, a forward tilted head, and a forward flexed cervical and thoracic spine (Rose, 1991; Sommerich et al., 1993).

Working at a computer often involves a combination of prolonged sitting, awkward body positioning, and specialized, monotonous tasks that impose static or repetitive loads on the shoulder and neck muscles (Bergqvist, Wolgast, Nilsson, & Voss, 1995; Carter & Bannister, 1994; Hales et al., 1994; Rose, 1991). Reaching for the mouse in a sagittal plane (in front of the user) requires shoulder flexion and scapula motion (elevation, protraction, and upward rotation). The degree of required motion to reach the mouse is dependent on the distance between the user's shoulder and the mouse. If the user is sitting too far away or possesses a short forearm length or a protruding stomach when the mouse is in front of the user, increased shoulder flexion and scapular movement (i.e., elevation and protraction) will be required. If the mouse is placed above the computer operator's seated elbow height, greater shoulder flexion is also required with increased scapular elevation by the trapezius and levator scapulae. If the mouse is placed at the right side of the standard keyboard, the right hand must move a minimum of 12 in. (30.48 cm). The left hand must traverse at least 8 in. (20.32 cm) from the home row of the keyboard to reach the mouse when using a standard keyboard set-up (Paul et al., 1996). In this scenario, shoulder abduction and external rotation can be required to position the hand on the mouse. The shoulder-to-shoulder width of computer operators may exceed the width of the keyboard and mouse arrangement which also may force the shoulders into flexion and abduction, the elbows into overextension, and wrists into ulnar deviation (Karlqvist et al., 1998; Rose, 1991). Scapular movement is dependent on how each computer operator positions and moves the shoulder girdle during mouse use (Perry, Rohe & Garcia, 1992).

Armstrong et al. (1995) emphasized that postural stressors need to be reduced when inputting data with a mouse; otherwise, there will be a greater risk of acquiring a MSD than the risk derived purely from static muscle loading. Prevention tips for mouse input outlined in CTDNews (1997b) included:

1. Use keyboard trays that are 26 - 30 in. (66.04 - 76.20 cm) long or those that have pull-out, cutting-board style mouse extensions.

2. Use mice that fit the hand size.

3. Use programmable mice that have drag lock features and memories for frequently used cursor positions.

4. Release the mouse from the hand when not in use.

5. Keep a neutral wrist floating above the surface and swinging the arm from the shoulder, thus avoiding resting on the wrist and pivoting from the wrist during mouse use.

6. Alternate hands on the mouse.

Karlqvist et al. (1994) investigated mouse use and posture. They compared upper extremity posture and movement during text editing under these conditions: (a) using only a keyboard, and (b) using a mouse with a keyboard. The researchers video recorded shoulder abduction and rotation, and wrist deviation. Observations revealed longer intervals of strenuous postures and higher performance (speed and accuracy) when the mouse was used with a keyboard. However, the mouse users' posture was much further from neutral than the nonmouse users' posture. The mouse users' shoulder rotation was outward greater than 30°, and their wrists were in ulnar deviation greater than 15° over 81% and 64% of working time respectively, versus only 4% and 0% of working time for nonmouse users. The mouse was placed laterally to the keyboard on the right side. This placement prevented upper arm movement in natural planes. Even though bodily postures were compromised, participants rated lower discomfort when using the mouse than the keyboard; however, participants stated that usually they felt discomfort in the whole arm after working with the mouse for a couple of hours. The study was over a 30-minute work period, and the researchers felt, in retrospect, that the test period was too short. Perhaps, EMG analysis of the shoulder will bring forth a more complete perspective of what is occurring in the shoulder during mouse use, since Karlqvist et al. (1998) described a discrepancy between reported shoulder pain symptoms and ranges of working motion of the shoulder over time.

Another mouse input study published by Karlqvist et al. (1998) looked at posture, muscular load, and perceived exertion for different positions of the mouse placed on a flat, adjustable work surface during 2 minutes of text editing per condition. Six mouse positions were used: a) two directly in front of the user, b) two 40 cm to the right of the user, and c) two 60 cm to the right of the user. The first of each pair was placed 10 cm from the front edge of the work surface, and the second of each pair was placed 20 cm from the front table edge. An optoelectronic three-dimensional motion analysis system was used to examine flexion of the neck, right shoulder, elbow, and wrist; abduction and rotation of the right shoulder; and ulnar deviation of the right wrist of 20 male and female computer operators. Surface EMG measured activity of the upper trapezius, deltoids, and extensors bilaterally. Results from this study revealed the following:

1. The lowest muscle activity was registered with the mouse placed in the far lateral position; although video recordings showed extreme outward, rotated and abducted shoulders. This was the least preferred position by participants.

2. The second lowest muscle activity was measured in the most preferred mouse set-up: the mouse directly in front of the right shoulder combined with arm support, and males chose the mouse to be placed deeper on the work surface than females.

3. A work surface height for mouse input less than 3 cm above elbow height supported the arm and shoulder without undue shoulder elevation.

4. Extreme outward shoulder rotation and abduction occurred when the mouse was located to the far lateral position on the work surface.

5. Arm support reduced muscle load in the neck/shoulder region.

6. When the mouse was placed directly in front of the torso, women used an

awkward mouse input technique involving an elevated and extended right shoulder.

The research group felt that the lateral position resulted in low muscle activity because the arm was well supported, and the shoulder height was low. The unexpected low muscle activity in this extreme lateral position showed that minor changes in computer and mouse workstation set-ups can impact the user's muscle activity levels because of a multitude of interdependent factors (e.g., forward leaning of the trunk, protracted shoulders, leaning on chair armrests).

Dowell and Gscheldle (1997) took a different approach to determine the effect of mouse location upon posture. Orthogonal photography determined reach and recline positions at 1-minute intervals with cameras situated parallel to the sagittal plane, and behind a one-way mirror to the right of the participant. Thus, forward/backward reaching of the arm and torso, and neck/shoulder flexion/extension were viewed; however, other postures, such as shoulder elevation and abduction, and ulnar deviation of the wrist, were undeterminable. Participants were trained to adjust the workstation equipment to meet their physical needs. Participants used a mouse for 25-minute intervals in three different locations. Each was on the work surface near and to the right of the keyboard at three different depths. Video recordings of the marked surface points on the participants (C1 vertebrae, glenohumerus joint, upper arm link, hip, elbow, torso link, forearm link, and wrist) indicated that mouse location had a significant effect on reach angle, but recline angle (in the chair) was independent of mouse location. The upper arm angle approached vertical as the forearm moved in toward the sides of the torso and the mouse location moved closer to the user. The experimenters believed that participants were more focused on their torso posture than mouse location, as recliners found ways to recline in their seats no matter where the mouse was located, and upright-sitters sat up when inputting data at all three mouse locations. Within subjects correlation was stronger than between subjects correlation because of participants' individual approach style to mouse location.

Armstrong et al. (1995) completed a biomechanical analysis to study the relationship between mouse usage patterns and UEMSDs. The authors recommended that gravitational force and postural stresses (e.g., extended reaching and leaning) be minimized and that the mouse be located directly in front of the user so that the elbow would remain close to the side of the torso. Armstrong et al. also felt that the workstation should include room near the keyboard so that both the keyboard and mouse could be adjusted for each operator as needed. While ergonomic design considerations exist for the keyboard (articulating arms and sliding drawers), similar attention has not been paid to the mouse, which may be positioned much higher and a considerable distance from the keyboard's spacebar (Bass, 1993).

Only one study has looked at mouse surface elevation in relationship to working posture. Damann and Kroemer (1995) measured wrist posture during computer mouse usage with a wrist monitor attached to the right forearm and hand. Four levels of surface height (80%, 100%, 120%, and 140% of seated elbow height) and two levels of wrist support (present or absent) were the independent variables. The use of a wrist support decreased wrist extension and radial deviation, and increased wrist flexion at 80%, 100%, and 120% of seated elbow height. Wrist extension was more prevalent than wrist flexion during computer mouse usage at all heights and wrist support conditions. The wrists were closest to neutral when the mouse was placed at 100-120% of seated elbow height. Damann and Kroemer (1995) acknowledged that they did not know what the implications would be for the shoulder when using a mouse at these heights.

Paul and Nair (1996) evaluated four keyboard and mouse tray designs using surface EMG of two forearm muscles of the dominant right hand, an electrogoniometer to measure wrist deviations, and a video camera to record elbow and shoulder postures. They studied 4 male and 4 female participants during a 30-minute word-processing task involving keyboard and mouse input. Four designs were chosen for their study. A winged design was 8 x 20 in. (20.32 x 50.80 cm) for the keyboard area plus another 8 in. (20.32 cm) at a 45° angle-swivel toward the computer operator for the mouse area. A sliding design consisted of a mouse tray that slides out to one side 8 in. (20.32 cm) from the underside of the keyboard tray. A keyboard tray and mouse tray combination was incorporated into their design.

The keyboard tray was adjustable in height and tilt, and the mouse tray was height-adjustable. The last design was two tiered where the mouse pad was located two inches above the keyboard and just over the number keypad (see Figure 1). The participants adjusted the keyboard and mouse trays to fit their own morphology and preferences. These conditions were compared to a reference condition of working on a plain work surface 29.50 in. (74.93 cm) above the floor.

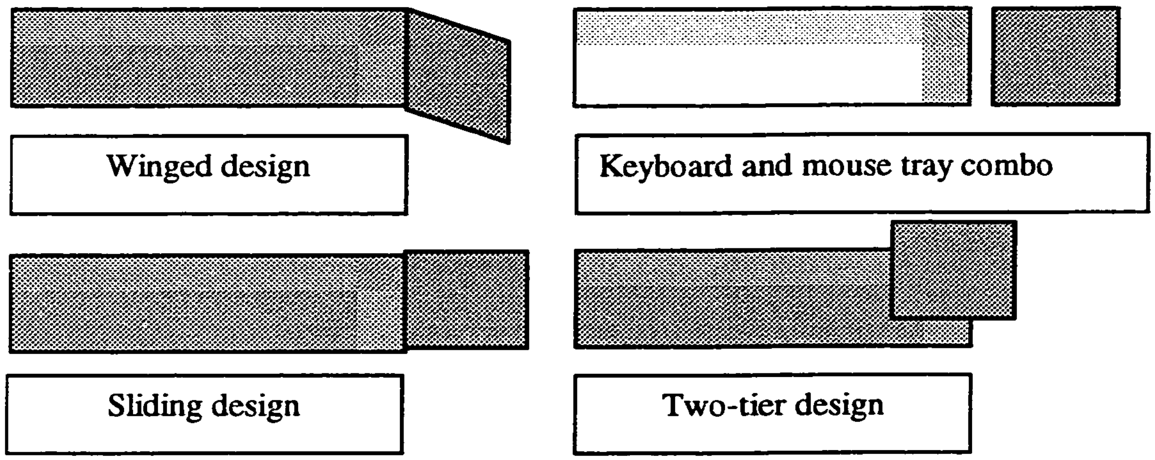

Figure 1. The keyboard and mouse designs evaluated in the Paul and Nair (1996) study.

Findings showed that the two-tier design caused the least amount of shoulder abduction and elbow flexion, and had the lowest amount of forearm flexor muscle activity. The two-tier and sliding designs were rated significantly superior to the other two designs for functionality and utility. The objective of the winged design was to diminish lateral movement of the arm by bringing the mouse pad closer to the user's body. However, it appeared to require greater accuracy in arm movement when moving between the keyboard and mouse. As such, the winged design performed inferior to the sliding and two-tier designs in all areas except wrist flexion. The combination design (made for freedom of individual fit) also performed poorer than the sliding and two-tier designs. The plain work surface imposed much greater postural deviations at elbow and shoulder joints, likely due to obstructing chair armrests (height-adjustable within 2 in. or

5.08 cm), and being much higher than participants' natural seated elbow heights. Shoulder elevation when using these keyboard and mouse tray designs was not addressed in this study. Paul and Nair (1996) recommended that additional research should be conducted to focus on muscle fatigue in the neck and shoulder regions with alternate keyboards and input devices.

METHODS

This study compared the electromyographic activity of the right and left upper trapezius during mouse input with three different mouse locations. This chapter describes the selection of the population, sampling technique, number of participants, apparatus, procedures of the experiment, and the experimental design for data analysis. The methodology is organized into the following subsections: (a) participants, (b) sampling technique, (c) instrumentation, (d) procedures, and (e) treatment of the data.

Participants

Eighteen students at San Jose State University were solicited to volunteer in the study. Both males and females between 18 and 50 years of age who were right-hand dominant were recruited. Students participated between the hours of 8:00 a.m. and 6:00 p.m. Participants gave informed consent in accordance with the guidelines established by San Jose State University's Institutional Review Board for Human Subjects (Appendix B). They were asked to wear sleeveless or loose shirts to provide easy access and visibility to their upper trapezius muscles for sensor placements. The participants were administered the modified standardized Nordic Questionnaire (Appendix C) and protocols for data collection; they were also given an opportunity to inquire about the study. The researcher screened participants to determine if they met the following requirements:

1. No history of shoulder injury or discomfort.

2. Ability to sit and use the computer mouse for up to 30-minute intervals for 99% of the 2-hour testing period.

3. Good or corrected vision.

4. Ten or more previous hours of experience interfacing with Windows 98 and Microsoft Office 97 software using an IBM compatible personal computer.

Sampling Technique

While participants were completing forms, the researcher matched participants to the treatment sequence of test conditions using a randomization process. This process involved using a treatment grid with 18 treatment slots. The researcher filled the slots by moving down and then across the grid using the last digit of participants' social security numbers as a tool to choose the order of treatment conditions the participant would be given. If a previous participant had been assigned to the targeted slot, the researcher would repeat the search task using the next digit to the left of the last one. If needed, this process was repeated with subsequent digits using the same pattern. This sequence continued until all the slots were full. If a slot became available due to ruined test data, that slot was put back into the randomization process in the same location on the grid as before the slot was full.

Instrumentation

The researcher used the ProComp+™/ Biograph® software (version 2.0) and hardware systems, and the Triode™ surface electrodes by Thought Technology, Ltd to measure electromyographic activity. Prior to the experiment, the electromyography (EMG) machine was calibrated to ensure an equal zero point between sensors (Appendix D). The calibration was rechecked during the experiment after 5, 10, and 15 test sessions to ensure that the machine's calibration figures were unchanged.

The Triode™ surface electrodes are disposable with adhesive backings that adhere to skin and preset electrode placements for consistent reliability of the inter-electrode distances. The electrodes were placed over the left and the right trapezius pars descendens muscles and attached to fiber optic leads (C: Model # 2418, and D: Model # 2439). The leads were inserted into corresponding ports on a battery-operated ProComp+™ (Model # AD2569). The ProComp+™ was taped down onto the left mouse tray at a close proximity to the participant to avoid any tension on the leads. A fiber optic cable linked the ProComp+™ to an IBM personal computer with an adapter to a serial port (see Figure 2).

The experimenter attempted to control the following factors that could influence EMG amplitude: type of electrode, electrode contact area, electrode placement, extraneous electrical interference, intrinsic radiated and amplifier noise, sampling rate, and directional movement of participants. The sampling rate when collecting data was 32 samples per second, and the possible range of microvolts was 0 - 400.

Razors, warm water, and washcloths were available to remove hair from the shoulder points of contact; however, this procedure was found to be unnecessary. The experimenter prepared the skin for testing by rubbing the electrode placement area with prep pads of 70% isopropyl alcohol. A measuring tape ascertained shoulder-to-shoulder and elbow-to-elbow widths. A timer counted 15 seconds for pre- and posttest resting heart rates, one 5-minute practice session, and two 5-minute rest intervals between test

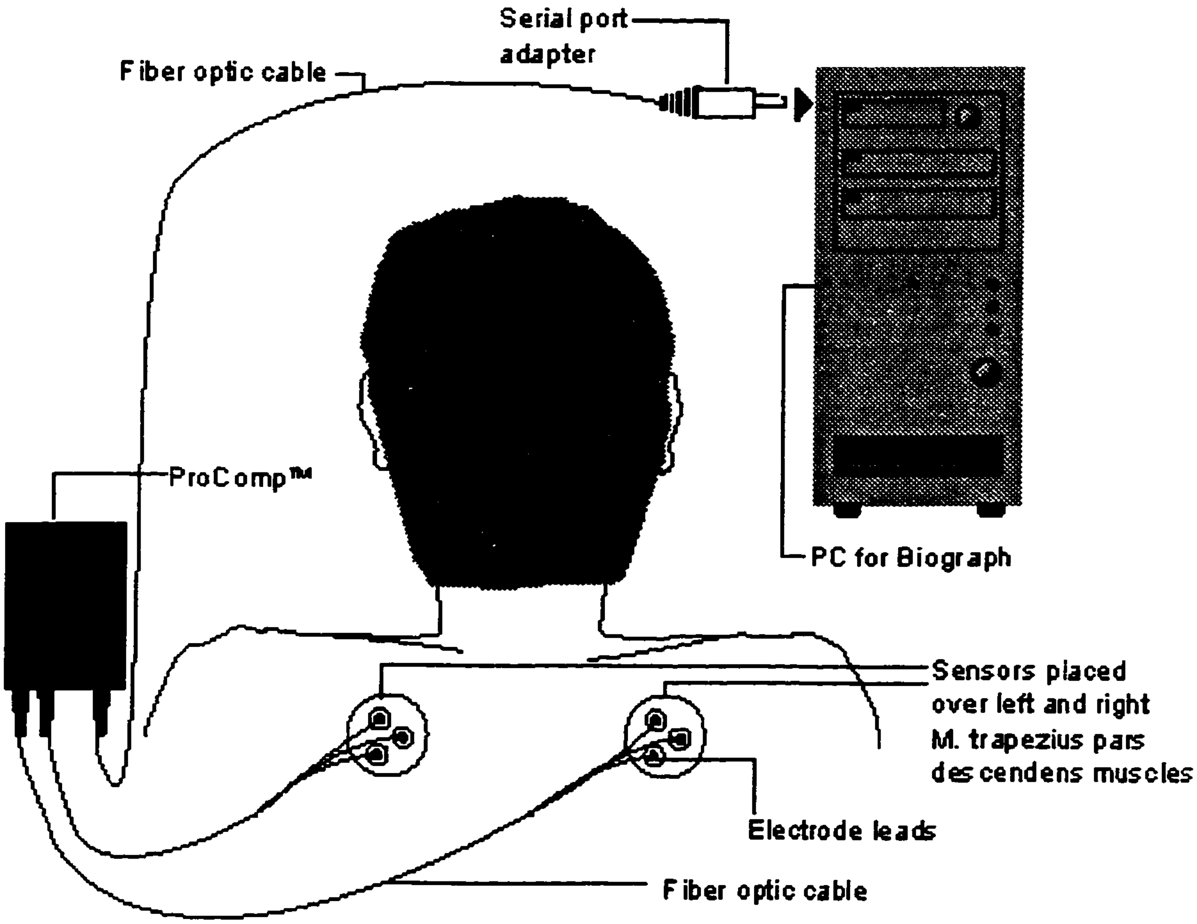

Figure 2. ProComp+™ hardware system configuration, including sensor placements over the upper trapezius muscles (bilateral) for EMG data collection during the experiment.

conditions.

The computer interface design was comprised of two IBM compatible computer systems with Windows 98 and Microsoft Office 97 IBM compatible software, one two-button Microsoft mouse, and one mouse pad. Depending on the test condition, a Dell™ standard keyboard, a Great Quality™ short keyboard, and a nonadjustable back-mounted Adaptables, Inc. numeric keypad cover were added to the computer interface (Keyboard Alternatives & Vision Solutions, 1999). Refer to Appendix E to view a photograph of the numeric keypad cover used in this study. The dimensions of the numeric keypad cover are 9-in. (22.86-cm) depth, 7.75-in. (19.69-cm) width, and 1.5- to 2.13-in. (3.81- to 5.41-cm) height, sloping in depth, front to back. A Hon Company adjustable chair without armrests, a computer table that was height-adjustable between 26 and 30 in. (66.04 - 76.20 cm) above the floor, a Human Sciences, Inc. adjustable height keyboard arm and tray, and VuRyser™

monitor risers were instrumental in adjusting the human-computer interface to meet ANSI/HFS 100 - 1988 standards (Human Factors Society, 1988). The combination keyboard and mouse tray consisted of a 24 in. (60.96 cm) wide keyboard tray with horizontally articulating daisy mouse trays attached to the underside of the keyboard tray at both ends (see Figure 3).

Procedures

Male and female volunteer students at San Jose State University participated in the study. The researcher identified students who were eligible for the study, and test appointments were scheduled using classroom sign-up sheets, and telephone and email communications. Participants were requested (verbally) not to perform any computer work or shoulder exercises after 6 p.m. on the day before their tests to control for fatigue

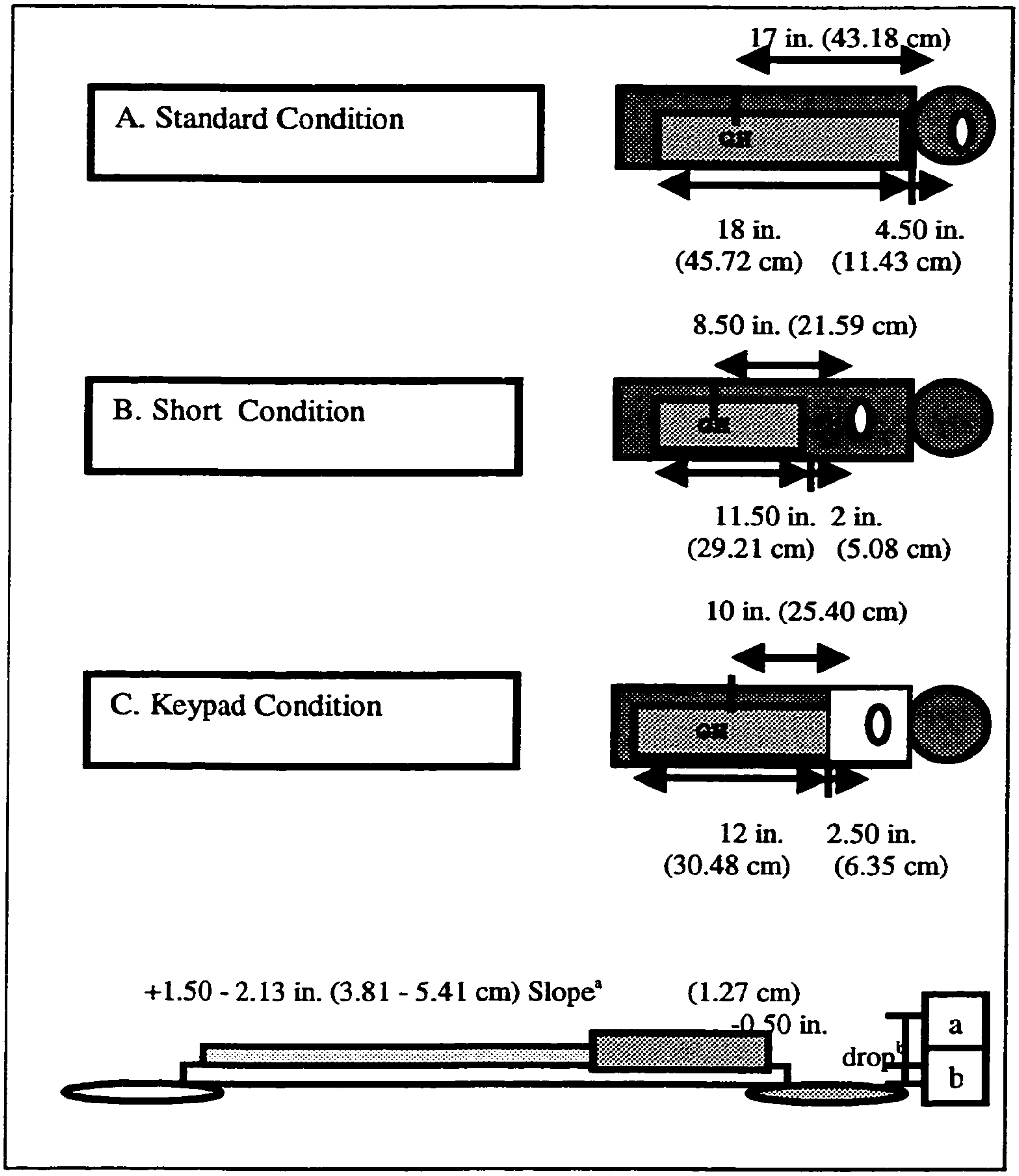

Figure 3. Dimensions of the three keyboard and mouse configurations used in the experiment (not to scale). Note that the lateral travel distance between the center of the keyboard keys and the mouse varies among configurations. The illustration of the mouse surface heights is relative to the keyboard tray height positioned at zero for the Short Condition (a = Keypad Condition, b = Standard Condition).

effects. The experiment began with participant orientation. During the orientation, participants completed the Modified Nordic Standardized questionnaire (Kuorinka et al., 1987), which inquired about musculoskeletal symptoms, physical characteristics, and work tolerances. Next, participants signed a consent form in accordance with University policy (Appendix F), listened to a brief introduction to the equipment and task (without the hypothesis stated or inferred), and then began the test preparation process.

Participants were admitted into the study by meeting the criteria on the Modified Nordic Standardized questionnaire and signing consents to undergo the experiment. The dependent measures of this study were the EMG recordings of the left and right M trapezius pars descendens muscles. Elbow-to-elbow and shoulder-to-shoulder widths were ascertained using a tape measure to compare the figures to average anthropometric ranges identified for the United States adult population since the distances affect shoulder and upper extremity positions in proportion to the keyboard and mouse positions (Appendix G). Finally, the experimenter cleaned the shoulder regions relative to the trapezius location, and located placements of the electrode sensors that attach to the electrode leads. This method was initiated by asking participants to shrug their shoulders while the shoulder regions were palpated and visually examined to isolate the muscle belly of the left and right upper trapezius. The experimenter located the muscle belly bilaterally with a tape measure placed along the horizontal distance between the seventh cervical vertebrae and the acromion tip, and a goniometer used as a T-square so that the placement was mirrored on each side of the upper trapezius muscles.

Appendix H describes how the experimenter set up the workstation for each participant according to ANSI/HFS 100, 1988 standards (Human Factors Society, 1988). The Biograph® system was prepared for participant testing (Appendix I). Pretest baseline EMG recordings were taken while participants sat in a relaxed posture with their hands resting in their laps. The researcher then provided verbal instructions for procedures related to the mouse tasks (Appenrodt & Andre, 1999). Refer to Appendix J for mouse task instructions and Appendix K through N to view photographs of mouse tasks.

Participants practiced performing mouse intensive activities developed by Interface Analysis Associates in Microsoft Office 97 and Windows 98 interfaces for 5 minutes. Tasks in Power Point involved tracing a template and moving objects. Participants edited and transcribed paragraphs in Word using the keyboard for text entry and the mouse for navigation and cutting and pasting text. In Excel, participants performed four different tasks. These entailed scrolling around in spreadsheets to find specific data, highlighting groups of cells, dragging data between cells, and clicking on cells. The final task was playing Solitaire. Cursor movement for these tasks included horizontal, vertical, and diagonal directions with most of the monitor screen being used to perform the tasks. There were five main tasks lasting 1 minute each. After each 1-minute interval, one program was closed and another one opened. Four spreadsheet pages in Excel contained subtasks, and pages were switched after 20-second intervals. Refer to Figure 4 for a description of the participants' tasks and the data collection

BIOGRAPH® TEST PROCEDURE							
90 s Baseline EMG	20 min T 1	5 min Rest	20 min T 2	5 min Rest	20 min T 3	5 min Rest	90 s Baseline EMG

TASKS				
Power Point	Excel	Word	Power Point	Solitaire
4 min • Click • Drag	1 min • Highlight • Scroll 1 min • Click • Scroll 1 min • Vertical Drag 1 min • Lateral Drag	4 min • Click • Keying • Right-Click • Highlight	4 min • Trace • Navigate Menus	4 min • Click • Drag • Double-Click

Figure 4. Diagram of testing and data collection protocol. Participants performed computer mouse-intensive tasks in three treatment (T) conditions while the Biograph® system recorded EMG activity in the left and right upper trapezius for three, 20-minute periods.

process.

Prior to beginning the testing session, the researcher verbally walked participants through the set of tasks. Next, participants performed a 5-minute practice test. Following the practice test, participants tested for 20 minutes in the same keyboard and

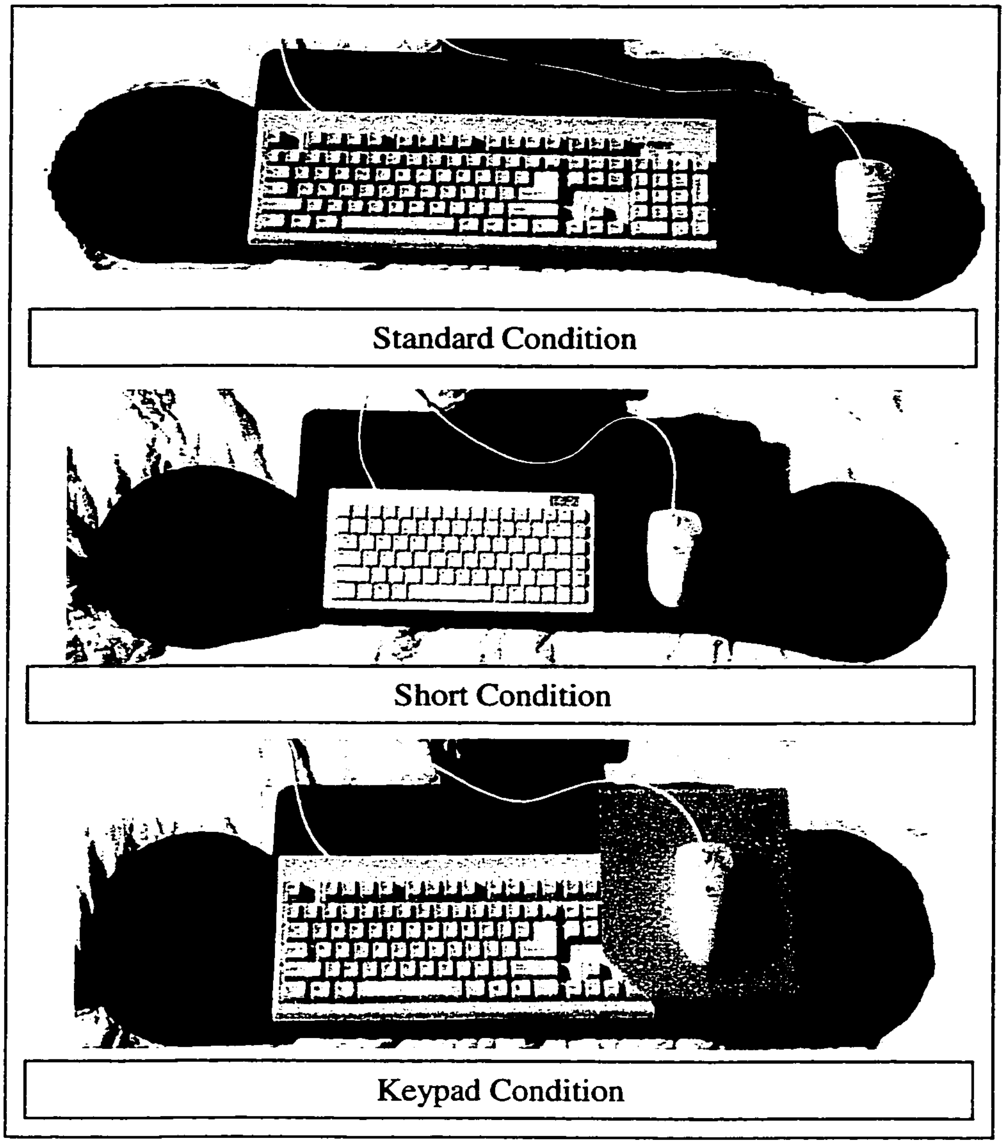

Figure 5. The three mouse placements adopted as treatment conditions for the research study.

mouse arrangement as previously practiced. The mouse-intensive activities were similar, but slightly varied from the practice sessions. However, the tasks were in the same order as the practice session. The three conditions were using the mouse with a standard keyboard, short keyboard, and standard keyboard with a number keypad cover (refer to Figure 5 for photos of conditions). The order of conditions was counter-balanced between participants. After the first test condition, participants took a 5-minute rest break and then performed the next 20-minute test-trial. The process was repeated again with the final test condition.

Behavioral observations, such as shoulder positioning, were made throughout the testing process to determine any postural or movement trends and to identify and record any events that might affect the data collection process (Appendix O). Posttesting EMG baselines of the left and right upper trapezius were recorded to check for any change in resting EMG levels since the pretesting phase. A posttesting user preference questionnaire (Appendix P) was given following the experiment to identify participants' subjective preferences.

Treatment of the Data

The statistical hypothesis was formulated with the assumption that no difference would be found between the different mouse conditions. A one-way repeated measures analysis of variance (ANOVA) design was used to determine the differences between the three levels of mouse condition: (a) number keypad cover, (b) standard keyboard, and (c) short keyboard. The one-way repeated measures ANOVA test was designed to be significant at the $p < .05$ level. The Sigma Stat, version 2.03 statistical package was used to determine the statistical findings. Findings were reported in terms of the mean scores and standard deviations of each of the three levels of mouse condition.

Since the normality test failed when analyzing the ANOVAs, a nonparametric Friedman Repeated Measures Analysis of Variance on Ranks was executed. Differences in median scores were analyzed among the mouse conditions for the left and the right upper trapezius. Median scores per treatment condition between the upper left and right trapezius were not compared. The means for baseline pre- and posttest EMG recordings were calculated and compared using a one-tailed t test to rule out fatigue effects.

RESULTS

Left and right upper trapezius electromyography (EMG) data for the three mouse conditions were computed for 18 of the 19 participants who engaged in the test sessions. One participant's data were excluded from the experiment, as he had not completed the final baseline resting EMG analysis due to a time constraint. Two-thirds of the participants were female and one-third male. The mean age was 27, the median was 25, and the range was 19 to 48. The average height and weight of participants were 5 ft 7 in. (170.18 cm) and 161 lb (60.09 kg), respectively. The height and weight figures obtained were consistent with the mean values reported for United States adult population anthropometric figures used as architectural design standards (Hoke, 2000). Moreover, the mean shoulder width measurement of male and female participants in the present study was 17.07 in. (43.36 cm) compared to the national average of 17.70 in. (44.96 cm) for the 50th percentile male and 16 in. (40.64 cm) for the 50th percentile female in Hoke's (2000) illustrated anthropometric data. The range of shoulder width in this study was 14.50 - 19.50 in. (36.83 - 49.53 cm); this range was nearly identical to Hoke's (2000) report of 14.40 - 19.40 in. (36.57 - 49.28 cm) for the range of 2.5 percentile female to 97.5 percentile male. Specific anthropometric standards for elbow width were unavailable in the literature for comparison purposes.

Figure 6 displays the root mean squared (rms) EMG signals in microvolts (μV) for the left and right upper trapezius muscles in each of the three mouse locations. Means (with standard deviations in parentheses) for the right upper trapezius muscle activity were 3.85 (3.23) for the standard keyboard, 3.45 (2.44) for the short keyboard, and 4.82 (3.41) for the keypad cover conditions. Means for the left upper trapezius muscle activity were 2.36 (1.35) for the standard keyboard, 2.72 (1.92) for the short keyboard, and 2.80 (2.15) for the keypad cover conditions.

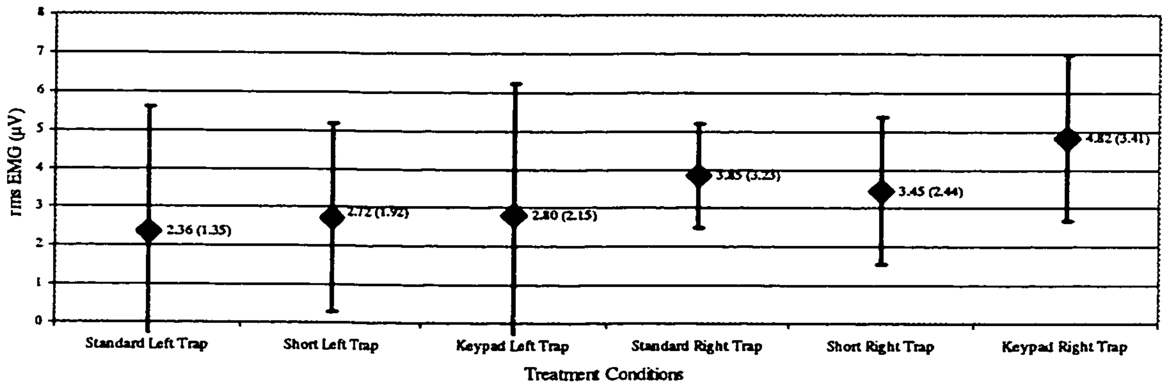

Figure 6. Root mean squared EMG signals and standard deviations (in parentheses) measured in microvolts for the upper right and upper left trapezius muscles when using the computer mouse in three different locations.

Surface EMG recordings over the upper trapezius muscle were analyzed using 2 one-way repeated measures Analysis of Variance (ANOVA) tests (left and right electrode placements). The right trapezius muscle activity was collapsed over the three mouse conditions. However, the normality test failed ($p < .05$); therefore a non-parametric Friedman Repeated Measures Analysis of Variance on Ranks was performed. Table 1 shows median score rankings for each treatment condition per participant. A rank of 1 indicates the lowest mean score and a rank of 3 indicates the highest mean score of the three treatment conditions for the left and right upper trapezius EMG activity. The prevalence of the number "3" in the last column of Table 1 for the upper right trapezius

EMG activity in the keypad condition indicates higher median EMG rankings.

Table 1

Median Ranks with Mean Scores (in parentheses) for each Participant

Participant	Left Standard	Left Short	Left Keypad	Right Standard	Right Short	Right Keypad
1	1 (2.02)	3 (4.57)	2 (2.72)	2 (5.96)	1 (4.72)	3 (7.08)
2	3 (1.33)	1 (1.39)	2 (1.46)	3 (14.77)	1 (5.43)	2 (11.57)
3	3 (2.52)	1 (2.12)	2 (2.43)	2 (5.96)	1 (4.60)	3 (6.28)
4	1 (0.85)	3 (0.93)	2 (0.89)	2 (0.85)	3 (0.96)	1 (0.51)
5	1 (5.39)	2 (8.22)	3 (9.62)	1 (5.04)	2 (11.33)	3 (12.62)
6	2 (0.84)	1 (0.74)	3 (1.69)	2 (2.15)	1 (1.36)	3 (7.11)
7	2 (2.87)	3 (3.48)	1 (2.78)	1 (1.47)	2 (1.64)	3 (1.71)
8	1 (1.29)	2 (1.40)	3 (1.56)	1 (1.69)	2 (2.45)	3 (3.59)
9	1 (1.02)	3 (1.28)	2 (1.03)	2 (2.89)	1 (2.30)	3 (2.92)
10	1 (1.92)	2 (2.07)	3 (2.78)	2 (2.98)	1 (2.23)	3 (4.04)
11	3 (3.65)	1 (2.99)	2 (3.13)	3 (4.47)	1 (3.54)	2 (4.04)
12	2 (2.82)	1 (2.14)	3 (3.29)	2 (1.82)	1 (1.40)	3 (2.30)
13	1 (2.34)	2 (2.46)	3 (3.26)	2 (6.33)	1 (4.17)	3 (7.48)
14	1 (1.71)	2 (6.01)	3 (6.41)	1 (1.81)	2 (2.34)	3 (3.35)
15	2 (1.43)	3 (1.49)	1 (0.93)	3 (1.91)	2 (1.71)	1 (1.07)
16	1 (1.43)	3 (1.88)	2 (1.49)	2 (4.03)	3 (5.08)	1 (3.01)
17	1 (3.18)	3 (3.65)	2 (3.41)	1 (1.60)	3 (2.21)	2 (1.78)
18	2 (1.85)	3 (2.17)	1 (1.55)	1 (3.54)	2 (4.67)	3 (6.30)

Note. Eighteen participants' median rankings (1 = lowest muscle activity, 2 = second lowest muscle activity, and 3 = highest muscle activity), and their respective mean EMG recordings in microvolts (in parentheses) for the upper left and right trapezius in the three mouse conditions.

As presented in Table 2, the differences in the median values among the treatment groups involving muscle activity of the right upper trapezius were greater than would be expected by chance, $X^2(2, N = 18) = 7.00$, $p < .05$. To isolate the group or groups that differed from the others, a multiple comparison procedure (Tukey Test) was performed. In order, median values for right upper trapezius muscle activity when using the standard keyboard, short keyboard, and keypad cover conditions were 2.94, 2.40, and 3.82. The difference of ranks between the keypad cover and the short keyboard was found significant at p < .05 for right upper trapezius muscle activity as shown in Table 3. The differences in the median values among the other treatment groups were not great enough to exclude the possibility that random sampling variability was responsible for the difference.

Table 2

Friedman Repeated Measures Analysis of Variance on Ranks (N = 18)

Group	Median	25%	75%
Right Standard	2.94	1.81	5.04
Right Short	2.40	1.71	4.67
Right Keypad	3.82	2.30	7.08

Note. Chi-square = 7.00 with 2 degrees of freedom.
p < .05.

Group	Median	25%	75%
Left Standard	1.97	1.43	2.87
Left Short	2.13	1.40	3.48
Left Keypad	2.58	1.49	3.26

Note. Chi-square = 4.11 with 2 degrees of freedom. No significant differences were found among treatment conditions for the upper left trapezius.

Pre- and posttesting heart rates were similar, and averaged 74 beats per minute (bpm) just before testing began and 72 bpm immediately following the last test session. Additionally, differences between pre- and postbaseline resting EMG levels were nonsignificant using a t test.

Table 3

All Pairwise Multiple Comparison Procedures (Tukey Test) for the Right Upper Trapezius (N = 18)

Comparison	Difference of Ranks	q
Keypad vs Short	15	3.54*
Keypad vs Standard	12	2.83
Standard vs Short	3	0.71

Note. A difference in ranks between the keypad cover and the short keyboard configurations was found in the Tukey Test when the right upper trapezius muscle activity was measured in the within-subjects statistical design.
*$p < .05$.

On the User Preference Survey scoring sheet (Appendix Q), 44% of participants preferred using the mouse with the keypad cover configuration, while the other participants' preferences were equally split between the other two mouse and keyboard configurations (see Figure 7). Appendix R displays participants' written comments on the User Preference Questionnaire for mouse placement that was completed immediately following the experiment.

When participants were asked about comfort level with each test condition, 50% of participants identified greater physical comfort using the mouse with the keypad cover configuration, 28% with the standard keyboard configuration, and 22% with the short

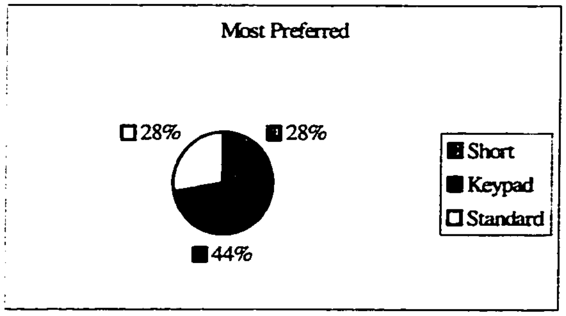

Figure 7. User's ratings for most preferred keyboard and mouse configuration.

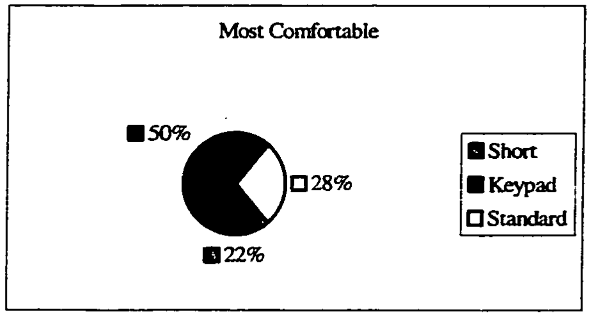

Figure 8. User's ratings for most comfortable mouse location.

keyboard configuration (see Figure 8). Discomfort during the testing sessions was reported by two-thirds of the participant group. Of those 12 participants, 8 stated that they were uncomfortable using the mouse with the standard keyboard, eight with the short keyboard, and three with the keypad cover (Refer to Figure 9). Order of test conditions showed no correlation to discomfort. Participants' interpretations of discomfort represented a wide range of responses. The range of responses may have been due to the fact that the writer failed to provide an operational definition for the word "discomfort." Reported discomfort for some individuals signified that they were uncomfortable with an unfamiliar workstation and new movement patterns, while discomfort for others indicated pain, soreness, or numbness. On the other hand, for some participants, discomfort symbolized a lack of control over a particular mouse placement condition (see Appendix S for additional responses).

Locations of discomfort or fatigue were varied, and included both shoulders, right thumb, right index, third and fifth finger, right base of palm near thumb (thenar eminence

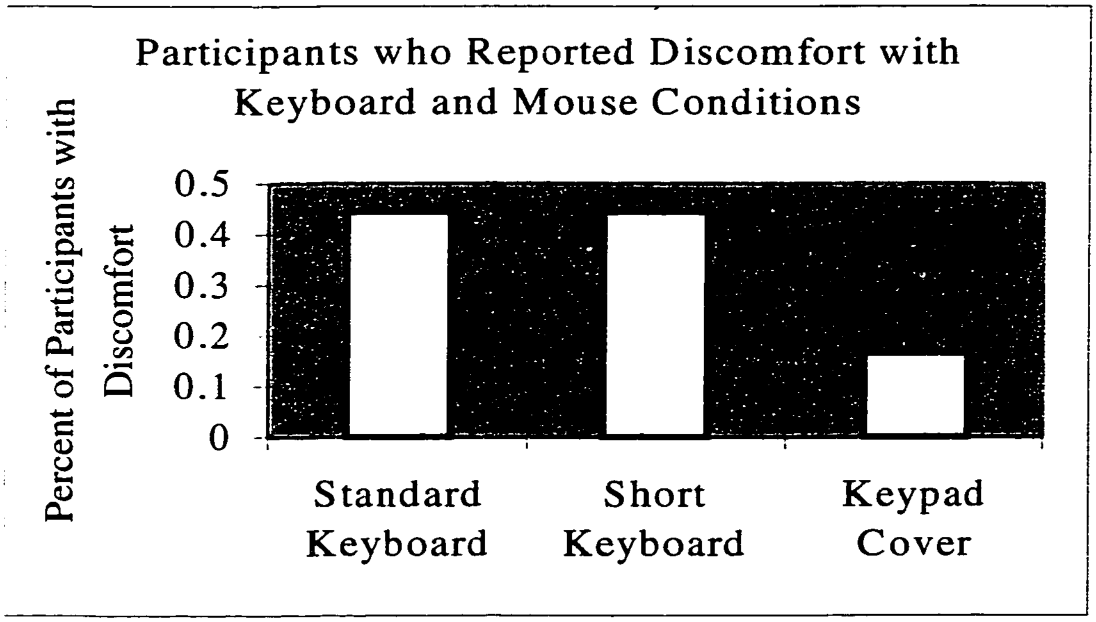

Figure 9. Participants' reported discomfort with each mouse location.

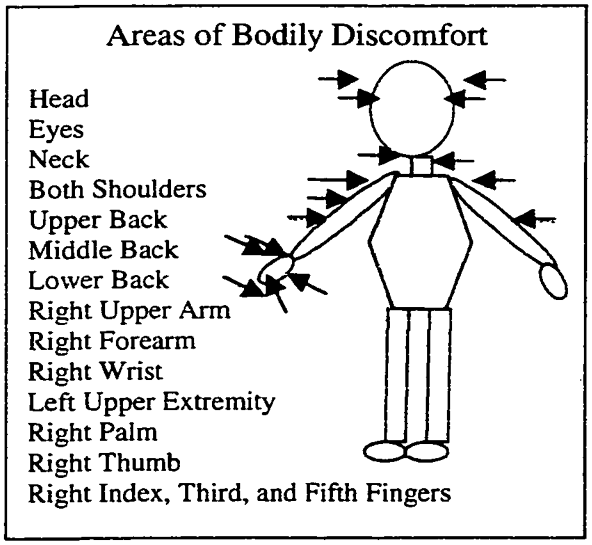

Figure 10. Specific areas of bodily discomfort as reported by participants.
Each arrow indicates that at least one person identified discomfort in the specified area of the body.

region), eyes; low, mid and upper back; right upper arm, right forearm, right wrist, left upper extremity, neck and head (Figure 10).

DISCUSSION

The purpose of this study was to examine electromyographic activity of the left and right upper trapezius with three different computer mouse placements. This section discusses critical aspects of the experimental results (electromyographic activity, computer operator technique, preference, comfort, discomfort, and implications of results) and offers suggestions for further research.

Electromyographic Activity

The hypothesis stating that there would be no significant difference in shoulder muscle activity between mouse locations was not supported for the right upper trapezius. In median value comparisons, participants demonstrated a greater amount of shoulder muscle activity when navigating the computer mouse on the numeric keypad cover than when the mouse was located next to the short keyboard on the keyboard tray. The mouse was placed one and a half inches further to the right from the center of the keyboard keys and 1.50 - 2.13 (3.81 - 5.41 cm) inches higher (due to the slope of the keypad cover) in the keypad condition than the short condition. These results expose an ergonomic risk of using mouse accessories to raise the mouse position relative to the keyboard height. This has not been previously identified in the literature. The preferred keyboard tray designs (two-tiered and sliding) of Paul et al.'s (1996) study are not supported here due to increased shoulder elevation when using a mouse placed higher than the keyboard height (when set at 90° to seated elbow height). However, the results of the present study do support the findings of Faucett & Rempel (1994) and Sauter et al. (1991), which indicate that mice situated above elbow height induce upper extremity musculoskeletal disorders.

This significant difference in EMG output for the right upper trapezius is a warning sign to office ergonomics professionals and the general public of the hazards of raising the height of the mouse above the computer operator's seated elbow height. It is suspected that participants slightly hiked or hunched the right shoulder to use the computer mouse on the numeric keypad cover. The elimination of shoulder elevation should be considered when planning for mouse placement and when designing keyboard and mouse trays, as well as mouse accessories.

There was no difference in EMG levels between the standard condition and the keypad condition, and this might be partly explained by the added seven inches (17.78 cm) of lateral reach to the right to use the computer mouse in the standard condition as compared to the number keypad condition. The upper trapezius muscle under study are also responsible for shoulder abduction, and possibly the higher EMG signals could have resulted from detecting motor unit action potentials caused by shoulder abduction. Most of the participants had to anchor their wrists in the standard condition because of the extended reach to the mouse. The numeric keypad cover was designed and marketed primarily to reduce the right arm's lateral reach to the mouse when compared to the standard keyboard and the right mouse placement arrangement. However, the product designers might not have recognized the increased risk of shoulder injury from static loading of the shoulder muscles to sustain an elevated posture.

Use of the numeric keypad cover also might reduce wrist extension associated with the mouse placed on the same height surface as the keyboard. Some ergonomics practitioners employ numeric keypad covers or raise the mouse to the same level as the keys on the keyboard with a book or other type of mouse riser to eliminate wrist extension. However, based on this study, the higher placement of the mouse could expose the right upper trapezius to dangerous levels of static muscle activity. Also, biomechanical compromises between various regions of the body need to be scrutinized carefully so a new injury site does not result from focusing on improving postural and movement dynamics of another body site.

It is uncertain if computer operators shift some of the workload from the wrist and hand to the shoulder when inputting with a mouse higher than seated elbow height. Damann & Kroemer (1995) showed that wrist position approached neutral when the mouse was placed at 100 - 120% of seated elbow height. However, the current study revealed that when the mouse was raised to above 100% of seated elbow height, right shoulder muscle activity might exceed a safe working level. To this date, no height range has been identified for maintaining a safe working posture when inputting with a mouse. Ergonomic standards recommend that keyboarding should be performed with the elbows positioned at 90° when seated. When conforming to this recommendation, many computer operators use the mouse at or slightly below seated elbow height as the mouse is positioned on the surface next to the keyboard (Armstrong et al., 1995). If the computer operator primarily used the mouse and rarely used the keyboard, the work surface might be lowered so that if the keypad cover was used, it would be positioned at seated elbow height. Still, wrist extension could be compromised when using the keyboard lower than seated elbow height, and the leg clearance for many computer operators is insufficient to drop the height of the mouse surface much lower than 90°. This height issue is also dependent on the thickness of the work surface.

Computer operators might be better candidates for a short keyboard and mouse arrangement than employing a numeric keypad cover if they (a) are accustomed to using the mouse with the right hand versus their left hand, (b) do not need the numeric keypad, and (c) abduct their shoulder or externally rotate their elbow to use the mouse with the standard keyboard. Compromises between the muscle activity of the hand, wrist, arm, shoulder, and neck during keyboard and mouse use need to be considered when arranging a computer workstation. Still, human-computer interaction can be complicated when attempting to reduce injuries to two or more regions of the body simultaneously.

Computer Operator Technique.

From a casual observer's perspective, participants generally varied their technique minimally within mouse conditions and mildly between mouse conditions during the experiment. In contrast, great variation in mouse usage style occurred between subjects. Shoulder elevation was difficult to detect as only 5 of the 18 participants showed noticeable shoulder hiking, and no correlation to mouse placement was apparent. Two participants were viewed leaning slightly to the left with the left shoulder raised higher than the right. This posture could possibly occur as an anchoring mechanism to stabilize the torso during mouse use. The results of this study show evidence that EMG activity and the behavioral observations of the shoulders were not analogous. Subtle elevation of the shoulders is difficult to discern visually. Consequently, recording EMG activity provides a valuable objective measurement.

When viewing movement patterns during computer mouse use, one half of the participants moved the mouse using at least moderate shoulder motion, while 16 used at least moderate wrist motion. Static holding of the shoulder while planting the wrist and moving the mouse primarily with wrist, hand, and finger motion can place the operator at a greater risk than using primarily dynamic shoulder and arm movement, except when using the mouse with an extended reach. The above-mentioned pattern was the case with the majority of the participants when operating the mouse in the standard condition.

Eleven participants noticeably abducted their right shoulder to use the mouse in the standard condition, while 2 abducted their right shoulder in all conditions, and 1 abducted the right shoulder in the standard and the keypad cover conditions only. Shoulder flexion was observed among 5 participants in all conditions. Neck movement increased the EMG readings to above 10.00 μV for the left and right upper trapezius during the preexperimental phase so care was used during the testing periods to not distract participants so they would continue to look straight ahead at the monitor screen. Still, 7 participants held their head tilted forward, 11 flexed their neck to look at the keyboard keys during the text-editing task, 3 briefly turned their head to the right with 1 averting eyes away from the monitor, 3 tilted the head to the left, and 4 tilted the head to the right. Most of these movements were brief, and a majority of participants appeared to be stretching, although a few participants maintained forward head positions through the entire test sequence.

Interestingly, participants generally performed idiosyncratic movements on a recurrent, but infrequent basis. For example, if a participant brought the left hand to the face during the fourth task of the first test condition, this same action would repeat itself during the next two test conditions. In each test condition, following the tracing task in PowerPoint (Task 4), at least 5 participants slightly shifted their thoracic region of the back and 2 took a deep breath.

Preference

More participants preferred the keypad cover placement for the mouse than the other two mouse placements. Participants who preferred the keypad condition stated their reasons as increased comfort (i.e., less fatigue in the right hand, less tension in the upper back and right shoulder, increased relaxation, or least physical strain), a close reach to the mouse, and limited postural movement needed to move the mouse. Those participants who preferred the mouse placement with the short keyboard reported their preference to be influenced by comfort, less muscle tension, less distance to reach the mouse, improved wrist posture, greater control of the mouse, and better height of the mouse placement. Most advocates of the mouse placement with the standard keyboard condition indicated that familiarity was key to their preference. Other reasons for the standard keyboard and mouse preference were listed as greater control of the mouse and increased relaxation of right hand and arm. One participant stated that the standard set-up was preferred because the mouse was out of the way and he rarely uses the mouse.

Both familiarity and gadgetry appeal might have played a role in some of the participants' preferences. Moreover, the question of preference did not merely address preference in terms of shoulder positioning, but mouse location in general. Participants might not have been perceptive of postural deviations of their right shoulder or knowledgeable of safe shoulder positioning when using the mouse since only 2 mentioned the shoulder when questioned about their preferences. The mean right upper trapezius EMG values in this study of 3.85 μV for the standard condition, 3.45 μV for the short condition, and 4.82 μV for the keypad cover condition when compared to participants' preferences indicate that participants' perceptions of relaxation in the shoulder region were inaccurate.

Preference criteria not mentioned by participants but regularly addressed in the field of ergonomics when deciding whether to use a short keyboard or a numeric keypad cover with the existing standard keyboard include the tactile sensation or "touch" of the keys of the short keyboard as compared to the standard keyboard; and the fit, adjustability, and sturdiness of the numeric keypad cover. Another preference criterion is the ergonomic cost of the proposed modifications. The price difference between the numeric keypad cover and a short keyboard is minimal (within $0.00 to $30.00, on the average) with short keyboards generally costing the same or more than numeric keypad covers. Alternative keyboards that are narrower than standard-sized keyboards usually are higher priced than short keyboards.

When keyboard trays are not wide enough to include a mouse, alternatives to using the mouse on the higher work surface should be considered. Switching to a wider keyboard tray, a short keyboard, or using a separate numeric keypad cover or mouse tray may be some of the options. An advantage to using a short keyboard or a numeric keypad cover is that the lateral reach to the mouse decreases, thus increasing work efficiency during combined keyboard and mouse use.

Comfort and Discomfort

Similar findings to preference resulted when participants addressed the issue of comfort and discomfort. A majority indicated feeling more comfortable using the mouse in the keypad cover condition, and more discomfort using the mouse in the standard and short conditions. Overall, most participants reported discomfort in at least one of the test conditions. Order of test conditions had no correlation to discomfort. Remarkably, participants had higher EMG activity of the right upper trapezius (4.82 μV) when using the mouse in their reported most comfortable location than in the other 2 conditions (short: 3.45 μV and standard: 3.85 μV). This conflict of findings has been seen before. Karlqvist et al. (1994) noted in their study that neck/shoulder discomfort was lower for the mouse group (19.3 mm) than the keyboard group (31.6 mm) on a 100 mm visual analogue scale during a videotaped postural analysis study, even though bodily postures were significantly more compromised for the mouse group.

Surprisingly, participants reported discomfort in several body sites. One participant recalled sharp, throbbing pain in the right shoulder and soreness in the right wrist in the first test condition (standard). Sometimes one task was uncomfortable for a participant. ("During the tracing exercise, my right index and third fingers became very sore and tired. The discomfort ran up the tendons from those fingers into my forearm.") On occasion, a technique method was reported as the pain culprit. ("When I finished dragging the mouse, especially long distances, I needed to lift and replace the mouse. At that time, I had discomfort at my right wrist.")

The difference in locations of discomfort, reasons for discomfort, and number of test conditions in which participants reported discomfort were highly variable between participants. Factors that may have influenced comfort and discomfort included a lack of micro breaks, the novelty of the tasks, the testing environment, and the limited use of the keyboard keys. Additionally, the researcher set up participants to sit centered on the home row "g" and "h" keys, whereas some participants had initially situated themselves closer horizontally to the mouse in the standard condition (i.e., between the "l" and ";" keys), thus increasing the lateral reach to the mouse from their usual and customary orientation. Another probable factor was that instructions to keep the left hand still and relaxed in the lap when not in use may have influenced participants to hold their body rigid instead of occasionally fidgeting which often allows the muscles to relax. Excessive focus on mouse tasks under test conditions and limited somatic awareness of tension and relaxation might have played a role in participants' comfort levels (Paul, Menon, & Nair, 1995). Also, it is hypothesized that when individuals perform movements repetitively they adjust to a comfort level even if the movement patterns are inefficient.

Implications for the Shoulder Positioning and Mouse Placement

Based on the electromyographic analysis of upper trapezius muscle activity in this study, and previous research on mouse placement, the following suggestions are provided:

1. The mouse could be used on the surface next to a short keyboard. This would reduce shoulder elevation and abduction.

2. The mouse could be used on the left-hand side of the keyboard with the buttons switched for left-hand use, if the computer operator prefers the standard keyboard. However, it might take some time before right-handed computer operators become comfortable using the left hand to control the mouse. This would place the mouse at the same level as the keyboard and close to the torso, which in turn would reduce shoulder elevation and abduction. Secondly, the workload of the right hand would decrease.

3. Avoid using keypad covers and other devices that raise the height of the mouse above seated elbow height, since this would diminish shoulder elevation.

4. The mouse could be used in conjunction with a short keyboard and an external numeric keypad. Swapping the locations of the numeric keypad and the mouse so that the active input device is placed closer to the torso would reduce the postural strain associated with an extended lateral reach.

5. In general, computer input tools could be optimally positioned so that the most frequently used tool promotes a relaxed shoulder and 90° seated elbow angle. This

would reduce the risk of injury.

<u>Suggestions for Further Research</u>

The following are recommendations for further study:

1. Conduct longitudinal studies to determine which mouse placements promote ergonomic advantages and movement efficiency. These studies could focus on injury trends and health risks involving computer input postures. For example, one question might be, would it be less detrimental to work with the shoulder abducted or elevated when using the mouse?

2. Repeat the present study comparing EMG muscle activity of the upper left and right trapezius as well as analysis of lateral forearm extensors to better understand the postural compromises in relationship to the different mouse placements.

3. Conduct electromyographic analysis of upper extremity muscle activity in field studies of computer work settings. The study of behavioral patterns involving EMG analysis in the natural work environment could present a more accurate picture of computer interaction than in a controlled environment. Moreover, visual analysis may have a subjective bias and offer only limited information as a diagnostic tool. However, using visual analysis in conjunction with EMG analysis may provide more inclusive and accurate information.

4. Assess placement options and the implications for posture and upper extremity muscle activity when using a separate numeric keypad with a short keyboard and computer mouse. Results could help identify the optimal location(s) of a separate

numeric keypad.

5. Replicate the present study by using forearm and wrist supports to determine if EMG activity would decrease in the left and right upper trapezius, and if one mouse placement condition would be preferred over another based on the EMG findings.

6. Compare EMG shoulder activity for both left- and right-handed trackball and computer mouse users. This is suggested because computer operators must often protract and elevate the preferred shoulder to operate a trackball as it usually sits higher and deeper on the work surface than the mouse when placed at the operator's seated elbow height. The associated health risks and postural compromises are unclear.

7. Identify postural changes, and left and right shoulder and extensor forearm muscle activity when using the Mousetrapper compared to the mouse placed on either side of the standard keyboard. Since the Mousetrapper allows access to the numeric keypad without creating an extended reach to the computer mouse, this comparison could determine postural demands and benefits.

CONCLUSION

The recent increased use of keyboard and mouse arrangements by a large sector of the world population has brought attention to related health and safety risks. Optimal placement of the computer mouse for reduced risk of most common UEMSDs has not been identified in the literature. Moreover, incomplete data have been reported between articles, partly due to the focus on only one or few body regions without regard to postural compromises of other body regions (Aborg et al., 1995; Armstrong et al., 1995; Damann & Kroemer, 1995; Dowell & Gscheldle, 1997; Hermans & Spaepen, 1995; Karlqvist et al., 1994). Simultaneous evaluation of multiple electromyography (EMG) sites would be informative but cumbersome in terms of data analysis. The use of mouse accessories has risen substantially over the past decade. Computer operator technique changes and postural compromises occurring from using mouse accessories are poorly understood. Until the completion of the writer's study, no research addressed the issue of using a numeric keypad cover for the mouse placement. Only one study has been identified that measured the interaction between shoulder elevation and mouse placement (Paul & Nair, 1996). More EMG analyses are needed to determine how input devices, postures, and movement patterns affect muscle activity.

The purpose of this study was to determine the effects of three mouse placement conditions on muscle activity of the right and left upper trapezius. The mouse placement conditions involved: (a) a numeric keypad cover, (b) a mouse tray surface next to and slightly below a standard keyboard, and (c) a keyboard tray surface next to a short keyboard. EMG results showed significantly higher right upper trapezius muscle activity when operating the mouse in the numeric keypad condition as opposed to the short keyboard condition.

In summary, health risks associated with sustained shoulder elevation need to be considered when setting up computer input tools and accessories for computer operators. Ergonomic risks of shoulder elevation have been ignored in previous studies. More extensive examination of the effects of computer tool placement, chair armrests, wrist rests, and postural habits on shoulder elevation and associated UEMSDs could shed light on this dormant field of research.

The implementation of numeric keypad covers should be employed with great caution due to the elevation of EMG values of the right upper trapezius as demonstrated by the writer's study. While it is clear that this accessory compromises the upper trapezius muscle because of increased EMG activity, it is unclear how the use of this accessory affects muscles responsible for shoulder abduction. Suggestions for future research include: (a) longitudinal studies of the effects of postural compensations associated with different pointing device locations, (b) EMG studies of the upper extremity muscles activity associated with various keyboard and pointing device arrangements; and (c) behavioral studies to determine the ability of computer operators to adapt to new input methods and behavioral patterns. If researchers can continue to clarify the physical affordances and constraints of workstation configurations, ergonomic practitioners will be better equipped to educate computer operators on the advantages and disadvantages of keyboard and pointing device arrangements.

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Appendix A

Various Designs for Mouse Placement

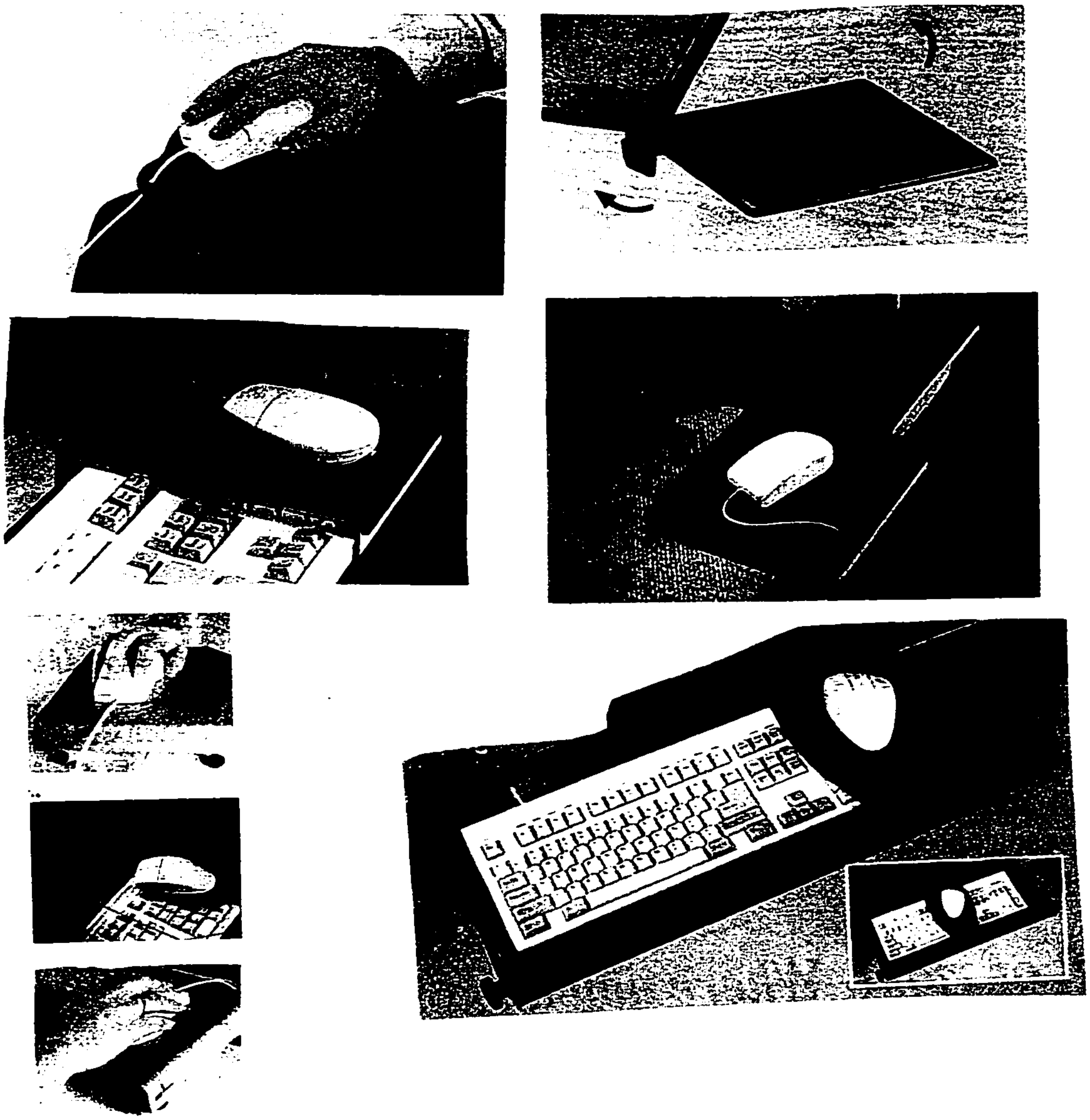

Illustration of available mouse placement accessories offered by AliMed Products, Dedham, MA. Reprinted with permission.

Appendix B

San José State
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Voice: 408-924-2480
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Human Subjects-Institutional Review Board Approval

TO: Rebecca Crane
3700 Alenhaven Rd.
Soquel, CA 95073

FROM: Nabil Ibrahim,
Acting AVP, Graduate Studies & Research

DATE: March 22, 1999

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

"Electromyographic Activity of the Upper Trapezius During Computer Mouse Input in Three Mouse Locations"

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 any and all data that may be collected from the subjects. The Board's 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 Nabil Ibrahim, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

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 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.

Appendix C

Modified Standardized Nordic Questionnaire

Code:____

Please answer the following questions:

1. How old are you?	___ Years old
2. What is your gender?	1. □ Female 2. □ Male
3. What is your weight and height?	___ lbs.; _ ft. _ In.
4. Are you right- or left-handed?	1. □ right-handed 2. □ left-handed
5. Do you have good or corrected vision?	1. □ Yes 2. □ No
6. How much experience have you had using the computer mouse with Windows 98 and Microsoft Office 97 on a PC computer?	1. □ Less than 10 hours 2. □ More than 10 hours
7. On the average, how often do you use the computer mouse during a day?	1. □ Less than 1 hour 2. □ 1-4 hours 3. □ 5-8 hours 4. □ More than 8 hours
8. Can you comfortably sit and use a computer mouse for up to 45-minute intervals and for up to 99% of a two-hour period?	1. □ Yes 2. □ No
9. In the past 6 months have you experienced any upper extremity, neck, shoulder or back discomfort?	1. □ No 2. □ Yes, my right shoulder 3. □ Yes, my left shoulder 4. □ Yes, both shoulders
10. Have you ever had shoulder trouble (ache, pain or discomfort)?	1. □ No 2. □ Yes, in my right shoulder 3. □ Yes, in my left shoulder 4. □ Yes, in both shoulders
11. Have you ever hurt your shoulder in an accident?	1. □ No 2. □ Yes
12. Do you have any other physical impairment that would limit your ability to sit and use the computer mouse for 45-minute intervals and up to 99% of a two-hour period?	1. □ No 2. □ Yes
13. Are your shoulders sore from recent physical activity?	1. □ No 2. □ Yes

Appendix D

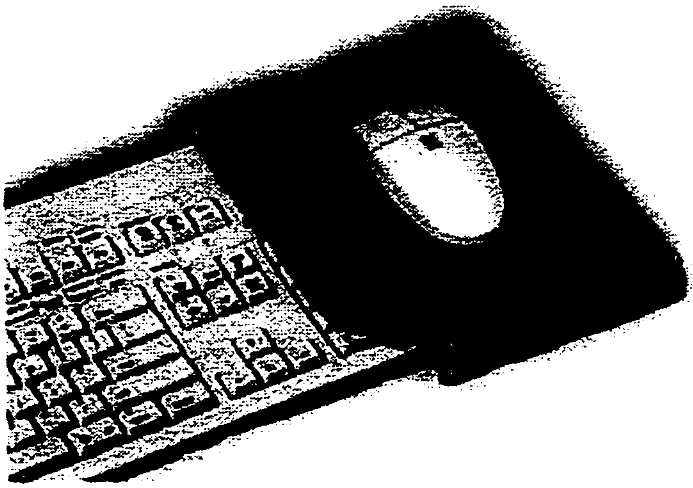
Zeroing Procedure for ProComp+™/ Biograph® Version 2.0, June 1999

The following steps were completed in numerical order to calibrate the Biograph® 2.0 system:

1. Place one end of zeroing cable (shortest cable) into upper right port of ProComp+™. Gently turn knob to right until tightness of knob on cable is barely felt.
2. Place other end of zeroing cable into Pro-SB interface that is connected to PC adapter. Gently turn knob to the right until tightness of knob on cable is barely felt.
3. Insert Leads C and D into corresponding ports on ProComp+™.
4. Insert zeroing plugs (with attached short tails) into Leads C and D.
5. Turn on Computer.
6. Select "Biograph® 2.0" from computer desktop screen.
7. Click "O.K."
8. Select "Load a Display Screen."
9. Select "Categories: EMG screens," and then "Display screens: 2 Channels for work/rest."
10. Click "Load."
11. When asked "Would you like to start a new session - recording or would you like to load a session for review (replay)?", select "review."
12. Select "client: base/mvc ADC offset with cursor keys."
13. Select "zero" for the session by double clicking the mouse.
14. Click "O.K." when reply states "session loaded successfully!" It contains the following data: "Input C: EMG (rms)" and "Input D: EMG (rms)."
15. Select "Zeroing" or type in a client's name
16. Choose "New session."
17. Turn on ProComp+™.
18. Screen will begin to collect data.
19. At upper tool bar, select "Config."
20. Scroll down and select "adjust sensor offsets."
21. Click on box adjacent to "Input C Myoscan-Pro 0 - 400µ."
22. Click on adjustment bar to the right of the screen.
23. Use arrow keys on keyboard to slowly fine-tune sensor ADC offset display until "corrected value" number is closest to zero in a positive value direction (ex: "0.5" but not "-0.5.").
24. Click "O.K."
25. Repeat steps 21 - 24 for zeroing Input D Myoscan-Pro 0 - 400µ box.
26. Click "Back to menu."
27. Click "Exit program" twice.
28. This ends the calibration process. Do not forget to replace fiber optic cable and lead plugs with data collecting counterparts before continuing to use the Biograph 2.0 system.

Appendix E

Adaptables NonAdjustable Numeric Keypad Cover
as Illustrated by Keyboard Alternatives & Vision Solutions, Inc., Roseville, CA.
Reprinted with permission.



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Appendix F

AGREEMENT TO PARTICIPATE IN RESEARCH
SAN JOSE STATE UNIVERSITY

PRINCIPAL INVESTIGATOR: Rebecca J. Crane, C.V.E.

TITLE OF PROTOCOL: Electromyographic Activity of the Upper Trapezius during Computer Mouse Input in Three Mouse Locations.

I have been asked to participate in a research study that is investigating the electromyographic activity of the upper trapezius during computer mouse usage. The purpose of the research is to determine the effects of computer mouse placement on shoulder muscle activity.

I understand that:

1). My participation will involve a test session of up to 2 hours of orientation, computer keyboard-mouse usage with a Windows 98 and Microsoft Office 97 software interface, and debriefing at San Jose State University's Stress Management laboratory.

2). The risks of this study are minimal, but may include: a skin abrasion from preparing the skin for electrode placement, skin irritation from the adhesive backing on the electromyographic surface electrodes, muscular soreness, visual strain, and general fatigue. A few shoulder shrugs, and one, five-minute and three, twenty-minute computer keyboard-mouse input sessions will be the extent of the required physical exertion.

3). The results of the research study may be published, but my name or identity will not be revealed. In order to maintain confidentiality of my records, Rebecca Crane will place a code next to my name and transfer only the code to all test research data sheets, and then keep my name separate from the research to where only she has access to my name.

4). The possible benefits of my participation in the research are to reduce the health risks of using a computer mouse.

Participant's Initials ______

5). Rebecca J. Crane, C.V.E., will answer any questions about my participation in this study at (408) 447-7853. Complaints about the procedures may be presented to Dr. Barbara Conry, Ph.D. (Thesis Advisor) at (408) 924-3031. For questions or complaints about research participant's rights, or in the event of research-related injury, contact Nabil Ibrahim, Ph. D. (Associate Academic Vice-President for Graduate Studies & Research) at (408) 924-2480.

6). I will not jeopardize or lose any service to which I am otherwise entitled if I choose to not participate in this study.

7). My consent is given voluntarily without being coerced; I may refuse to participate in this study or in any part of this study, and I may withdraw at any time, without prejudice to my relations with SJSU. In signing this consent form, I am not waiving any legal claims, rights, or remedies.

8). I have received a copy of this consent form for my file.

Participant's signature ________________________ Date

9). I certify that I have explained to the above individual the nature and purpose, the potential and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature.

10). These elements of informed consent conform to the Assurance given by San Jose State University to the Department of Health and Human Services to protect the rights of human subjects.

11). I have provided the participant a copy of this signed consent document.

Signature of Investigator ________________________ Date

Participant's Initials ______

Appendix G

Participants' Measurements

Code: ____

Shoulder-to-shoulder width ________

Elbow-to-elbow width ________

Appendix H

Select ANSI Standards

In terms of the height of the keyboard support surface, the ANSI standards state that the seated user should be able to adopt a keyboarding posture where the upper arm and forearm are greater than 70° and less than 135°. Based on anthropometric data of the 95th percentile male and the 5th percentile female, ANSI standards recommend that the keyboard work surface range in height from at least 23 to 28 inches (58.42 to 71.12 cm). A footrest must be provided if the keyboard work surface is non-adjustable and the computer operator cannot keyboard with a correct arm angle while maintaining the feet flat on the floor (American National Standards Institute, 1988).

The seat pan and seat back angles are crucial elements to a computer workstation. Workstation designs that are based on a reclining posture may require a tilted keyboard work surface to avoid discomfort and unacceptable wrist angles. The angle between the upper and lower leg, with the lower leg perpendicular to the floor, must be between 60 and 100°; however, if the lower leg is supported as well, the angle could increase to 140°. If fixed, the seat pan must be fixed at a point between 0 and 10° but if the seat pan is adjustable, the adjustment range should include at least a portion of the 0 to 10° range. The seat pan must support the body weight at the thigh and buttock. The seat back, in conjunction with the seat pan, must permit a working posture with a torso-to-thigh angle somewhere between 90 to 105° (American National Standards Institute, 1988).

A backrest or lumbar support (between the L3-L5 vertebrae) needs to be provided based on a person's posture and preference, and the task and chair features. Armrests are optional, but if provided, the inside distance between armrests must be at least 18.2 inches (46.23 cm) to accommodate large hips of the 95th percentile female (American National Standards Institute, 1988).

Appendix I

ProComp+™/ Biograph® Version 2.0, Experimental Protocol

The following steps were completed in numerical order to operate the EMG equipment during the test sessions:

Pretest and Posttest Baseline EMG Protocol:

1. Turn on Computer.
2. Select "Biograph 2.0" from computer desktop screen.
3. Click "O.K."
4. Select "Define and run a work/rest protocol."
5. Select "Load a display screen."
6. Select "Categories: EMG screens," and then "Display screens: 2 Channels for work/rest."
7. Click "Load."
8. When prompted to define and run a work/rest protocol, enter "15 seconds" rest, "60 seconds" work, and "15 seconds" rest in the corresponding fields.
9. When asked "Would you like to start a new session - recording or would you like to load a session for review (replay)?", select "New."
10. For Pretest protocol, select "New client" and enter first name of participant and identification number. For Posttest protocol, highlight client name.
11. Click on "O.K."
12. When prompted to "Start new session," turn on the ProComp+™. The screen will change to display the battery level and prompt the session to start.
13. Click on "Start."
14. After a data collection session, decide whether data are clean. If it is not clean, reset the software for re-recording data by clicking on "Back to menu," follow steps 4 - 9, highlight client name, click "O.K," and follow steps 13 - 14. If the data are clean, label the session "b1" for pretest or "b2" for posttest.
15. The statistical analysis will take only a few minutes to be calculated. Afterward, the screen will prompt to "Print the session."
16. Click on "Print the session." Click "No color." Click "Print."
17. Click on "Back to menu" (located at bottom right of screen).

Ergonomics EMG Protocol:

1. From the main menu, choose "Start a protocol that will automatically run for a fixed time."
2. Click on "Ergonomic."
3. Choose client name by highlighting it.
4. Click on "Start new session."
5. Make sure ProComp+™ is turned on. (Check that power switch of ProComp+™ device is turned on and double-check that leads are secure at all entry points.)
6. Click on "O.K." when ready to start collecting test data.
7. Three, 20-minute sessions follow with a rest prompt between sessions. Click on "O.K." to start the second two sessions following the rest intervals.
8. Following the final data collection phase, the computer will prompt the researcher to "Save data."
9. Enter name of session, "Test."
10. The statistical analysis will take several minutes to be calculated.
11. The screen will prompt to print the session. Click "No color." Click "Print."
12. Afterward, click on "Back to menu."

Appendix J

Test Instructions

1. Welcome and introduction to experiment.

Before we begin please read, sign, and initial both copies of the agreement to participate in research. One is for you to keep. Also, please complete this brief questionnaire. During this interval, record the last two digits of the social security number and the participant number on all papers referring to the participant. Check the randomizing test condition grid to select the treatment by social security number that the participant will be receiving, and then set-up the computer system for the first test condition. *Please use the restroom now if you need to because once we begin testing it will be difficult to pause the session.* (Pause for potential restroom break).

2. Describe experiment.

This study looks at mouse input with different mouse arrangements. In this experiment, you will be using the mouse to trace template images by hand, scroll, highlight, edit, select, and move data in the Windows 98 and Microsoft 97 software interfaces. There will be one 5-minute practice trial and three different 20-minute test trials. More detailed instructions on your task will be given in a few moments. The electromyography machine, commonly known as an EMG, will be measuring the load on your shoulder muscles during the tasks through surface electrodes that will be placed on your skin. The electrodes are harmless and you will barely be able to feel them.

3. Prepare participant

'First, I need to measure the width between your shoulders and between your elbows so please relax your arms at your sides and position your arms as if you were keying. Take measurements. *Now, let's take your 15-second heart rate. I will find your carotid artery alongside your neck so relax while I take your pulse.* Take pulse using a 15-second timer, and then multiply by four to record beats per minute.
Next, your shoulders will be palpated to find the muscles needed for testing, and your skin will be [shaven and] cleansed so that there is a good connection once the electrodes are applied. Prepare EMG and participant for testing. If the muscles are not clearly identified, the participant will be prompted to shrug the shoulders to locate the muscle under study.

4. Adjust workstation for participant.

I will now adjust the workstation to your body, and then I can help you make minor adjustments so you are comfortable. How do you feel now? Make adjustments until the participant reports feeling comfortable when asked, and is set up per ANSI standards with the center of the torso between the "G" and "H" keys on the keyboard, and the elbows at 90° directly facing the keyboard.

5. Participant instructions

Now, relax your shoulders and stay stationary in your chair so that you remain in the correct position in relation to the mouse arrangement. If possible during the test periods, do not perform extraneous activities, such as stretching or touching your face, so the EMG machine won't pick up on noncomputing activity. Let's walk through the test instructions both visually and verbally. When I tell you to start:

(a) Open the existing file name 'PRACTICE' by double-clicking the mouse on the icon over the word 'Practice' on the start up page of Windows 98.
(b) Double-click on the '1_sample' icon;
(c) Select and drag each object into the box. Select and drag each object out of the box. Continue this sequence until I say 'select file.'
(d) At that point, click on the 'File' menu and scroll down and select 'Exit.'
(e) When asked if you wish to save, select 'No.'
(f) Next, double-click on the '2_sample' icon.
(g) Highlight all the 'B' cells by scrolling down the page. Continue to scroll down and up while highlighting the 'B' cells until I say 'switch to clicker.'
(h) Then, click on the 'Clicker' page at the bottom of the page you are on to open the next task.
(i) Move the mouse down to each highlighted box and click the mouse on each box. Continue this activity until I say 'switch to vertical drag.'
(j) Click on the 'Vertical Drag' page at the bottom of the page you are on to open the next task.
(k) On this task, drag each number to the colored square below it by selecting the item you need to move, pointing the cursor to the border of the selection, and dragging the selection to the upper-left cell of the paste area. Then drag each number to the Color Square above it. Repeat the sequence until I say 'switch to dragster.'
(l) Click on the 'Dragster' page and begin dragging the numbers up to the highlighted region so that they are in a numerical order vertically down the page. Then, drag them back down to the highlighted region below in the same numerical order. Continue until I say 'select file.'
(m) Click on the 'File' menu and scroll down and select 'Exit.'
(n) When asked if you wish to save, select 'No.'
(o) Double-click on the '3_sample' icon.
(p) Edit the paragraphs using the mouse and keyboard in combination until I say 'select file.'
(q) Click on the 'File' menu and scroll down and select 'Exit.'
(r) When asked if you wish to save, select 'No.'
(s) Double-click on the '4_sample' icon.
(t) At the left-bottom portion of the page, select 'AutoShapes,' and then select 'scribble.'
(u) Try to trace the drawing as closely as possible. If the utensil changes from a pencil, go back and reselect 'scribble' and continue tracing until I say 'select file.'
(v) Click on the 'File' menu and scroll down and select 'Exit.'

(w) When asked if you wish to save, select 'No.'
(x) Double-click on the '5_sample' icon.
(y) Play solitaire until I say 'stop and rest.'
(z) *I will close the program and reset the computer for the next test session at that time.* (This includes changing the keyboard and mouse arrangement and clicking the mouse on 'Game' and 'Exit' so that the program returns to the same starting point as the previous test session).
(aa) Make sure you keep your left hand in your lap as still as possible unless you are using it during the editing task. Also, during the rest periods, focus on relaxing your body and try to remain quiet.
(bb) On each task, work as quickly and as accurately as possible.
6. Practice test.
(a) Do you have any questions? Let's do a practice run before the actual test. I will time you for a 5-minute period and provide prompts for switching programs. Rest you hands in your lap. Remember to start by double-clicking on the Test 1 icon. Are you ready? Begin. Prompt the participant to switch at 1-minute intervals, and on Test 2 every 20 seconds (between Excel tasks). *Stop.*
(b) Give any verbal reinforcement of instructions necessary based on the practice trial. *Now, do you have any questions?*
7. Prepare Biograph® and ProComp+™ for pretest baseline.

Before the first test starts I need to check your baseline shoulder muscle activity. Enter the participant I.D. number to create a file in work-rest session field, and turn on the Pro-Comp+™. *Place your hands in your lap and relax your shoulders. I will test your resting EMG activity for a 1½ minute period. Ready? Begin resting.* Click the "O.K." button to begin the test period. Afterward, name the session as b-1 and print out the results. Prepare the Biograph® for the Customized Ergonomic Protocol, select the participant's I.D. number, and double-check that the ProComp+™ is turned on and all leads and sensors are secure prior to starting the program.
8. Start test sessions for data collection.

Are you ready to begin the first test trial? O.K., first place your right hand down by your side to be in the starting position. When I say 'begin' start the test by double clicking the 'TEST' icon in the Windows 98 start-up page, and proceed just as you did on the practice section. Ready? Begin. Press the start button when the right hand touches the mouse. Provide a brief verbal prompt if the participant pauses, asks a question about the task, or shows questioning facial expressions. Provide instructions to switch tasks at the specified periods. When the Biograph® computer program has completed a 20-minute interval, tell the participant, *Stop and relax. You may stand up and stretch but be careful not to tangle the wires or detach the electrodes.* Set rest interval of 5 minutes until next practice trial. *O.K. Now, I am going to modify your keyboard and mouse arrangement.* Repeat instructions for practice and test, and rest intervals twice. Provide positive feedback by saying, *good job* in between trials.

9. Posttest participant feedback

After the last test session, state, *the electromyography program will compute the results of your test periods and this will take a few minutes. In the meantime, I will take your resting pulse rate again and then give you this brief posttest questionnaire to complete.* When the questionnaire is complete, review it for completeness and legibility.

10. Prepare Biograph® and ProComp+™ for posttest baseline.

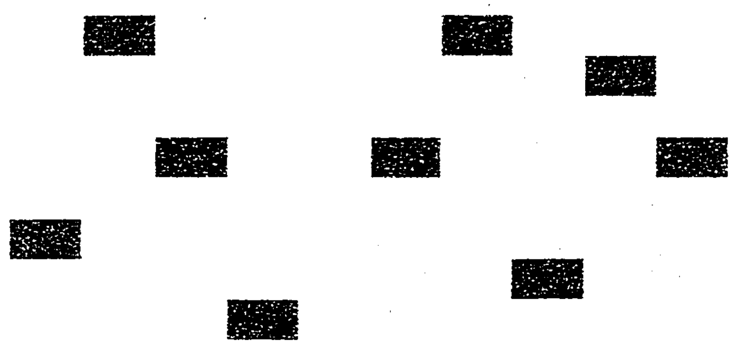
Once the statistics are ready, print out the results and set up the computer to collect data for the posttest baseline EMG. *Now, I will measure your posttest baseline EMG level for 1½ minutes. Remain seated and relaxed with your hands resting in your lap.*

11. Thank participant for completing experiment.

You are all done now. Let me remove the electrodes. Thank you for participating in this study. Also, keep this experiment confidential since we still have other people to test, and we would not want all your time and effort to go to waste by others knowing what to expect. This should be published and in the San Jose State University library next year with the Human Factors Engineering theses if you are interested in seeing the results.

Appendix K

Computer Mouse Task - Clicker



This task involved point and click mouse functions with cursor movements throughout the screen.

Mouse Task as illustrated in the Appenrodt and Andre (1999) study. Interface Analysis Associates, Cupertino, California, provided the task.
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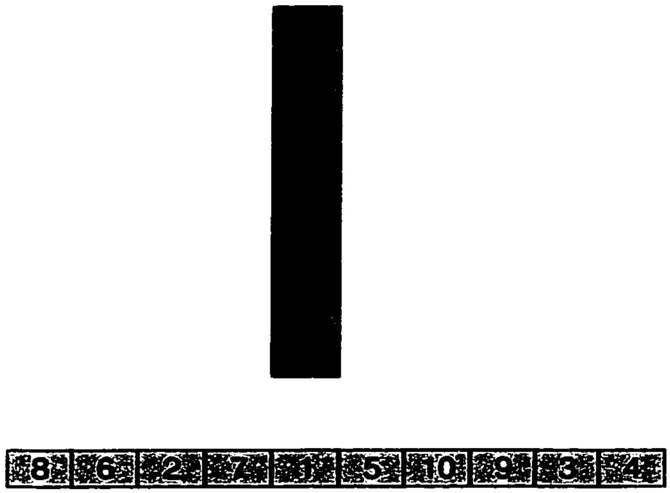
Appendix L

Computer Mouse Task - Dragster



This task involved point and click, vertical and diagonal click and drag mouse functions with cursor movements ranging from the bottom of the screen to the upper half of the screen.

Mouse Task as illustrated in the Appenrodt and Andre (1999) study. Interface Analysis Associates, Cupertino, California, provided the task.
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Appendix M

Computer Mouse Task - Scroller Coaster

8	11	42	19	24	5	36	A	A	1	4	5	4	1	4	5
12	17	4	5	4	11	42	A	A	3	8	11	19	17	36	53
18	25	8	11	8	17	4	5	4	5	12	17	5	19	42	61
24	35	12	17	12	25	8	11	8	7	18	25	11	23	54	1
-13	0	18	25	18	35	12	17	12	11	24	35	17	31	36	17
36	53	24	35	24	0	18	25	18	13	30	0	25	18	42	19
12	61	30	0	-13	53	24	35	24	17	36	53	3	8	4	5
18	66	36	53	36	61	30	0	-13	19	42	61	5	12	8	11
24	70	42	61	42	66	36	53	36	23	54	1	36	53	36	17
-13	102	A	A	54	70	42	61	42	31	68	3	24	43	24	25
36	30	A	A	72	102	54	77	54	37	78	5	4	9	4	35
18	42	60	42	53	95	68	99	68	41	42	7	8	20	28	0
24	11	35	11	35	46	78	115	78	1	4	11	12	30	42	53
-13	23	11	23	-12	12	118	159	118	3	8	13	18	42	60	61
36	78	1	3	8	11	118	159	118	5	12	17	35	17	13	30
42	96	138	5	12	17	30	0	-13	7	18	19	0	19	17	36
54	24	11	7	18	25	36	53	36	11	24	23	13	5	19	42
68	-13	13	11	24	35	42	A	A	13	30	31	17	11	23	54
78	36	17	13	30	0	54	A	A	17	36	37	19	17	31	36

This task involved point and click and click and drag mouse functions with the cursor movement in both vertical and horizontal directions, with scrolling on the right side of the screen.

Mouse Task as illustrated in the Appenrodt and Andre (1999) study. Interface Analysis Associates, Cupertino, California, provided the task.
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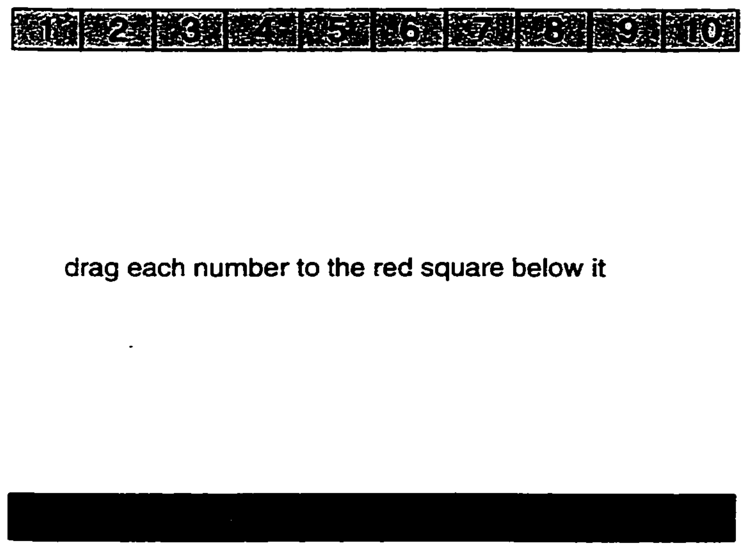
Appendix N

Computer Mouse Task - Vertical Drag



This task involved point and click, vertical click and drag mouse functions, and cursor movements from the top of the screen down to the bottom of the screen.

Mouse Task as illustrated in the Appenrodt and Andre (1999) study. Interface Analysis Associates, Cupertino, California, provided the task.
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Appendix O

Behavioral Observations

Code:____ 1 2 3

Mouse technique

Pinches mouse
Does not rest hand on mouse
Moves via wrist motion
Moves via shoulder motion
Hovers fingers over mouse
Holds with thumb and ff rf tf if
Ulnar deviation
Radial deviation
Pronated hold
Supinated hold
Wrist extension
Wrist flexion

Postural observations

Shoulder flexion/extension (f /e)
Shoulder abduction/adduction (b/d)
Shoulder internal rotation/external rotation (i/e)
Shoulder elevation/depression (e/d)
Elbow flexion/extension (f/e)
Neck flexion/turning R or L (f/r/l)
Head tilted forward/tilted R or L/off-centered to R or L (f/tr/tl/or/ol)
Reclining/perching/slouching in chair (r/p/s)
Ankles crossed
Shifts off center of keyboard to R or L/leans to R or L in chair (r/l/lr/ll)
Hands touching face/head frequent or seldom (tff/tfs/thf/ths)
Extra mobile/fidgeting/jerky movements (m/f/j)
Tensing or stretching body (identify site) (t/s)

Interaction during testing

Talkative with questions of process
Uneasiness displayed (comment on behavior)
Coughing/sneezing/yawning (c/s/y)
Negative/listless affect/distracted (n/l/d)
Thoracic breathing/breath holding (t/b)

Appendix P

User Preference Questionnaire

Code: ____

1. Rank the mouse locations for personal comfort by writing a "1" for most comfortable, "2" for next comfortable and "3" for least comfortable below.

   A. Short _____ B. Keypad Cover _____ C. Standard _____

2. Did you feel discomfort or fatigue associated to the mouse placement in any location(s)?

   1. ☐ Yes 2. ☐ No

If you answered YES to number 2, please respond to the questions 3-5, if you answered NO to number 2, skip to number 6.

3. Which location(s) bothered you?

   A. ☐ Short B. ☐ Keypad Cover C. ☐ Standard

4. In which specific regions did you experience discomfort or fatigue?

☐ Lower extremities
☐ Hips or buttocks
☐ Low back
☐ Mid to upper back
☐ Neck
☐ Head
☐ Shoulders (circle left, right, or both)
☐ Right fingers (circle: thumb, index, third, fourth, and/or fifth)
☐ Left upper extremity
☐ Right upper arm
☐ Right forearm
☐ Right wrist
☐ Right palm
☐ Eyes

5. Describe the discomfort or fatigue you felt and relate it to each specific region marked above.

6. Which of the three mouse locations do you prefer most? Choose <u>one</u>.

A. ☐ Short B. ☐ Keypad Cover C. ☐ Standard

7. If you had a specific preference, why do you like that location best?

Appendix Q

Scoring Sheet for User Preference Questionnaire

1. Rank the mouse locations for personal comfort by writing a "1" for most comfortable, "2" for next comfortable and "3" for least comfortable below.

A. Short _____ B. Keypad Cover _____ C. Standard _____

Score by percent of responses per choice

2. Did you feel discomfort or fatigue associated to the mouse placement in any location(s)?

1. ☐ Yes 2. ☐ No

If you answered YES to number 2, please respond to the questions 3-5, if you answered NO to number 2, skip to number 6.

3. Which location(s) bothered you?

A. ☐ Short B. ☐ Keypad Cover C. ☐ Standard

Score by percent of responses per choice

4. In which specific regions did you experience discomfort or fatigue?

☐ Lower extremities
☐ Hips or buttocks
☐ Low back
☐ Mid to upper back
☐ Neck
☐ Head
☐ Shoulders (circle left, right, or both)
☐ Right fingers (circle: thumb, index, third, fourth, and/or fifth)
☐ Left upper extremity
☐ Right upper arm
☐ Right forearm
☐ Right wrist
☐ Right palm
☐ Eyes

Score by percent of total participants marking a specific response

5. Describe the discomfort or fatigue you felt and relate it to each specific region marked above.
For discussion purposes only

6. Which of the three mouse locations do you prefer most? Choose <u>one</u>.

A. ☐ Short B. ☐ Keypad Cover C. ☐ Standard

Score by percent of responses per choice

7. If you had a specific preference, why do you like that location best?
For discussion purposes only

Appendix R

Participants' Responses on Mouse Placement Preferences

Short	Keypad	Standard	Response
	1		"I like the keypad cover because I felt less fatigue in my hand as the test went on. The positioning was also very comfortable."
1			"It felt the most comfortable."
1			"Less muscle tension, not reaching, better wrist posture."
		1	"Standard is how I learned to use the mouse so that's why I am most comfortable with that position."
1			"Short = comfort."
	1		"Less tension in upper back and shoulder."
	1		"Most comfortable."
	1		"Least amount of moving."
	1		"I felt the most relaxed and felt comfortable, and not tight."
	1		"Higher and closer."
		1	"Felt like had more control of fine motor by hand -fingers with shoulder use."
		1	"It is the one I am used to. It feels more natural than the others."
		1	"My hand and my arm is relaxed so my body doesn't feel so tense quickly."
	1		"Least strain or discomfort."
1			"I felt I had more control of the mouse in that position."
	1		"I felt more relaxed using keypad cover maybe because of the distance from my body."
		1	"Because it is out of the way. I rarely use a mouse."
1			"It was at the perfect distance and was easiest to control. At the same level as the keyboard was perfect, height was perfect."

Appendix S

Reported Discomfort Associated with Treatment Condition and Treatment Order

Location standard (first in order): Affected area: Low back, neck, head, shoulders, right wrist, eyes (Sharp, throbbing pain on shoulders, soreness on the right wrist.")
Location standard (second in order): Affected area: Right shoulder, left upper extremity, right forearm, right wrist ("felt like I a strain because I had to reach so far to the right.")
Location short (third in order): Affected area: Mid to upper back pain on right side, right shoulder, right forearm ("Ache, tension.")
Location standard (first in order): Affected area: Right shoulder, right fifth finger, right upper arm, right forearm, right wrist ("Stiff wrist, numbness in finger.")
Locations standard and short (second and third in order, respectively): Affected area: Mid to upper back, neck third finger, and right wrist pain ("Strain in finger, upper back, ache in wrist and third finger.")
Location short (second in order): Affected area: Mid to upper back, both shoulders, and eyes ("Tightness and a need to stretch out. My eyes just got tired of staring at a screen.")
Locations short, keypad cover, standard: Affected area: Low back, neck, head, both shoulders, right thumb, right palm at base of thumb, eyes ("For me, all were uncomfortable, but the short was most uncomfortable.")
Location: short (first in order): Affected area: Low back, right upper arm ("Uncomfortable because not enough room to move my arm so my arm was feeling tired. The lack of room for mobility made my body tense, that is why my lower back was feeling uncomfortable.")
Location: short, keypad, standard: Affected area: Right index and third fingers, right forearm ("During the tracing exercise my right fingers became very sore and tired. The discomfort ran up the tendons from those fingers into my forearm.")
Location: short (second in order): Affected area: Right wrist, eyes (" When I finished dragging the mouse, especially a long distance, I needed to lift and replace the mouse; at that time, I had discomfort at my right wrist.")
Location: standard (second in order): Affected area: Mid to upper back, right shoulder ("Upper back discomfort felt like I was reaching for too long, leaning to the side too much. Shoulder was in an awkward position - felt fatigued.")
Location: short, keypad, standard: Affected area: Right shoulder, right index finger, eyes ("Shoulder - trapezius muscle tightened, right finger - aching, eyes - strained.")