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Effect of graphic input device and repetition on wrist posture

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EFFECT OF GRAPHIC INPUT DEVICE AND REPETITION ON WRIST POSTURE

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ABSTRACT

Effect Of Graphic Input Device and Repetition On Wrist Posture

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This study investigated the Wacom Intuos2 pen and tablet and/or standard Microsoft mouse on wrist posture of 20 experienced users. Wrist posture was compared across repetition, input device, and session. A graphic computer task was performed while devices were repeated or alternated across two 30 minute sessions. Neutral wrist range was defined within 15 degrees of 0 in any direction. Input device and session interacted to impact wrist extension, $F(3,16) = 9.42$, $p<.001$ and ulnar deviation, $F(3, 16) = 3.23$, $p<.05$. The repetition group revealed less extension for mouse than pen; movement was outside the neutral range. More ulnar deviation was observed in the second session for mouse than pen; movement was inside the neutral range. A significant repetition by session interaction effect for wrist flexion was revealed: $F(1, 16) = 6.83$, $p<.05$. This finding was localized in the repetitive group, which revealed little to no flexion during the first session; both groups were inside the neutral range.

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CHAPTER 1

Introduction

Computer operators report a wide range of health complaints related to the musculoskeletal and nervous systems. The cause of many of these problems is associated with the use of a graphic input device (Armstrong, Martin, Franzblau, Rempel, & Joshnson, 1995; Bergqvist, Wolgast, Nilsson, & Voss, 1995; Keir, Bach, & Rempel, 1999). The number of people using an input device is on the rise because of growth in technology and software more dependent on use of input devices. Thus, cumulative trauma injuries may also be on the rise. There is a sub group of computer users who are dependent on graphic input devices to perform their jobs, specifically graphic designers, mask designers and computer aided design and drafting designers. This study focused on this sub group of computer users in order to see how wrist posture was influenced between the two input devices.

Computers have become an integral part of daily life in the areas of business, entertainment, education, and communication systems. The increased use of this technology has led to a subsequent rise in the number and type of musculoskeletal disorders and other physical problems (Armstrong, Martin, Franzblau, Rempel, & Joshnson, 1995; Bergqvist, Wolgast, Nilsson, & Voss, 1995). One of the tools needed to successfully navigate a modern day computer is a graphic input device. Many types of graphic input devices are available, such as: pen and tablet, mouse, touchpad, trackpoint, trackball and joystick. This study compared wrist posture between the use of two of these devices (a standard Microsoft mouse and a Wacom Intuos2 pen and tablet) and whether the device was alternated or repeated across two 30 minute sessions.

Risk Factors Associated With Mouse Use

Rempel (1992) found that chronic musculoskeletal and upper-extremity cumulative trauma disorders of the tendons and nerves associated with repetitive work, such as computer work, increased at a rate of about 20% in the three-year period from 1989-1992. This is a concern for employees, workers' compensation insurance carriers, and regulatory agencies. In 1994, two years after Rempel's study, Coll, Zia, and Coll compared a keyboard, a pen, and a mouse while performing a computer based task and only three out of 63 of their participants had any familiarity with even using a computer mouse. Rempel's study does not specifically say those increases were caused by mousing, but only by repetitive computer work. The increase may not be from mousing, in his study, but from keyboarding, leading us to believe the numbers today may actually be higher. According to the United States Census Bureau, about 92 million adults in the United States used a computer in 1997, 37% of all American households had computers, and half of all employed adults in the U.S. used a computer on the job in 1997 (US Census Bureau, 1999).

In a 2003 study by Andersen, Thomsen, Overgaard, Lassen, Brandt, Vilstrup, Kryger and Mikkelsen, which surveyed 5658 trade union workers, found carpal tunnel syndrome most closely related to mouse use, specifically those who used the mouse for an excess of 30 hours per week. Anderson et al. specifically pinpointed the increase in carpal tunnel syndrome (tingling or numbness in the right hand) to time spent using a mouse and not time spent using a keyboard. Therefore, using a mouse is a risk factor in an incident case of self-reported tingling or numbness. Other predictors for onset of tingling/numbness were other medical disorders, previous accidents and smoking. Females were also found to be at higher risk for carpal tunnel syndrome. Graphic designers, mask makers, and computer aided designers and drafters use the mouse for 30 plus hours a week and, therefore, are a high risk group for development of cumulative trauma disorders.

Former US Secretary of Labor Robert Riech named computer-related and cumulative trauma disorders "the occupational hazard of the information age" (Rizzo 1994, p. 9) and stated, said the solution would be to prevent musculoskeletal disorders from occurring in the first place, through education and training by ergonomists.

Non-neutral positions arise from excessive wrist extension, wrist deviation, arm abduction, and pronation positions used by many computer operators. A 1997 National Institute for Occupational Safety and Heath (NIOSH) study reported how computer operators have a wide range of health issues related to their musculoskeletal and nervous systems. People diagnosed with carpal tunnel syndrome, on average, miss more than 30 days of work per year, which is greater then the median days lost reported for back pain. Rempel, Keir, and Bach (1997) found in mouse users an increase in carpal tunnel pressure while in a wrist extension position of greater than 30 degrees compared to a resting hand. Using a computer mouse and other non-keyboard computer input devices could cause muscle tension and pain among computer users (Hagberg, 1994). This results in musculoskeletal symptoms of various types (e.g., pain, numbness, stiffness, and fatigue), across different parts of the body (e.g., neck, shoulder, back, arm, and hand), which occur with varying frequency and intensity between and among users (Johansoon & Shahnavaz, 1994). Nerve and tendon problems arise from repeated or sustained exertions in certain postures that are considered unnatural. Performing computer work contributes to operators working in postures and positions that are not voluntarily assumed. These unnatural postures are assumed specifically to perform computer related tasks (Armstrong, 1986a). Right-handed computer users often use a mouse to the right, or above and to the right of an extended keyboard. In many cases, the arm is extended, the shoulders are raised, or the elbows are abducted for several minutes at a time without pause or apparent awareness by the user (Harvey & Peper, 1997).

Frequency and duration of exposure are also important factors of upper limb disorders. The task requirements and job description for computer aided design and drafting, graphic designers and mask designers require constant mouse use. The job function does not allow for the forces and postural stresses to be distributed among body parts, leaving the mouse hand overloaded and more at risk for cumulative trauma disorder.

History of Graphic Input Device

According to Roch (1996) the mouse, joystick and light pen all originated from military devices developed around the time of World War II. What helped to create these tools were the interaction between fire control systems and the human operator, framed by post-war interaction with computers. The designers of the mouse, Douglas Engelbart and William English, worked at Stanford Research Institute in Menlo Park, California during the 1960's. Prior to that, Engelbart was an officer in the United States Navy for five years and English was a radar technician, also in the United States Navy.

The mouse and joystick consist of two components: a pointer device that moves a cursor in a direction relative to the current position on an absolute plane and push button technology, which originally was developed for mobile ground communications (push button radios) and first used in World War II. Engelbart and English combined the button with a pointer device to create interactivity for the average person working on a computer and called it a mouse (Roch, 1996).

The mouse and the graphical user interface revolutionized how the human operator interacted with a computer (Cringely, 1996). It reduced the cognitive demands formerly needed by making it unnecessary for the user to remember codes and functions. The pull-down menu computer interface combined with the mouse made it easier for novices to use a computer with no prior knowledge and to discover how to operate some aspect of the computer. The invention of the mouse and its "point and click" technology helped to bring computers and technology to the masses.

Software designers and manufacturers create software that is mouse-intensive, and software programs render the user dependent on the non-keyboard input devices. A great deal of this software is made specifically for the graphic arts community: web design, illustration, computer aided design, and other drafting and photo retouching programs. Keyboard commands are limited in these programs and when they are present they require a higher cognitive load of the user, as the structure is inconsistent and rarely made to be meaningful, memorable, or logically related to the task (Raskin, 2000).

About 40 years after the mouse made its first appearance, at least half of office and non-office workers use computers everyday, and 37% of American households use computers in their homes (U.S. Census Bureau, 1999). Computers are found in almost every branch of society and are meant to be used to increase work efficiency and productivity. Most people who use a computer at work use it between one and 10 hours per day, depending on their specific job function.

Statement of Purpose

This research focused on a group of computer users who regularly use a graphic input device to perform their job functions and to maintain their livelihood. The primary job function of graphic designers, mask designers (silicon chip designers), and computer aided design and drafting designers involves 7-12 hours per day of computer use. At least 65% of their work involves using some sort of a graphic input device (Johnson, Dropkin, Hewes, & Rempel, 1993).

The main software programs on which these groups of computer users depend are designed to be used specifically with a graphic input device only (e.g., limited keyboard commands and limited short cut keys). Accompanying this increase in use is an increase in the incidence of work-related musculoskeletal disorders in office environments (U.S. Department of Labor, 1998). These disorders are linked to prolonged work on video display terminals (Armstrong et al., 1994; Bergqvist, Wolgast, Nilsson, & Voss, 1995). Awkward postures of the upper extremity, contact pressure, static muscle loading, repetition and force are identified in the literature as being risk factors contributing to cumulative trauma disorders (Karlqvist, Hagberg, & Selin, 1994; Schoenmarklin, Marras, & Leurgans, 1994).

The occupational risk factors associated with hand or wrist cumulative trauma disorders include wrist posture, repetition, duration, and grip force (OSHA, 1999; Schoenmarklin, Marras, & Leurgans, 1994). As individual risk factors, body and hand posture, repetition, duration, and force do not significantly impact workers' health. However, studies show that a combination of these risk factors can cause musculoskeletal disorders; therefore the total effect of these risk factors is greater than the sum of their parts (Armstrong et al., 1994; Bergqvist, Wolgast, Nilsson, & Voss, 1995; Palmer, 2003). The Occupational Safety and Health Administration (OSHA) (1999) recommended limiting exposure to these modifiers could help to reduce the risk of an injury. Input devices are used repeatedly throughout the day and in most cases are used with awkward posture, excessive force and duration. Average use of an input device includes all of OSHA's defined ergonomic risk factors and, therefore, is a threat to the health and safety of those using them. Repetition includes performing tasks over and over again and awkward posture refers to the body being in a non-neutral position. The average user of an input device adapts both of these. This study focused on the effect of two graphic input devices and repetition on wrist posture across two 30 minute sessions.

Research Questions

For the purpose of this study the following research questions were asked:

1. How does input device (mouse or pen) and repetition (repetitive input device or alternative input device) affect wrist posture?

2. How does input device affect wrist posture?

3. How does repetition affect wrist posture?

Assumptions

The assumption that the Greenleaf WristSystem would not adversely influence performance of a computer task was made for the purpose of this study.

Delimitations

This study was delimited by the following factors:

1. right-handed individuals only.

2. people who are familiar with computers, and specifically those who knew how to play the game of Solitaire. These participants were also familiar with the procedure of mousing and using a pen and tablet.

3. to healthy individuals, who did not have any signs or symptoms of any type of wrist, finger, arm, and/or shoulder pain.

4. a standard Microsoft mouse. While there are currently many mouse designs on the market, the standard Microsoft mouse is the most commonly used mouse since it is standard equipment for most desktop computers.

5. in order to prevent a bias in this study, it was determined that participants for this experiment would be experienced with both pen and mouse input devices.

Definitions

The following terms are defined to clarify their meaning in the context of this research.

Cumulative trauma disorder. Cumulative trauma disorder is a disorder of the soft tissue caused by repeated, forceful and awkward movements of the body over a period of time. Throughout this study the term cumulative trauma disorder is used instead of the term repetitive strain injury when describing a general type of injury.

Wrist posture. Posture describes the position of the body, in relation to the environment, and is one of the risk factors associated with cumulative trauma disorder. Stressful postures are a major cause of disease and lost work in many hand-intensive industries. One of the major goals in the design of work equipment and methods is to avoid the need for workers having to perform repeated exertions in these unnatural or stressful positions (Armstrong, 1986a). Awkward postures often are significant contributors to musculoskeletal disorders because they increase the work and the muscle force that is required (OSHA, 1999). There are four motions of the wrist: extension, flexion, radial deviation and ulnar deviation. Radial and ulnar deviation are associated with side-to-side motions of the wrist and these motions are associated with tenosynovitis at the base of the thumb or de Quervain's disease. Flexion (the act of bending the wrist down) and extension (the act of bending the wrist up) of the wrist are related to the elevation of the mouse with respect to the elbow. Flexion and extension of the wrist are associated with tenosynovitis of the flexor and extensor tendons in the wrist and with carpal tunnel syndrome (Armstrong et al., 1984).

Repetition. Repetition is used to describe the number of times in a certain period of time a task is performed or a series of motions performed over and over again with little variation (OSHA, 1999). This is one of the risk factors associated with cumulative trauma disorder. Regardless of which input device is used (mouse or pen) repetition is a risk factor, because of the number of times the motion is performed. Although safe limits are not yet known, repetitiveness should be reduced if a problem exists and cannot be controlled by regulating other factors. In this way, repetition can be used to determine when and how often a user needs to take breaks or to restructure jobs to include a wider variety of motions (Armstrong, 1986b). For the purpose of this study, repetition is defined as repetitive input device (mouse/mouse or pen/pen) or alternative input device (mouse/pen or pen/mouse) across two 30 minute sessions.

Graphic Input Device. A graphic input device is a "mechanism for communicating information such as a particular location or choice of object on a display, to a system" (Raskin, 2000, p.34). A graphic input device is used to deliver information from the user to the computer. For the purpose of this study, two modes of input were used: a pen and tablet combination and a mouse.

Significance of Study

This study compared the effects of using a mouse and/or a pen and repetition across two 30 minute sessions on wrist posture. Alternating hand positions and postures by alternating input devices may help to reduce cumulative trauma disorders in a community of people who are dependent on graphic input devices. Alternating hand positions from the mouse to the pen may help users increase the variety of hand postures and movements throughout the workday. Matias, Salvendy and Kuczek (1998) suggested that one of the causes of cumulative trauma disorder is the repetitiveness found in job design. If people dependent on graphic input devices can alternate hand positions during the day by using alternative input devices, this can add variety and help to reduce the number of repetitions they perform. In turn, this may help to reduce the potential cumulative trauma disorder and help maintain the health of the work force.

Studies have been conducted on mouse use and mouse placement (e.g., where the mouse is placed in relation to the body (Aaras & Ro, 2000; Rempel, Jacobson, Brewer, Martin, 2000)) as well as on pens and pencils, and grip strength (Udo, Otani, Udo, & Yoshinaga, 2000). Since very few studies have been conducted comparing mouse posture to pen posture, specifically concentrating on people who are graphic input device-dependent for their livelihood, this study can contribute information about performance issues. Hagberg (1995) found it to be important to vary work postures and work movements more than several times a day. This leads to the conclusion that alternating types of graphic input devices during the course of one's work day may be beneficial to those communities of people who are dependent on graphic inputs to perform their job function.

Results of this study can assist ergonomists, employers, and employees in understanding repetition and input device on wrist posture. Results can be considered, along with other available research studies, when deciding which types of graphic input devices to use and how to use them (e.g., alternating devices and how often), in attempt to minimize cumulative trauma disorder risk factors.

CHAPTER 2

Review of Literature

The literature search for this project included: a search on Pubmed and other search engines available at San José State University and Stanford Lane Medical Library. Also, references from previous studies were retrieved as well as the use an on-line service from a human performance search company. Searching through all these areas revealed few scholarly studies on the use of a pen and even fewer when searching for a computer pen. Therefore, the section on using a pen and posture is sparse compared to the amount of literature found on mouse use and its affect on posture.

The purpose of this study was to compare wrist posture on repetition and two input devices (mouse and pen) across two 30 minute sessions. The following articles assist the reader in understanding the depth and breadth of previous studies done, which relate to the present topic of wrist posture, input devices and repetition. In this way, the reader can have a better grasp on why the present study was undertaken.

Cumulative Trauma Disorder and the Computer Operator

People generally use their hands to perform work. Armstrong, Castelli, Evans and Diaz-Perez (1984) hypothesized that some histological evidence of mechanical insult occurs in all wrists and that the location of these changes corresponds to the location of maximum stress concentration in the carpal tunnel. A histological study of six cadaver hands showed there was sufficient repetitive stress in nearly everyone's wrist to produce some tissue changes inside the carpal tunnel.

According to the Digest of education statistics the percent of on the job computer workers, using graphic design applications in 2001 was 28.9% and at home usage for graphic design applications was 25.5%.

Reported here are the results of a NIOSH 1997 study (though this study was published in 1997, the statistics were collected in 1994). The study provided epidemiologic evidence associated with musculoskeletal disorders of the upper extremity. Of a sample of 250,000 private establishments, about 32% (approximately 705,800 cases) reported cases of overexertion or repetitive motion. Of that group, 92,576 (13%) injuries or illnesses occurred as a result of repetitive motion, including typing or key entry, repetitive use of tools, and repetitive placing, grasping, or moving of objects other than tools. Of these repetitive motion injuries, 55% affected the wrist, 7% affected the shoulder and 6% affected the back. The median time away from work was 18 days as a result of injury or illness from repetitive motion. Therefore, in the year 1994, 50,916 people in the sample reported problems in the wrist area.

Work related musculoskeletal disorders currently account for one-third of all occupational injuries and illnesses reported to the Bureau of Labor Statistics. Employers pay more than $15-$20 billion in workers' compensation costs for these disorders every year and that number is growing. The Bureau of Labor Statistics reports with a sample population of 577,814, on the nature of musculoskeletal disorders with days away from work by nature of injury or illness for the year 2000. Those statistics are as follows: carpal tunnel syndrome, 4.8% (27,697 cases), musculoskeletal disorder system and connective tissue disorders, except tendonitis, 1.9% and tendonitis 2.2% (14,445 cases).

When the statistics were categorized by case characteristics of repetitive typing or key entry the total number of cases was 12,268.

Fogleman and Brogmus (1995) reviewed workers compensation claims of computer-related cumulative trauma disorders of the upper-extremity associated with the use of a mouse from the year 1989 to 1993. In 1988, there were zero claims and in 1993 there were over 325,000 claims. They found a higher proportion of strains, hand injuries, upper arm injuries and lower arm injuries and a lower proportion of wrist injuries. Of all cumulative trauma disorders of the upper-extremity claims analyzed, 51% involved wrist injury, and 46% of all mouse-related cumulative trauma disorders of the upper-extremity involved wrist injury. Although the number of mouse-related claims was a small proportion of all claims (6.1% out of 17.3% of all computer-related claims), these claims were a growing problem and deserved research attention.

One study by Matias, Salvendy and Kuczek (1998) suggested the main cause of cumulative trauma disorder is job design and the secondary and lesser cause is posture associated with the workplace design. To help reduce the incidence of cumulative trauma disorder, jobs requiring a large percentage of time working on a computer need to be analyzed and redesigned to vary tasks.

History of the Drafting Task

From a Manual Task to a Computer/Technology Task

In the 1960's, research began on the concept of computer graphics (Hornbuckle, 1967). For the purpose of the study presented here, computer graphics refers to taking drawing and drafting tasks traditionally performed by hand using paper, pencils, rulers and various other drafting hand tools and recreating the process on the computer. "A properly designed graphic system can provide an information transfer media similar and in some ways superior to paper and pencil, and computers make particularly good erasures" (Hornbuckle, 1967, p. 17). Up until the 1960's, people interacted with computers through character and a text based keyboard. The next step was to develop a computer system capable of performing drawing and drafting tasks. Studies were conducted on creating a way for humans to communicate with computers, through visual means, using a graphic input device like a pen and tablet. According to Hornbuckle's 1967 study, graphical communications were concerned with applying pattern recognition techniques to aid the user.

Graphic input devices are data entry instruments used to control cursor position and to select functions. In the case of a computer mouse, cursor movements on the screen correspond to movements of the mouse. The functions are selected by using the fingertips to press buttons located on top of the mouse. The user moves the mouse, and the cursor moves in a corresponding fashion on the monitor. Typically, the mouse is on a horizontal surface located to the right of the keyboard. Usually, mouse movements occur on top of a foam pad called a mouse pad. When the user positions the mouse to the side of the keyboard, as the majority of users do, the user has no choice but to engage in shoulder abduction, adding excess stress on the shoulder and back muscles (Harvey et al., 1997). Mouse placement relates to space constraints and resolving this issue is a challenge (Sanders & McCormick, 1993).

In the case of the pen, the cursor movement corresponds to pen movement, while functions are selected using either the fingertips to press buttons located on the side of the pen or by pressing the pen down on the tablet. To move the cursor, the user drags the pen around in corresponding movements on a tablet located to the right of the keyboard. The tablet and the screen maintain a 1-to-1 relationship, for example: the upper right hand corner of the monitor equaling the upper right and corner of the tablet. Placement of the tablet relates to space constraints and, therefore, the user may be operating it in a non-neutral position, adding excess stress to the shoulder and back area (Harvey et al., 1997).

The development of the light pen and mouse were being explored during the 1960's and by today's standards look quite primitive. English, Engelbart and Berman (1967) analyzed the above mentioned display selection devices for a computer aided text-manipulation system. They tested the speed and accuracy of the devices, as well as the ease of getting to and gaining control of a given selection device (learning rate and error rate) and the effects of its associated operating posture. The experiment used a target acquisition task on experienced and inexperienced participants.

The light pen used in English et al. consisted of a hand held pen coupled to a photomultiplier tube by a fiber optic bundle. The operator pointed at the desired character, and then pressed a switch on the pen to make a selection. This procedure is quite similar to how the Wacom Pen operates.

"The major advantage of the light pen (over the mouse) appeared to be its psychological naturalness of operation in pointing at the item to be selected. This means an untrained user can quickly understand it and gain enough proficiency to do useful work" (English, Engelbart, & Berman, 1967, p. 14).

The mouse is constructed from two potentiometers, mounted orthogonally, each of which had a wheel attached to its shaft. This was enclosed in a 2 inch x 3 inch x 4 inch wooden case. "As the case is moved over the surface the wheels ride over the surface and turn the potentiometers shaft, with combined sliding and turning action depending upon the relative orientation of the motion and the wheel axes" (English, Engelbart, & Berman, 1967, p. 7).

Both devices (mouse and light pen) performed well. They were generally faster and more accurate than the other two devices (joystick and grafacon) tested at that time. Inexperienced users performed best with the light pen and experienced users found the mouse to be best. However, the study tested only 11 participants and no statistical computations were performed.

Ergonomic Risk Factors Using a Mouse

Ergonomic risk factors are a combination of many concerns including: repetition, pressure and force combined with user posture, mouse design and application of device. Discussed below are several key areas related to this current study.

Repetitiveness of work was found to be significantly associated with prevalence of reported discomfort in the wrist, hand, or fingers. Latko, Armstrong, Franzblau, Ulin, Werner and Albers reported this in a 1999 study. Repetitive work is associated with upper limb discomfort, tendonitis and carpal tunnel syndrome in workers.

According to Armstrong et al. (1994), one of the risk factors associated with mousing includes the amount of force that is applied by the fingers and hand to click a button. The mouse is used, as a tool, to select commands to operate the computer and to move objects from one location to another. Two methods of using the mouse are pointing and clicking, and dragging. Pointing and clicking involves positioning the cursor at a given location and clicking the mouse button. Dragging requires the user to hold down the mouse button while moving the mouse. The limitations are the actual joint movements of the user and available workspace for the system and the user. Use of the mouse requires exertion of force with the fingers and palm to overcome the button, gravity, inertia and friction forces.

Static forces on the mouse occur while pressing a button. The typical way someone holds a mouse is by applying a pinch force using the thumb and pinky to stabilize movement of the mouse. The weight of the mouse affects the amount of force needed to operate it. Another force mechanism involved in holding the mouse is the amount of force needed to click the button. Dragging can cause finger mouse friction to the thumb and pinky. Drag forces occur horizontally, side to side, which directly affects the thumb or opposing fingers. All these factors affect the forces and friction as they relate to the hand (Armstrong et al., 1994).

A 2000 study by Johnson, Hagberg, Hjelm and Rempel attempted to measure and characterize force exposure during computer mouse use. They found that while performing administrative research, support staff type work, workers used the mouse about 78 times per hour and about 23.7% of their workday. Relatively low forces were applied to the sides and button of the mouse.

In order to reduce the magnitude of force and the risk of upper limb disorders, the design of the mouse needs to include: minimizing mouse weight and button force, maximizing mouse-finger friction (e.g., surface texture, indentations on side of mouse), orienting buttons to reduce the vertical force component, maintaining the mouse for proper tracking, providing feedback to users and training users to use minimum force of exertion and relaxing between exertions (Armstrong et al., 1994).

Contact stress is also a risk factor in terms of the relationship to the magnitude of force divided by the area of contact. It is better to have contact pressure on areas where the nerves are not underlying the surface like the pulps of the fingers and fleshy areas at the base of the thumb (Armstrong et al., 1994).

Wahlstrom, Hagberg, Johnson, Svensson and Rempel's 2002 study found that working with a computer mouse under time pressure and verbal provocation (stress conditions) lead to increased physiological and psychological reactions compared to control conditions. They found mental stress induced muscle activity and, therefore, stress can influence the amount of force applied to the computer mouse.

Awkward Posture of the Wrist

Awkward or non-neutral postures of the wrist have been identified in the literature as risk factors. The four motions of the wrist are: extension, flexion, radial deviation and ulnar deviation. (Refer to Appendix A for joint posture definitions and range of motion of the wrist). Radial and ulnar deviation are associated with side-to-side motions of the mouse. Flexion and extension of the wrist are related to the elevation of the mouse or pen and tablet with respect to the elbow. Inward rotation of the forearm is necessary to position the hand over the mouse. Neutral posture of the forearm can be achieved when holding a pen combined with proper use (Armstrong et al., 1994).

O'Driscoll, Horii, Ness and Cahalan (1984) studied wrist strength including grasping, holding and pulling and object with the hand, and range of motion. They concluded that with the wrist in only 15 degrees extension or in a neutral radio-ulnar deviation, grip strength was reduced to two thirds to three fourths of normal.

In 1993, Brand and Hollister demonstrated the optimal range of motion for the wrist during hand function is a 10-degree extension. This is based on determining the resting length of the muscle acting on the wrist. At resting length, muscles can exert a maximum contraction with the least amount of force compared to other ranges.

Several other research studies have shown extremes of flexion/extension and radial/ulnar deviated wrist postures beyond 20 degrees raise intracarpal pressure. These extreme postures increase the risk of wrist and hand injuries (Keir et al., 1999; Karlqvist et al., 1994).

According to Rempel and Horie (1994) the lowest carpal tunnel pressure occurs with wrist extension between 0 and 15 degrees. As the wrist extends, carpal tunnel pressure increases. Recommendations have been made for the wrist to be positioned between a 0 and 15 degree wrist extension (neutral range of the wrist) during typing tasks to minimize carpal tunnel pressure. Typing positions in more extreme postures (> 30 degrees) should be avoided (Bach, Honan & Rempel, 1997). In 1997, Rempel et al.

studied 37 healthy individuals and found a wrist extension angle of 30 degrees or greater created carpal tunnel pressure significantly greater than that associated with a neutral wrist posture.

Limerick, Shemmell, Scadden and Plooy (1999) compared wrist posture while using a trackball and a mouse. They concluded that both devices caused extreme ulnar deviation and wrist extension. Average wrist posture while using the mouse was 19.1 degrees extension and 10 degrees ulnar deviation. The track ball increased wrist extension (25.1) and decreased ulnar deviation (6 degrees).

Karqvist et al. (1994) compared upper body postures between using only a keyboard and using both a mouse and keyboard to edit text. Ulnar deviation was significantly greater during mouse use (17.6 degree) compared with non-mouse use (1.8 degree). During mouse use participants spent 34% of the time working in ulnar deviation between 15-30 degree and 30% of the time working in ulnar deviation greater that 30 degrees, compared with only 2% and 0% respectively during non-mouse use.

There is no significant increase in carpal tunnel pressures with deviation, except in extreme ranges of ulnar deviation and radial deviation (> 15 degrees). However, the negative biomechanical effect of repetitive strain on the tendons within the carpal canal has been documented (Armstrong & Chaffin, 1979). Repetitive ulnar deviation of less than 15 to 20 degree can increase pain symptoms in computer operators (Hunting et al., 1981). Radial deviation of 15 degree or more increases carpal tunnel pressures during keyboard use and should be avoided (Bach et al., 1997). Neutral position equals 0 degrees and all motions of joints are measured from defined zero as the starting position (see Appendix A).

Typical mouse users tend to engage in ulnar deviations to control mouse position. Typical mouse users stabilize the wrist on a surface, which would restrict arm movements and would proceed to move the wrists from side to side, leaving them prone to injury. Mice are problematic due to their small size. A finger-palm enclosure (see Appendix B), where most or all of the inner surface of the hand is in contact with the object while enclosing it (Kroemer, 1986) is required to hold a mouse. Wrist/forearm positions used in precision gripping (the position used for writing with writing instruments such as a pen) are inherently lower stress than those positions used with current mice. Writing positions typically require the dorsal or backside of the wrist to face away from the sagital plane of the body. In order for mousing activities to have less stress, the elbow should be flexed, the mousing surface should be easily reached, and the palm must be permitted to face toward the sagital plane of the body. It is desirable that the graphic input device be located directly in front of the user so that the user can keep the elbow close to the side of the torso (Armstrong et al., 1995).

While using a writing instrument, users are permitted to have the arm in a more neutral, less pronated position than while using a mouse. This neutral posture can help to prevent awkward ulnar/radial deviations, or side-to-side movements, associated with mouse use. The wrist is more flexible and has a wider range of motion in extension and flexion behaviors than in ulnar and radial deviations (Ryu, 1991).

Awkward Postures During Computer Mouse Use

Johnson et al. 1993 studied patterns of hand activity during mouse use with the goal of identifying how mouse use varies between different software applications: word processing, database/spreadsheet and graphics/drawing tasks. Using video taping analysis of 10 computer operators, the results showed the mouse was used 31% of the time during a word processing activity, 42% of the time during spreadsheet/database activity, and 65% of the time during a graphic/drawing activity. The most common mouse-related hand movements involving dragging included: click-hold, click/drag-any direction, click/drag-vertically, and click/drag/keystrokes.

> Dragging accounted for 50% of mouse use during word processing activity, 43% of mouse use during spreadsheet/database activity, and 35% of mouse use during graphic/drawing activity. There were 247 button clicks during a normalized hour of word processing activity compared with 544 clicks during spreadsheet/ database activity and 976 clicks during graphics/drawing activity. Two distinct types of mouse operation style were observed. The operators were evenly divided with respect to mouse operation style: approximately half used the entire arm to control mouse movement, and the other half controlled the mouse using the wrist and fingers alone (Johnson et al., 1993, p.12).

Dragging operations involve prolonged pinching and thus may place more strain on the tendons and muscles of the hand and forearm than do other mouse operations. This means the mouse design is likely to have an effect on those performing graphic/drawing activity more than those performing database activities (Armstrong et al., 1994).

Analyzing pen versus mouse postures may provide useful information for determining if these patterns can be accomplished in more neutral positions.

Wahlstrom, Svensson, Hagberg and Johnson (2000) compared differences between work methods and gender in computer mouse use. The study consisted of 15 men and 15 women. Results found females had greater wrist extension, greater wrist range of motion and tended to work with greater ulnar deviation. Females also applied higher forces to the mouse and had higher muscular activity in the right extensor digitorum.

The vertical location of the mousing surface and a wrist support does affect wrist extension and flexion. Recommended work surface height, promoting the least wrist extension, is achieved when the musing surface is located between 120% -140% of seated elbow height and when there is a wrist support present (Damann & Kroemer, 1995). Damann et al. (1995) focused on the effects the mouse pad surface height and wrist support had on wrist posture. Wrist extension, flexion, radial deviation, and ulnar deviation data were collected via a wrist monitor attached to the right hand and forearm. Damann et al. (1995) concluded the presence of a wrist support decreased wrist extension and radial deviation, and increased wrist flexion. The higher pad surface height resulted in increased flexion and ulnar deviation, and decreased extension and radial deviation. Wrist extension was reduced by the presence of a wrist support on the mouse pad at all but the highest height. As the arm is lowered, greater wrist extension exists and, as the arm is raised, the wrist goes from extension to flexion. While using a wrist support, there is a strong possibility the user is resting on the carpal tunnel area and resting on a nerve.

Mouse Design, Carpal Tunnel Pressure and Wrist Posture

In a study by Keir, Bach and Rempel (1999) comparing the mouse design of three different types of mice and their relationship to carpal tunnel pressure, results showed all three computer mice were associated with similar carpal tunnel pressures and wrist posture. Their study compared a standard Microsoft mouse, a Contour mouse and an Apple II ADB mouse. All three mice required the user to operate using a pronated position of the hand. There was a significant increase in carpal tunnel pressure while using the mouse versus the resting position with the hand on the mouse. They found significant results proving the dragging task created higher pressures than the pointing task. There are two differing factors between dragging and pointing with the mouse. First, the button is depressed for a greater percentage of the task cycle during dragging. Second, pinch forces on the side of the mouse are about three times greater during dragging tasks than pointing tasks (Johnson et al., 1994). This means there is greater fingertip loading of longer duration during a dragging task than during pointing. The increase in pressure with dragging is consistent with a previous study that evaluated carpal tunnel pressure during pinching (Keir et al., 1998).

Two factors may account for the elevated carpal tunnel pressure during computer mouse use: (1) wrist extension and (2) the fingertip force applied to depress the button and to grip the sides of the mouse. Rempel et al. (1998) suggested efforts be made by employees, employers, and manufacturers to reduce the wrist extension associated with mouse use, reduce sustained button down activities (e.g., dragging) and interrupt prolonged mouse use with other tasks for the mousing hand.

When postures are compared between those participants with and without carpal tunnel syndrome, the results show affected participants adopt a wrist extended posture and apply unnecessarily high finger force more frequently than participants who are not affected (Armstrong & Chaffin, 1979). Carpal tunnel syndrome may be accelerated by highly repetitive work performed with the wrist deviated in extension, combined with any other stressors which increase muscle tension. Therefore, computer users may be at risk for carpal tunnel syndrome because of the potential for occupational overuse of the fingers.

Wrist extension/flexion deviations appear to be much more significant risks factors for carpal tunnel syndrome risks than do ulnar/radial deviations (Hedge & Powers, 1995). In the literature, cases of carpal tunnel syndrome resulting from wrist extension are prevalent during mouse use. Many factors affect the degree of wrist extension. These include: a) the design of the mouse, b) the method most operators use to hold and operate the mouse, c) the use of wrist supports and d) work surface height and the relationship of the wrist to the elbow and shoulder (Armstrong et al., 1994).

Wrist extension, which is an upward motion, causes participants to torque against gravity. Having the wrist in an extended position for a long period of time is one of the most common mousing positions and, therefore, it could be deducted that participants work against gravity. While mousing, it is important to keep the wrist in a neutral posture as much as possible (Snook, Vallancourt, Ciriello & Webster, 1995).

Mousing, in general, promotes a fully pronated forearm. Forearm rotation has been shown to affect carpal tunnel pressure. However, in Rempel, Bach, Gordon, and So's, 1998 comparison study, it appears there is relatively little effect of pronation in the range tested. The data indicate minimal effect of forearm posture, from neutral to full pronation, on carpal tunnel pressure. Highest mean pressure (55 mmHG) was recorded in full supination and 90 degrees MP flexion and lowest pressures (12 mmHG) were recorded at 45 degrees pronation and 45 degrees MP flexion.

In contrast to using a traditional mouse, Aaras, Ro and Thoresen (1999) compared an Anir vertical mouse, with a traditional mouse. The Anir mouse claims to support a more neutral position of the forearm, less pronation, by allowing the forearm to be in a horizontal position vs. a vertical one used for all traditional mice. They studied 67 participants, 32 of which used the Anir vertical mouse and 35 who used a traditional mouse for a six month period. Participants using the Anir vertical mouse reported significant benefits which included: less neck, shoulder, forearm, wrist and hand pain and less headaches and less musculoskeletal sick leave, while the participants in the control group actually felt worse in the same categories.

Use of Arm Supports

Karlqvist, Bernmark, Ekenvall, Hagberg, Isaksson and Rost (1998) found operators who used a computer mouse in addition to a keyboard, had more awkward postures and movements compared with operators using just a keyboard. Design work is often performed on a fixed table immediately in front of the operator. The keyboard is usually located on the table directly in front of them, forcing artists to place the mouse further away from the users body. Long hours of work with the mouse, as well as work with the mouse in a less than optimal location on the table seems to be a risk factor for upper-limb symptoms.

Karlqvist et al. found a neutral posture with relaxed arms, and the use of arm supports has the least perceived exertion and that users preferred this position. The EMG results showed activity in both trapezius muscles in this position was low. Short operators (all women) showed a numerically higher activity in the four examined muscles (left and right trapezius and left and right extensor digitorium) than tall operators. This finding could be related to lower muscle force among women and to anthropometric differences, which also influence biomedical load movements. Narrow-shouldered operators and short operators worked with larger outward rotation and abduction of the shoulder in a position with the mouse lateral to the keyboard than did the broad-shouldered and tall operators. Short and narrow-shouldered operators, therefore, worked in more strenuous postures. The tall and broad participants posture consisted of a larger inward rotation of the shoulder with the mouse placed immediately in front of them.

Another finding illustrated it is easier to support the arm against the work surface when the table is above elbow height. EMG showed less shoulder muscle load during work in positions with the arm supported against the worktable or armrest than during work without support. According to an Allan Hedge's lecture for Humanscale (2001), Scandinavian studies tend to advocate supporting the arms while doing computer work. This study tested upper arm and back muscles and found reduced tension. They did not measure lower arm, wrist or hand activity, which could be affected by supporting the arms. Fernstrom and Ericson (1997) found the use of an arm support was shown to decrease shoulder muscle load, but increase forearm load. Arm rests alleviate certain muscle tension while increasing others, leading one to wonder if they are beneficial.

One common posture mouse users tend to employ is to rest the extended right hand on a surface. The use of this posture in mouse users, has been known to cause weakness, numbness and difficulty in holding a pen and in turn, produces pressure on the wrist. This position is usually maintained for several hours a day and is another risk factor associated with the task of mousing (Davie, Katifi, Ridley & Swash, 1991).

Upper Arm, Shoulder and Back Posture

A study by Karlqvist et al. (1994) examined shoulder posture with and without mouse use, and also included measurement of wrist deviation. Mouse operators spent 64% of the working time with the operative wrist deviating more than 15 degrees towards the ulnar side, while non-mouse operators spent 96% of the time with the corresponding wrist in neutral position towards radial deviation. The rotation in the shoulder was at all times in neutral position towards inward rotation for non-mouse operators, while mouse operators worked 81% of the time with the shoulder rotated outward more than 30 degrees. Operators who use the mouse spend more time in ulnar deviation wrist positions than operators who use the keyboard only. Fernstrom and Ericson (1997) came to the same conclusion; mouse operators work with the wrist deviated towards the ulnar side and shoulder outwardly rotated, while non-mouse operators work with the wrist in an approximately neutral position and shoulder inwardly rotated.

A Canadian study by Atwood (1989) employed word processor typesetting operators, board design draftspersons and computer aided design and drafting operators.

Atwood found an association between musculoskeletal discomfort and shoulder abduction, which occurred during operation of a graphics mouse and tablet. The pain or stiffness in the right arm/shoulder was related to operator's position required to use the graphic mouse. Operators required position, due to the design of the workstation, included extension and abduction of their right arm in order to reach the graphic mouse.

Harvey and Peper (1997) found when the mouse is used to the right of an extended keyboard it leads to significant increase in muscle tension in the upper shoulder, back and arm. Significantly lower muscle tension was observed with trackball use in a central position. Elevated muscle tension occurs without the apparent awareness by the user. Low or inaccurate awareness of increased muscle tension may lead to discomfort, pain, or future injury not only in muscles related to using a mouse, but also in muscles related to other computing tasks.

Harvey et al. (1997) suggested that a computer pointing device should be used in a position more central to the body whenever possible. The extended keyboard, while reducing the risk of hand injury for keyboarding, may unintentionally lead to significant increase in upper and lower trapezius and posterior deltoid muscle tension during mouse use. In many cases, participants are so focused upon the computing tasks at hand that they become aware of muscle tension only after pain occurs, passing the opportunities for remedial breaks (Harvey et al., 1997).

Handwriting Motions

Sovik, Arntzen and Teulings (1982) described the proper muscle use in hand writing. By means of the EMG-method they found a correlation between muscle activities used in the writing position (grip) and the writing motions. Activating, for example, the m.abductor pollicis brevis causes pressure on the thumb against the barrel of a pen. Normally, a pen is held between the three first fingers, all of which are flexed to some extent. The upper part of the writing instrument should rest on the basis of phalanx proximalis of the second finger, whereas the lower part of the instrument is supposed to rest on the left side of phalanx distalis of the third finger. The last two fingers are not supposed to take part in activities in writing act and will only support the hand. The hand itself is lightly pronated and dorsal-flexed during the writing. In analyzing different writing movements, Sovik et al. found that abduction (upward) and adduction (downward) movements falling into a direction of 45 degrees to the writing line are the fundamental and easiest movements in writing (mid-range of motion). Sovik et al. found that almost every child wrote with fingers too flexed and stiff and the position of the pen was too low. High muscle activity found in the fingers and hand resulted in a correspondingly heavy grip and point pressure on pen and paper.

Pen and Tablet

A study performed by Kotani and Horii, completed in 2002, compared a mouse to a pen-tablet system (Wacom Intuos I-600). The method of measurement, EMG, was used in four muscles: the biceps brachii, the flexor digitorum superficialis, the extensor digitorum and the trapezius. Five subjects used the pen-tablet system and the mouse on five consecutive days in a fully randomized study. When the pen-tablet system was being used, low amplitudes of EMGs for the biceps brachii, the flexor digitorum superficialis and the extensor digitorum were found, and no significant difference in muscular load was found for the trapazius using either the mouse or the pen-tablet system. None of the participants had any experience with a pen-tablet system. They used their experience of holding a regular pen and applied that experience to using a pen-tablet system in a fashion that was very smooth. The learning process for the pen-tablet system was relatively short. Error rate was lower in the pen-tablet system than in mouse operations. Participants felt comfortable using the pen-tablet system.

The way one holds an instrument, such as a pen or a mouse, imposes physical limitations on the selection of joint configurations (Shillings, Jooost, Thomassen, Arnold, Meulenbroek & Ruud, 2000). Some of these constraints are immediately manifested while other constraints are likely to evolve through increased use of the instrument, so that the task could be performed more comfortably. Complex tasks like writing and drawing involve cognitive kinematic and dynamic processes. The performance of fine motor tasks, like small scale drawing, is at least, in part, determined by comfort considerations in terms of joint excursions, such as pointing movements involving the whole arm.

A study by Wells, Lee, Bao and Trainor (1997) that involved playing Solitaire, performing a drawing activity and editing tasks tested 3 conditions: mouse, pen and tablet and pen and tablet on lap. Kinematic measurements of wrist and forearm angle and EMG for eight muscles from the shoulder and arm were taken along with a subjective measure of body discomfort. Mouse users had high muscle activity in all but two muscles: trapezious and flexor digitorum. Pen and tablet users had lower muscle activity in six of the tested muscles: first dorsal interossues, flexor digitorum, extensor digitorum, extensor carpi ulnaris, pronator teres and infraspinatus. Mouse users used less shoulder muscle movements while mousing, while pen users used less forearm muscle movements. Wrist postures between using the mouse and the pen and tablet are clearly different and it is not certain that one poses more risk of injury. The pen, however, offered forearm postures closer to an ideal mid-pronated posture. Wells at el., concluded that providing variety in work and minimizing physiological monotony may be the best solution (i.e., changing ones input device throughout the work day) for input dependent computer users.

The mouse and pen have qualitatively different postures; the mouse has close to straight fingers with mild extension, ulnar deviation and moderate pronation whereas the pen has a two or three finger pinch grip with higher extension, very close to neutral deviation and posture father from pronated (Wells et al., 1997).

Current ergonomic recommendations favor neutral postures, such as, little deviation or flexion/extension and mid pronation (90 degrees), and counsel against pinch grips (Wells et al., 1997). One could argue that wrist posture cannot be evaluated without some knowledge of finger position. Suggestions have been made that there is a reciprocal relationship between finger and wrist position, such as, the more flexed the fingers, the more extended the wrist (Wells et al., 1997). The mouse and the pen show a reciprocal relationship as well. In the case of the pen, a more extended wrist position may not be problematic, since pen use shows higher angular velocities than mouse use. This is probably related to the larger displacements required of the pen.

Wells et al. (1997) compared the use of a pen/tablet on a desk with elbow support and use of the laptop, the lap condition was preferable. The lap position showed lower muscle activity in the hand and shoulders, but with similar or higher forearm extensor activity. The wrist kinematics showed higher wrist extension in the lap, but lower extensor muscle activity than with the mouse. In comparing mouse to pen, both with elbow support, the pen shows lower arm muscle activity, but higher shoulder activity. Although the wrist postures are different between the mouse and the pen, it is not clear that one is worse than the other and poses more risk of injury. The pen may encourage forearm posture closer to an ideal mid-pronated posture.

It is becoming clear that there is probably no one single ideal posture or device, which can be used consistently without harm or injury to the musculoskeletal and/or nervous systems. Variety is the key. The pen offers variety in that the tablet can be placed in different positions, and for editing using handwriting recognition, without being constrained by keyboard position. Alternating between the mouse and pen would offer even greater variety, as the hand postures used are different. Other risk factors, such as local contact pressure, need to be considered when recommending input devices and support conditions.

Ergonomic Risk Factors Using a Pen

Combination wrist/forearm postures have significant effects on wrist range of motion (Marshall, Mozrall, & Shealy, 1999). Wrist posture has been known to be a risk factor in the development of CTS, yet there are no reported injuries of development of CTS during writing tasks.

Ballpoint pens can lead to writer's cramp (occupational cervicobrachial disorders-OCD) in office workers. A new pen, Dr. Grip Pen, has been developed to alter the grip in such a way as to reduce the gripping pressure. Dr. Grip Pen has a cylindrical grip area that flares out at the bottom, near the pen-tip, and has a diameter ranging from 11.9-13.6mm. The grip is constructed of a 2 to 3 mm-thick silicon rubber sleeve which is softer and less slippery in comparison with the conventional pen (Udo, Otani, Udo &Yoshinaga, 2000).

The Dr. Grip design has been licensed by Wacom and is currently used in their Intuos2 pen. This is the pen that was used in this thesis. Udo et al. tested the new pen and found the Dr. Grip pen design helps to reduce the muscular load on the upper limb compared to a regular pen and, therefore, mitigates fatigue in this area.

There were three main findings in the study. First, Udo et al. have reported that the optimum diameter for reducing gripping pressure ranges from 12 to 14mm. The diameter of an average pen is about 8.3mm. Having a larger grip area means that the users have a larger contact area with the fingers, and this might help to reduce gripping pressure (writing grip, see Appendix B). Second, the grip type friction coefficient of the rubber material had the lowest EMG's of the flexor pollicis brevis and the lowest pen-point pressure due to a higher friction coefficient between the grip and the fingers. Third, the design of the Dr. Grip pen incorporates a grip area that tapers out by a gradient of 2 degrees, at the end nearest the pen tip. It has been found that the gripping pressure of the thumb decreases by about 5.1% when holding a tapered object as compared to a straight object. For these three reasons, it is believed that the Dr. Grip design is effective in reducing the muscle load during writing.

A study by Balogun, Akomolafe and Amusa, 1991, tested grip strength and its effects on elbow position. They found participants to have the greatest grip strength when standing with the elbows extended. Participants have the lowest grip strength when seated with the elbows flexed. The weakest position for the amount of grip strength an average pserson has, is when a person is sitting with their elbows flexed, such as when sitting in front of a computer. Designers and manufacturers of input devices need to take this into effect when designing graphic input devices. Relaxation is induced in the sitting posture. Muscles are strongest at lengths slightly longer than their normal resting lengths in the fully extended position of the joints they serve.

Summary

Gestalt psychologists believe that whole is greater than the sum of its parts. This means that all the elements of a structure need to be organized and identified in such a way that all the parts can be processed together as a unit to reveal the organization and to work together in harmony (Wickens & Hollands, 2000, pp. 87-88). This can be applied to humans operating computers, in the sense that the task, the means of accomplishing that task (the graphic input device), and, the biomechanics associated with the performance of the task all need to work together. Taking all this into consideration will allow the goal of completion of the task to be accomplished consistently and reliably insuring ease of use and without causing harm to the human operator.

Whether all this can be accomplished with the current state of the tool (graphic input device) remains to be seen. The literature does not support the current standard mouse design proposed for use in this study. Using a computer mouse that helps to keep a more neutral, less pronated, position of forearm has been shown throughout the literature to help to reduce the amount of reported pain level in the wrist/hand, forearm, shoulder and neck (Aaras, Ro, 2000; Bach et al., 1997, & Ryu, 1991).

Several studies (Armstrong et al., 1994, Brand et al., 1993, O'Driscoll et al., & Rempel et al., 1994) support having the forearm in a neutral position, thereby allowing the wrist to be in a more neutral position and alleviating the pressure that was put on the carpal tunnel area. This is the position that the hand is in during pen use. Therefore, it would apply to the Wacom pen as well.

CHAPTER 3

Methods

The purpose of this research was to study the interaction of input device (mouse or pen) and repetition (pen/pen, mouse/mouse, mouse/pen or pen/mouse) on wrist posture. Studies have been conducted on mouse use and mouse placement (e.g., where the mouse is placed in relation to the body) (Aaras et al., 2000; Rempel et al., 2000). Studies have also been conducted on pens/pencils and grip strength (Udo et al., 2000). The literature, however, is sparse of studies comparing mouse posture to pen posture and their effects on a community of people who use these tools 65% or more of their workdays (Johnson et al., 1993). Therefore, a study was performed comparing wrist posture when using a Microsoft serial mouse and a Wacom Intuos2 pen and tablet.

This study compared wrist posture during a cycle of highly repetitive computer graphic input device task while using a standard Microsoft serial mouse and a Wacom Intutos2 graphic pen and tablet. Participants played Solitaire on a laptop computer with either a mouse or pen while seated in a neutral position. The Greenleaf WristSystem tracking glove was used to measure wrist posture as: flexion, extension, ulnar deviation, and radial deviation.

In the review of literature section many of the studies cited have attempted to determine a neutral range of acceptable wrist motion while operating an input device. A position of 30 degrees wrist extension increases carpal tunnel pressure (Rempel et al., 1997), while a position of wrist extension between 0-15 degrees has the lowest carpal tunnel pressure. As the wrist extends carpal tunnel pressure increases (Rempel et al., 1994). It is the consensus of these studies that leads this current research to consider 15 degrees or less mid range or acceptable wrist motion range and greater than 15 degrees to be considered non-neutral or extreme ranges of motion.

Participants

Twenty unpaid volunteers consisted of university faculty, artists, graphic designers and computer aided design and drafters. Participants' ages ranged between 23 and 58 years. They were recruited through networking with faculty, community members and via e-mail. Participant selection was based upon a working knowledge of using a mouse and using a computer pen (Wacom or other brand). A phone prescreening identified acceptable participants, who were defined as right hand dominant persons, with no prior arm, wrist, or hand conditions that could affect mouse or pen use. Chosen participants filled out a screening form (Appendix C) and a consent form (Appendix D).

A pilot study was conducted on two test participants. The test participants were San José State University graphic design students. The protocol for the study included: a10-minute warm up period on both mouse and pen devices, 20- minutes of test time per input device, one 15-minute break and the completion of symptom forms after each device tested. The pilot study revealed that a baseline for the symptom forms for participants was missing; therefore filling out a symptom form prior to the start of the experiment was adapted for the actual study. By talking with the pilot participants it was found participants would be able to work at a productive rate if they had familiarity with the pen and the mouse and knew how to play Solitaire. Lastly, by talking to the pilot study participants and getting their input, it was decided that a 20-minute period was too short of a period of time, therefore testing period was increased to 30-minute intervals.

The benefit to participants was that the researcher ergonomically assessed them resulting in a better understanding of good techniques to use while operating a computer. There were very minimal risks to the participants.

Participants were read the testing procedure by the experimenter(Appendix E). The task to be performed was to play the game Solitaire on the computer. This task involves dragging and clicking motions, which are the same motions participants use in a work context. They were asked to work at a self directed productivity rate and encouraged to complete a game within a two-minute period.

During a Solitaire game played quickly and intensely, on average, a user will click the input device about 75 times. Therefore, a half an hour of playing Solitaire could yield 1600 input device clicks and about 21 games played. It is presumed that the participants in this study yielded similar results as that they were instructed to work at a rate similar to work.

During the data collection portion of the experiment, participants' names were connected with the original data and were stored in the computer. When the data were put into a spread sheet for analysis names were removed and a participant number was inserted. Since 20 participants participated in this research the analysis is numbered 1-20.

Experimental Design and Procedures

San Josė State University Human Subject-Institutional Review Board approved this study and its methods prior to data collection (see Appendix F). The experiment was a multi factorial design with two independent variables: repetition and input device. Repetition had two levels: (a) same input device (mouse/mouse or pen/pen) or alternating input devices (pen/mouse or mouse/pen). In the alternating input device condition the order of input device was counterbalanced across participants. Input device had two levels: (a) standard Microsoft mouse, (b) Wacom Intuos2 pen and tablet (Appendix G). The dependent variable wrist posture was measured as: ulnar, radial, extension, flexion.

The 20 participants were placed into one of four groups: mouse/pen (M/P), pen/mouse (P/M), mouse/mouse (M/M), pen/pen (P/P). The M/P and the P/M groups performed the graphic input device task using both modes of input consecutively in counterbalanced order. The M/M group used the mouse in both conditions and the P/P group used the pen and tablet in both conditions.

A repeated measures design was used to minimize experimental error (Keppel, Saufley, & Tokunaga, 1992). The primary problem with repeated measure designs is the influence of residual or carry over effects from previous conditions. To observe the influence of the independent variable without distortion, this experiment had four groups. By having the M/M and the P/P groups, where the repeated measure was the same task, consideration was made with regard to fatigue and carry over effects and, without distortion, the influence of the independent variable in the M/P and the P/M groups was shown. The effects of repetition were included by using this design, since half the subjects had repetition as a variable.

Wrist posture was the dependent measurement. The measurement of posture, or range of motion, of the wrist included: (a) wrist flexion, (b) wrist extension, (c) radial deviation, and (d) ulnar deviation.

The total amount of time that was requested of each participant for this experiment was approximately two hours. Each testing condition was 30 minutes and each participant was given two test conditions, making the actual test time one hour. In addition to the actual test portion, each participant was given a 10-minute warm up on each condition and a 15-minute break between tests. Upon arrival, participants were welcomed and thanked for participating. They were then asked to sign a consent form and explained the symptom form which they filled out on an as needed bases. At the end of each testing session, if a participant had any symptoms, he or she was asked to report them on the symptom form. This was done to determine level of body discomfort (see Appendixes H and I for examples). During the test condition participants were encouraged to work at a rate similar to work. There were two periods of data collection using the Greenleaf WristSystem and on three occasions participants were asked if they had any body discomfort.

Symptom Form

Participants were pre-screened to insure that they had no prior history of wrist disorder. However, participants with any kind of fatigue or discomfort prior to the experiment were asked to complete a symptom form to establish a preliminary baseline. In addition participants completed a symptom form after each intervention to indicate where and how much discomfort participants experienced while performing mouse and pen conditions. Symptom forms were used for demographic purposes only. They were used, along with the participant screening tool, to help describe the sample studied.

The symptom forms outline places on the hand, dorsal and palmer sides, where the participant may have signs of body discomfort. The symptom forms included subjective ratings of body discomfort: soreness, stiffness and numbness. Participants indicated the intensity of each symptom on a scale of zero to three, and identified the location of the symptom only if they reported symptoms at all. Three locations on the palmer or front side of the extremity (fingers and thumb, hand and wrist, and forearm), and the same three locations on the dorsal or back side of the extremity are presented on the form (Snook et al., 1995).

Instrumentation

The Greenleaf WristSystem (Appendix J) was used for static measurements of the wrist and to analyze dynamic wrist motion during the graphic input device tasks. The Greenleaf WristSystem is a wrist goniometer system. All participants wore lycra fingerless wrist sensor gloves. The glove contains two biaxial transducers that detect wrist movements of flexion, extension, radial deviation, and ulnar deviation. The data were transferred from the Greenleaf data recorder onto a Macintosh computer hard drive. Greenleaf's Movement Analysis System software was used to display the recorded data.

Data for each testing session were collected separately for each participant. Upon start of the test session the participant was told to hold the wrist straight, to insure the Greenleaf WristSystem was working correctly, for example: numbers close to zero, greater or less than five degree in either direction and that the glove was fit properly.

Some participants flicked the wrist prior to the researcher turning off the Greenleaf WristSystem at the end of the 30 minute test session. The researcher made a note in each participants' file as to whether or not any extraneous data were included in the total data collected. In these two instances, pure test data were extracted from the entire test session.

Once the test session for each participant was complete, the researcher examined all data collected by transferring the data from the Greenleaf WristSystem to a Macintosh computer with Movement Analysis System software. The software allowed the researcher to view the Greenleaf data in graph and spreadsheet format. Visually, the data could be examined in a graph format (see Appendix K for sample graph). In this system, the X and Y axes are labeled as time in seconds and wrist angles. The graph shows where, in seconds, the pure data began and where it ended. These two numbers were written down and those numbers were recorded on the report sheet in the segment session boxes and a report was generated that included the pure data. Information on the report included: min value, max value, mean value and standard deviation for all four motions of flexion, extension, radial and ulnar deviation. It is important to note that during the 30 minute sessions participants wrist angles were measured in all 4 directions. The graph in Appendix K shows the wide variability during a 30 minute session. Participants crossed the neutral line of extension/flexion as well as the neutral line of ulnar/radial all during the 30 minute session.

Materials and Task

In the present study, the standard Microsoft mouse was selected, as it is the most common mouse included with consumer computers. The Wacom Intuos2 was used in this study because it is the latest technology in pen and tablet systems. The Wacom tablet size used in this research was 3/8" deep x 13" wide x 11" long. Wacom has licensed and uses the Dr. Grip pen design in the Intuos2 pen. In comparison to a regular pen, the Dr. Grip design helps to reduce muscular load on the upper limb compared to a regular pen in three ways. The three ways are: larger grip area and grip type which helps to reduce gripping pressure and a 2 degree taper out at pen tip which helps to reduce thumb gripping pressure (Udo, Otani, & Yoshinaga, 2000).

Participants used two graphic input devices: a standard Microsoft serial mouse (Microsoft Corp., Redmond, WA, USA) and a Wacom Intuos2 graphics tablet (Wacom Technology Corp., Vancouver, WA, USA). Each device allowed participants to perform a dragging task ('drag and drop') and a pointing task ('point and click').

Software settings, the clicking speed and ease of tracking were set so the mouse and the pen move across the screen similarly. This was done in the control panel, which allows you to designate tracking and clicking speed. This was done to ensure as similar settings as possible in both devices and to help to eliminate any bias towards either input device.

Workstation Setup and Recommended Posture

Participants used a Sony-Vio, model PCG 971L, laptop computer with mouse or pen to complete the tasks. Although the workstation varied throughout the experiment, the computer remained constant. Participants were seated in a height-adjustable chair, with no arm rests or arm rests positioned in such a way as to not interfere with the participant's elbow. The literature supports users' mousing at elbow height and keeping the elbow close to the body (Attwood, 1989; Harvey et al., 1997). Participants were asked to use this position while performing the tasks. The graphic input device was approximately at elbow height and did not require shoulder flexion. The standard Microsoft mouse and Wacom Intuos2 graphics tablet were placed on an adjustable keyboard platform or a surface that allowed the participant to work in a neutral position. The monitor height and depth were adjusted for each participant's specific eye height and comfort level. Participants were seated and were able to perform the experiment while in the recommended posture.

Prior to the start of the testing session, physical ergonomics were checked to ensure participants were seated in a neutral position. The researcher asked participants if they were comfortable and if any minor adjustments needed to be made. The researcher observed all participants during the entire testing sessions and provided feedback on ergonomic position. If a participant began using a non-neutral position the researcher pointed this out to the participant and corrections were allowed. This was done in such a way as not to disrupt the participant from performing the primary task, which was playing Solitaire. In this way, the researcher had the participants working in as neutral position as possible throughout the entire 30 minute testing interval.

It has been determined that placing the graphic input device in as neutral a position as possible (e.g., no shoulder abduction, no wrist deviations) has the least repercussions on the body (Matias et al., 1998; Armstrong et al., 1994). The graphic input device was placed in a position that kept the participant in the recommended posture. Appendix L shows an example of a participant from this study seated in the recommended posture, which places participants with their feet flat on the floor, knees at right angles or slightly greater, lower back supported by the chair, shoulders relaxed, elbows in line with the body and head aligned with with neck and shoulder. Participants had their forearms parallel to the floor (90 degrees or slightly greater).

The goal is, through the recommended posture, to enable participants to keep their wrist neutral during the experiment. This position was chosen based on the information provided through the literature, so as to create the least amount of stress on the body.

According to Pascarelli and Quilter (1994), the mouse should be held loosely, as if holding a bird, without gripping it, because holding the mouse tightly, in any way, creates tension in the fingers. This 'floating' position while mousing is difficult, if not impossible, to maintain due to the design of the mouse. The mouse does not take into consideration the form and the function that the human body is designed and capable of maintaining for extended periods of time. During the experiment most participants were not able to maintain this position for more than seconds before resorting to dropping their wrist down on a surface.

Data Analysis

Data for each test session (two test sessions per participant) were analyzed, providing information on how the intervention (pen or mouse) affected posture. All statistical analyses were performed using the SPSS software program for the PC, version 11.0. An alpha level of less than .05 was used to determine statistical significance.

To analyze the results of this study ANOVA tests were performed. A 4 (input device) x 2 (test session) ANOVA with repeated measures on the last factor was performed on wrist extension, wrist flexion, ulnar deviation, and radial deviation. A 2 (repetition) x 2 (input device) ANOVA was performed on wrist extension, wrist flexion, ulnar deviation, and radial deviation. A separate one way ANOVA was conducted with session 2 (alternative and repetitive) on wrist extension, wrist flexion, ulnar deviation, and radial deviation.

CHAPTER 4

Results

This research focused on a group of computer users who regularly use a graphic input device to perform their job functions and to maintain their livelihood. The primary job function of graphic designers, mask designers (silicon chip designers), and computer aided design and drafting designers involves 7-12 hours per day of computer use. At least 65% of their work involves using some sort of a graphic input device (Johnson et al, 1993).

For the purposes of this study, the following research questions were asked: 1. How does input device (mouse or pen) and repetition (repetitive input device or alternative input device) affect wrist posture? 2. How does input device affect posture? 3. How does repetition affect posture?

Based on the results of the Participant Screening Tool (Appendix C) 20 participants (8 females and 12 males) between the ages of 23 and 58 years old participated in the research. The participants had an average of 15 years of experience using a computer. Prior to their participation in this study, three of 20 participants had an ergonomic evaluation of their computer workstation.

Wrist extension, flexion, ulnar deviation and radial deviation were measured during computer input device use. A 4 (input device groups) x 2 (test session) ANOVA with repeated measures on the last factor was performed on wrist extension, wrist flexion, ulnar deviation, and radial deviation. A 2 (repetition) x 2 (input device) ANOVA was performed on wrist extension, wrist flexion, ulnar deviation, and radial deviation. A separate one way ANOVA was conducted with session 2 (alternative and repetitive) on wrist extension, wrist flexion, ulnar deviation, and radial deviation. The raw data can be found in Appendix M. Data is interlaced in the results section for research question number one: How does input device (mouse or pen) and repetition (repetitive input device or alternative input device) affect wrist posture? The study was set up as a repeated measure, so for groups M/M and P/P repetition is incorporated within the design of the study and it is not analyzed separately within this results section. The results of the data collected are presented in this chapter.

Input Device as a Function of Session

A 4 x 2 (input device by session) ANOVA was conducted on: wrist extension, flexion, ulnar and radial deviation. The analysis will be presented by the order of the dependent measures.

Input Device – Wrist Extension

The ANOVA examining extension across two sessions for the four input device groups revealed a statistically significant session by input device interaction effect on wrist extension, $F(3, 16) = 9.42$, $p < .001$ (see Table 1). Regardless of the session, greater wrist extension was found for the pen than for the mouse. Further it was found in session two the groups that alternated input device has less wrist extension than all other group (see Figure 1). This same interaction revealed that the alternative input device groups (M/P and P/M) had significantly less wrist extension for the mouse than for the pen regardless of session. The stability of these data may be limited by the small number of participants in each group.

Table 1.

Analysis of Variance Source Table for Input Device by Session on Wrist Extension

Source	df	MS	F
		Between subjects	
Intercept	1	31044.40	410.88
Input Device	3	56.93	.75
Error	16	75.56	
		Within subjects	
Session	1	35.10	1.31
Session * Input Device	3	252.98	9.42*
Error	16	26.86	

* $p < .05$

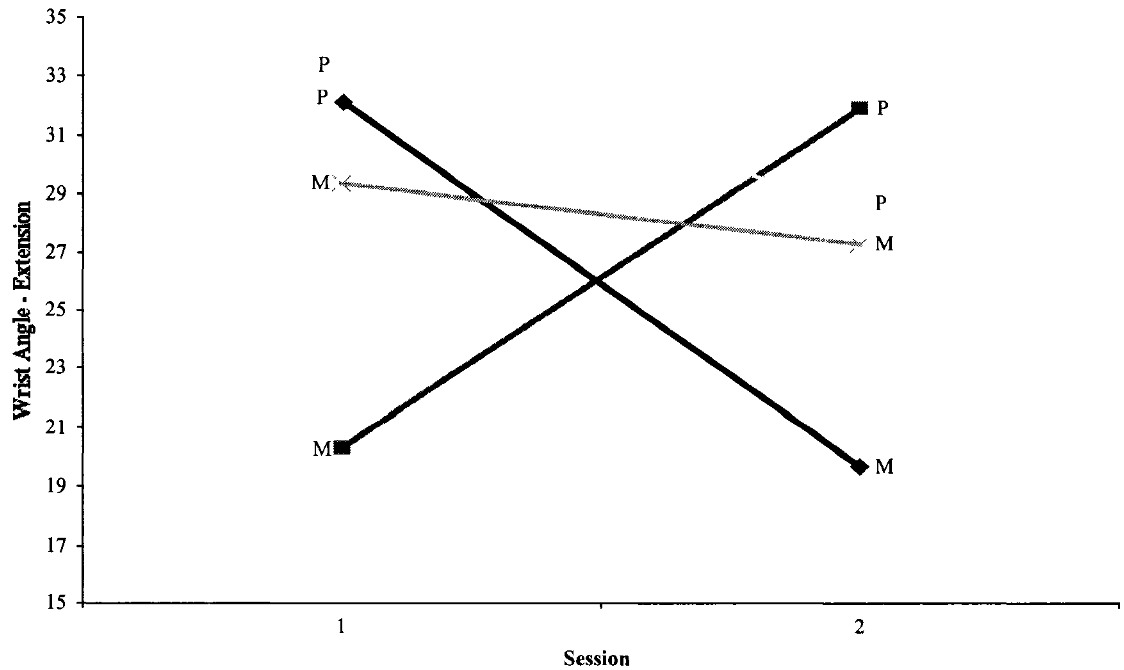

Figure 1. Mean wrist extension by input device.

Input Device – Wrist Flexion

The ANOVA examining wrist flexion for the input device groups across two sessions failed to reveal any statistically significant effects. The data for this analysis can be found in Table 2.

Table 2.

Analysis of Variance Source Table for Input Device by Session on Wrist Flexion

Source	df	MS	F
	Between subjects		
Intercept	1	1064.92	12.27
Input Device	3	44.38	.51
Error	16	86.80	
	Within subjects		
Session	1	19.57	.67
Session * Input Device	3	70.98	2.40
Error	16	29.53	

Input Device – Ulnar Deviation

The ANOVA examining ulnar deviation across two sessions for the four input device groups revealed a statistically significant session by input device interaction effect, $F(3, 16) = 3.23$, $p < .05$ (see Table 3). It was found regardless of the session, the pen required less ulnar deviation than the mouse, except for the alternating group that had the mouse in session one. The ulnar deviation interaction by input device is illustrated in Figure 2. Upon checking the raw data, two outliers were found in the mouse/mouse group, which may have been a cause of the high mean value for ulnar deviation (M=10.79) that resulted.

Table 3.

Analysis of Variance Source Table for Input Device by Session on Ulnar Deviation

Source	df	MS	F
		Between subjects	
Intercept	1	1599.34	45.33
Input Device	3	39.64	1.12
Error	16	35.28	
		Within subjects	
Session	1	.23	.03
Session * Input Device	3	21.83	3.23*
Error	16	6.75	

* $p < .05$

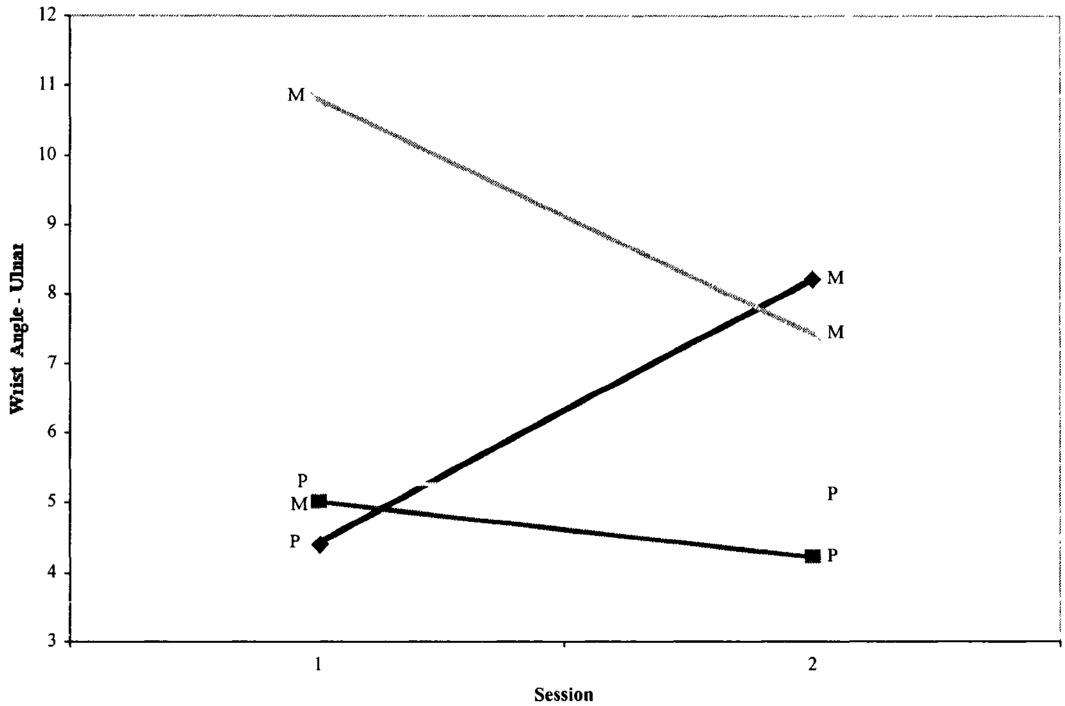

Figure 2. Mean ulnar deviation by input device.

Input Device – Radial Deviation

The ANOVA examining radial deviation for the input device groups across two sessions failed to reveal any statistically significant effects. The ANOVA source table can be found in Table 4.

Table 4.

Analysis of Variance Source Table for Input Device by Session on Radial Deviation

Source	df	MS	F
	Between subjects		
Intercept	1	1352.57	66.43
Input Device	3	40.25	1.98
Error	16	20.36	
	Within subjects		
Session	1	2.97	.28
Session * Input Device	3	11.55	1.10
Error	16	10.57	

Repetition as a Function of Session

A 2 x 2 (repetition by session) ANOVA was conducted on 4 variables: wrist extension, wrist flexion, ulnar and radial deviation. The analyses will be presented in the order of the dependent variables.

Repetition – Wrist Extension

The ANOVA examining wrist extension for the repetition across the two sessions failed to reveal any statistically significant effects. The ANOVA summary table is shown in Table 5.

Table 5.

Analysis of Variance Source Table for Repetition by Session on Wrist Extension

Source	df	MS	F
		Between subjects	
Intercept	1	31044.40	448.76
Input Device	1	134.51	1.94
Error	18	69.18	
		Within subjects	
Session	1	35.10	.54
Session * Repeat	1	20.96	.32
Error	18	64.87	

Repetition – Wrist Flexion

The ANOVA examining wrist flexion across two sessions for the two repetition device groups revealed a statistically significant session by repetition interaction effect, $F(3, 16) = 6.83$, $p < .05$. The ANOVA source table is shown in Table 6. The first group that alternated devices had more wrist flexion in session one, than the group who did not alternate devices. Inspection of Figure 3 indicates the session one groups started at different wrist flexion prior to the outset of the repetition or alternative variable. It is important to remember that input device is collapsed into session one and session two data (the M/M and the P/P groups are merged into the repetitive group and the M/P and P/M are groups merged together in the alternative group).

Table 6.

Analysis of Variance Source Table for Repetition by Session on Wrist Flexion

Source	df	MS	F
	Between subjects		
Intercept	1	1064.92	13.37
Input Device	1	87.82	1.10
Error	18	79.66	
	Within subjects		
Session	1	19.59	.71
Session * Repetition	1	188.57	6.83*
Error	18	27.60	

* $p < .05$

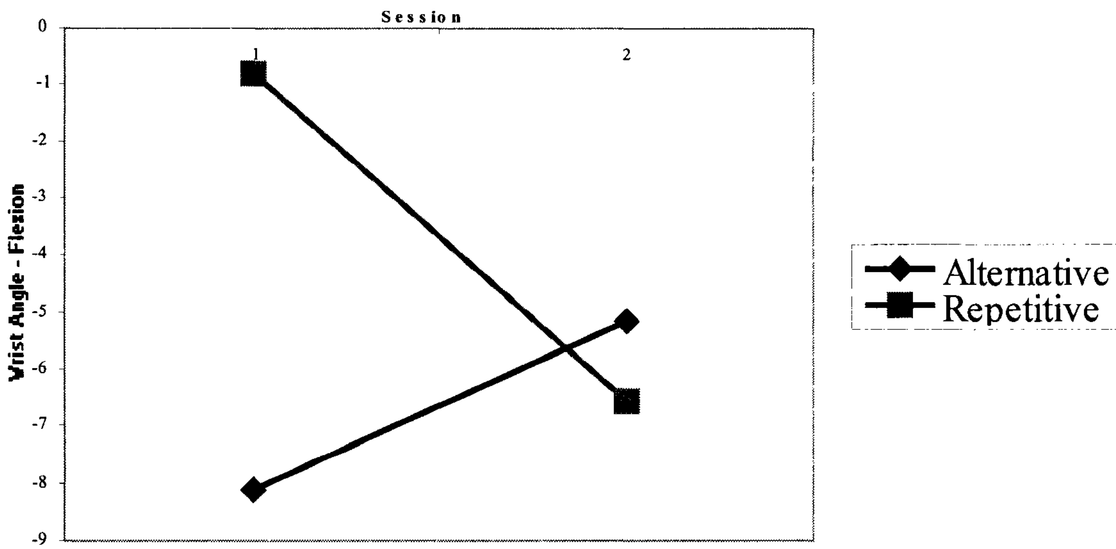

Figure 3. Mean wrist flexion for repetition group.

Repetition – Ulnar Deviation

The ANOVA examining radial deviation for the repetition device groups across two sessions failed to reveal any statistically significant effects. The ANOVA source table is presented in Table 7.

Table 7.

Analysis of Variance Source Table for Repetition by Session on Ulnar Deviation

Source	df	MS	F
	Between subjects		
Intercept	1	1599.34	44.03
Input Device	1	29.67	.82
Error	18	36.32	
	Within subjects		
Session	1	.23	.03
Session * Repetition	1	27.91	3.45
Error	18	8.10	

* $p < .05$

Repetition – Radial Deviation

The ANOVA examining radial deviation for the repetition device groups across two sessions failed to reveal any statistically significant effects. The ANOVA source table is shown in Table 8.

Table 8.

Analysis of Variance Source Table for Repetition by Session on Radial Deviation

Source	df	MS	F
		Between subjects	
Intercept	1	1352.56	57.68
Input Device	1	24.46	1.04
Error	18	23.45	
		Within subjects	
Session	1	2.97	.26
Session * Repetition	1	1.68	.15
Error	18	11.23	

Second Session - Repetitive or Alternative

Data were collapsed into alternative (M/P or P/M) and repetitive (P/P or M/M) groups. The data were examined for the second session only where there was either a repetition of input devices or a switching (or alternative) input device used. No significant results were found for wrist flexion, wrist extension, ulnar and radial deviation. These findings are presented in Table 9.

Table 9.

Analysis of Variance Source Table for Repetition on Wrist Flexion

Source	df	MS	F
	Between subjects		
Repetition	1	9.51	.15
Error	18	63.13	

Analysis of Variance Source Table for Repetition on Wrist Extension

Source	df	MS	F
	Between subjects		
Repetition	1	24.64	.39
Error	18	63.35	

Analysis of Variance Source Table for Repetition on Radial Deviation

Source	df	MS	F
	Between subjects		
Repetition	1	19.50	1.28
Error	18	15.23	

Analysis of Variance Source Table for Repetition on Ulnar Deviation

Source	df	MS	F
	Between subjects		
Repetition	1	1.35E-02	.00
Error	18	22.30	

Symptom Forms

The symptom forms were used in this experiment to determine body discomfort and there were three opportunities for participants to fill out the form, prior to testing, after the first test session and after the second test session. If the participant had no body discomfort, no form was filled out. Only two people filled out forms prior to testing; nine filled out forms after the first session; 10 filled out forms after the second session. Nine participants did not fill out the symptom forms.

In the pen/mouse group three participants filled out symptom forms. Those participants had a little stiffness in either the fingers or in the ulnar side of the hand. In the mouse/pen group three participants filled out symptom forms. One participant had a little soreness on the back of the lower arm, one had a little soreness by the wrist, and one had soreness on the ulnar side of the forearm. In the pen/pen group two participants filled out symptom forms. One participant had a little stiffness on the front side forearm and the other had a little soreness on the backside wrist area. In the mouse/mouse group three participants filled out the symptom form. One participant had a little stiffness on the front side forearm; another on the elbow (which is not on the symptom form) and the last one had a little soreness on the front side of the hand by the pinky finger.

Test sessions were half an hour long and total testing time was one hour. The original purpose of the symptom form was to gather data from participants over days as opposed to an hour. Since the use of the symptom form was not used as it was originally intended, it is uncertain as to the value of the information gathered by its use.

In summary, it was found that both the mouse and the pen cause the wrist to be in extreme ranges of motion for the position of wrist extension, which is greater than 15 degrees of wrist extension. Both input devices significantly affected ulnar deviation as well, yet both groups were less than 15 degrees of ulnar deviation, which is within the neutral range.

CHAPTER 5

Discussion and Conclusions

This research focused on a group of computer users who regularly use a graphic input device to perform their job functions and to maintain their livelihood. The objective of this study was to see if wrist posture was a factor in pen and mouse use and to see which device kept the wrist in a more neutral position. The research questions were: 1. How does input device (mouse or pen) and repetition (repetitive input device or alternative input device) affect wrist posture? 2. How does input device affect posture? 3. How does repetition affect posture?

The following groups were studied in this experiment. Input device – mouse and/or pen: four groups with two testing sessions and repetition - repetitive input device or alternative input device: two sessions with two groups. Results in four categories of wrist posture were analyzed: wrist extension, wrist flexion, ulnar deviation, and radial deviation.

Wrist Extension

The null hypothesis that input device and repetition would not affect wrist posture as measured by wrist extension was rejected. A significant input by repetition effect was found for wrist extension.

According to Rempel et al. (1994) the lowest carpal tunnel pressure occurs with wrist extension between 0 and 15 degrees. As the wrist extends, carpal tunnel pressure increases. Recommendations can be made for the wrist to be positioned between a 0 and

15 degree wrist extension (neutral range of the wrist) to minimize carpal tunnel pressure. Extreme postures above 15 degrees should be avoided.

The results of this study revealed that mouse and pen users used extreme ranges of motion for the position of wrist extension, above the neutral or mid-range level of 15 degrees. The mean wrist extension for each group of this study ranged from 19.70 to 33.33 degrees extension. This is the only category of wrist posture where wrist angles were outside neutral range.

One of the factors that may account for the elevated carpal tunnel pressure during computer mouse use is wrist extension (Rempel et al., 1998). Wrist extension in combination with other stressors, including highly repetitive work can be a factor in increase muscle tension.

Wrist extension/flexion deviations appear to be much more significant risks factors for carpal tunnel syndrome risks than do ulnar/radial deviation (Hedge et al, 1995).

Both mousing and pen techniques used by the participants in this study revealed participants tend to extend their wrist more than any other position. This makes sense for the mouse, since most users rest the wrist area of their arm on a surface restricting elbow and shoulder movements, and extend the wrist so then the fingers can lie on top of the mouse. In the case of the participants in this study who used a pen they may have planted their hand and operate pen from the wrist joint.

This study found that there were differences in pen and mouse users. Wrist extension above 15 degrees, were found in all groups indicating all groups were outside a mid- range value. Studies have shown that repeated motions outside the mid range value would be at a higher risk for injury (Rempel et al., 1994; Hedge et al, 1995).

Since extension angles the wrist in an upward motion it causes participants to torque against gravity. From this, it could be deducted that participants are working against gravity. Therefore, it is important to keep the wrist in as neutral posture as possible (Snook et al., 1995). By alternating input devices, this may be able to be achieved.

Wrist Flexion

The null hypothesis that input device and repetition would not affect wrist posture as measured by wrist flexion was rejected. Input device and repetition interacted to affect wrist flexion.

Even though there was a significant affect for this group all groups were found to be in the acceptable range of under 15 degree flexion. According to the literature, these are acceptable, mid-range values.

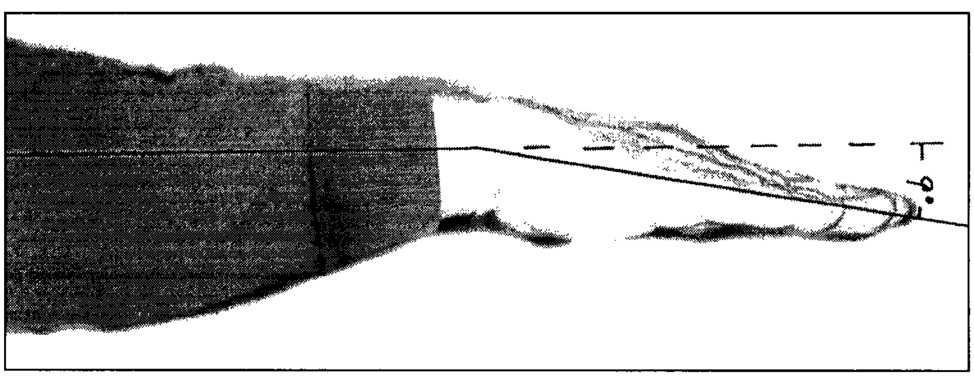

Figure 4. Participant showing 9 degrees flexion

The data on flexion revealed that the numbers were at zero or close to neutral (between -4.46 and -8.11 degrees). This is logical considering the common way operators use a mouse. When resting the palm on a surface and the finger on top of the mouse, the wrist is automatically in an extended position. There are two possible ways to use a pen and a mouse for that matter. One, the operator keeps his or her palm squarely on the surface. In this method the wrist will extend and flex. Second, the operator uses larger muscles, that is, shoulders and upper arm, to perform the task of operating a pen (more coordinated movements rather than isolated movements). In this method the wrist will not extend or flex as much.

Flexion and extension of the wrist are related to the elevation of the mouse or pen and tablet with respect to the elbow. Inward rotation of the forearm is necessary to position the hand over the mouse. Neutral posture of the forearm can be achieved when holding a pen combined with proper use (Armstrong et al., 1994).

The groups that alternated devices reduced the amount of flexion while the groups that used the same device had increased the amount of flexion (see Figure 3, in Chapter 4). Participants use certain muscle configurations to perform the mousing and pen tasks. When participants used the same device for the second session they were using the same muscle configurations because they were using the same devices. When they alternated devices they then had the opportunity to use different muscle configurations and thereby, in the case of flexion, reduce the amount of time in the flexed position. This result confirms what the data shows in the extension data set, which is by alternating devices throughout the work day operators may be able to reduce some of the risk factors associated with computer usage. This finding could be considered when assigning input devices to graphic input device users.

Ulnar Deviation

The null hypothesis that input device and repetition would not affect wrist posture was rejected. Pen groups had greater ulnar deviation, yet only one mouse group had a value of above 15 degrees (outside of neutral). Two outliers were found in this group. This may have been a result of the relatively low number of participants in this study.

Karqvist et al. (1994) compared upper body postures between using only a keyboard and using both a mouse and keyboard to edit text. Participants in this study were not ergonomically evaluated or positioned for the study, but "all operators were studied at their ordinary workstations: i.e., chair/desk design and height, space and surroundings varied for both groups." Ulnar deviation was significantly greater during mouse use (17.6 degree) compared with non-mouse use (1.8 degree). During mouse use participants spent 34% of the time working in ulnar deviation between 15-30 degree and 30% of the time working in ulnar deviation greater that 30 degrees, compared with only 2% and 0% respectively during non-mouse use. In this present study participants were ergonomically assessed, which may be a reason for ulnar deviation being in a more neutral range. Only one participant for only one 30 minute test period yielded results outside of a neutral range of 15 degrees for ulnar deviation. Several articles in the review of literature section, as well as the one just mentioned, found participants had ulnar deviation, outside of a neutral range of greater than 15 degrees, but in this present study, only one person deviated outside of 15 degrees neutral.

Typical mouse users tend to engage in ulnar deviation to control mouse position. A typical mouse user would stabilize the wrist on a surface, restricting arm movements. These numbers are confirmed by Karlqvist et al. (1994) study, which found mouse operators spent 64% of the working time with the operative wrist deviating more than 15 degrees towards the ulnar side, while non-mouse operators spent 96% of the time with the corresponding wrist in neutral position towards radial deviation.

Radial Deviation

The null hypothesis that input device and repetition would not affect radial deviation was accepted. This study failed to reveal any statistically significant data for radial deviation.

In this study only one participant for only one testing period (30 minutes) had radial deviation outside of a neutral range of 15 degrees. This group of users did not deviate radially outside of neutral.

Delimitations

The study included measurement of wrist posture or wrist range of motion only. The value of using the symptom form is inconclusive in this experiment. The study yielded significant results despite the low number of per group participants. The study would have had more power if the sample population were larger.

Limitations

The experiment was done in a variety of locations. Although the researcher assessed participants to make sure they were seated in an ergonomically correct position, the environment may have been somewhat artificial and not the same as in a normal work setting.

Participants were required to wear a glove on their right hand to obtain data for wrist range of motion. Wearing a glove during computer mouse use was unfamiliar. Although the glove was lightweight and did not restrict movement, application of the glove could result in a difference of sensation, resulting in a difference in body discomfort.

A floating position where the hand is placed on top of the mouse or held loosely could not be maintained by participants during the experiment, even though this position was explained to them and they were encouraged to use this position. Participant's typical mousing posture consisted of having the wrist down on a surface. This position would be categorized as having the wrist in an extended position or in an extreme range of motion. Typical mouse users plopped their wrist down on the mouse pad or hard surface and then controlled the movements of the mouse with their fingers, without the palm of their hand on the mouse. To operate the mouse, they are forced to "wag" their wrist back and forth using the wrist and the digits. Their wrist was in an automatic extension position. Despite teaching the participants about a neutral wrist position, participants had difficulty maintaining a neutral posture while mousing, which leads one to wonder if it is the design of the mouse itself that causes one to mouse using the wagging method.

Observation yielded limited shoulder and elbow movement. Joints, muscles, tendons and nerves function most efficiently while operating in a mid-range of motion.

When body parts are made to operate in extreme ranges of motion, in an isolated fashion, then it seems to reason, there is an increase exposure to possible injury.

The researcher observed pen users to either plant the wrist on the Wacom tablet and wag the wrist back and forth or to use the shoulder area and kept the wrist more in neutral.

Recommendations for Further Research

To further understand the effects of input devices on wrist posture, additional studies are recommended. These include:

1. A study using EMG to analyze muscle force in certain forearm muscles, whose tendons pass through the wrist area in order, to see which, pen or mouse, can keep muscle tension and force to a minimum in the wrist area. This present study used wrist posture only as the dependent variable as measured by the Greenleaf WristSystem.

2. A study exploring writing postures, which provide different angle distributions, because the weight of the instrument is not on the wrist but rather the fingers. This could be compared to mouse wrist posture.

3. A study comparing the forces needed to click and tap between the Wacom pen and the mouse.

4. A study comparing writing positions and their effect on using a Wacom pen and tablet.

5. A study on placement positions and wrist postures between a Wacom pen and tablet and a mouse.

6. A study researching an input device that provides feedback when the wrist goes into a non-neutral position. This could be used to train mouse users to mouse inside the neutral range.

7. A study including biomechanical analysis of wrist and arm movements in a similar study as this one.

8. Throughout the literature review, 15 degrees was considered neutral or mid-range acceptable values. Two of the three findings of this research, though significant, were inside the neutral range. Perhaps 15 degrees is too generous as an acceptable mid-range value. An area for future research would be to re-examine the acceptable mid-range values and reassess them.

Conclusion

It is becoming clear that there is probably no one single ideal posture or device, which can be used consistently. Variety may be the key. Alternating types of GIDs, thereby varying work postures and work movements during highly repetitious graphic activities, may prove to help the communities of people who are GID dependent to perform their job function (Hagberg, 1995). The pen offers variety in many ways including that the tablet can be placed in different positions.

Research indicated that people who write with a pen do not develop repetitive strain injury in the wrist area. Writing and using a mouse are complex wrist postures. Wrist posture while using a pen may not be a factor in development of a repetitive strain injury.

The mouse and pen have qualitatively different postures; the mouse has nearly straight fingers with mild extension, ulnar deviation and moderate pronation whereas the pen has two or three finger pinch grip with higher extension, very close to neutral deviation.

A study performed by Kotani et al, completed in 2002, compared a mouse to a pen-tablet system (Wacom Intuos I-600). This study found the pen to be more accurate than the mouse and to feel more comfortable to the users. Pen users rated higher on performance than mouse users and there is a relatively short (1 day) learning curve for pen users.

Current ergonomic recommendations favor more neutral positions, with little deviation or flexion/extension, mid pronation (90 degrees) and they counsel against pinch grips. One could argue that wrist posture cannot be evaluated without knowledge of finger posture. Research suggests that there is a reciprocal relationship between finger and wrist posture, that is, the more flexed the fingers, the more extended the wrist, (Wells et al., 1997). The mouse and the pen show this reciprocal relationship, and the more extended wrist position during pen use may not be problematic. Pen use shows higher angular velocities than mouse use. This is probably related to the larger displacements required by the pen.

It is becoming clear that there is probably no one single ideal posture or device, which can be used consistently: variety is the key. The pen offers variety in that the tablet can be placed in different positions. Alternating between the mouse and pen would offer further variety, as the hand postures used are different. Other risk factors, such as local contact pressure, need to be considered in recommending input devices and support conditions.

In this study a neutral position for the shoulder and arm was used. Yet even this position is still a static position. Wide variability exists as far as ergonomic benefits are concerned of graphic input devices. For example, one device may help to decrease loads on muscles in the forearm while increasing loads on other muscles (e.g., neck, shoulder, or hands). Providing users with an alternative pointing device varies the muscular load and could result in a reduction of chronic muscle pain. User awareness of proper posture needs to be emphasized and rest breaks encouraged (Galinsky, Swanson, Sauter, Hurrell, & Schleifer, 2000). This could be put into practice by creating jobs that have a variation in the type of work tasks performed during the course of a day (Hagberg, 1995). Ergonomics redesign of work environment, job design, and job tasks have been the focus of attempts to minimize or even eliminate many of the risk factors for carpal tunnel syndrome and other types of musculoskeletal discomfort (Hedge et al, 1995).

In jobs where hand motions are the main work activity and torque is required to perform a job, Ciriello, Snook, Webster and Dempsy (2001) found by alternating torque activities, users were able to tolerate greater maximum torque rates than if a single task was performed during a work day. Therefore, alternating tasks during the work day between a pen and a mouse may help to increase tolerance for an input device activity.

In drawing tasks comparing a pen versus a mouse, the pen is two times faster than the mouse. (Apte & Kimura, 1993) The pen user interface is heralded as more natural and powerful than the mouse, due to the ease of use in pointing, handwriting, gesturing and drawing. In addition, some subjects said the pen was easier to use than the mouse.

Apte et al. concluded that for both input devices extension is the culprit. Other journal studies such as Rempel, Keir, & Bach, (1997) agree extension causes less blood flow, increased carpal tunnel pressure and other physiological problems.

In an article by Wintemute (1992) that discusses the prevention of motor vehicle injuries, childhood drownings and firearm violence the conclusion is three fold. The first advocates behavioral changes on the part of the individual. The second advocates policy change as concerned community leaders. The third is product redesign practices. These same three conclusions can be applied to input devices associated with computers.

To address two of the above mentioned conclusions, widespread ergonomic training could be advocated as public policy. Ergonomic training could be a requirement for anyone who uses a mouse for two or more hours a day. This would include teaching neutral or mid-range positions in order to minimize the risk factors associated with input device use.

Training employees on proper use of their equipment can not only save companies millions of dollars in workers compensation claims, but it can also ensure a healthier workforce, including less time off due to pain and injury and higher productivity.

Training will only be as effective as people are ready willing and able to make those changes to their computer work behavior. The transtheoretical model suggests four stages of behavioral change: contemplation, determination, action and maintenance (Glarz, Lewis & Rimer). Awareness of these stages could have a big impact on the effectiveness of any ergonomic program implemented.

To address the third conclusion of Wintemute's article would be to redesign both tools in such a way as to diminish the need for such extreme wrist extension. High extension values for both groups found in this study, along with similar results in many other studies, show that a redesign of these products is needed or massive ergonomic training is needed to help prevent repetitive strain injuries from occurring in input device users. Computer users need to be educated and know the risk factors involved in using input devices.

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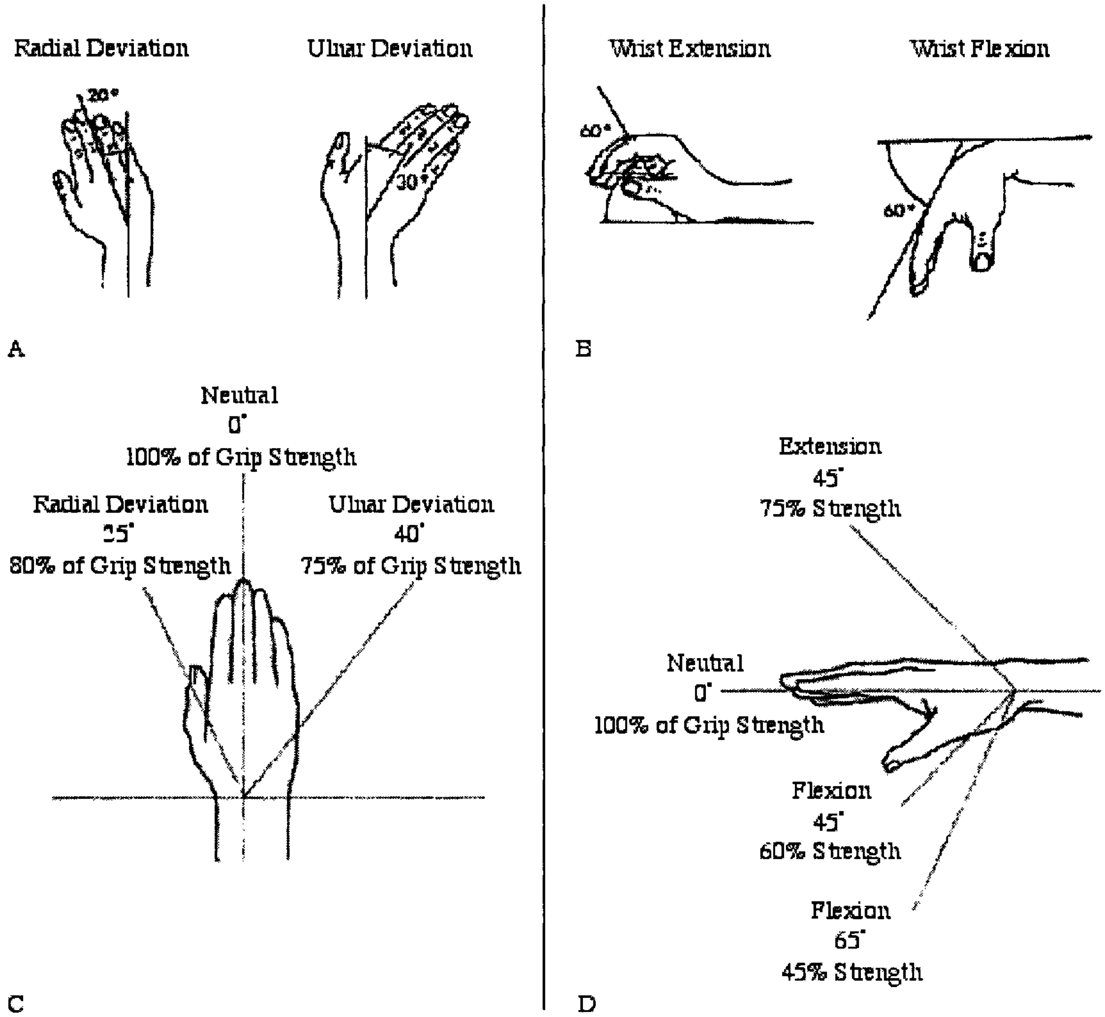
APPENDIX A

Joint Posture Definitions and Range of Motion of the Wrist

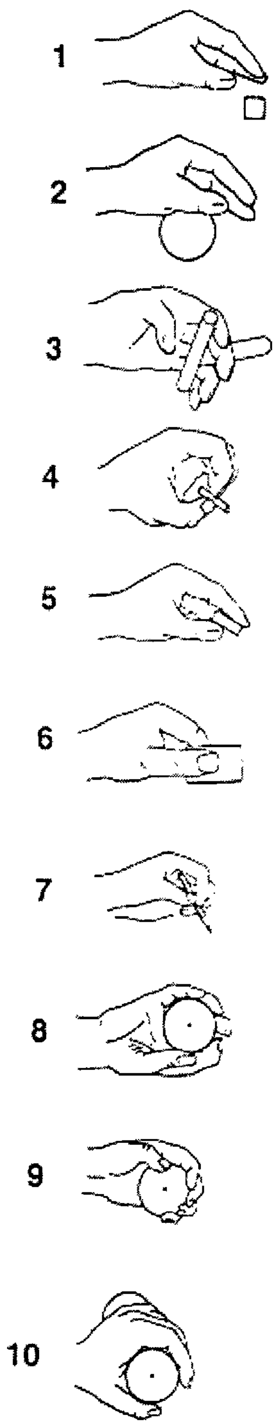


A & B: Swanson, A.B., Swanson, G.G., & Goran-Hagert, C. (1990). Evaluation of impairment of hand function. In J.M. Hunter, L.H. Schneider, E.J. Mackin, & A.D. Callahan (Eds), *Rehabilitation of the hand: Surgery and therapy* (pp.109-138). St. Louis: C.V. Mosby.

C & D: Kiser, D.M. (1987). Physiologic and biomechanical factors for understanding repetitive motions injuries. *Seminars in Occupational Medicine, 2,* 1, 1-18.

APPENDIX B

Neutral Posture while Using a Computer



1. **Finger Touch:** One finger touches an object without holding it.

2. **Palm Touch:** Some part of the inner surface of the hand touches the object without holding it.

3. **Finger Palmer Grip (Hook Grip):** One finger or several fingers hook(s) onto a ridge, or handle.

4. **Thumb-Finger Grip (Tip Grip):** The thumb tip opposes one fingertip.

5. **Thumb-Finger Palmer Grip (Pinch or Plier Grip):** Thumb pad opposes the palmer pad of one finger.

6. **Thumb-Forefinger Side Grip (Lateral Grip or Side Pinch):** Thumb opposes the (radial) side of the forefinger.

7. **Thumb-Two-Finger Grip (Writing Grip):** Thumb and two fingers oppose each other at or near the tips.

8. **Thumb-Fingertips Enclosure (Disk Grip):** Thumb pad and the pads of three or four fingers oppose each other near the tips.

9. **Finger-Palm Enclosure (Collet Enclosure):** Most, or all, of the inner surface of the hand is in contact with the object while enclosing it.

10. **Power Grasp:** The total inner hand surface is grasping the handle which runs parallel to the knuckles and generally protrudes on one or both sides from the hands.

Kroemer, K.H.E. (1986). Coupling the hand with the handle: An improved notation of touch, grip, and grasp. *Human Factors,* 28,3, 337-339.

APPENDIX C

Participant Screening Tool

Introduction

This questionnaire is part of a study being performed for a Master's thesis in Human Factors and Ergonomics at San José State University. Your participation will assist us in providing understanding to both the ergonomic and industrial design professions of the real needs of graphic input device user. All survey responses are anonymous.

Instructions:

Fill out the following questionnaire.

Send completed questionnaire to Janice Lilien

You will be contacted, and an appointment time will be set up if you qualify to be a participant in the study.

Thank you for your time.

Janice Lilien
Human Factors Engineering Master's Candidate
Emily Wughalter
Professor of Human Performance at San José State University
Telephone: 408/961-8146

Please answer the following questions:
(Information is confidential)

Participant's Name: ________________________ Today's Date: _____________
Telephone Number: Work __________________ Home ____________________
E-mail Address: ____________________________

4. Age: __________ years

5. Gender: _____Male _____ Female

6. Have you ever had an ergonomic evaluation of your computer workstation current or otherwise?

7. Do you have a working knowledge on recommended computer workstation setups?

8. Which hand do you use for mousing? (circle one) Right Left

9. How many hours per day do you use a computer? __________

10. How many years of experience do you have using a computer? _____________

11. Have you used a computer mouse for one year or more? ____YES ____NO

12. What type of mouse do you use? (circle one)
MS mouse: optical Serial (standard mouse that come with most PC's)
Mac mouse: round oval?
Trackball Other: __________

13. Have you used a pen and tablet for one year or more? ____YES ____NO

14. Have you used a Wacom pen and tablet? Yes No
Any other brand of pen and tablet? Yes No
If yes which one: ____________________

15. Have you been diagnosed by a physician as having an arm, wrist, or hand repetitive motion injury in the last year? ____YES ____NO

16. Have you ever injured your wrists or hands? ____YES ____NO
If yes, explain____________________________________

17. Have you had any pain or discomfort, numbness or tingling in your arms, wrists, or hands in the last year? ____YES____NO

18. Do you know how to play Solitaire on a computer? ____YES ____NO

APPENDIX D

Written Consent Form

San José State
UNIVERSITY

College of Applied Sciences and Arts
Department of Human Performance

WRITTEN CONSENT FORM

I, ______________________________ volunteer to participate in the research project entitled "EFFECT OF GRAPHIC INPUT DEVICE ON WRIST POSTURE," to be conducted ____________, under the direction of Janice Lilien and Emily Wughalter.

The procedures have been explained to me, and I understand them fully and they are: a 10 minute warm up period wearing the Greenleaf Wrist System getting familiar with the input device, 30 minutes of test time wearing the Greenleaf Wrist System per input device, one 15 minute break and the completion of symptom forms as a preliminary and after each device tested.

I understand there are no risks, benefits or compensation associated with my participation in this study. I understand that the results may be published but no infor-mation that could identify me will be included. I understand that this consent and data may be withdrawn at any time without penalty. I have been given written notification of the principal investigators as well as the department chairperson's phone numbers.

Janice Lilien (principal investigator): 650/988-1623

Emily Wughalter (advisor): 408-924-3043

Dr. Lou Freund (ISE Department Chair): 408-924-3890

I have been given the right to ask questions, and my questions, if any, have been answered to my satisfaction. I understand the data will be reported in group form, and individual data will be kept confidential.

______________________________ ______________
Participant's Signature Date

______________________________ ______________
Investigator's Signature Date

If you would like a summary of the findings, please complete the following information:

Name: ______________________________

Address: ______________________________

____

Thank you very much for your participation!

APPENDIX E

Testing Procedure

1. Welcome and thank you for participating.

2. Describe study. *This is a study that will examine wrist posture while using a graphic input device. It will take approximately 2 hours. I will be putting a glove on your right hand that you will keep on while you are working. The task involves playing solitaire on the computer for 30 minutes. The goal is to complete as many games of solitaire as you can in the allotted time. Prior to the start of the test, you will be given a 10 minute warm-up period. After the task you will fill out a form and take a 15 minute break. After the break, you will be asked to repeat the same procedure.*

3. Fit WristSystem glove.

4. Participants reads and signs the consent form and fills out preliminary symptom form.

5. Researcher adjusts workstation for participant. *You will be working at this workstation to perform computer tasks. When you are ready you can begin the 10 minute warm up period.*

6. Calibrate Greenleaf WristSystem.

7. *Now we can start the trial period. Remember to try to complete as many games as possible.*

8. Set timer. Instruct participant to begin. Start recording data from Greenleaf.

9. At the end of the testing session, turn off data collection. Have participant complete symptom form and give them a 15 minute break. Instruct participant to walk around or to do some sort of stretching, whatever they wish.

10. After break. Now *we will start the second half of the study.*

11. Repeat steps 3 to 9.

12. Thank participant for being in study.

APPENDIX F

Human Subject-Institutional Review Board

San José State
UNIVERSITY

Office of the Academic Vice President
Associate Vice President Graduate Studies and Research
One Washington Square
San José, CA 95192-0025
Voice: 408-924-2480
Fax: 408-924-2477
E-mail: gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

To: Janice Lilien
680 Mountain View Avenue
Mountain View, CA 94041

From: Nabil Ibrahim, N Ibr
AVP, Graduate Studies & Research

Date: November 15, 2002

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

"Effect of Graphic Input Device on Wrist Posture."

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subjects portion of your project is in effect for one year, and data collection beyond November 15, 2003 requires an extension request.

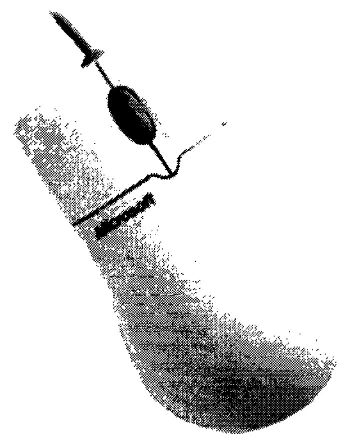
Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services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

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

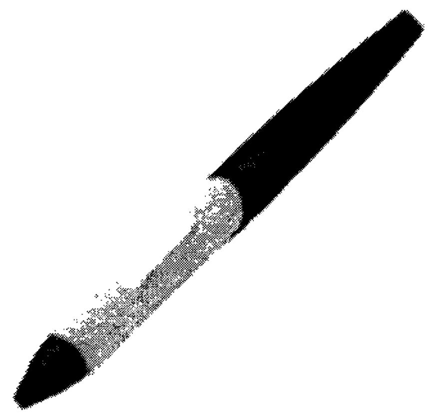
APPENDIX G

Input Devices

Microsoft Mouse
(Microsoft Corp. Redmond, WA, USA)



Wacom Intus2 Pen
(Wacom Technology Corp.
Vancouver, WA, USA)



APPENDIX H

Symptom Form

RIGHT ARM EVALUATION — Back

Circle the appropriate numbers below for each column.

Fingers and Thumb

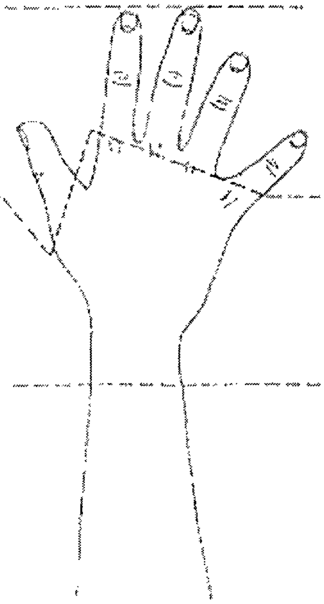
Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Hand and Wrist

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Forearm

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb



Back

Now indicate the location on the drawing. Use:

So for Soreness

St for Stiffness

N for Numbness

APPENDIX I

Symptom Form

RIGHT ARM EVALUATION -- Front

Circle the appropriate numbers below for each column

Fingers and Thumb

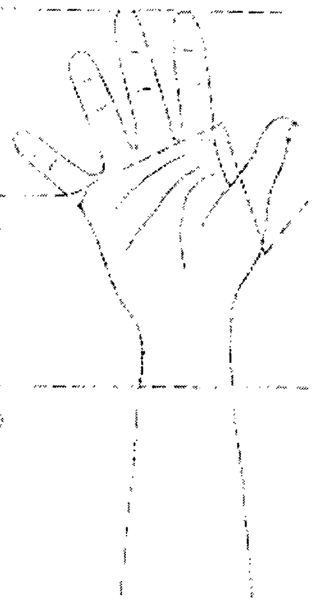
Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Hand and Wrist

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

Forearm

Soreness (Pain)	Stiffness	Numbness (Tingling)
0 = No soreness	0 = No stiffness	0 = No numbness
1 = A little sore	1 = A little stiff	1 = A little numb
2 = Somewhat sore	2 = Somewhat stiff	2 = Somewhat numb
3 = Very sore	3 = Very stiff	3 = Very numb

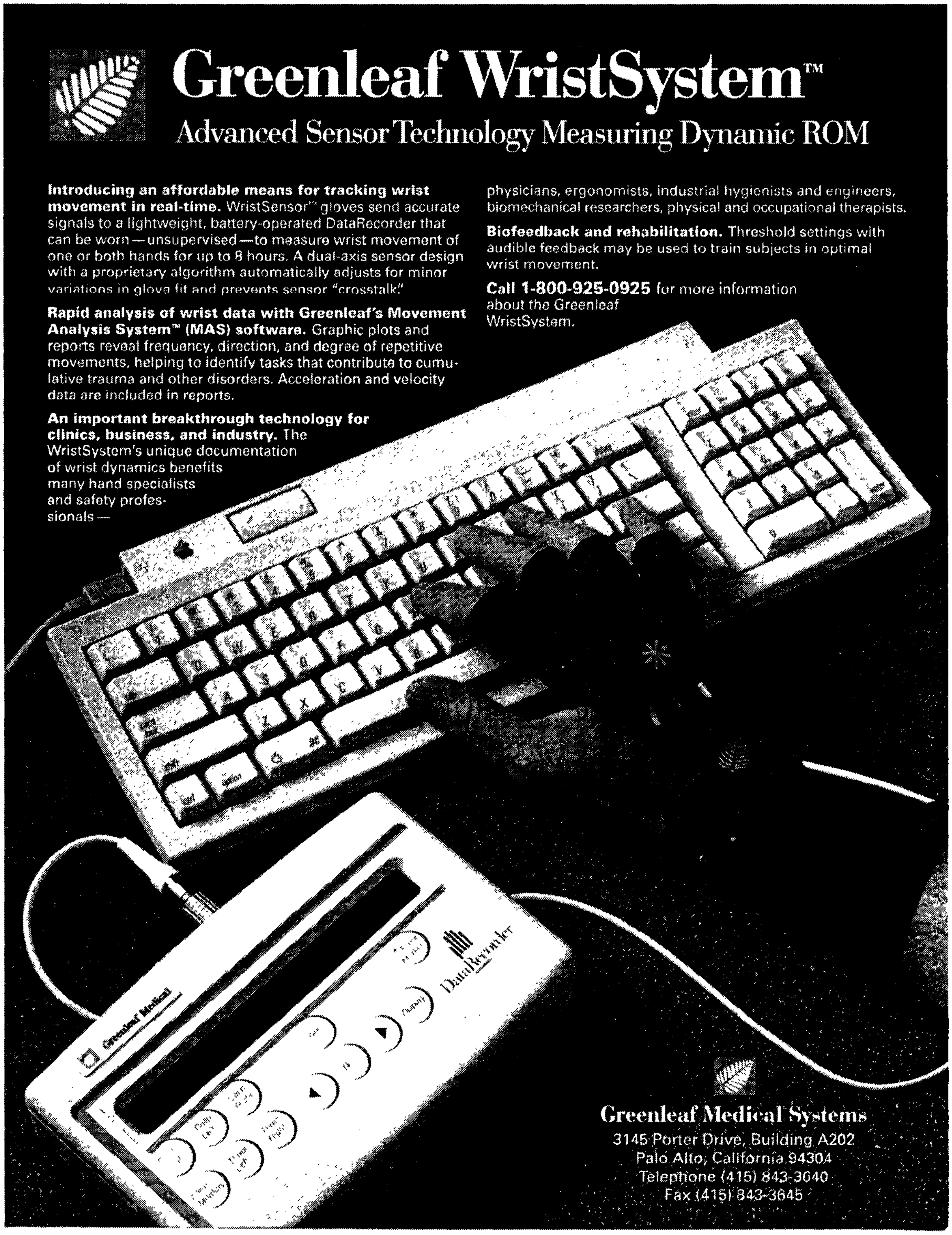


Front

Now indicate the location on the drawing. Use:
So for Soreness
St for Stiffness
N for Numbness

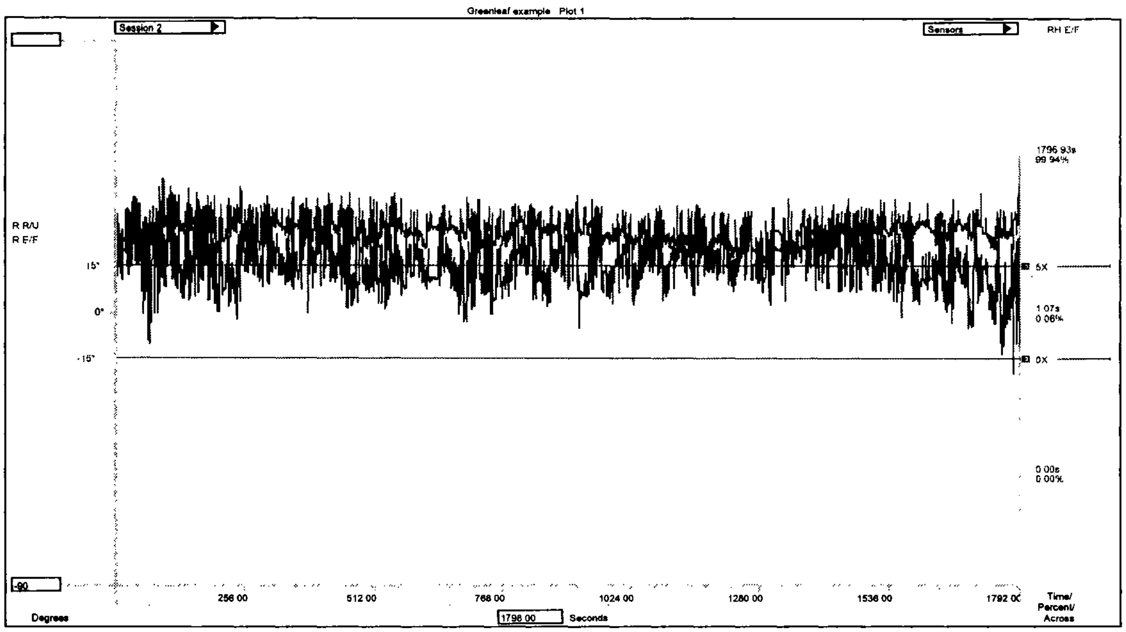
APPENDIX J

Greenleaf Medical Wrist System



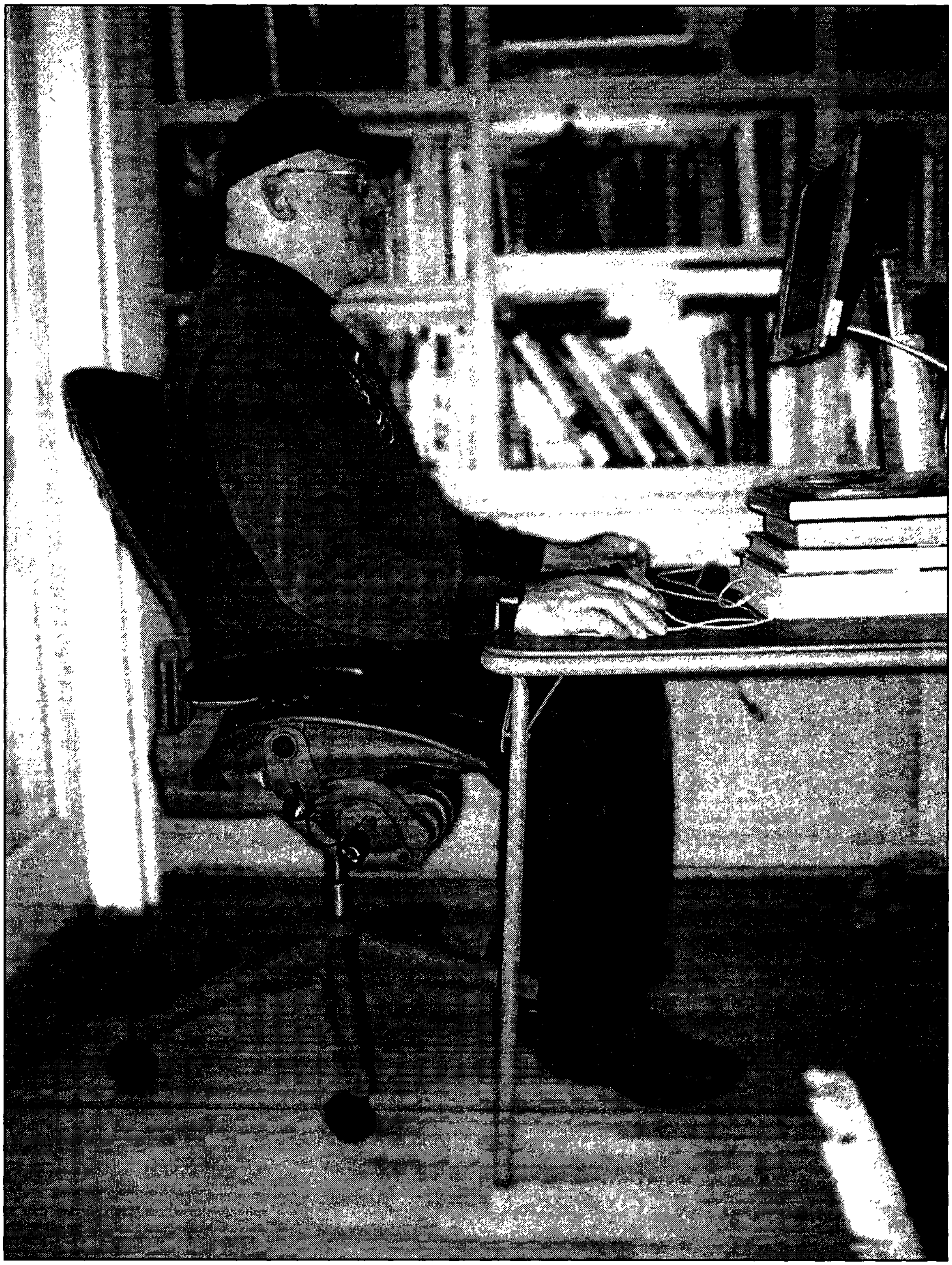
APPENDIX K

Example of Greenleaf Wrist Data Plot



APPENDIX L

Neutral Posture While Using a Computer



APPENDIX M

Raw Data

			Session 1 Mean				Session 1 ST DEV					Session 2 - Mean				Session 2 ST DEV			
#	InputD	Repeat	Flex 1	Ext 1	Radial 1	Ulnar 1	Flex 1	Ext 1	Radial 1	Ulnar 1	Flex 2	Ext 2	Radial 2	Ulnar 2	Flex 2	Ext 2	Radial 2	Ulnar 2	Age
1	0	0	-5.2	22.7	-5.5	6.7	3.9	6.6	3.8	5.1	-6.8	21.8	-14.3	5.9	5.9	4.7	7.1	4.2	51
2	0	0	-31.1	35.5	-11.5	0.9	21	5.5	3.6	0.4	-20.95	21.65	-8.85	4.55	18.6	6.3	3.9	3.4	32
3	0	0	0	33.7	-3.2	2.1	0	3.9	2	1.7	0	29.8	-2.3	6.7	0	9	1.5	5.2	29
4	0	0	0	33.97	-3.67	8.41	0	9.34	3.12	5.71	-2.42	13.57	-3.78	17.27	1.95	6.58	3.02	7.71	32
5	0	0	-4.4	35.14	-5.08	4.01	0	5.45	3.46	3.74	-2.67	11.65	-8.81	6.63	0.55	2.79	5.8	5.37	23
6	1	0	-10.4	10.54	-5.76	2.31	12.47	4.05	3.46	2.02	0	36.62	-1.76	1.8	0	3.26	1.86	1.56	36
7	1	0	-12.3	28.68	-2.5	7.85	7.75	5.55	1.65	4.15	0	35.3	-1.9	3.1	0	8.2	1.3	3	58
8	1	0	-5.68	15.42	-0.66	0.77	2.72	3.68	0.22	1.67	-18.86	29.56	-3.15	2.31	14.8	4.09	1.42	2.5	58
9	1	0	-10.5	16.88	-0.92	9.76	7.69	4.59	1.07	6.19	0	20.37	-3.27	7.66	0	3.56	1.85	5.95	32
10	1	0	-1.6	29.85	-10.87	4.22	0	3.41	6.04	3.46	0	37.8	-2.88	6.49	0	4.37	3.37	4.54	46
11	2	1	-0.4	19.03	-14.46	1.74	0	10.78	4.74	1.36	0	22.29	-13.03	4.68	0	9.96	4.81	4.14	39
12	2	1	0	31.82	-7.12	3.17	0	6.51	3.71	3.14	-4.14	26.82	-7.81	3.76	4.98	5.96	3.96	4.19	28
13	2	1	0	32.89	-0.51	10.59	0	3.76	0.18	4.12	0	24.95	-0.95	12.91	0	4.61	0.55	5.47	30
14	2	1	-1.33	36.39	-5.05	11.47	0.46	8.45	3.41	8.26	-5.05	25.53	-11.24	1.96	3.33	10.7	4.66	1.7	52
15	2	1	0	46.54	-15.44	0	0	5.74	2.75	0	-12.6	44.11	-4.64	2.25	9.11	5.3	2.29	2.39	47
16	3	1	-6.34	32.77	-2.91	16.27	4.17	5.2	1.6	7.99	-20.24	30.54	-4.67	9.35	18.2	6.34	3.39	6.48	25
17	3	1	0	30.78	-2.12	8.76	0	5.03	1.76	6.58	-4.93	28.42	-5.1	4.76	1.29	4.79	2.84	4.19	47
18	3	1	0	33.74	-5.01	7.9	0	3.68	3.38	6.24	0	27.62	-6.13	6.75	0	7.03	4.02	6.53	30
19	3	1	0	26.35	-5.15	16.63	0	3.85	4.62	7.23	-18.53	27.55	-6.76	15.93	13.4	6.51	6.22	7.6	29
20	3	1	0	23.22	-3.42	4.43	0	3.9	3.03	4.38	0	22.49	-10.42	0.38	0	3.82	3.96	0.47	43