**The Effects of Keyboard Height, Wrist Support and Keying Time on Wrist Posture and Trapezius EMG during Keyboarding**

by

Victor Leo Paquet III

Thesis Submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in Partial Fulfillment of the Requirements for

the Degree of

Master of Science

in

Industrial and Systems Engineering

APPROVED:

Karl H.E. Kroemer, Chairperson

Jeffrey C. Woldstad

Dennis L. Price

Blacksburg, Virginia

May, 1995

THE EFFECTS OF KEYBOARD HEIGHT, WRIST SUPPORT AND KEYING TIME ON WRIST POSTURE AND TRAPEZIUS EMG DURING KEYBOARDING

by

Victor Leo Paquet III

Committee Chairman: Karl H.E. Kroemer

Department of Industrial and Systems Engineering

Virginia Polytechnic Institute and State University

The purpose of this study was to investigate the effects of keyboard height, the presence or absence of a wrist support, and keying time on different risk factors associated with musculoskeletal disorders experienced by VDT operators. Measurements of wrist posture, activity of the trapezius muscles, shoulder abduction and typing performance were recorded at fixed intervals during a controlled 40 minute keying task. Ratings of musculoskeletal comfort were recorded before and after each keying task. Six subjects performed the keying tasks on six different days. A different keyboard height and wrist support condition was tested on each day.

For wrist extension, ANOVA showed that the effects of Keyboard Height, Wrist Support, and Height x Keying Time were significant. For ulnar deviation, the main effects of Keyboard Height and Keying Time were significant. For forearm pronation, only the effect of Wrist Support was significant. Mean shoulder abduction ranged between 0 and 2 degrees. Mean EMG activity for all keying tasks was 5.3 %MVC. Subjects made an average of 26.5 errors during each keying task (.6 errors/min.), and an average of 1.64 errors for each time

interval (.8 errors/min.). For the reported change in musculoskeletal comfort of the back, neck, left and right shoulders, left and right upper arms, left and right forearms, left wrist, and left hand, the main effect of Wrist Support was significant. In all cases the decrease in musculoskeletal comfort was greater when the wrist support was absent. Subjects preferred wrist supports, and heights at or greater than seated elbow height. The keying condition that was preferred most by subjects was when the keyboard was positioned at elbow height and when the wrist support present. The condition preferred least was when the keyboard was positioned 5 cm below elbow height and when the wrist support was absent.

These results indicate that the use of wrist supports can decrease wrist extension and musculoskeletal discomfort during keying tasks. Keyboard heights at or above seated elbow height may help decrease wrist extension but keyboard heights above elbow height may increase ulnar deviation.

This work is dedicated to my brother, Shane.

## ACKNOWLEDGMENTS

This study was accomplished with the cooperation of the Industrial and Systems Engineering Department at Virginia Polytechnic Institute and State University. Equipment and facilities were provided by the Human Factors Engineering Center, particularly by the Industrial Ergonomics and Environmental and Safety Laboratories. Subject funding was provided by the NIOSH Training Project Grant T010H07241.

I am grateful for the guidance and expertise of my committee members, Dr. Kroemer, Dr. Woldstad and Dr. Price. Their patience and advice over the past two years has been extraordinary. A special thanks is given to my committee chair Dr. Kroemer whose guidance and encouragement made completion of this project possible.

I would also like to thank my friends at Virginia Tech for their support, advice and encouragement. I would especially like to thank Michael Mitchell for his help in developing the computer interface used in the experiment and for the use of his computer during the experiment. Thanks also to Andrew Gellatly for his advice throughout the development of my thesis and participation as one of my pilot subjects.

Finally, I would like to thank my family for their encouragement during all my years in college. Their support has motivated me to reach my current goals and still drives me to attain higher ones.

## Table of Contents

## List of Tables

## List of Figures

Figure Number Page

# 1. INTRODUCTION

## 1.1 Rationale

Technological developments during the past decade have had a marked effect on the nature of individual job tasks in the workplace. The increasing presence of video display terminals (VDTs) in office environments has changed the jobs of secretaries and data input personnel. Punch cards are no longer used for data input. No longer is a carriage return used after completing a line of text, nor a new piece of paper inserted after a page is typed. Typographical errors are simply retyped, eliminating the need for liquid paper or erasers. As a result, it is not uncommon for VDT operators to maintain the same static postures at their workstations for hours, keying over 12,000 characters per hour (Carpi, 1989).

Numerous studies reported a high incidence of musculoskeletal disorders among VDT operators (Bammer, 1988; Knave, Wibom, Voss, Hedstrom and Bergovist, 1985; and Low, 1990). Worker's Compensation claims for musculoskeletal disorders have been steadily increasing over the past decade (Brogmus and Marco, 1991), and the direct and indirect costs of these injuries can have a large impact on employee productivity (Smith, 1987; Pagnanelli, 1989; and Manuele, 1991). As a result, the causes of musculoskeletal disorders experienced by VDT operators are being investigated by researchers.

Two major types of musculoskeletal disorders reported by VDT operators are those of the wrist and those of the neck and shoulders. The former has been researched extensively in the U.S., while the latter has been the focus of research in Scandinavian countries and Australia (Sauter, Schleifer and

Knutson, 1991). The occupational risk factors associated with the relatively high incidence of carpal tunnel syndrome of keyboard operators include the highly repetitive nature of the keying tasks (i.e., repetitive hand and finger motions) and extreme deviations of the wrist during typing (Arndt, 1983; Kroemer, 1989; and Lyon, 1992). Shoulder and neck discomfort also appears to be associated with the static postures and muscular loading of the shoulder muscles during keying tasks (Arndt, 1983; Bendix and Jessen, 1986; Grandjean, 1984; Hagberg and Sundelin, 1986; and Weber, Sancin and Grandjean, 1984).

Common design recommendations for reducing musculoskeletal problems of VDT operators include adding wrist supports and height-adjustable keyboard surfaces to VDT workstations. Wrist supports are advertised as a way to reduce the muscular load on the shoulders and facilitate neutral wrist posture during typing activities. VDT workstations having adjustable keyboard surfaces allow employees to set the keyboard to a preferred height. Standards recommend adjustable keyboard surface height ranges so that the 5th percentile female as well as the 95th percentile male are able to maintain an elbow angle greater than 70 degrees while sitting erect during typing activities (ANSI/HFS Standard 100-1988).

How effective are wrist supports and height-adjustable keyboard surfaces for reducing the musculoskeletal problems of VDT operators? Presently, data supporting such VDT workstation design recommendations are inconclusive. More human factors research is needed to investigate how workstation factors affect the physical demands of keyboard work.

## 1.2 Experimental Approach and Objectives

Previous studies have not considered the effects of wrist supports and keyboards heights on wrist posture and muscular load on the shoulders under the same experimental conditions. Additionally, the effect of keying time on wrist posture and shoulder muscle activity remains unclear.

The primary purpose of this study was to investigate the effects of keyboard height, the presence or absence of a wrist support and keying time on wrist posture and muscular activity of the shoulder muscles. A survey of localized muscle discomfort was also developed and used to estimate the effect of keying on localized muscle discomfort. Awkward wrist postures, high shoulder muscle activity and muscular discomfort are risk factors for wrist and shoulder injuries. The results of this study can be used to help determine how keyboard height, the presence and absence of a wrist support, and keying time influence these risk factors.

The objectives of the study were the following:

*Objective 1:* To determine how keyboard height, the presence or absence of a wrist support and keying time affect wrist posture and shoulder muscle activity during a prolonged keying task.

*Objective 2:* To determine how different keying conditions affect subjects' subjective ratings of localized musculoskeletal discomfort.

# 2. BACKGROUND

## 2.1 Overview

A brief description of the anatomical reference system is given, followed by a description of the musculoskeletal system of the upper extremity. General principles of EMG used to measure muscle activity and fatigue are reviewed. Subjective rating scales for measuring localize musculoskeletal discomfort are introduced. Previous studies applicable to neck/shoulder and wrist disorders of VDT operators are then summarized.

## 2.2 Anatomical Reference System

The anatomical reference system was developed to provide a standard system for characterizing body position. For a person in the standard anatomical position (standing erect, with the head, the toes, and palms of the hands facing forward, and with the fingers extended), three reference planes (mid-sagittal, transverse, and lateral) are used to describe the relative position of body parts (Kroemer, Kroemer and Kroemer-Elbert, 1986) (see Figure 2.1).

## 2.3 Musculoskeletal System of the Upper Extremity

A brief description of the bones, articulations, movements, and muscles of the shoulder, arm and wrist is given below.

### 2.3.1 Shoulder

The shoulder region of the human body consists of three bones, three articulations and seventeen muscles. These muscular and bony structures allow the shoulder girdle and humerus twelve directions of shoulder movement.

#### 2.3.1.1 Bones and Articulations

The three bones in the shoulder region which participate in the movement of the upper extremity are the clavical (collar bone), scapula

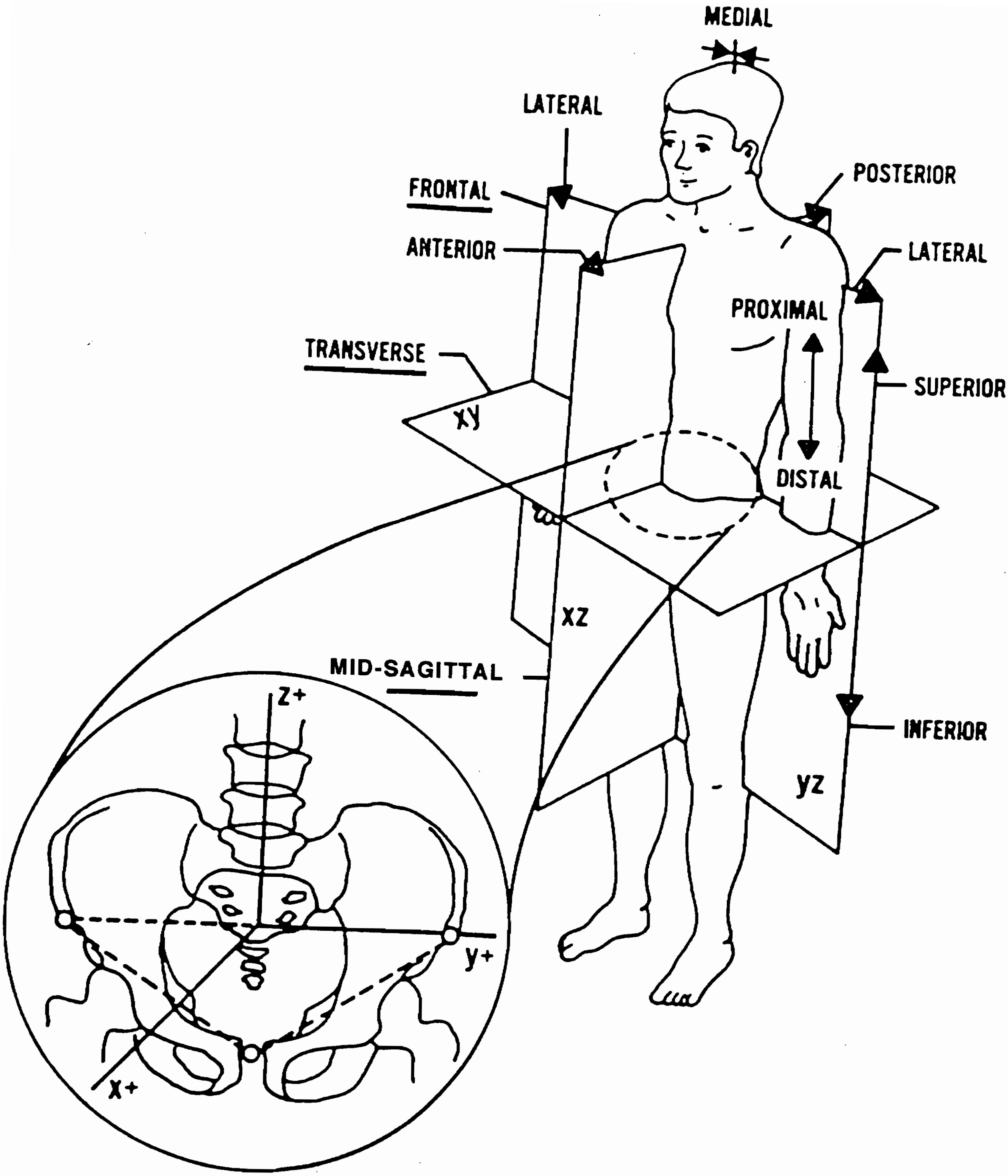



**Figure 2.1.** The anatomical reference system. Taken from Kroemer, Kroemer and Kroemer-Elbert (1986).

(shoulder blade) and the humerus (bone of the upper arm). The joints that allow bone movement in the shoulder region are the sternoclavicular joint, the acromioclavicular joint and the glenohumeral joint. The anterior end of the clavical articulates with the sternum at the sternoclavicular joint. The sternoclavicular joint is the only joint that connects the upper extremity to the thorax (Brunnstrom, Lehmkuhl and Smith, 1983). The sternoclavicular joint is a saddle joint (both articulating bones have concave and convex surfaces) that contains an articular disc and allows the clavical three degrees of freedom. The distal end of the clavical articulates with the acromion process of the scapula at the acromioclavicular joint to form the shoulder's frame. The scapula is secured posteriorly to the skeleton only by muscle allowing the scapula to move over the upper back (Brunnstrom et al., 1983). The scapula articulates with the humerus at a ball-and-socket joint, the glenohumeral joint. Figure 2.2 shows the major bones and articulations of the shoulder region.

2.3.1.2 Shoulder Movements

The articulations and muscular attachments in the shoulder allow six directions of movement at the scapulothoracic and sternoclavicular joints, and six directions of movement at the glenohumeral joint. The six shoulder movements that occur at the scapulothoracic and sternoclavicular joints are retraction, protraction, elevation, depression, upward rotation and downward rotation. As the shoulder is retracted, the scapula moves toward the mid-line of the back, and the clavical and scapula move posteriorly. As the shoulder is protracted, the scapular moves away from the mid-line of the back, and the clavical and scapular move anteriorly. During shoulder elevation, the distal end of the clavical and the acromion process move superiorly. When the shoulder is

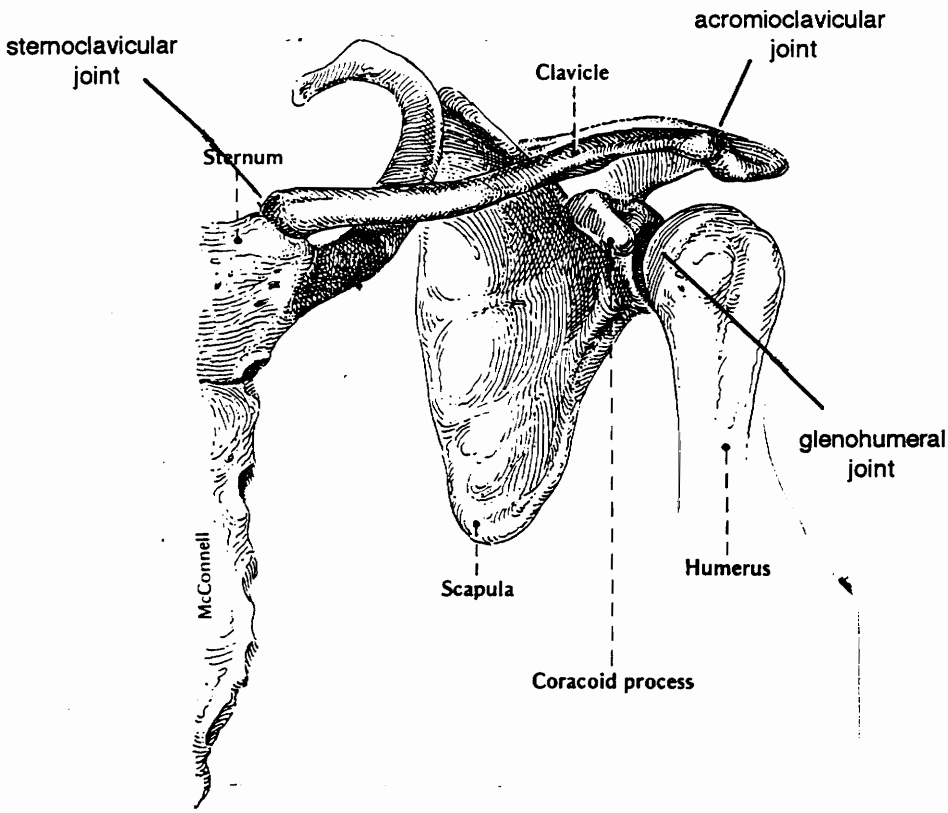



**Figure 2.2.** Major bones and articulations of the shoulder region. Taken from Landau (1976).

depressed, the clavicle and acromion process move inferiorly. As the shoulder is rotated in an upward direction, the inferior medial borders of the scapula are rotated laterally and the glenoid fossa face superiorly. During downward rotation, the glenohumeral joint faces inferiorly. Figure 2.3 illustrates the shoulder movements of retraction, protraction, elevation, depression and upward rotation.

The six directions of movement at the glenohumeral joint include: shoulder abduction, adduction, extension, flexion, medial rotation, and lateral rotation. During shoulder abduction, the humerus is raised in the frontal plane away from the medial plane. As the shoulder is adducted, the humerus is lowered in the frontal plane toward the medial plane. When the shoulder is flexed, the humerus is raised in the sagittal plane away from the frontal plane. During shoulder extension, the humerus is lowered in the sagittal plane toward the frontal plane. When the shoulder is rotated medially, the humerus is rotated about it's longitudal axis in a counterclockwise direction. As the shoulder is rotated laterally, the humerus is rotated about its longitudal axis in a clockwise direction. Humerus movements of shoulder flexion, abduction, adduction, extension, flexion, medial rotation and lateral rotation are shown in Figure 2.4.

2.3.1.3 Muscles

The muscles in the shoulder region can be divided into two general categories: muscles which support the shoulder girdle and muscles which act on the humerus.

The shoulder muscles which attach the shoulder girdle to the head, neck, and trunk include: serratus anterior, trapezius, rhomboideus major, rhomboideus minor, pectoralis minor and levator scapulae. Contractions of

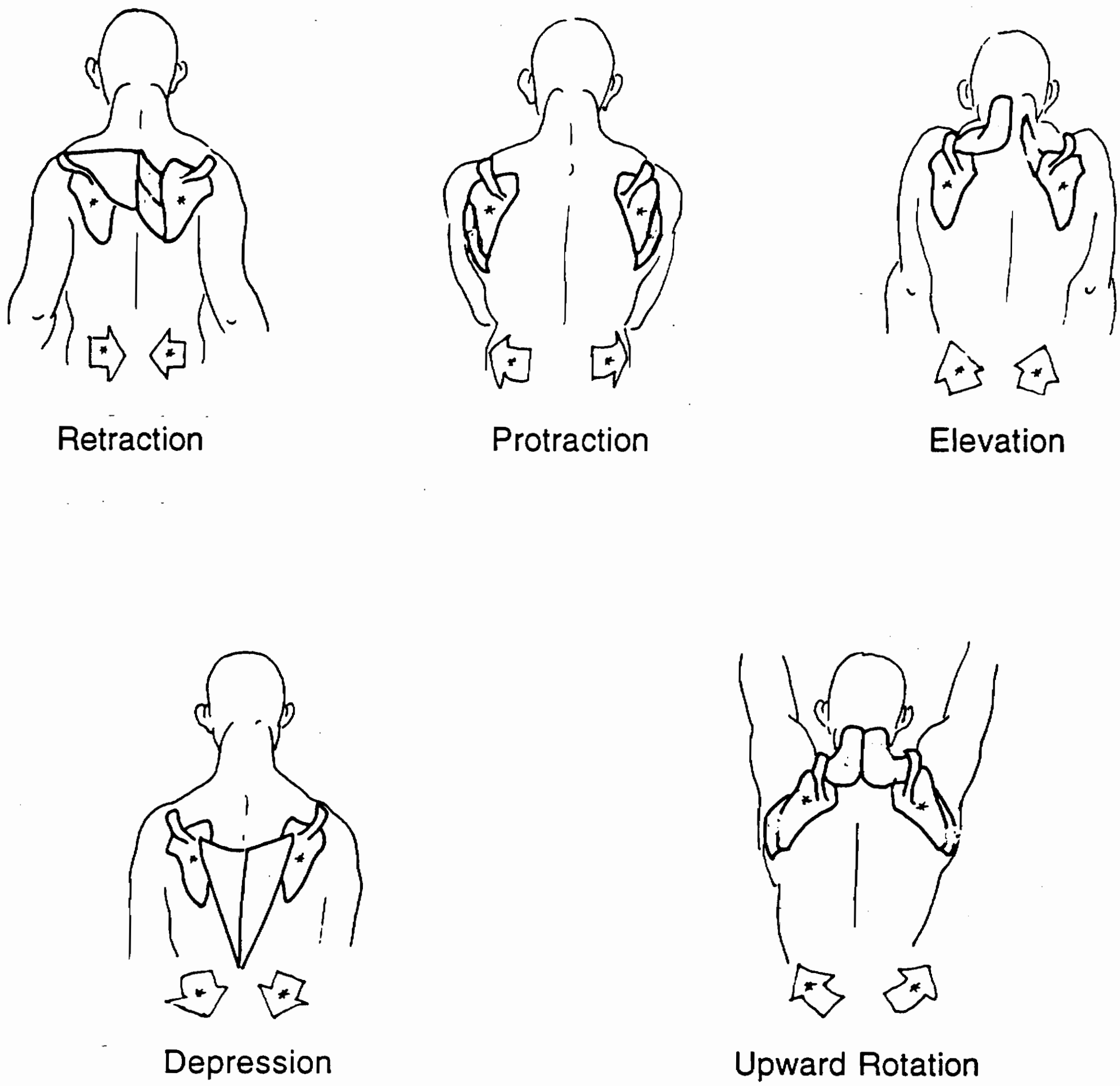



**Figure 2.3.** Movements of the shoulder girdle. Modified from Kapit and Elson (1977).

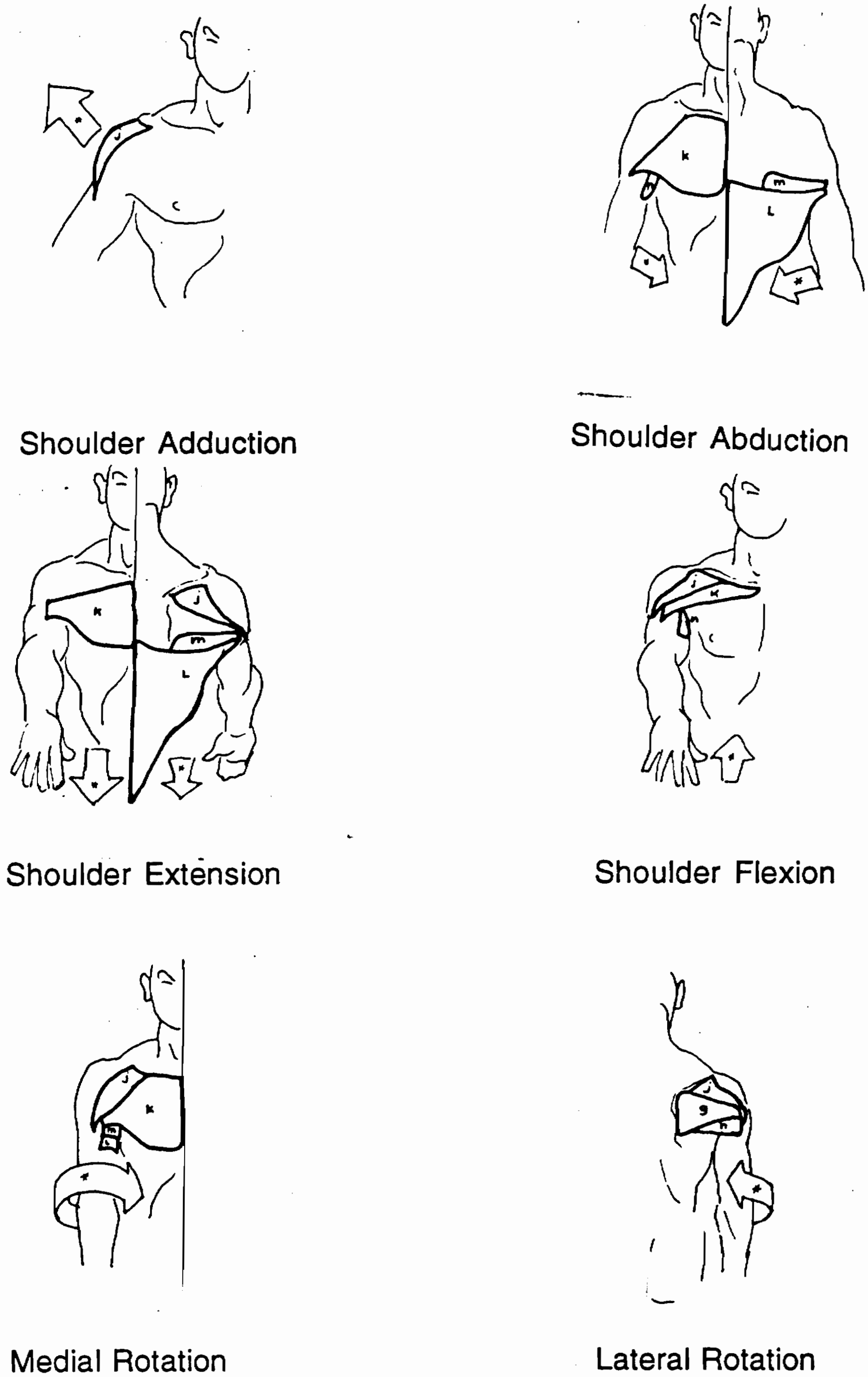



**Figure 2.4.** Movements of the humerus. Modified from Kapit and Elson (1977).

these muscles cause the motions at the scapulothoracic joint and sternoclavicular joint. The trapezius, rhomboids, levator scapulae, serratus anterior and pectoralis minor are illustrated in Figure 2.5.

The trapezius is a superficial muscle. The trapezius attaches proximally to the spinous processes of the seventh cervical vertebrae (C7), each of the twelve thoracic vertebrae, the ligamentum nuchae, and the occipital bone, and attaches distally to the distal end of the clavical, the acromion, and the spine of the scapula. The fibers of the upper portion (descending portion) of the trapezius are oriented in an upward diagonal direction and their contraction causes shoulder elevation and upward rotation.

The principal movers of the humerus include: the deltoid, supraspinatus, infraspinatus minor, teres minor, subscapularis, teres major, coracobrachialis, biceps, triceps, latissimus dorsi and pectoralis major. The biceps and triceps are not attached to the humerus but are attached to the scapula, and cross the shoulder joint (therefore acting on both the shoulder and the elbow). The latissimus dorsi and pectoralis major are the two muscles in the shoulder region which connect the trunk and the humerus but are not attached to the scapula. The locations of the principal muscles that move the humerus are shown in Figure 2.6.

### 2.3.2 Arm, Wrist and Hand

#### 2.3.2.1 Bones and Articulations

The humerus is the bone of the upper arm, while the ulna and radius make up the bony structure of the forearm. When the forearm is supinated the ulna lies medial to the radius. The humerus articulates posteriorly with the ulna and radius at the ulnohumeral and radiohumeral joints. The radius and ulna

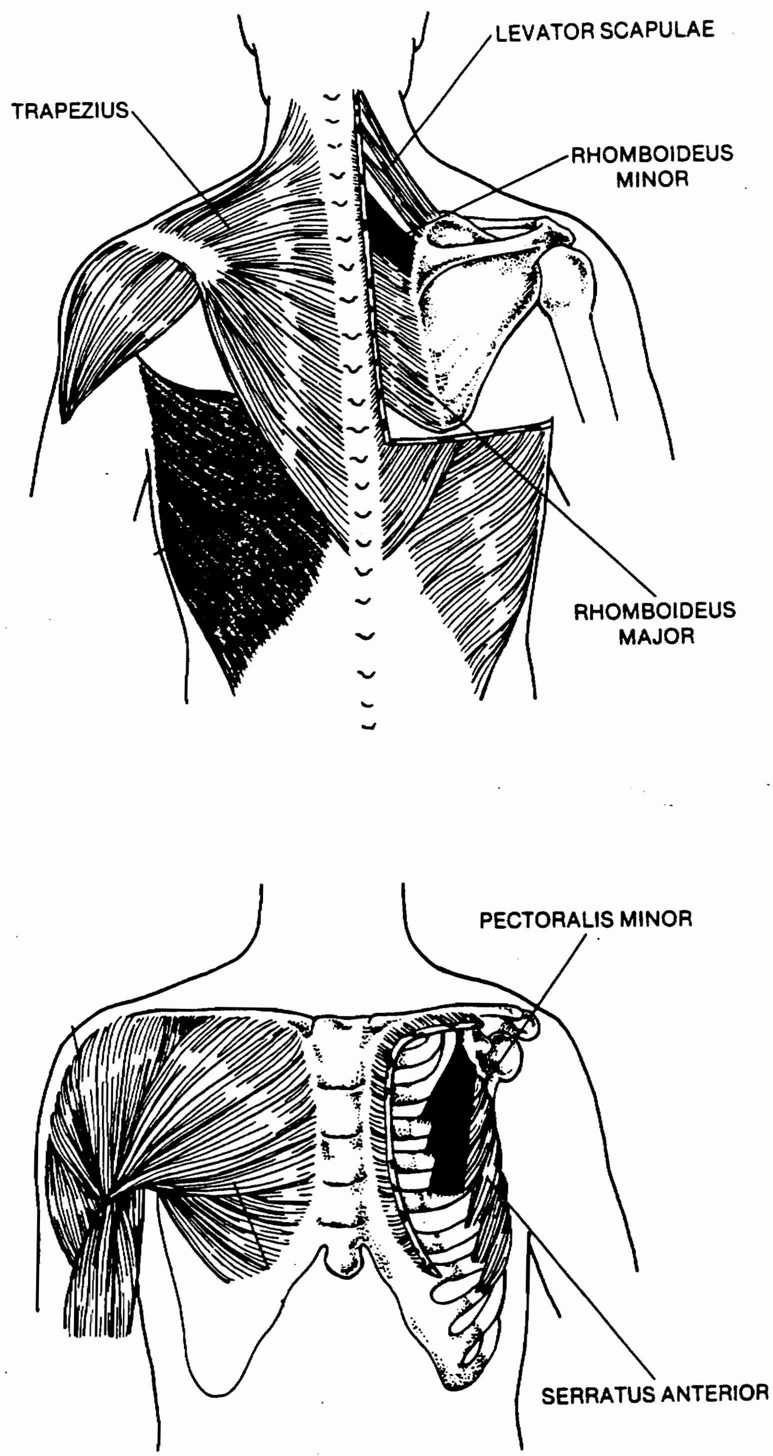



**Figure 2.5.** Supporters of the shoulder girdle. Taken from Langley and Christensen (1978).

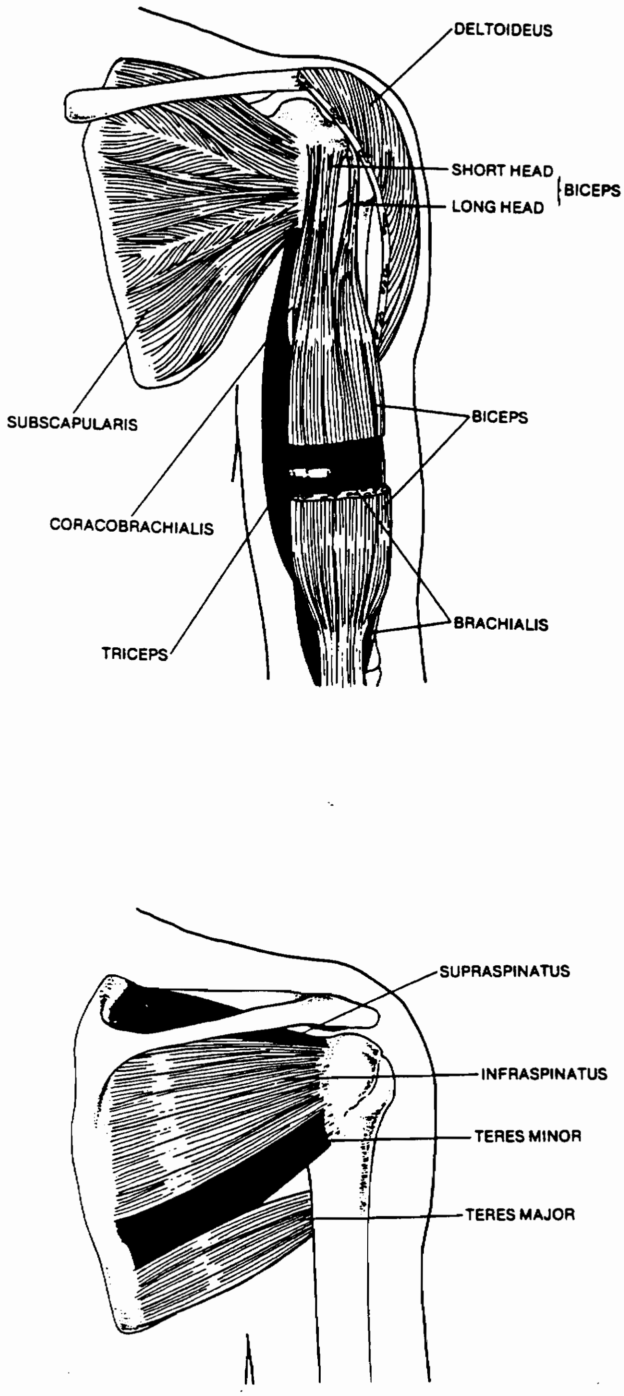



**Figure 2.6.** Movers of the humerus. Taken from Langley and Christensen (1978).

have proximal articulations. The ulnohumeral and proximal radioulnar joints are found at the elbow. The distal radioulnar joint lies proximal to the carpal bones.

The bony structure of the wrist consists of eight bones aligned in two rows. The proximal row of carpal bones consists of the scaphoid, lunate, pisiform, and triangular; and the distal row contains the trapezium, trapezoid, capitate, and hammate. The intercarpal joints lie between the carpal bones. The scaphoid and lunate are connected to the radius at the radiocarpal joint; a joint which allows two degrees of freedom. The midcarpal joint, actually a complex row of articulations, is located between the two rows of the carpal bones.

The hand has five metacarpal bones and fourteen phalanges. Each metacarpal bone articulates proximally with at least one of the distal carpal bones, and with the adjacent metacarpals. The carpometacarpal of the thumb (digit 1 of the hand) articulates with the trapezium in a saddle joint, and the carpometacarpals of the remaining digits (digits 2 through 5 of the hand) articulate with the trapezoid, capitate and hammate bones. The metacarpals articulate with the proximal phalanges at the metacarpalphalangeal joints (knuckles). The thumb has only two phalanges (proximal and distal), and the remaining digits have an additional middle phalange. The articulations of the phalanges (interphalangial joints) are hinge joints. The thumb has one interphalangial joint while each of the remaining digits have proximal and distal interphalangial joints. The bones of the arm, wrist, and hand are shown in Figure 2.7.

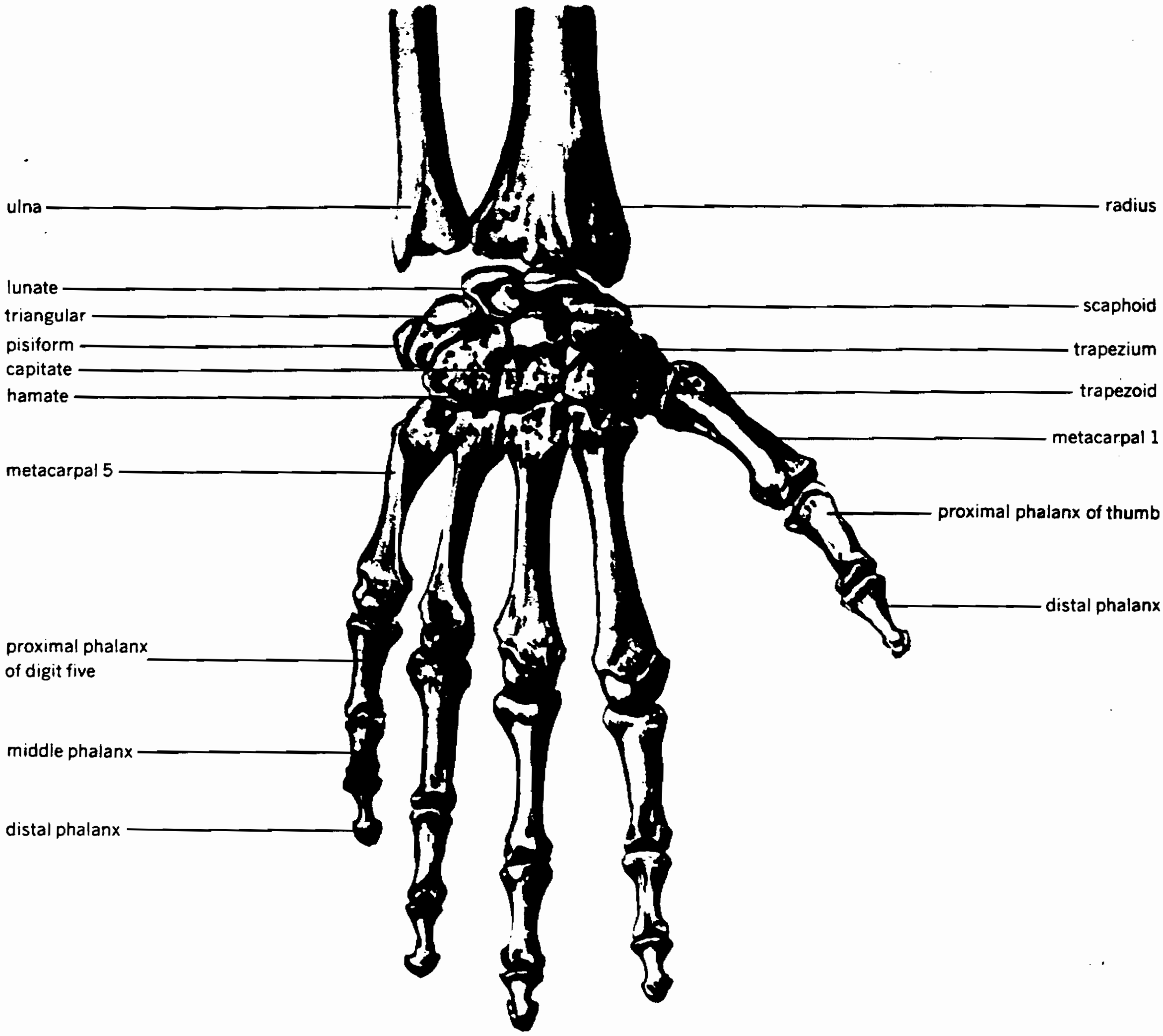



**Figure 2.7.** Bones of the arm, wrist and hand. Taken from McClintic (1975).

2.3.2.2 Movements at the Elbow

The radius and ulna form a hinge joint with the humerus that allows the forearm to be flexed or extended. The angle between the humerus and forearm decreases during elbow flexion and increases during elbow extension.

The proximal and distal radioulnar joints allow forearm supination and pronation. During full supination the radius and ulnar are nearly parallel, and during pronation the radius crosses over the ulnar.

2.3.2.3 Movements at the Wrist

The wrist is in the neutral position when the third metacarpal joint, center of wrist rotation and lateral epicondyle of the humerus are aligned. The motions of the wrist are extension/flexion and radial/ulnar deviation. When the wrist is flexed, the hand is pulled toward the anterior part of the forearm, and when the wrist is extended, the hand is pulled toward the posterior portion of the forearm. During radial deviation, the hand is pulled toward the radius and during ulnar deviation the hand is pulled toward the ulna. The wrist can deviate in the ulnar direction approximately twice as much as it can deviate in the radial direction (Brunnstrom et al., 1989). Wrist rotation occurs when wrist extension/flexion and radial/ulna deviation are combined.

2.3.2.4 Muscles

The muscles of the arm can be divided into two groups: those which act on the forearm, and those which act on the bones of the wrist and hand.

There are eight major muscles which act on the forearm. The biceps brachii is the primary forearm supinator and elbow flexor. The brachialis and brachioradialus muscles contribute to elbow flexion. The pronator teres, primarily assists in forearm pronation, but is also an elbow flexor. The triceps brachii is the primary elbow extensor and the anconeous assists in elbow extension. The supinator is a forearm supinator, while the pronator quadratus is the principal forearm pronator.

The major muscles which act on the wrist can be divided into flexors and extensors. The wrist flexors include the flexor carpi radialis, flexor carpi ulnaris, palmaris longus, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicus longus and abductor pollicus longus. The wrist extensors include the extensor carpi radialis longus and brevis, extensor digitorum, extensor indicis proprius, extensor digiti minimi proprius, and extensor pollicis brevis and longus.

Because most of the flexors and extensors are located toward the radial or ulnar side of the forearm, many participate in radial and ulnar deviation, in addition to wrist flexion and extension. Simultaneous contractions of the carpi ulnaris and flexor carpi ulnaris cause ulnar deviation. Radial deviation results when the extensor carpi radialis longus, flexor carpi radialis, abductor pollicis longus and extensor pollicis brevis contract simultaneously. Figures 2.8 and 2.9 illustrate various movements and muscles of the arm.

2.3.2.5 The Intrinsic Hand Muscles

There are nineteen intrinsic hand muscles which include: four lumbrical muscles, eight interosseous muscles, four thenar muscles, three hypothenar muscles, and palmaris brevis. These muscles act on the digits and play a major role in the grasping functions of the hand (Brunnstrom et al., 1989).

2.3.2.6 The Carpal Tunnel

Eight digital flexor tendons, the tendon of flexor pollicis longus, and the median nerve pass through a narrow groove on the anterior side of the wrist

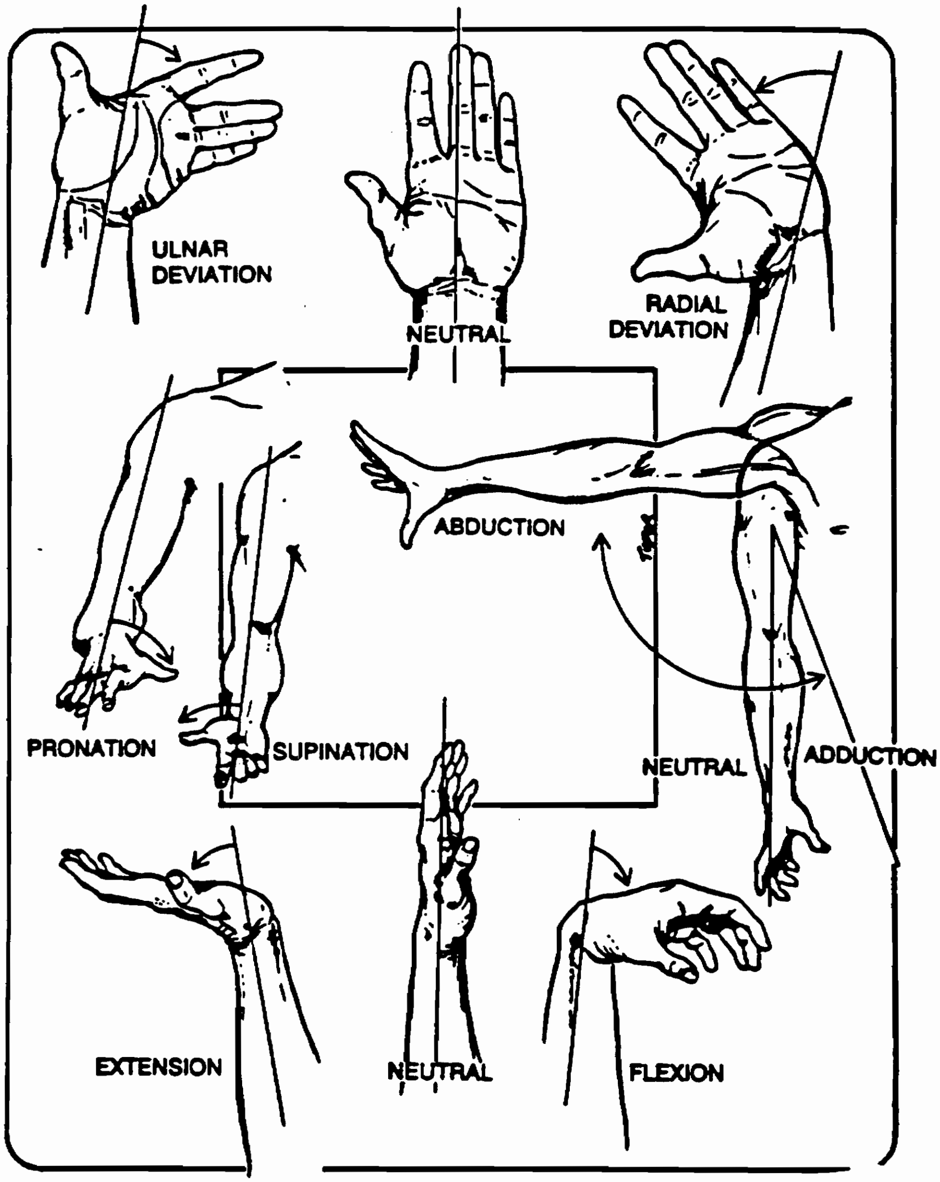



**Figure 2.8.** Some motions of the shoulder, forearm and wrist. Taken from Putz-Andersen (1988).

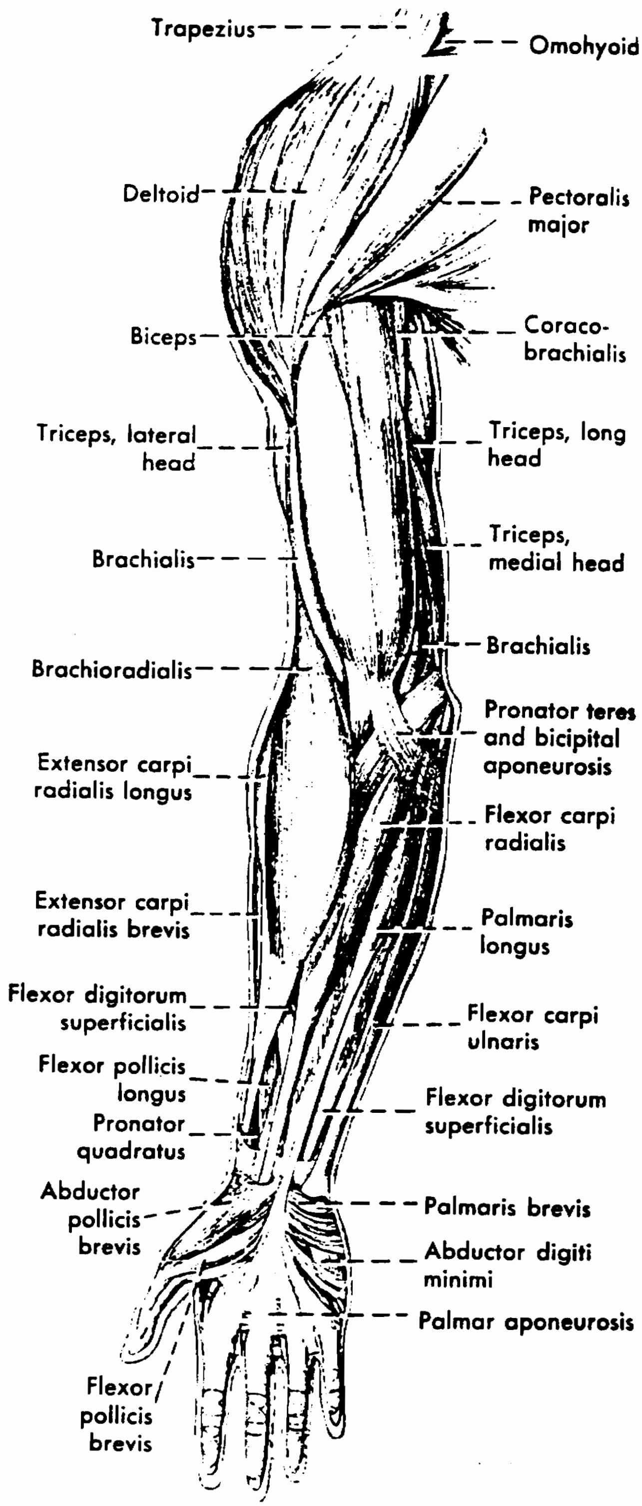



**Figure 2.9.** Muscles of the arm, wrist and hand. Taken from Gardner and Osburn (1973).

known as the carpal tunnel. This tunnel is formed by the carpal bones and the flexor reticulum (a ligament attached to the ulnar sides pisiform and hammate, and to the radial sides of the scaphoid and trapezium). All eight digital flexor tendons are surrounded by a common synovial sheath, while the tendon of flexor pollicis longus has its own synovial sheath. During movement of the fingers or hand, the tendons slide through these sheaths. The flexor carpi radialis tendon passes through another tunnel in the groove of the trapezoid. The median nerve, which branches to the first four digits, is located between the digital flexor tendons and the flexor carpi radialis tendon in the carpal tunnel (Leeson and Leeson, 1989) (see Figure 2.10).

## 2.4 Surface EMG to Estimate Isometric Muscular Activity and Fatigue

Surface electromyography (EMG) is an important tool for estimating muscle activity from voltage differences on the skin when the muscle beneath the skin is activated. Muscle architecture, the motor unit, muscle action potential and surface EMG methods are reviewed in this section.

### 2.4.1 Muscle Architecture

EMG is used to measure the electrical activity of a muscle during muscle contraction. Skeletal muscle consists of groups of muscle fibers (fasiculi) surrounded by connective tissue called fascia. The fascia serve to connect the muscle fibers to the tendon, group the muscle into working units, and allow individual fibers to move independently (Lamb and Hobart, 1992). There are three types of muscle fascia which are interconnected: the epimysium surrounding the muscle, the perimysium surrounding each muscle fasiculum, and the endomysium surrounding each muscle fiber. Within the endomysium

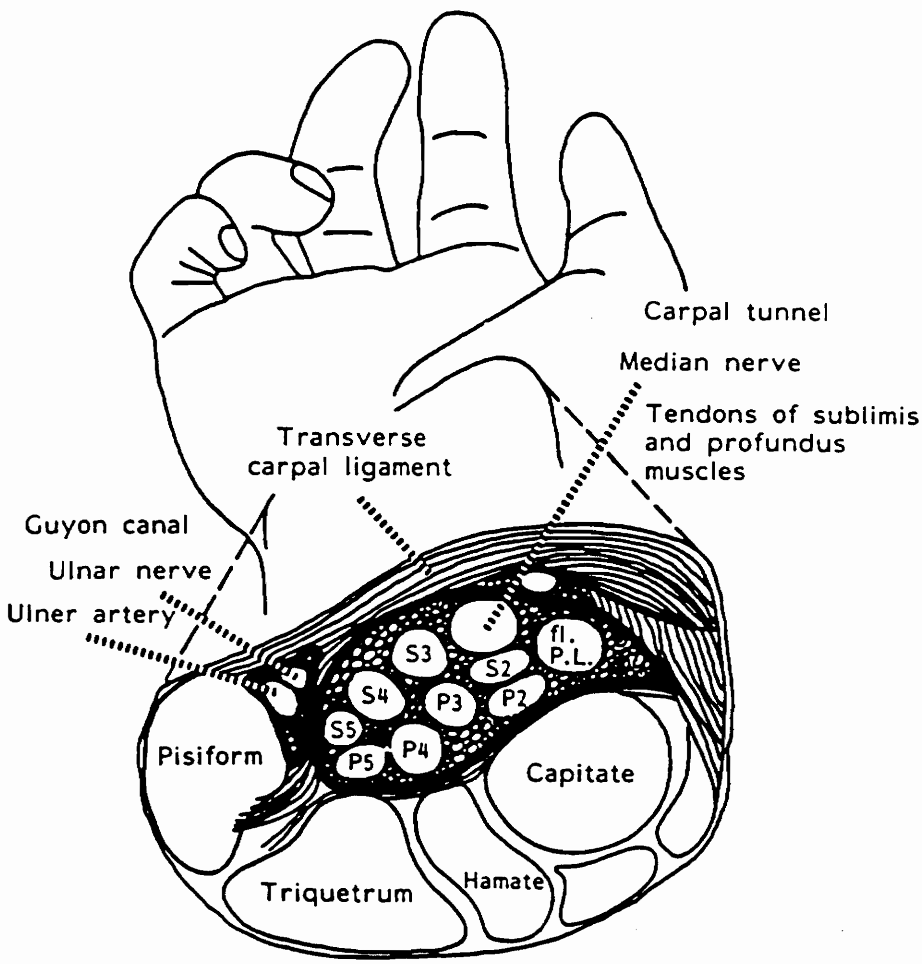



**Figure 2.10.** The carpal tunnel. Taken from Kroemer (1989).

lies a plasma membrane called the sarcolemma which contains cylinder-shaped myofibrils and transverse processes that connect adjacent myofibrils and muscle fibers. The sarcolemma contains two layers of lipid that allow ions to move into or out of a cell. Each myofibril is surrounded by a sarcoplasmic reticulum, is approximately 1 micron in diameter, and has the same length as the muscle fiber (Lamb and Hobart, 1992). A myofibril is made up of connected sacomeres which have thick (myosin) and thin (actin) myofilaments. These myofilaments are protein molecules which over-lap and are parallel to one another. Projections from the myosin filaments (crossbridges) are oriented towards the actin filaments. Muscle contraction occurs when the actin rods move towards each other and the over-lap between the actin filaments and myosin filaments increases (Kroemer, Kroemer and Kroemer-Ebert, 1986).

### 2.4.2 The Motor Unit

Groups of muscle fibers share the same nerve fiber. A nerve cell body, an axon, and group of muscle fibers supplied by an axon are called a motor unit. A signal from the cell body will cause all the supplied muscle fibers to contract. Muscles used for fine movements have a small number of fibers per motor unit, while muscles used for crude movements have a large number of fibers per motor unit (Lamb and Hobart, 1992).

### 2.4.3 Muscle Action Potential

Chemical differences between the intracellular and extracellular fluids of the muscle cell result in a muscle action potential. The intracellular fluid is highly concentrated in potassium ($K^+$) ions and organic ($A^-$) ions, while the extracellular fluid is highly concentrated in sodium ($Na^+$) and chloride ($Cl^-$) ions. The $K^+$ and $Cl^-$ ions are small enough to pass through channels in the cellular membrane, the $Na^+$ ions have difficulty passing through, and the $A^-$ ions do not pass through and remain in the intracellular fluid.

Concentration gradients force the $K^+$ ions to diffuse through the channels into the extracellular fluid and the $Cl^-$ ions to diffuse into the intracellular fluid. The result is a polarization of the membrane: a positive charge on the outside of the membrane and a negative charge on the inside of the membrane. The difference in potential between the inside and outside of the cell is approximately -80 mV (Lamb and Hobart, 1992). The extracellular $K^+$ and $Na^+$ ions repel each other, and the $Na^+$ are forced through the channels into the intracellular fluid. The sodium-potassium pump helps maintain the difference in potential at the membrane by transporting intracellular $Na^+$ ions back to the extracellular fluid, and extracellular $K^+$ ions back to the intracellular fluid (Lamb and Hobart, 1992).

When a muscle fiber is stimulated by a nerve cell, the cellular membrane becomes more permeable to $Na^+$ ions, and the $Na^+$ ions pour into the intracellular fluid. This causes a rapid depolarization and reversal of polarization of the cell membrane. A rapid increase of the $K^+$ ions into the extracellular fluid and an eventual decrease of the $Na^+$ influx into the intracellular fluid results in a repolarization of the cell. The depolarization, reversal of polarization, and repolarization of the muscle's action potential propagate away from the source of the signal in both directions along the muscle fiber and sarcoplasmic reticulum (Lamb and Hobart, 1992). The change in action potential causes the sarcoplasmic reticulum to release calcium into the sarcoplasmic matrix, which eventually causes muscle contraction.

2.4.4 Surface EMG Methods and Instrumentation

Two electrodes are commonly placed over the skin of a muscle in line with the muscle fibers and a third electrode (a ground) is placed over an area that has little muscular activity (a bipolar electrode arrangement). The first two electrodes detect potential differences of the muscle of interest while the third acts as a reference electrode to filter out unwanted signals (noise). During muscle contraction, the signal at each of the first two electrodes is different due to the depolarization, polarization reversal, and repolarizations which propagate along the muscle fibers. The noise caused by other sources is reduced because the signal from the reference electrode is subtracted from the signals of the electrodes on the muscle of interest (Basamajian and De Luca, 1985).

In addition to unwanted noise caused by the external environment, there are a number of other factors which affect the EMG signal. Different electrical properties of muscle tissue, fatty tissue and skin may alter the EMG signal. The distance between the two electrodes on the muscle of interest and the resistance of the skin-electrode interface also affect the signal. The electrodes may also detect signals from muscles other than the muscle of interest (cross-talk). These factors create large variability in EMG signals between different subjects and different experimental sessions. Therefore, calibration of the EMG signals is critical and must be performed for each subject during each experimental session.

Electrode gel, applied between the skin and electrodes to decrease the skin's electrical resistance, becomes more effective as it seeps into the skin. Therefore, at least 15 to 20 minutes should be allowed between the time in which the gel is applied and the time in which EMG measurements are taken (Rockwell, 1992).

The raw EMG signal is amplified with a preamplifier and main amplifier. The signal is usually transformed (normalized) into a root-mean-square (RMS) signal. The RMS signal is the moving average of the signal over time (Leveau and Andersson, 1992). The maximum voluntary contraction (MVC) of a muscle (the muscle activity recorded during the greatest muscular effort for that muscle) can be measured, and a common approach is to report the muscle's activity as a percent of MVC (%MVC) (LeVeau and Annersson, 1992). Intra-subject RMS signals seem to be linearly related to force, but large inter-subject variations exist between RMS signals and force generation (LeVeau and Andersson, 1992).

Some researchers have reported that increased RMS signals during sustained isometric contractions of a constant load may indicate localized muscle fatigue (Marras, 1992; LeVeau and Andersson, 1992; Wiker, 1986). It is thought that the increase in EMG activity results from an increased recruitment of motor units needed to maintain the muscular contraction as the muscle fibers fatigue.

The raw EMG signal consists of different action potentials which change (fire) at different frequencies. The power of an EMG signal can therefore be broken down by individual frequencies. The spectrum of signal powers over a range of frequencies is called a frequency power spectrum. It is believed that as the muscle fatigues, the powers of the higher frequencies decrease while those of the lower frequencies increase. Thus, the power spectrum shifts from higher to lower frequencies (see Figure 2.11). The changes in EMG frequency

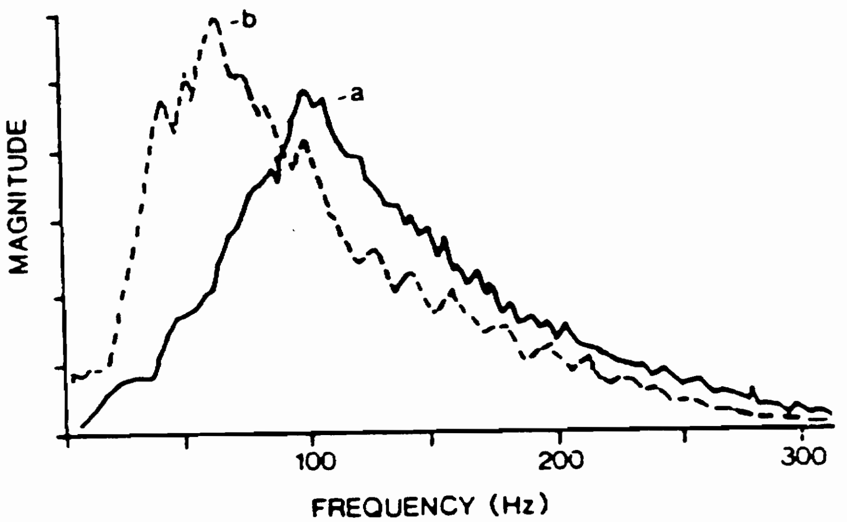



**Figure 2.11.** Shifts of the EMG frequency spectrum due to localized muscle fatigue during sustained isometric contractions. Taken from Redfern (1992).

caused by localized muscle fatigue are thought to be a result of either an increase or decrease in the recruitment of motor units, or a synchronization of active motor units (Wiker, 1986). For statistical purposes, the sampling period for the power spectrum analysis should be at least 3.4 seconds (Wiker, 1986).

The most common measures used to determine whether a shift in the power spectrum has occurred are the median power frequency (in which the power of the signal distributed equally above and below the frequency) and the mean power frequency (Redfern, 1992). Figure 2.12 illustrates how the median frequency of the power spectrum decreases over time with different levels of muscle exertion. The use of spectral analysis has shown that median power frequencies may decrease as much as 80% over sustained static exertions of high loads and short periods. The use of spectral analysis to determine fatigue caused by small sustained static exertions over long periods is not well established (Redfern, 1992). Wiker (1986) explained that many researchers have found inconsistent relationships between EMG signals and localized fatigue of the shoulder muscles. Nevertheless, the decrease in MPF is a common measure for the assessment of localized muscle fatigue.

2.4.5 Surface EMG of the Trapezius

Because the trapezius is superficial, it's activity can be estimated with surface electromyography. Electrodes are commonly placed on the descending portion of the trapezius centered between the C7 vertebra and acromion process when evaluating the muscular load on the neck and shoulders during keying tasks (Bendix and Jessen, 1986; Erdelyi, Sihvonen, Helen and Henninen, 1988; Hagberg and Sundelin, 1986; and Weber et al., 1984). The EMG activity of the trapezius may range between 2 and 8 %MVC (Weber et al.,

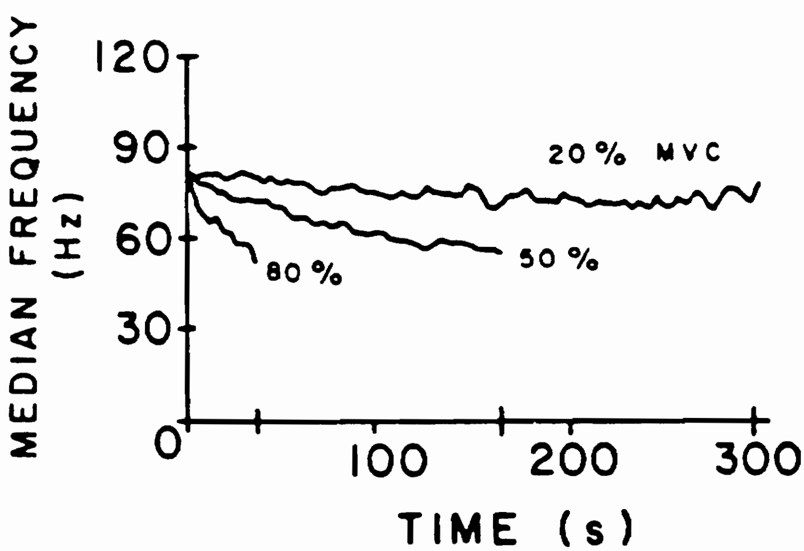



**Figure 2.12.** Change in MPF during sustained isometric contractions. Taken from Redfern (1992).

1984; Hagberg and Sundelin, 1986; Bendix and Jessen, 1986; and Woersted, Bjorklund and Westgaard, 1991).

## 2.5 Rating Scales to Estimate Musculoskeletal Discomfort during VDT Operation

Studies have shown that musculoskeletal discomfort is associated with the operation of VDTs (Ong, 1984; and Knave, Wibom, Hedstrom and Bergquivst, 1985). Researchers have used worker ratings to estimate the magnitude of localized musculoskeletal discomfort experienced during VDT operation. One commonly used rating scale, developed by Corlett and Bishop (1976), is a 7 point scale ranging from extremely comfortable (1) to extremely uncomfortable (7). Ratings of discomfort are given for different body areas to estimate localized musculoskeletal discomfort. Several VDT studies using comfort rating scales to evaluate factors thought to influence musculoskeletal discomfort during VDT operation are described below.

Gallimore and Brown (1993) used the rating scale developed by Corlett and Bishop (1976) to investigate differences in musculoskeletal discomfort associated with reading and search tasks under three different VDT workstation conditions (use of the C-Sharp device to reduce eye strain, use of a glare shield, and no device to reduce eye fatigue). Differences between post-session and pre-session comfort rating scores for various body areas (e.g., head, neck, shoulder, back and wrist) were compared between each tested condition to determine which condition was associated with the greatest change in musculoskeletal discomfort. Gallimore and Brown reported differences in the change in musculoskeletal comfort between different workstation conditions.

Sauter, Schleifer and Knutson (1991) performed a study of 539 VDT operators to examine the association between postural and workstation characteristics and self-reports of musculoskeletal discomfort. The postural and workstation characteristics were collected by observing forty of the VDT operators. Self-reports of musculoskeletal discomfort were obtained from the entire cohort using the 7 point rating scale developed by Corlett and Bishop (1976). The site and frequency of musculoskeletal discomfort were also recorded onto a body pictograph. Using these methods, Sauter, Schleifer and Knutson (1991) were able to identify workstation and postural characteristics associated with the musculoskeletal discomfort of specific body regions.

Shute and Starr (1984) performed two studies of telephone operators who used VDTs throughout their entire working day to examine how table top design and chair design affected musculoskeletal discomfort. Over a period of weeks, telephone operators performed their job tasks with non-adjustable and adjustable table tops and chairs. Subjective rating scales were used to assess the effects of the furniture on musculoskeletal discomfort. Using these methods, Shute and Starr (1984) concluded that adjustable table tops and chairs reduced musculoskeletal discomfort during VDT operation, and that adjustable table tops and chairs were particularly effective when used simultaneously.

Lu and Aghazadeh (1993) performed a study of six college students to examine the relationship between VDT vertical position relative to seated eye height and musculoskeletal discomfort during a 35 minute keying task. Students performed keying tasks under three conditions: center of VDT screen at eye height, 25 cm above eye height, and 25 cm below eye height. After each keying task, subjective ratings of musculoskeletal discomfort for various body regions were recorded on a 5 point rating scale ranging from no discomfort (1) to extremely severe discomfort (5). Lu and Aghazadeh concluded that placing the center of the VDT screen at seated eye height reduced the musculoskeletal discomfort caused by the keying tasks.

## 2.6 Neck and Shoulder Problems Experienced by VDT Operators

Symptoms associated with musculoskeletal disorders of the neck and shoulders include: localized muscle fatigue, pains, discomfort, and cramps. These symptoms are thought to be caused by prolonged static postures that place excessive loads on the shoulder musculature (Grandjean, 1984). Musculoskeletal complaints of the neck and shoulder areas are among the most frequently reported by VDT operators. Grandjean (1984) reported that approximately 15% of VDT operators complain of daily arm and shoulder pain. Such frequent reports may be a warning for cumulative trauma injuries (Karwowski, Eberts and Salvendy, 1990).

Studies have shown that the muscular load of the trapezius during keying tasks is relatively small; approximately 2-8 percent of the MVC (Bendix and Jessen, 1986; Hagberg and Sundelin, 1986; and Woersted, Bjorklund, and Westgaard, 1991). Loads placed on the neck and shoulders as low as 5% MVC have been reported to have potential physiologic effects (Sjogaard, Christensen and Pedersen, 1991). The remainder of the section summarizes research about factors associated with neck/shoulder problems of VDT operators.

*Takala, Viikari-Juntura, Moneta, Saarenmaa, and Kaivanto (1991)*

Takala, Viikari-Juntura, Moneta, Saarenmaa and Kaivanto (1991) performed a longitudal survey of 351 female bank cashiers to determine various occupational and non-occupational characteristics associated with neck and shoulder CTDs. The cashiers completed questionnaires three, six, and eight months after the original survey. Age, stress, work task characteristics and the season of the year were found to be associated with neck and shoulder symptoms. Takala et al. (1991) concluded that environmental factors seem to have a greater effect on reporting neck and shoulder symptoms than individual biological factors. These researchers did not explain how predictive the environmental factors were of the symptoms, and failed to describe the individual job tasks of the workers in the study.

*Ong (1984)*

Ong (1984) surveyed 36 female VDT operators and 41 "conventional office workers" and found that musculoskeletal complaints were more common among the VDT operators. The major causes for the complaints were prolonged static work postures, chair design and insufficient work breaks.

*Low (1984)*

Low (1990) conducted a mail-in survey of 174 Australian workers who worked at least one hour per day with a keyboard. Low (1990) found that 65% of the workers who reported having a musculoskeletal problem attributed it solely to keyboard work. The most common musculoskeletal symptoms included soreness, aches and discomfort of the upper extremities. Similar symptoms were also reported in the neck and shoulders of VDT operators. Low (1990) also found that keyboard operators who rested their arms more frequently were less likely to develop musculoskeletal symptoms.

*Knave, Wibom, Voss and Hedstrom (1985)*

In a cross-sectional survey of 400 VDT operators and 150 office employees who did not use VDTs regularly, Knave, Wibom, Voss, and

Hedstrom (1985) concluded that VDT operators reported more frequent musculoskeletal problems. Musculoskeletal discomfort of the neck, shoulder and back was more common among VDT operators. These researchers also found that women had significantly more ($p<.001$) musculoskeletal complaints of the right hand, shoulders and neck than men.

*Linton and Kanwendo (1989)*

Linton and Kanwendo (1989) investigated the relationship between various psychological variables of the work environment, and neck and shoulder pain reported by secretaries. They administered questionnaires to 420 secretaries and compared the prevalence of neck and shoulder discomfort of secretaries who the researchers thought worked in poor psychological work environments to the prevalence of neck and shoulder discomfort of secretaries who the researchers thought worked in good psychological work environments. Subjects working in poor environments were 2.85 times more likely to have frequent neck pain and 3.32 times more likely to have frequent shoulder pain than those working in good environments. Workload, job dissatisfaction, monotonous work tasks, and unpredictable job demands were cited as potential causes of stress for the secretaries. These results demonstrate a relationship between certain psychological aspects of the environment and muscular discomfort , but do not imply that psychologically poor work environments alone cause musculoskeletal discomfort.

*Sauter, Schleifer and Knutson (1991)*

In a study of 40 VDT operators who had suffered from localized musculoskeletal discomfort, Sauter, Schleifer and Knutson (1991) investigated the relationship between certain workstation characteristics and work posture.

In a multiple regression analysis they found that discomfort of the upper extremity increased with increased keyboard height above elbow level. They also found that ulnar deviation of the right hand was a significant predictor of right arm discomfort.

*Weber, Sancin and Grandjean (1984)*

Weber, Sancin and Grandjean (1984) studied the effects of using a wrist support and changing keyboard height on EMG of the trapezius, body posture and ratings of physical discomfort. Twenty trained typists performed six consecutive 10 minute typing tasks. During each of the typing tasks the keyboard was set at the subject's preferred height, 5 cm above preferred height, or 5 cm below preferred height. Each task was performed with and without a wrist support. EMG activity of the right trapezius was recorded during the keying tasks and subjects rated the severity of muscle tension in the neck and parts of their upper extremities after completing each task.

Weber, Sancin and Grandjean (1984) found that EMG activity was significantly lower ($p<.05$) when a support was used than when a support was not used. Additionally, these researchers reported a significant increase ($p<.001$) in EMG activity as the keyboard height was increased when a wrist support was not used. There were also significant differences between the mean subjective ratings of discomfort in the neck and upper extremity when a wrist support was used and when support was not used.

Shoulder abduction increased significantly ($p<.001$) with increasing keyboard height when a wrist support was used. As a result, the researchers concluded that subjects abducted their shoulders to accommodate for different keyboard heights while using a wrist support, and changed their elbow angle to adapt to different keyboard heights when no support is used.

*Bendix and Jessen (1986)*

Bendix and Jessen (1986) performed a study of twelve secretaries suffering from muscle pain in the trapezius or brachial extensor muscles. They examined the effect of wrist supports (mounted at various heights relative to the space bar of a standard typewriter) on the resultant load on the trapezius and brachial extensors during fifteen minute typing tasks. There were four experimental conditions: 1) no wrist support and the spacebar located at elbow height, 2) wrist support positioned 1 cm lower than the space bar and the spacebar located at elbow height, 3) wrist support positioned 0.5 cm above the space bar and the space bar located at elbow height, and 4) wrist support positioned 0.5 cm above the space bar and the space bar located 3 cm above elbow height. A ten minute rest period was allowed between trials. EMG data were taken from the descending portion of the trapezius and from the radial extensor muscles.

Contrary to the results of Weber, Sancin and Grandjean (1984), Bendix and Jessen (1986) reported that the load on the trapezius was greater when subjects typed with a support than when they typed without a support. The researchers also found that the load on the trapezius increased as the height of the wrist support increased, and was highest when the typewriter's spacebar was 3 cm above elbow height. The mean static loads on the trapezius ranged from 2.4 %MVC (with no wrist support and space bar located at elbow height) to 6.8 %MVC (wrist support 0.5 cm above space bar which was located 3 cm above height). Eight of the twelve secretaries, however, preferred using the wrist supports while typing.

*Erdelyi, Sihvonen, Helin and Hanninen (1988)*

Erdelyi, Sihvonen, Helin and Hanninen (1988) studied the effects of elbow angle and arm supports on EMG activity of the descending portion of the trapezius during three minute typing tasks. Twelve people who suffered from shoulder pain and 8 people who did not suffer from shoulder pain took part in the study. There were 3 different elbow angles conditions: 75 degrees, 90 degrees, and 105 degrees, and 3 different arm support conditions: no support, a support which could move on the horizontal plane, and a support which hung from the ceiling by strings. They found that EMG activity was lowest when the arm was supported. They also reported that EMG activity of the trapezius was greater with those who reported shoulder pain. Typing speed and skill had no effect on EMG activity. The researchers concluded that the EMG activity of the trapezius muscle was not affected by typing activities but by the muscular effort required to hold the head, neck, shoulder, and arms in a fixed position. They recommended that elbow angles be greater than 100 degrees and arm supports be used to reduce the load on the trapezius during typing tasks.

*Hagberg and Sundelin (1986)*

Hagberg and Sundelin (1986) investigated the effects of break periods during keying tasks on the EMG activity of the trapezius and subjective ratings of musculoskeletal discomfort of six female VDT operators. Subjects were studied on three to five different days. On one of the days, subjects were required to pause for 15 seconds for every 6 minutes of keying. Hagberg and Sundelin (1986) found that the median muscular exertions of the right and left trapezius muscles were approximately 3 %MVC, while peak loads were 10 %MVC. These researchers found a significant ($p<.05$) negative correlation between the number of pauses and muscular exertion of the trapezius (muscular exertion decreased as the number of pauses increased). Discomfort ratings were also significantly lower ($p<.01$) for sessions with short pauses than for sessions without short pauses.

*Woersted and Bjorklund (1991)*

Woersted and Bjorklund (1991) investigated the effects of typing task complexity on the EMG of the trapezius of eighteen subjects. They found that EMG activity of the trapezius increased as typing tasks complexity increased for eight of the 18 subjects.

*Karwowski, Noland, Eberts and Salvendy (1990)*

Karwowski, Noland, Eberts and Salvendy (1990) investigated the effects of work/rest schedule of data input on body posture and perceived muscular discomfort of 12 VDT operators of the U.S. Postal Service. There were three levels of work/rest schedule: 50 minutes data input and 10 minutes rest, 2 hours data input and 15 minutes rest, and flexible work/rest schedule (input data until tired). Ten minutes of video during each of the experimental tasks was analyzed. They reported that work/rest schedule affected neck flexion angle and frequency of back support use. For muscular discomfort, the effect of keying time was significant ($p<.01$).

## 2.7 Musculoskeletal Disorders of the Wrist

### 2.7.1 Types of Disorders

Disorders associated with the repetitive movements of the wrist, hand and fingers include: tendonitis, tenosynovitis, ganglion, Guyon tunnel syndrome, Raynauld's syndrome, and carpal tunnel syndrome (Kroemer, 1989). Tendonitis is a disorder in which the tendon becomes inflamed and eventually damaged. Tenosynovitis occurs when the tendon sheath swells and places pressure against the tendon. Types of tenosynovitis in the hand include DeQuervain's disease and "trigger finger" (Kroemer, 1989). A ganglion is a swelling of a specific area in the tendon sheath. Guyon tunnel syndrome is a disorder in which the ulnar nerve is compressed in the Guyon tunnel. Raynauld's syndrome (or "white finger") results from insufficient circulation in the fingers and is caused by vibration and cold temperatures. Carpal tunnel syndrome (CTS) occurs when the tendons of the finger flexors swell and place pressure on the median nerve in the wrist's carpal tunnel, and is highly prevalent among VDT operators.

### 2.7.2 Carpal Tunnel Syndrome

CTS is a musculoskeletal disorder in which the synovial fluid within the tendon sheath in the carpal tunnel decreases. Tendons then become irritated as they slide through the sheath and the sheath becomes inflamed and swells. The median nerve is then pinched between the swelled tendon sheath and the flexor recticulum. Eventually, the compression begins to damage the median nerve. This reduces the function of the first four digits of the hand, causes numbing, tingling or painful sensations in the hand or fingers, and can increase the dryness of the hand's skin.

Reported non-occupational risk factors of CTS include: age, gender, pregnancy, use of oral contraceptives, acute trauma and fitness (Hahn, Chin, Ma, and Rebello, 1991; Hoyt, 1984; and Kroemer, 1989). Anthropometric dimensions of keyboard users have also been associated with CTDs (Green and Briggs, 1989).

Occupational factors associated with CTS include: repetitive wrist deviations, forceful wrist deviations, vibration, and cold temperatures (Cannon, Bernacki and Walter, 1981; Gengel, Washburn and Wick, 1991; Hoyt, 1984; Kroemer, 1989; Johnson, 1985; and Silverstein, Fine and Armstrong, 1987). Johnson (1985) and Arndt (1983) also reported that work-related mental stress was associated with the incidence of CTS.

Biomechanical evidence suggests that wrist deviation (particularly wrist extension or flexion) increases pressure in the carpal tunnel (Armstrong and Chaffin, 1979). The additional pressure placed on the tendons during wrist deviation increases the likelihood of tendon inflammation which places pressure on the median nerve. Incidence of carpal tunnel syndrome is related to pressure placed on the median nerve (Armstrong and Chaffin, 1979). Prolonged wrist deviations from the neutral position during typing increases the carpal tunnel pressure, and therefore may contribute to CTS in VDT operators.

2.7.3 Wrist Posture During VDT Operation

Several studies have investigated factors affecting wrist posture during keying tasks.

*Powers, Hedge and Martin (1992)*

Powers, Hedge and Martin (1992) investigated the effects of a full motion arm support on 12 female VDT users and keyboard slope on 16 female VDT users. There were 3 experimental conditions during which subjects were required to type for approximately 50 minutes. In the first condition, subjects used a positively sloped keyboard on a work surface located 68 cm above the floor. The second condition was identical to the first, except subjects performed the typing tasks using a full-motion-arm support. In the third condition, subjects used a negatively sloped keyboard on the work surface without the forearm supports. Wrist posture was measured using a two-camera video motion analysis technique.

Powers, Hedge and Martin (1992) found that subjects maintained less wrist extension during the typing tasks when they used the negatively sloped keyboard, but reported no significant decreases in wrist posture when the full motion arm support was used. Powers, Hedge and Martin (1992) concluded that negatively sloped keyboards might reduce the risk of CTS by decreasing wrist extension during keying tasks, but that full motion arm supports were not likely to reduce the risk of CTS.

*Price, Fayzmehr and Beaton (1989)*

Price, Fayzmehr and Beaton (1989) performed short-term observations of nine female typists and long-term field observations of eight female typists. Wrist posture and many other aspects of body position were examined. For the short-term observations, the researchers used a three-camera video motion analysis technique and took five frames of video from the front, the side and above each typist on three different days. The long-term observations were recorded on a two-camera video motion analysis system. A mechanical vibration microphone was used to record typewriter vibrations during typing activities. The long-term observations were conducted during 8 hour sessions and data were collected during approximately 100 random 90 second intervals.

In the short-term trials, Price et al. (1989) found that the typists held their wrists in an average of 19.4 degrees right wrist extension, 18.0 degrees left wrist extension, 27.3 degrees right ulnar deviation, and 23.9 degrees left ulnar deviation. Price et al. (1989) also reported that the typists' right shoulders were averaged 23.3 degrees flexion and 1.73 degrees abduction, and left shoulders averaged 23.7 degrees flexion and 1.2 degrees abduction.

In the long-term observations, Price et al. (1989) found that subjects rested their left hands and left their workstations more frequently as the 8 hour sample periods progressed. Price et al. (1989) also found that average wrist extension was 17.2 degrees and decreased an average of 9.8 degrees throughout the day, average ulnar deviation was 6.4 degrees and increased an average of 16.4 degrees throughout the day, and average shoulder abduction was 5.2 degrees and increased an average of 4.3 degrees as the day progressed. Price et al. (1989) concluded that as the day progresses, typists change their body posture to relieve the prolonged static loads on the upper extremity during typing.

*Jedrziewski (1992)*

Jedrziewski (1992) performed a study of 12 males and 12 females to investigate the effects of keyboard height and keyboard slope on wrist posture during 2 minute keying tasks. Keyboard heights were adjusted relative to each subject's seated elbow height: 10 cm below, 5 cm below, 0 cm (at elbow height), 5 cm above, and 10 cm above elbow height. Keyboard slopes varied relative to the horizontal: 45 degrees below, 22 degrees below, 0 degrees (parallel with the horizontal), 22 degrees above, and 45 degrees above the horizontal. Subjects typed for two minutes during each of the experimental conditions, and wrist monitors were used to record ulnar/radial deviation, flexion/extension, and pronation/supination during the last five seconds of the experimental condition.

Jedrziewski (1992) found that keyboard slopes of 45 degrees below the horizontal and keyboard heights greater than 5 cm above seated elbow height caused wrist flexion which differed significantly ($p<.05$) from the neutral position. Jedrziewski (1992) also reported that low keyboard heights and keyboard slopes above the horizontal reduced ulnar deviation. Pronation, however, was lowest when the keyboard was above elbow height and was sloped below the horizontal. Jedrziewski reported that keying tasks in which the keyboard was positioned 10 cm below elbow height and angled 45 degrees above the horizontal were considered extremely uncomfortable. Keyboards positioned below elbow height and angled 22 degrees below the horizontal were found to be the most comfortable.

## 2.8 Summary

The anatomy and movement capabilities of the upper extremity were reviewed in this section. The use of EMG for estimating muscle activity and fatigue, and the use of rating scales to measure musculoskeletal discomfort were reviewed. Two major types of musculoskeletal disorders associated with VDT work were identified: those of the neck and shoulders, and those of the wrist. Studies have shown that prolonged static work postures, keyboard height, chair design, insufficient work breaks are among the potential occupational factors which are associated with neck and shoulder problems from VDT work. There is no clear evidence as to whether or not the presence of a wrist support to reduces the static load on the shoulders. Environmental factors associated with disorders of the wrist (particularly CTS) include repetitive or forceful wrist deviations, hand vibration and cold temperatures. Keyboard slope and keyboard height are among the factors found to affect wrist posture during VDT work. Although studies have examined the association between certain environmental factors on shoulder loading or wrist posture during VDT work, no study has examined the relationship between environmental factors and wrist posture and shoulder muscle loading simultaneously. This study was designed to investigate the effects keyboard height, the presence of a wrist support and keying time on wrist posture, muscluloskeletal loading of the trapezius, and ratings of musculoskeletal discomfort under the same experimental conditions.

# 3. EXPERIMENTAL METHOD

## 3.1 Overview

The major purpose of the experiment was to investigate the effects of keyboard height, presence or absence of a wrist support, and keying time on different factors associated with the musculoskeletal disorders experienced by VDT operators. The dependent measures included: wrist extension, ulnar deviation, wrist pronation, RMS EMG signal of the descending portions of the trapezius muscles, mean power frequency of the EMG signals, shoulder abduction angle, subjective assessments of localized musculoskeletal comfort, and error rates. Wrist posture, EMG, and shoulder abduction measurements were taken from both the right and left sides of the body. The experiment was conducted in the Environmental and Safety Laboratory located on the fifth floor of Whitemore Hall at Virginia Polytechnic Institute and State University. Subjects were required to perform six forty-one minute keying tasks, each occurring on a different day. The procedures that were used to collect and analyze data were practiced in pilot tests (see Appendix A for pilot test results).

## 3.2 Subjects

Six right-handed females participated in the experiment. The subjects were recruited from Virginia Polytechnic Institute and State University, could type at least forty words per minute, and had no medical history of upper extremity disorders. Subjects ranged from 21 to 44 years in age, 158 and 173.5 cm in height and 43 and 80.5 kg in weight. The subjects typed between 40 and 80 words per minute on a 3 minute typing test. Table 3.1 provides the age, height, weight and tested keying rate of each subject.

**Table 3.1**

Age, height, weight and tested keying rate of each subject.

| Subject | Age (yr) | Height (cm) | Weight (kg) | Keying Rate (words/min.) |
|---|---|---|---|---|
| 1 | 26 | 164.5 | 49.7 | 40 |
| 2 | 30 | 162 | 67.5 | 51 |
| 3 | 44 | 163 | 61 | 80 |
| 4 | 25 | 163 | 80.5 | 53 |
| 5 | 23 | 173.5 | 69.5 | 68 |
| 6 | 21 | 158 | 43 | 40 |
| Mean (Std Dev.) | 28.2 (8.3) | 164.0 (5.1) | 61.9 (13.7) | 55.3 (15.9) |

Each subject attended six two-and-one-half-hour experimental sessions, each session occurring on a different day. Each subject was paid $5.00 per hour and was awarded an additional $10.00 for completing all six experimental sessions.

Several workstation measurements were made after the subject was initially "fitted" to the workstation to ensure that the subject was seated at the same height and same distance from the CRT and keyboard during each experimental session (see Table 3.2).

**3.3 Apparatus**

The experimental apparatus consisted of a VDT workstation, three measurement systems, and one data recording system (described below). Subjects performed the experimental tasks at the VDT workstation. The three measurement systems recorded wrist posture, muscular activity of the descending portions of the trapezius muscles, and shoulder abduction. A schematic of the experimental apparatus is provided in Figure 3.1.

3.3.1 Computer Workstation

The major components of the computer workstation included: a Macintosh IIsi computer, thirteen inch color monitor, standard keyboard, height-adjustable keyboard surface, height adjustable monitor surface, chair with an adjustable seat pan height and low back rest, wrist support, and head reference bar. The layout and dimensions of the workstation, and dimensions of the keyboard and wrist support are given in Figure 3.2. The experimental apparatus helped to ensure that the subject faced the CRT and had the hands on the keyboard during the keying tasks. The subject was required to place the forehead against a piece of cardboard which was attached to the head reference bar to help keep the head fixed during the keying tasks.

**Table 3.2**

Workstation measurements for each subject

| Subject | S. Ear Height (cm) | S. Elbow Height (cm) | Chair to Keyboard (cm) | Head Ref. Height (cm) | Head Ref. to CRT (cm) |
|---|---|---|---|---|---|
| 1 | 106.25 | 64.5 | 6.5 | 116.5 | 40 |
| 2 | 114.2 | 67.5 | 8.5 | 122 | 47 |
| 3 | 113.5 | 65.4 | 11 | 116 | 41.5 |
| 4 | 109 | 67.5 | 10 | 116 | 45 |
| 5 | 116 | 67.6 | 12.5 | 124.5 | 48 |
| 6 | 107 | 60 | 5 | 111 | 38 |
| Mean (Std Dev.) | 111.0(4.1) | 65.4(3.0) | 8.9(2.8) | 117.7(4.8) | 43.3(4.0) |

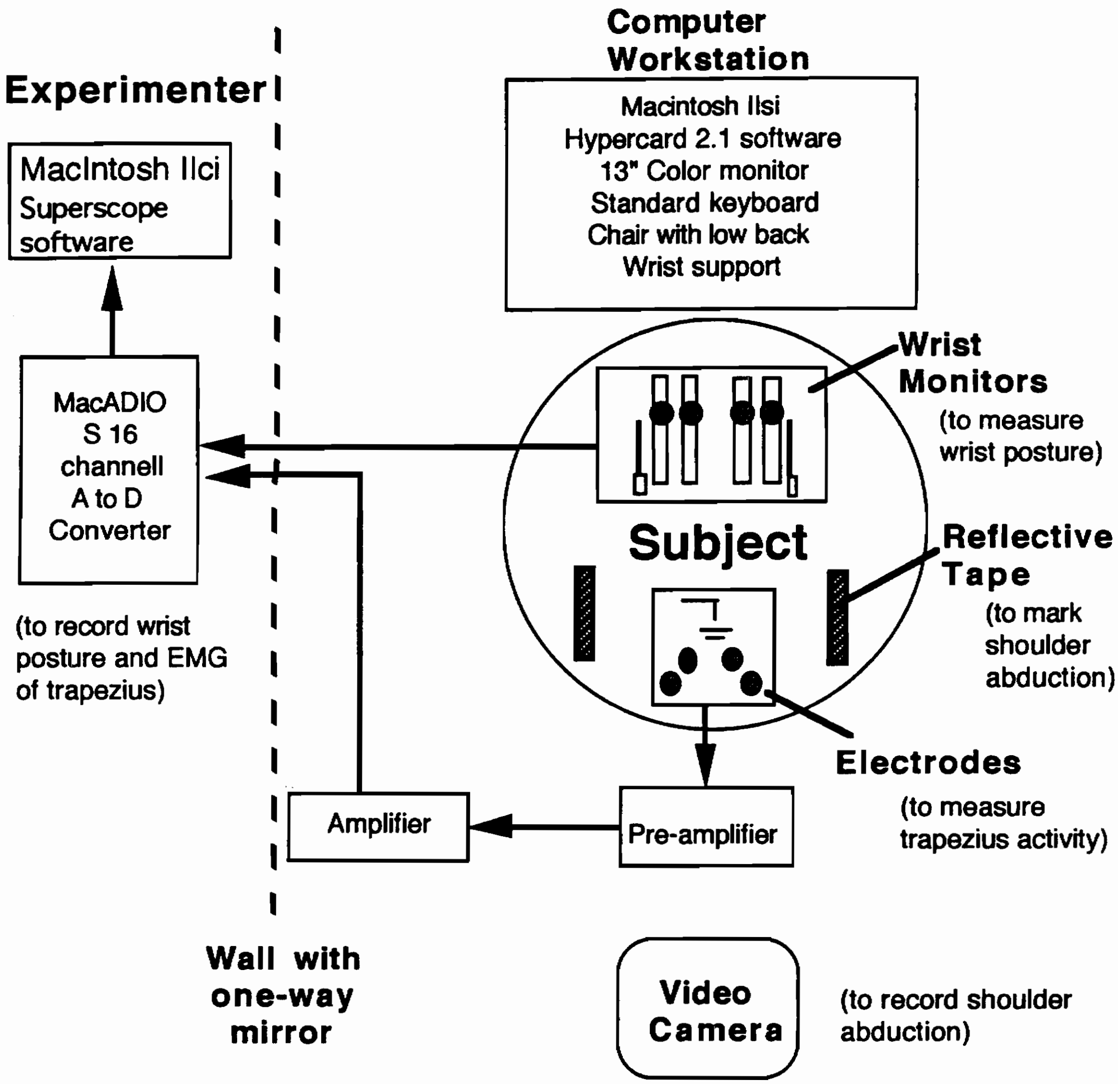



**Figure 3.1.** Schematic of the experimental apparatus.

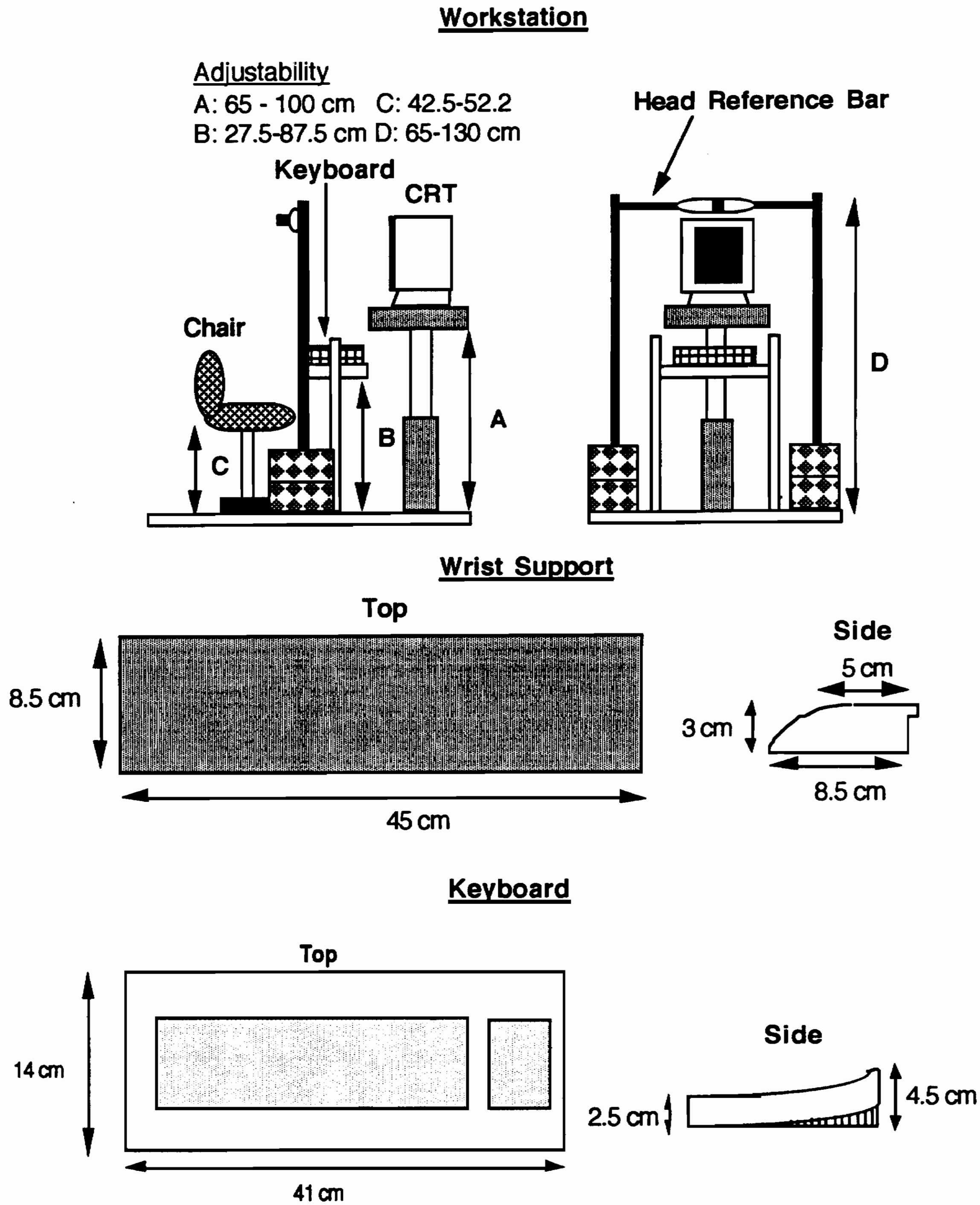



**Figure 3.2.** Dimensions of the computer workstation, wrist support and keyboard.

The monitor displayed a Hypercard interface having start, stop and reset buttons, a dictation window, and an output window as shown in Figure 3.3. The start button activated the Hypercard stack, text to be typed appeared in the dictation window (an automatically scrolling Hypercard field), and keyed text appeared in the feedback window (a Hypercard field which scrolled as each line of typed text was completed by the subject). Each of the windows displayed two lines of text. The windows were centered on the CRT. The scrolling rate of the dictation window was 75% of each subject's typing speed tested at the beginning of the first experimental session (see Section 3.5 - Experimental Protocol).

### 3.3.2 Wrist Posture Measurement System

The wrist posture measurement system consisted of two wrist monitors developed by the Biodymanics Laboratory at Ohio State University (Schoenmarklin and Marras, 1991). Each wrist monitor weighed 0.5 kg and provided quantitative measures of wrist position (Schoenmarklin and Marras, 1991). One wrist monitor was attached to each wrist. The wrist monitor consisted of three devices and provided one of the three measures (wrist flexion-extension, radial-ulnar deviation, forearm pronation-supination). The devices used to measure flexion-extension and radial-ulnar deviation were identical. They consisted of a potentiometer mounted on two metal strips connected by a pin. One metal strip was 16 cm long and 1.25 cm wide while the other strip was 9 cm long and 1.25 cm wide. The longer metal strip was fixed to the forearm with Velcro, while the shorter strip moved through a slide fastened to the hand similarly. The metal strips could rotate 360 degrees about the pin and the angle between the strips was measured with the potentiometer.

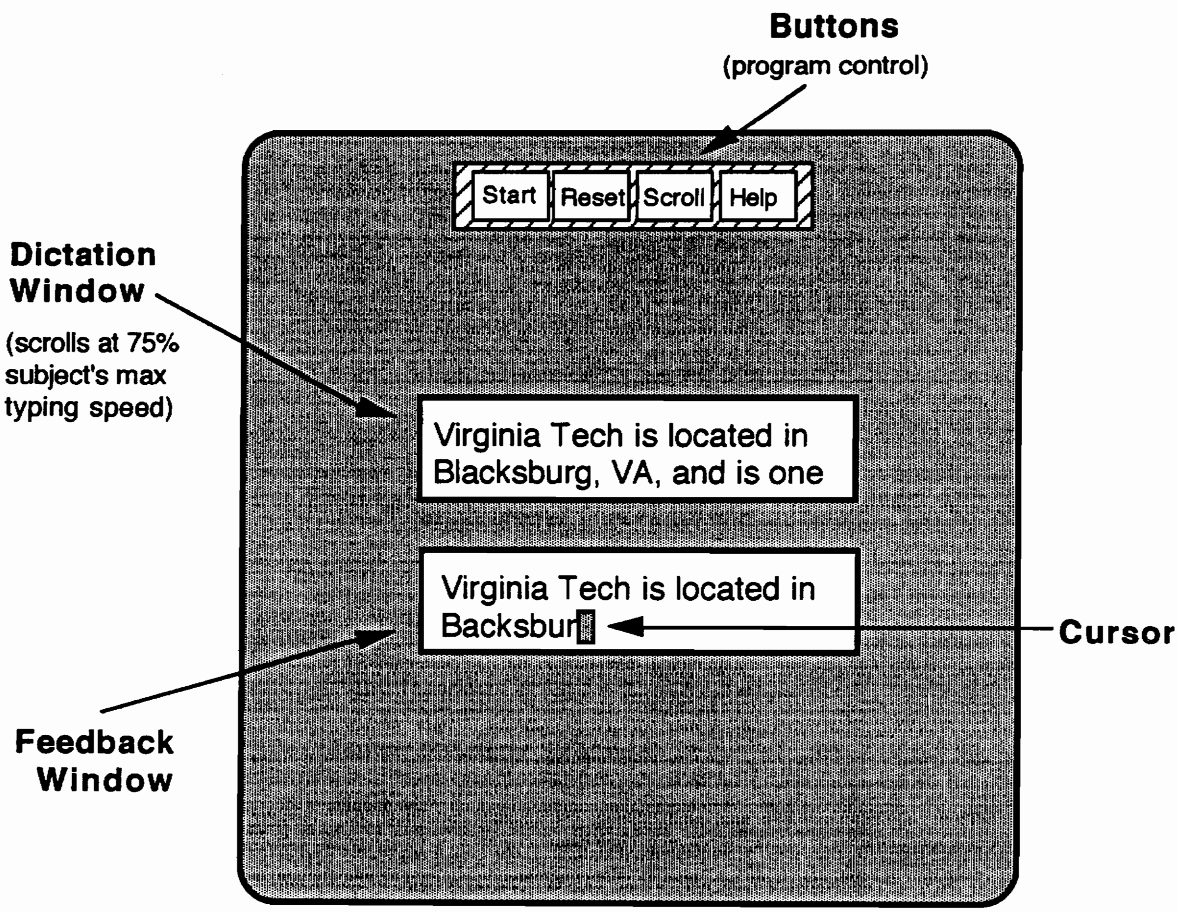



**Figure 3.3**. The computer interface.

The third device measured pronation-supination, and consisted of a rod, two brackets, and a potentiometer. The rod, having a length of 16.25 cm and diameter of 0.16 cm, was connected to the two brackets. The brackets were attached to the proximal and distal parts of the forearm with Velcro. The distal bracket was connected to a potentiometer and rotated about a fixed rod, and the proximal bracket attached to a stationary cuff that encircled the forearm. Signals produced by the potentiometers were delivered to the Data Recording System through wires (channels).

3.3.3 Fitting and Calibration of Wrist Posture Measurement System

First, the lateral epicondyle, articulation between the lunate and capitate, the olecranon, and second metacarpalphalangial joint were marked. These marks helped determine the wrist's neutral measuring planes.

The radial/ulnar deviation measuring device was attached to the subject's arm first. The subject sat upright with the shoulder abducted ninety degrees from the trunk and the elbow flexed ninety degrees. The device was placed on the subject's arm so that the potentiometer rested directly over the articulation of the lunate and capitate, the long metal strip rested on the forearm, and the short metal strip rested on the hand. The potentiometer was secured to the wrist with Velcro tape. The tape was wrapped around the forearm and the base of the device, one inch proximal to the potentiometer. The long metal strip was aligned with the lateral epicondyal and secured to the forearm with Velcro tape. The slide was placed over the small metal strip, aligned with the third metacarpal joint, and secured to the hand with Velcro tape.

For the attachment of the wrist flexion/extension measuring device, the subject abducted and rotated the shoulder 90 degrees (the subject's forearm was perpendicular to the transverse plane and the subject's hand was in the coronal plane). The potentiometer was placed over the styloid process of the wrist so that the short metal strip rested on the lateral side of the hand and the long metal strip rested on the lateral side of the forearm. The base of the device was secured to the forearm with Velcro tape. The slide was placed over the small metal strip, and fixed to the lateral side of the hand with Velcro tape so that the metal strip remained aligned with the lateral side of the hand while the subject flexed and extended the wrist. The long metal strip was aligned with the styloid process and the olecranon, and secured to the forearm with Velcro tape.

The subject remained in the same position while the pronation/supination measuring device was fitted. The potentiometer was secured to the long metal strip of the flexion/extension measuring device with Velcro tape. The cuff was fastened to the proximal portion of the forearm. The rod was aligned with the styloid process and olecranon, and connected with the potentiometer and cuff. The rod was tightened at the center point of rotation to the cuff with a screwdriver. Wires connecting the wrist monitors to the Data Recording System were then attached to the potentiometers. This fitting process was repeated for the second wrist monitor. The fitted wrist monitor is shown in Figure 3.4.

The subject wore the wrist monitors during the calibration procedures. During the calibration of the radial-ulnar deviation measuring device, the subject remained seated with one shoulder abducted 90 degrees from the trunk and the elbow flexed 90 degrees. A voltage reading was recorded by the Data Recording System while the wrist was neutral. This reading was assigned a value of zero degrees. The subject then performed ulnar deviations in 15

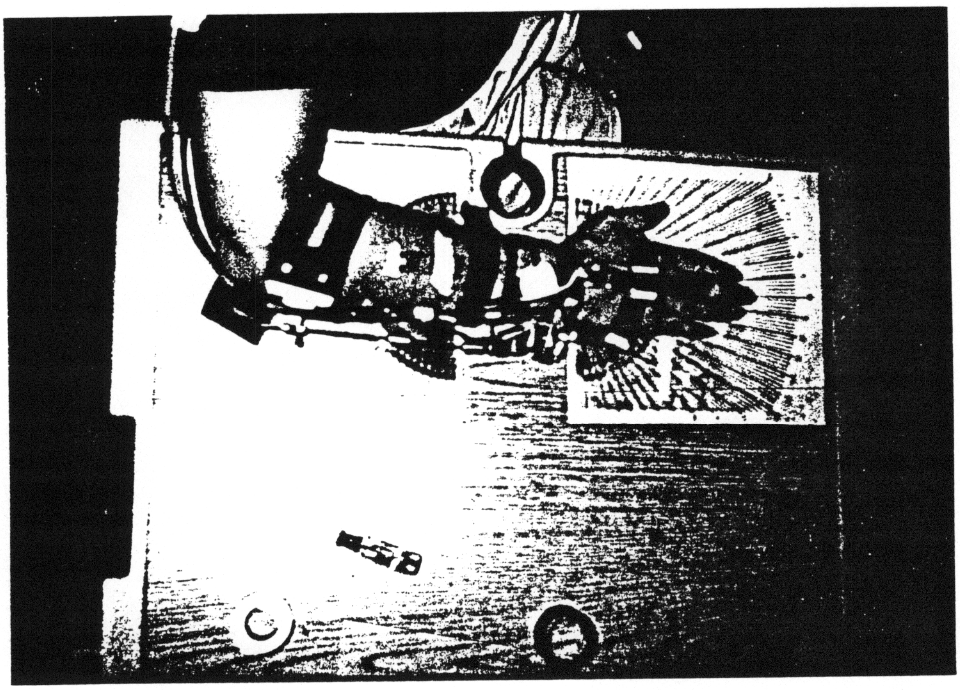


**Figure 3.4.** The fitted wrist monitor.

degree increments up to a maximum possible ulnar deviation. The angles (recorded in positive degrees) were measured with a protractor, and the corresponding voltages were recorded by the Data Recording System. The subject then performed radial deviations in 15 degree increments up to a maximum possible radial deviation, and the angles (recorded in negative degrees) and voltages were obtained in the same manner. The ulnar/radial deviation calibration procedure was repeated for the second wrist monitor.

The subject remained seated, with the shoulder abducted and rotated the shoulder 90 degree and the elbow flexed 90 degrees for the flexion/extension calibration. A voltage reading was recorded by the Data Recording System while the wrist was neutral. The subject then performed wrist extensions in 15 degree increments up to a maximum extension. The angles (recorded in positive degrees) were measured with a goniometer, and the corresponding voltages were recorded with the Data Recording System. The subject then performed wrist flexions in 15 degree increments up to a maximum flexion. The angles (measured in negative degrees) and voltages were obtained in the same manner. The extension/flexion calibration procedure was repeated for the second wrist monitor.

The subject was next required to stand with the arms next to the body and the elbows flexed 90 degrees for the pronation/supination calibration measurements. The subject grasped the center of the handle of a goniometer. Voltage was recorded while the subject grasped the handle which was aligned vertically, and the voltage reading was assigned a value of zero degrees. The subject pronated the wrist in 15 degree increments up to a maximum pronation. The angles (recorded in positive degrees) were measured with a goniometer, and the corresponding voltages were recorded by the Data Recording System. Forearm supination (recorded in negative degrees) was calibrated in the same manner. The pronation/supination calibration procedure was repeated for the second wrist monitor.

The voltages and angles of wrist position had a linear relationship ($R^2 > 0.99$). A typical regression equation developed from the wrist calibration data is provided in Figure 3.5. The regression equations were used to predict angles from the wrist monitor voltage outputs during the experimental sessions.

3.3.4 EMG Measurement System

The raw EMG signals of the descending portion of each trapezius were recorded with a bipolar surface electrode system consisting of two surface electrodes, a ground, preamplifier, variable gain amplifier, and MacADIOS Audio to Digital (A to D) interface. The surface electrodes were Hewlett Packard foam Ag/AgCl electrodes having a 10 mm diameter. The electrodes were placed 2.5 cm apart and centered between the C7 vertebra and acromion process, following recommended and practiced EMG configurations (Bendix and Jessen, 1986; Erdelyi et al., 1988; Hagberg and Sundelin, 1986; and Soderberg, 1992). The ground was connected to the subject's left ear-lobe. Wires connected each pair of surface electrodes to a pre-amplifier, and a cable connected the preamplifier to the amplifier. The amplified raw signals of the right and left trapezius then traveled through another cable to the Data Recording System.

3.3.5 Fitting and Calibration of EMG Measurement System

At the beginning of each experimental session, the subject was given a shirt which had been altered to expose the upper portions of the trapezius

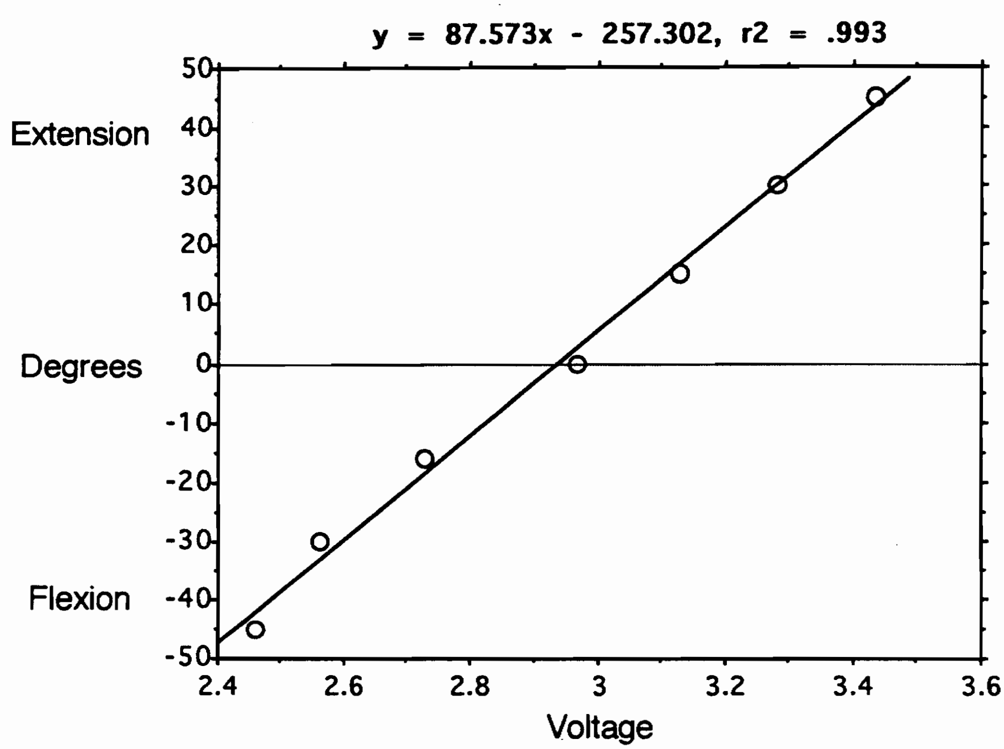



**Figure 3.5.** A typical regression model developed from the wrist position calibration data.

muscles. The center point between the C7 vertebra and acromion process of each shoulder was marked with permanent ink. Electrode gel was placed on five electrodes. Two electrodes were attached to the upper portion of each trapezius muscle 2.5 cm apart centered between the C7 vertebra and acromion process. The electrodes were traced on the subject's skin to ensure consisted placement of electrodes for each trial. One electrode (the ground) was attached to the subject's right earlobe. Wires were connected to each electrode, and linked the electrodes to the preamplifier.

The EMG calibration was performed approximately 30 minutes after the electrodes had been attached, allowing the electrode gel to seep into the subject's skin. The subject flexed the shoulder 90 degrees. An anchored strap was placed around the subject's hand, and the subject was required to perform three maximum shoulder elevations (shrugs) for each shoulder. This body posture and type of muscular effort was found to produce the most trapezius muscle activity during the pilot tests and therefore seemed to be the most appropriate measure of MVC activity (See Appendix A: Pilot Subject Results). The subject was required to perform each exertion for five seconds and rested for several minutes between efforts. The greatest activity for the three efforts was considered the MVC activity. Figure 3.6 shows a subject performing a MVC effort.

3.3.6 Data Recording System

Both the Wrist Posture Measurement System and the EMG Measurement System were connected to a Macintosh Data Recording System. This system consisted of a Macintosh IIcx computer having a MacADIOS II Analog-to-Digital board, color monitor and Superscope software. The MacADIOS A to D

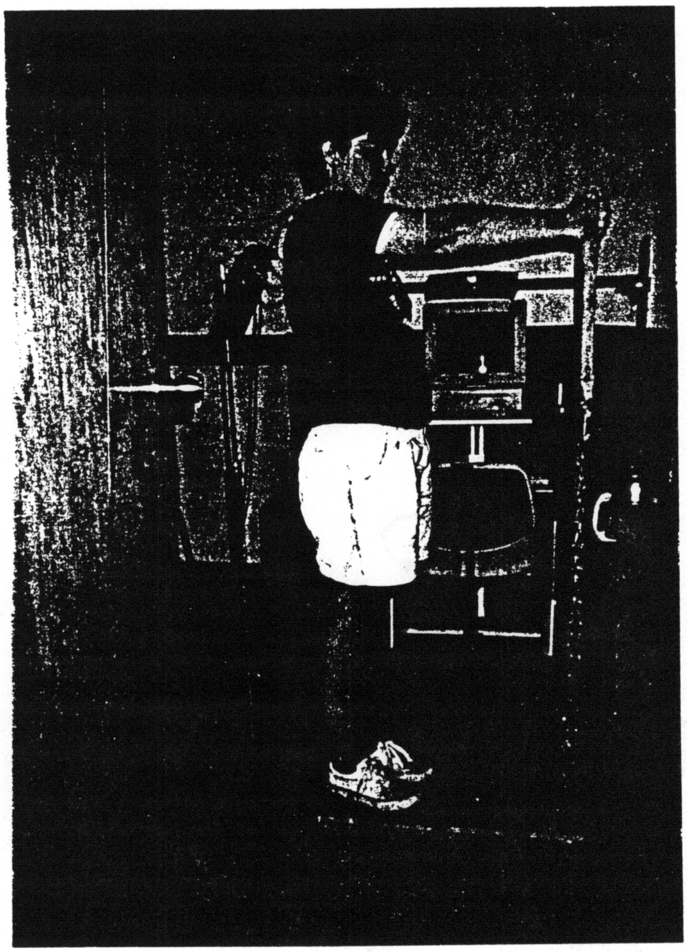


**Figure 3.6.** Subject performing a MVC effort.

interface converted the analog signals of the six potentiometers (three on each hand), and the two raw analog EMG signals to digital signals. Signals from the potentiometers were sampled at 30 HZ for 10 second intervals and EMG signals were sampled at 500 HZ for 5 second intervals.

Superscope Software for the Macintosh was used to transform the RMS EMG signal and power frequency spectrum from the raw EMG signal. The RMS signal was calculated from each 5 second sample of raw EMG data. The power frequency spectrum was determined with a fast Fourier transform on the raw EMG data. The fast Fourier transform function returned the raw signal in a number notation of the power for each frequency from approximately 0 to 250 Hz. The MPF for each spectrum was calculated with Microsoft Excel for the Macintosh.

3.3.7 Shoulder Abduction Measurement System

Shoulder abduction was measured using a video-recording technique which was piloted by the experimenter. Reflective tape was attached to each subject's arms and over the subject's spine. An 8 mm video recorder was positioned 2.5 meters behind the subject and 1 meter from the floor during the experimental session. Each typing task was taped in its entirety and later played back on a television screen. Shoulder abduction was measured as the angle between the extended line made from the tape on the vertebrae and extended lines made from the tape on the arms. Measurements were taken from individual video frames. The reflective tape was traced onto transparencies with a marker. A protractor was used to determine the angles between the lines traced onto each transparency. The average angle for the time interval was recorded as the subject's average shoulder abduction.

### 3.3.8 Fitting of Shoulder Abduction Measurement System

Reflective tape was fastened in line with the olecranon and acromion process of each arm, and was fastened in line with the cervical and thoracic vertebrae of the back while the subject sat erect. The tape was fastened several cm proximal to subject's olecranons, several cm inferior to the subject's acromion processes, on the C7 vertebra, and on the thoracic vertebrae. Figure 3.7 shows a subject in 0 degrees and 45 degrees of right and left shoulder abduction.

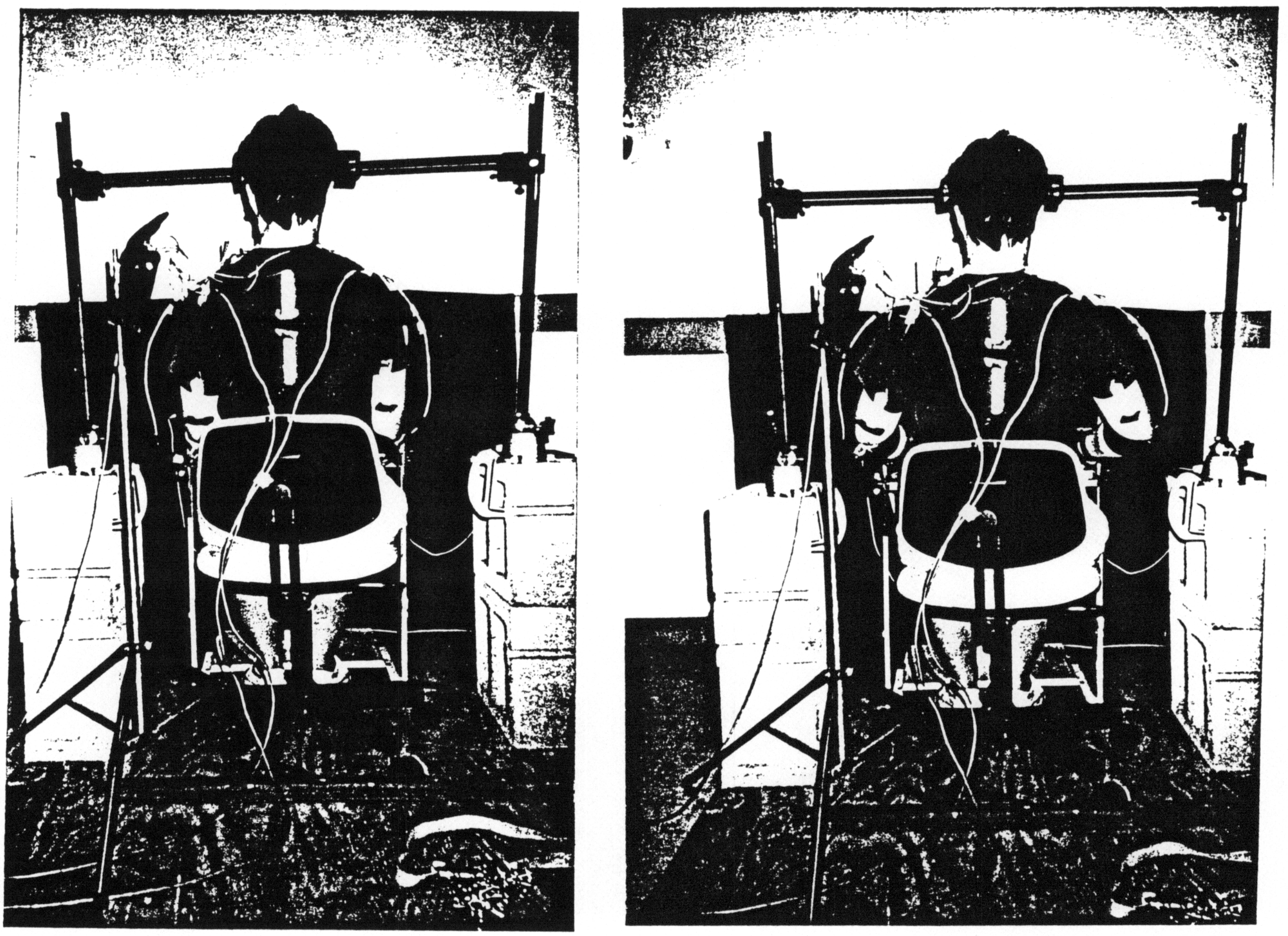
## 3.4 Procedures

### 3.4.1 Experimental Design

The proposed experiment was a repeated-measures factorial design having four within-subject factors: Keyboard Height, Wrist Support, Keying Time and Side of Measurement. Because the order of Keying Time and Side of Measurement could not be randomized, only the Keyboard Height and Wrist Support experimental treatments were counterbalanced. The two counterbalanced treatments followed a Latin Square design (see Figure 3.8).

The dependent measures for the repeated measures design included: wrist extension, ulnar deviation, wrist pronation, RMS EMG signal of the descending portion of the trapezius, MPF of trapezius EMG, shoulder abduction angle and error rate.

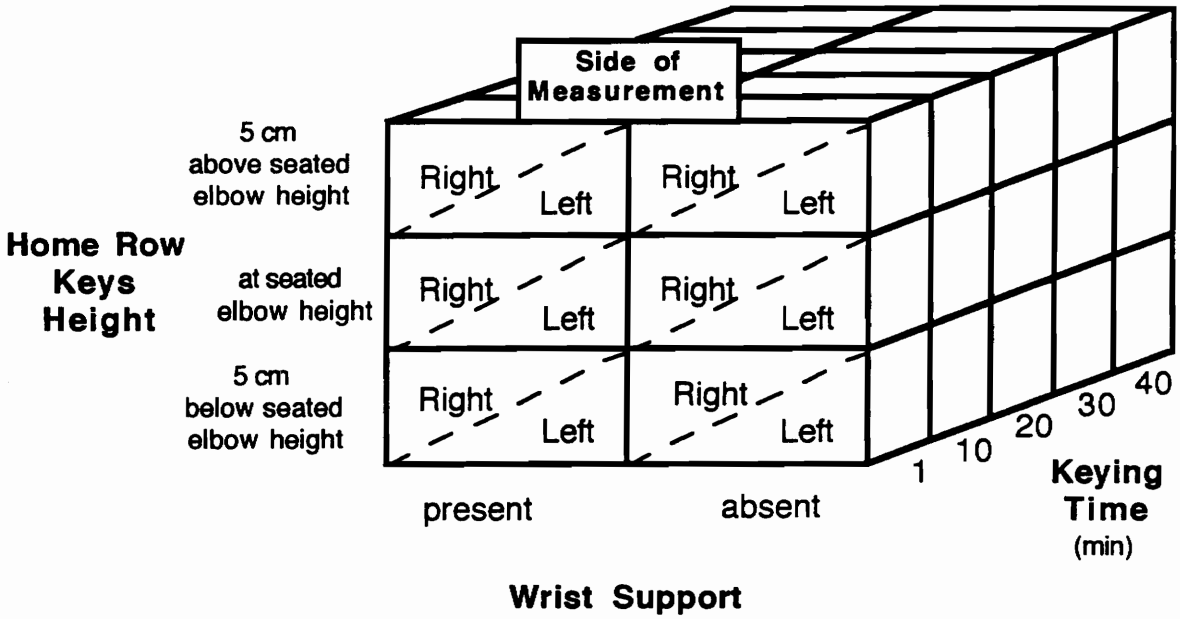
Side of Measurement was not an independent factor for the dependent measure of error rate. Thus, the experimental design for error rate was repeated-measures having three within subjects factors: Keyboard Height, Wrist Support and Keying Time.



A. B.

**Figure 3.7.** Subject seated at the VDT workstation with: (A) the shoulders abducted 0 degrees and (B) the shoulders abducted 45 degrees.

## 4 Factor Repeated Measures Design




## Conditions:

C1 - keyboard 5 cm above elbow height, wrist support present
C2 - keyboard at elbow height, wrist support present
C3 - keyboard 5 cm below elbow height, wrist support present
C4 - keyboard 5 cm above elbow height, wrist support absent
C5 - keyboard at elbow height, wrist support absent
C6 - keyboard 5 cm below elbow height, wrist support absent

## Order of Conditions: Latin Square

**Subject**

| Order | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| 1 | C1 | C2 | C3 | C4 | C5 | C6 |
| 2 | C2 | C3 | C4 | C5 | C6 | C1 |
| 3 | C6 | C1 | C2 | C3 | C4 | C5 |
| 4 | C3 | C4 | C5 | C6 | C1 | C2 |
| 5 | C5 | C6 | C1 | C2 | C3 | C4 |
| 6 | C4 | C5 | C6 | C1 | C2 | C3 |

**Figure 3.8**. Experimental Design.

Subjective ratings of localized muscle comfort for the neck, back, shoulders, upper arms, lower arms, wrists, hands and fingers were recorded on a seven point scale before and after each keying task. The difference in ratings before and after each task was considered to be the change in comfort.

At the end of the last experimental session, subjects rated their preference of keying conditions from 1 (preferred most) to 6 (preferred least). Brief descriptions of the independent and dependent variables follow. Table 3.3 summarizes the variables.

3.4.1.1 Independent Variables

1. Keyboard Height was the vertical distance from the top surfaces of the home row keys to the subject's seated elbow height. There were three levels of Keyboard Height : 1) 5 cm above elbow height, 2) at elbow height and 3) 5 cm below elbow height.
2. Wrist Support had two levels: 1) support present during the keying task and 2) support absent during the keying task.
3. Keying Time was the point in time from the start of the keying task to the beginning of the sampling periods for wrist posture, EMG of the trapezius, and shoulder abduction. Wrist posture data was collected at keying times: 1, 10, 20, 30 and 40 minutes. EMG data was collected at keying times: 2, 11, 21, 31 and 41 minutes. Shoulder abduction was recorded when both wrist posture data and EMG data of the trapezius were collected.
4. Side of Measurement was the side of the body for a given measure of wrist posture, EMG activity and shoulder abduction. It had two levels: 1) right and 2) left.

**Table 3.3**

Experimental Variables for ANOVA

*Independent Variables (within subjects)*

1. Keyboard Height - 3 levels
   - 5 cm above seated elbow height
   - at seated elbow height
   - 5 cm below seated elbow height

2. Wrist Support - 2 levels
   - support present
   - support absent
3. Keying Time - 5 levels for Wrist posture and EMG data; 10 levels for Shoulder Abduction
   - 1, 2 minutes
   - 10, 11 minutes
   - 20,21 minutes
   - 30, 31 minutes
   - 40, 41 minutes

4. Side of Measurement - 2 levels
   - right
   - left

*Dependent Variables*

1. Wrist extension

2. Ulnar deviation

3. Forearm pronation

4. Average RMS EMG signal of the trapezius

5. MPF of the EMG power spectrum

6. Shoulder abduction

7. Overall errors

8. Interval errors

3.4.1.2 Dependent Variables for ANOVA

1. Wrist extension was the average wrist extension recorded at 30 HZ during a 10 second sample period.
2. Ulnar deviation was the average ulnar deviation recorded at 30 HZ during a 10 second sample period.
3. Forearm pronation was the average forearm pronation recorded at 30 HZ during a 10 second sample period.
4. Average RMS EMG signal of the trapezius was the average RMS signal (%MVC) recorded at 500 HZ during a 5 second sample period. This signal was used to estimate the activity of the descending portion of the trapezius muscle during the sampling period.
5. Mean Power Frequency (MPF) was the weighted mean frequency of the signal's power calculated from the EMG power spectrum recorded at 500 HZ during the 5 second sample period.
6. Shoulder abduction angle was the average shoulder abduction recorded at 0.5 HZ during a 10 second sampling period. The sampling periods coincided with the wrist posture and EMG sampling periods.
7. Overall errors was the number of typographical errors during the entire keying task.
8. Interval errors was the number of typographical errors during each of the sampling periods.

3.4.1.3 Subjective Ratings

Subjective assessments of musculoskeletal comfort of the hands, wrists, forearms, upper-arms, shoulders, neck and back were surveyed at the beginning and end of the experimental session. The subject was asked to rate the comfort of each body part from 1 (very comfortable) to 7 (very uncomfortable) immediately before and after each keying task. The difference between the ratings before and after each task was considered to be the change in comfort caused by the keying condition. The survey was sensitive to changes in musculoskeletal comfort experienced by subjects during the pilot tests (see Appendix A). A copy of the questionnaire is supplied in Appendix D. At the end of the last experimental session, subjects also ranked their preference of keying conditions from 1 (preferred most) to 6 (preferred least).

#### 3.4.1.4 Controlled Factors

It was necessary to control for potential confounders. The controlled factors included:

- Gender (all subjects were female)
- CRT height in relation to seated eye height (top of CRT always at eye height)
- Chair seat-pan height (height at which subject could place feet flat on floor with knees bent 90 degrees)
- Rate of dictation (dictation window scrolled at 75% of subjects typing speed measured on a three minute test)
- Distance of eyes from CRT (measured during first session and held constant)
- Difficulty of text (controlled for syllables per word, word length and word frequency)
- Horizontal distance between the front edge of the chair and the keyboard (measured during first session and held constant)

- Order of keying conditions (counter-balanced in a Latin Square design)

3.4.2 Experimental Tasks

During each 40 minute typing task, the subjects typed a group of passages taken randomly from Timed Writings About Careers (Fries and Clayton, 1975). The groups of passages were presented to the subjects in a counterbalanced order. Each paragraph of the text was controlled, having an average syllable intensity of 1.5 syllables per word, average length of 5.6 keystrokes per word, and had words commonly found in business (Fries and Clayton, 1975).

The displayed text was shown in the dictation window and the typed text was shown in the feedback window (see Figure 3.3). Subjects were told not to correct typographical errors and to hold their hands over the keyboard during the keying tasks. Subjects completed the musculoskeletal comfort survey immediately before and after each keying task.

## 3.5 Experimental Protocol

The experiment was held in the Virginia Polytechnic Institute and State University Environmental and Safety Laboratory located on the fifth floor of Whittemore Hall. Each subject participated in six experimental sessions which occurred on different days. Subjects were asked to avoid activities that might fatigue the shoulder or arm muscles prior to the experiment.

Before beginning the first experimental session, subjects performed a three minute typing test to establish their typing proficiency. The test text was a short excerpt from Timed Writings About Careers (Fries and Clayton, 1975). Subjects who did not type at least 40 words per minute with no more than 2 errors per minute were excused from the study.

After the test, subjects were given written instructions for the experiment (see Appendix B). The experimenter then explained procedures of the experiment and answered the subject's questions. The subject then read and signed an Informed Consent Form (see Appendix C).

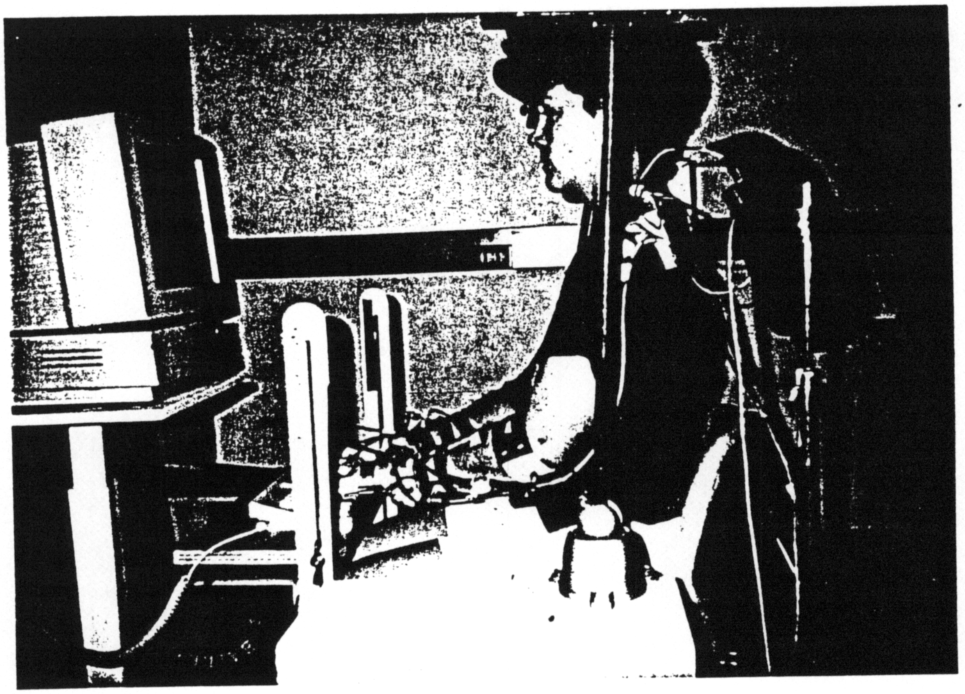
A number of fitting and calibration procedures preceded the experimental typing task (see section 3.2). The EMG Measurement System was attached to the subject's trapezius muscles, and the MVC activity of the trapezius muscles were determined. The wrist monitors were attached to the subject and calibrated. Reflective tape was fixed over the subject's arms and spine.

The experimenter then adjusted the computer workstation for the subject. The experimenter adjusted the height of the seat pan so that the subject was able to sit with the feet flat on the floor and the knees flexed approximately 90 degrees. The 90 degree knee flexion was estimated by the experimenter by inspection. The experimenter adjusted the top edge of the CRT to the subject's seated ear height and adjusted the keyboard height for the appropriate condition. The seat-pan height, CRT edge height, seat distance from the keyboard, and the head reference height was recorded during the first experimental session and the measurements were used to prepare the workstation before each subject's remaining experimental sessions.

The experimenter activated the Hypercard program and gave a brief description of the interface. The experimenter instructed subjects not to correct typographical errors, to use the chair's low back rest, to keep feet flat on the floor, and to keep the hands over the keyboard. While seated at the workstation, the subject completed a survey of localized musculoskeletal comfort for various parts of the body (see Appendix D).

The subject then performed the keying task. Wrist posture data, EMG data, and shoulder abduction data were collected at regular intervals without the subject's knowledge. The wrist posture data were collected at 30 HZ for 10 seconds, while the EMG data were collected at 500 HZ for 5 seconds. The shoulder abduction sampling periods were 10 seconds. Immediately following the keying task, the subject was required to complete a second survey which was identical to the first. The subject was debriefed and paid after completing all six experimental conditions. Figure 3.9 shows subjects performing the keying tasks during two different experimental conditions.

A.



B.

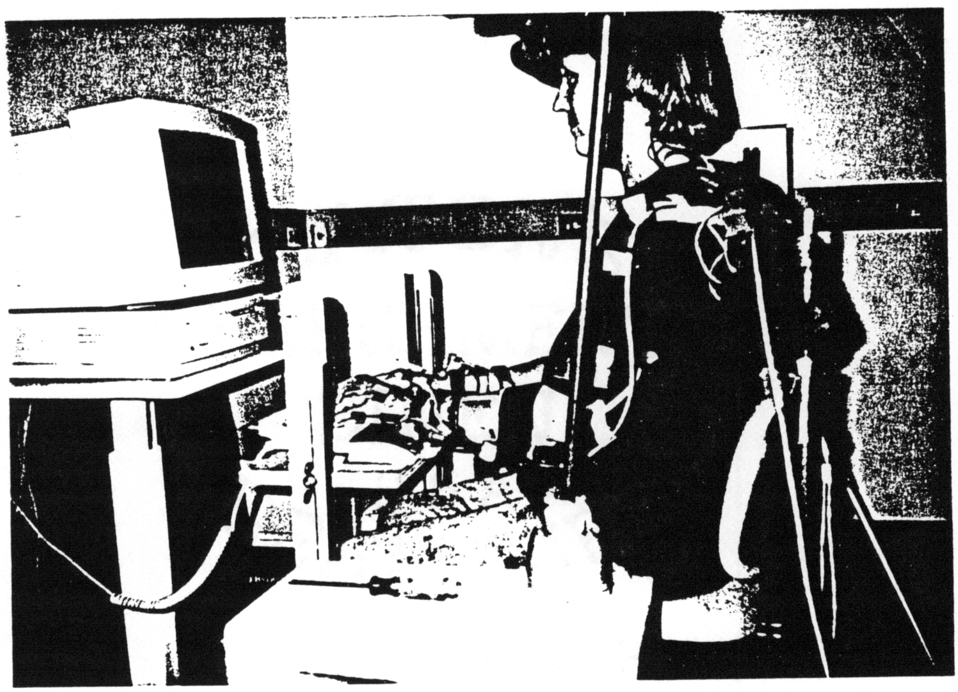


**Figure 3.9.** Subjects performing the keying tasks when: (A) the keyboard was located 5 cm below the subject's elbow height and the subject was not using a wrist support, and (B) the keyboard was located 5 cm above the subject's elbow height and the subject was using a wrist support.

# 4. DATA ANALYSES

## 4.1 Overview

Data analyses were performed to determine the main effects and interactions of independent variables, and differences between levels of each significant independent variable having more than two levels. Each analysis is described below.

## 4.2 Descriptions

### 4.2.1 Analysis of Variance

Analysis of variance (ANOVA) was used to determine the effects of Keyboard Height, Wrist Support, Keying Time and Side of Measurement on the dependent measures of wrist posture, EMG RMS values, MPF of trapezius EMG and shoulder abduction (see section 3.3 for definitions). ANOVA was also used to examine the effects of Keyboard Height and Wrist Support on the over-all errors, and was used to examine the effects of Keyboard Height, Wrist Support and Keying Time on interval errors. A Greenhouse-Geisser correction was used to eliminate the positive bias caused by heterogeneity of variance (how the experimental conditions affect the variability of each subject differently).

### 4.2.2 Means Comparison Contrast Analysis

Post-hoc unplanned comparisons tests are not valid for the within-subject effects of a repeated measures design because such tests assume independence between the means being compared. Therefore, a means comparison contrast analysis was performed to investigate differences between levels of each significant effect that had more than 2 levels.

#### 4.2.3 Descriptive and Non-parametric Statistical Analysis

Non-parametric statistical analyses were performed on the survey data. Friedman two-way analysis of variance tests was used to investigate the main effects of Keyboard Height and Wilcoxin signed rank test was used to investigate the main effects of Wrist Support on the change in musculoskeletal comfort after the keying task. Friedman two-way analysis of variance test by ranks was used to investigate significant differences in keying condition preferences. Multiple comparison tests of mean ranks was used to determine which keying conditions were significantly different in preference.

# 5 EXPERIMENTAL RESULTS

## 5.1 Overview

For wrist extension, the effects of Keyboard Height, Wrist Support, and Keyboard Height x Keying Time were significant ($p<.05$). For ulnar deviation, the effects of Keyboard Height and Keying Time were significant ($p<.05$). For forearm pronation, the effect of Wrist Support was significant ($p<.05$). No significant effects were found for shoulder abduction. Mean EMG activity for all keying tasks was 5.3 %MVC, but no significant effects were found for EMG activity or MPF. Subjects averaged 26.5 errors during each keying task (.6 errors/min.), and averaged 1.64 errors for each time interval (.8 errors/min.), but no significant effects were found for over-all errors or interval errors.

Subjects' musculoskeletal comfort decreased after the keying task. For the change in musculoskeletal comfort, the effect of Keyboard Height was not significant. However, for the change in musculoskeletal comfort of the back, neck, left and right shoulders, left and right upper arms, left and right forearms, left wrist and left hand, the effect of Wrist Support was significant ($p<.05$). The decrease in musculoskeletal comfort was consistently greater when the wrist support was absent than when a wrist support was present.

Subjects tended to prefer wrist supports and heights positioned at or above their seated elbow heights. The condition preferred most by the subjects was when the keyboard was positioned at elbow height and the wrist support was present. The condition preferred least by the subjects was when the keyboard was positioned 5 cm below elbow height and the wrist support was absent.

## 5.2. Analysis of Variance

### 5.2.1 Wrist Extension

The ANOVA showed that for wrist extension the effects of Keyboard Height (p=.0004), Wrist Support (p=.0013), and Keyboard Height x Keying Time (p=.0166) were significant (see Table 5.1) . Means comparison contrast analyses for the effect of Keyboard Height showed that wrist extension decreased as keyboard height increased, and that wrist extension was significantly different when the keyboard was 5 cm below elbow height than when the keyboard was 5 cm above elbow height (p=.0001) and at elbow height (p = .0016) (see Figure 5.1). Average wrist extension was greater when a support was absent than when a support was present (see Figure 5.2). For the Keyboard Height x Keying time interaction, wrist extension tended to decrease with time when the keyboard was at or below elbow height, but tended to increase with time when the keyboard was above elbow height (see Figure 5.3). The remaining effects for wrist extension were not significant. Figures 5.4 and 5.5 show the non-significant main effects of Keying Time and Side of Measurement.

### 5.2.2 Ulnar Deviation

The ANOVA showed that for ulnar deviation, the effects of Keyboard Height (p=.0449) and Keying Time (p=.0303) were significant (see Table 5.2). Means comparisons contrast analysis for the effect of keyboard height showed that ulnar deviation was significantly greater when the keyboard was 5 cm above elbow height than when it was at elbow height (p=.0379) or below elbow height (p=.0239) (see Figure 5.6). Mean comparisons contrast analysis for the effect of keying time showed that ulnar deviation tended to increase with time,

**Table 5.1**

ANOVA summary table for wrist extension

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 7482.056 | 1496.411 | | | |
| Within Subjects | | | | | | |
| H | 2 | 7849.883 | 3924.942 | 21.706 | .0002 | **.0004*** |
| HxS | 10 | 1808.265 | 180.826 | | | |
| WS | 1 | 18526.726 | 18526.726 | 42.198 | .0013 | **.0013*** |
| WSxS | 5 | 2195.223 | 439.045 | | | |
| BS | 1 | 51.332 | 51.332 | .161 | .7052 | .7052 |
| BSxS | 5 | 1598.342 | 319.668 | | | |
| KT | 4 | 13.416 | 3.354 | .199 | .9360 | .8677 |
| KTxS | 20 | 337.110 | 16.855 | | | |
| HxWS | 2 | 8464.136 | 4232.068 | 5.249 | .0276 | .0631 |
| HxWSxS | 10 | 8062.207 | 806.221 | | | |
| HxBS | 2 | 487.887 | 243.943 | 1.776 | .2188 | .2260 |
| HxBSxS | 10 | 1373.588 | 137.359 | | | |
| WSxBS | 1 | 274.574 | 274.574 | .524 | .5017 | .5017 |
| WSxBSxS | 5 | 2621.381 | 524.276 | | | |
| HxKT | 8 | 773.434 | 96.679 | 4.941 | .0003 | **.0166*** |
| HxKTxS | 40 | 782.665 | 19.567 | | | |
| WSxKT | 4 | 97.771 | 24.443 | 1.164 | .3563 | 35.47 |
| WSxKTxS | 20 | 420.066 | 21.003 | | | |
| BSxKT | 4 | 68.618 | 17.154 | .517 | .7240 | .6117 |
| BSxKTxS | 20 | 663.356 | 33.168 | | | |
| HxWSxBS | 2 | 1025.253 | 512.627 | 2.811 | .1075 | .1102 |
| HxWSxBSxS | 10 | 1823.964 | 182.396 | | | |
| HxWSxKT | 8 | 368.438 | 46.055 | 2.864 | .0129 | .0959 |
| HXWSxKTxS | 40 | 643.172 | 16.079 | | | |
| HxBSxKT | 8 | 377.582 | 47.198 | 3.035 | .0092 | .0924 |
| HxBSxKTxS | 40 | 622.141 | 15.554 | | | |
| WSxBSxKT | 4 | 168.384 | 42.096 | 2.311 | .0932 | .1471 |
| WSxBSxKTxS | 20 | 364.361 | 18.218 | | | |
| HxWSxBSxKT | 8 | 452.271 | 56.534 | 4.388 | .0227 | .1167 |
| HxWSxBSxKTxS | 40 | 515.339 | 12.883 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

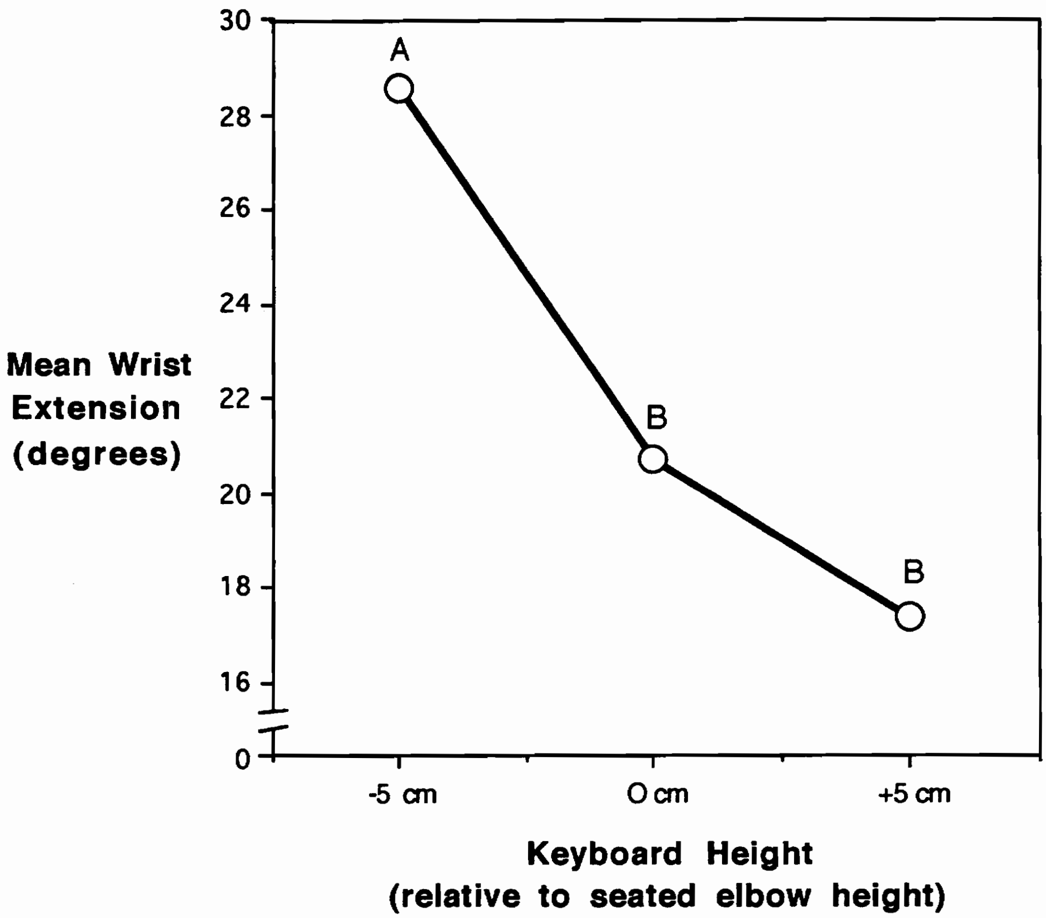



**Figure 5.1.** The effect of Keyboard Height on wrist extension. Values with different letters indicate statistically significant differences ($p<.05$).

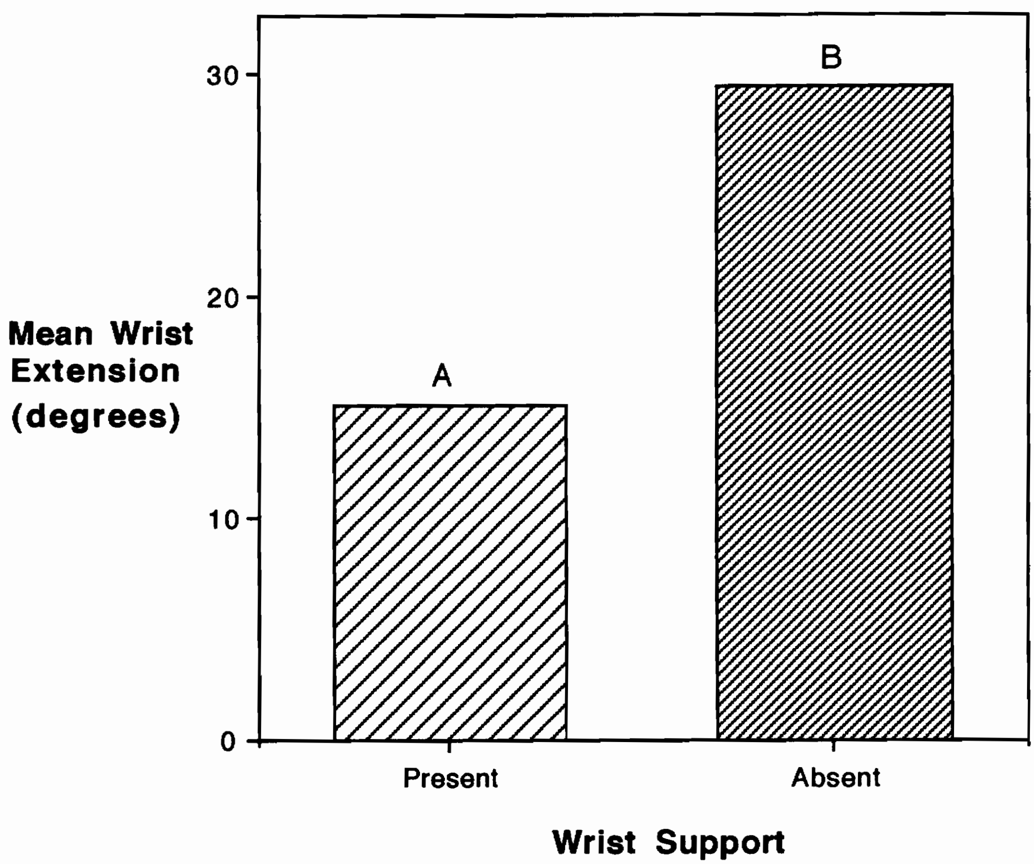



**Figure 5.2.** The effect of Wrist Support on wrist extension. Values with different letters indicate statistically significant differences ($p<.05$).

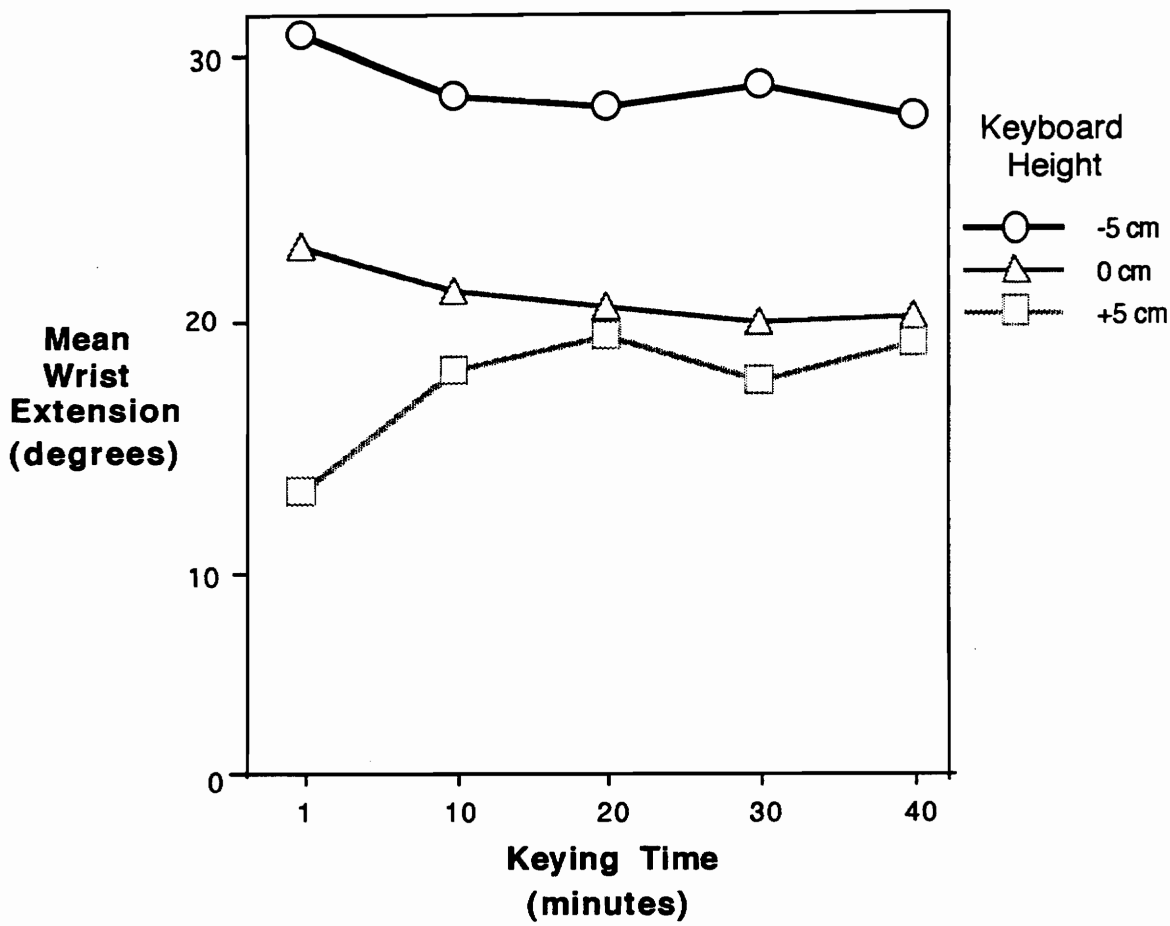



**Figure 5.3.** The Keyboard Height x Keying Time interaction on wrist extension.

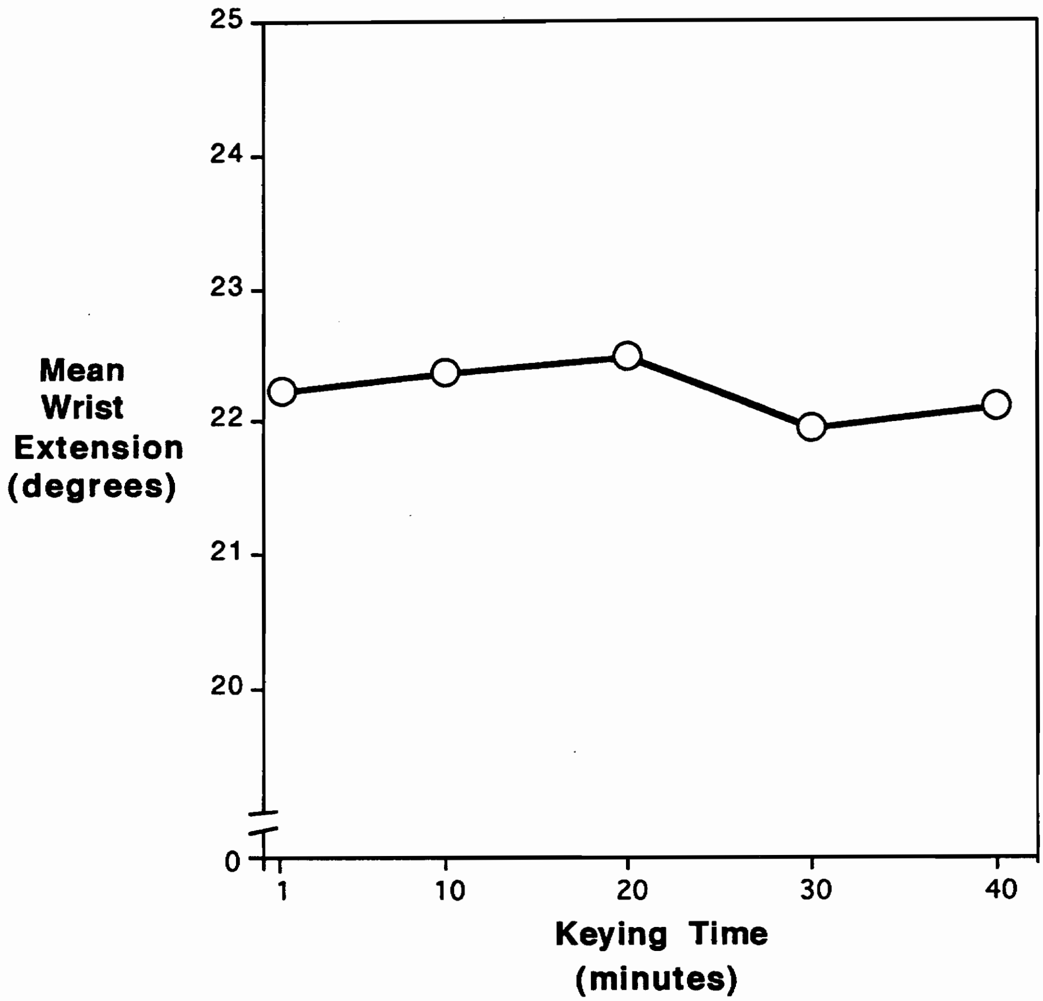



**Figure 5.4.** The non-significant effect of Keying Time on wrist extension.

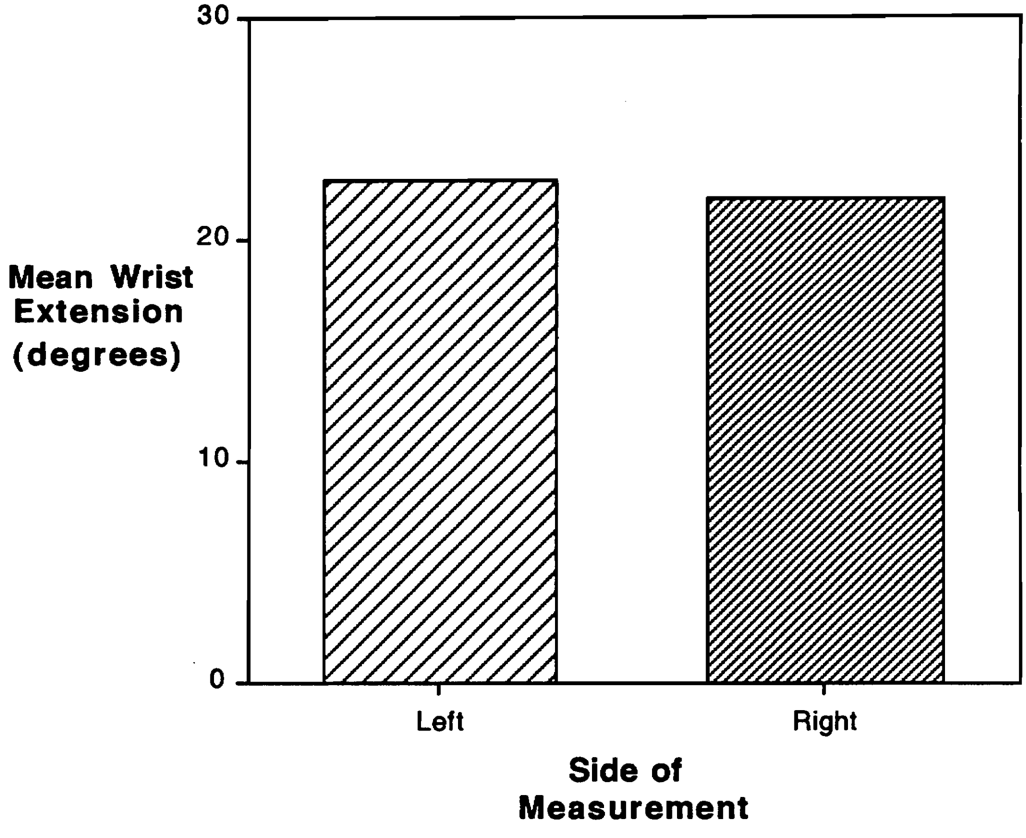



**Figure 5.5.** The non-significant effect of Side of Measurement on wrist extension.

**Table 5.2**

ANOVA summary table for ulnar deviation.

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 1143.5 | 228.7 | | | |
| Within Subjects | | | | | | |
| H | 2 | 2550.013 | 1275.006 | 4.410 | .0424 | **.0449*** |
| HxS | 10 | 2891.223 | 289.122 | | | |
| WS | 1 | 27.728 | 27.728 | .032 | .8647 | .8647 |
| WSxS | 5 | 4309.135 | 861.323 | | | |
| BS | 1 | 601.323 | 601.323 | .508 | .5078 | .5078 |
| BSxS | 5 | 5917.288 | 1183.458 | | | |
| KT | 4 | 473.922 | 118.481 | 6.006 | .0024 | **.0303*** |
| KTxS | 20 | 394.560 | 19.728 | | | |
| HxWS | 2 | 832.491 | 416.246 | .892 | .4401 | .4190 |
| HxWSxS | 10 | 4666.351 | 466.635 | | | |
| HxBS | 2 | 631.728 | 315.864 | .523 | .6082 | .5496 |
| HxBSxS | 10 | 6041.167 | 604.117 | | | |
| WSxBS | 1 | 53.847 | 53.847 | .046 | .8379 | .8379 |
| WSxBSxS | 5 | 5800.553 | 1160.111 | | | |
| HxKT | 8 | 148.968 | 18.621 | 1.297 | .2726 | .3140 |
| HxKTxS | 40 | 574.137 | 14.353 | | | |
| WSxKT | 4 | 207.813 | 51.953 | 2.268 | .0978 | .1625 |
| WSxKTxS | 20 | 458.087 | 22.904 | | | |
| BSxKT | 4 | 16.980 | 4.245 | .189 | .9413 | .8147 |
| BSxKTxS | 20 | 449.190 | 22.459 | | | |
| HxWSxBS | 2 | 202.235 | 101.117 | .192 | .8286 | .8009 |
| HxWSxBSxS | 10 | 5277.486 | 527.749 | | | |
| HxWSxKT | 8 | 148.777 | 18.597 | 1.163 | .3451 | .3570 |
| HXWSxKTxS | 40 | 639.821 | 15.996 | | | |
| HxBSxKT | 8 | 64.356 | 8.044 | .599 | .7730 | .6148 |
| HxBSxKTxS | 40 | 537.293 | 13.432 | | | |
| WSxBSxKT | 4 | 108.654 | 27.164 | 1.741 | .1805 | .2239 |
| WSxBSxKTxS | 20 | 312.005 | 15.600 | | | |
| HxWSxBSxKT | 8 | 104.678 | 13.085 | .996 | .4538 | .4209 |
| HxWSxBSxKTxS | 40 | 5525.310 | 13.133 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

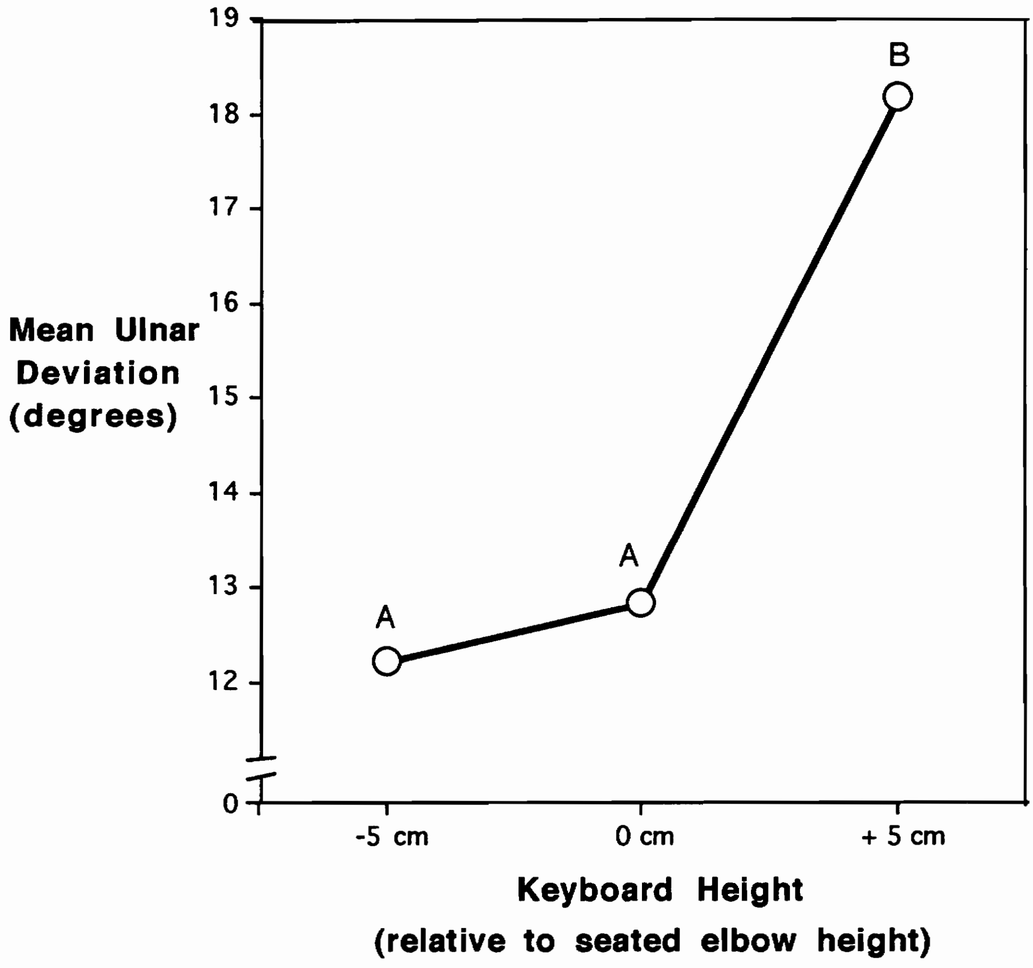



**Figure 5.6.** The effect of Keyboard Height on ulnar deviation. Values with different letters indicate statistically significant differences ($p<.05$).

and was significantly different at 1 minute than at 30 minutes (p=.0082) and 40 minutes (p=.0128) (see Figure 5.7).

### 5.2.3 Forearm Pronation

For forearm pronation, only the effect of Wrist Support on was significant (p=.0027) (see Table 5.3). Average pronation was greater when a wrist support was present than when it was absent (see Figure 5.8).

### 5.2.4 Shoulder Abduction

Average shoulder abduction ranged between 0 and 2 degrees, and tended to increase with increasing keyboard height (see Figure 5.9). However, there were no significant effects for shoulder abduction (see Table 5.4).

### 5.2.5 EMG Measurements

Mean EMG activity of the trapezius muscles during all conditions was 5.3 %MVC. Mean power frequency for all conditions was 93.3 HZ. No significant effects for EMG activity or mean power frequency were found (see Tables 5.5 and 5.6). However, the Wrist Support x Keying Time interaction (p=.1066) may indicate that MPF decreases with time when the wrist support is absent, but remains about the same with time when a wrist supportis present (see Figure 5.10).

### 5.2.6 Over-all and Interval Errors

The ANOVA summary tables for over-all errors and interval errors are provided in Tables 5.7 and 5.9. Mean over-all errors was 26.5 errors (.6 errors/min.) and mean interval errors was 1.64 (.8 errors/min.). No significant effects were found for over-all or interval errors.

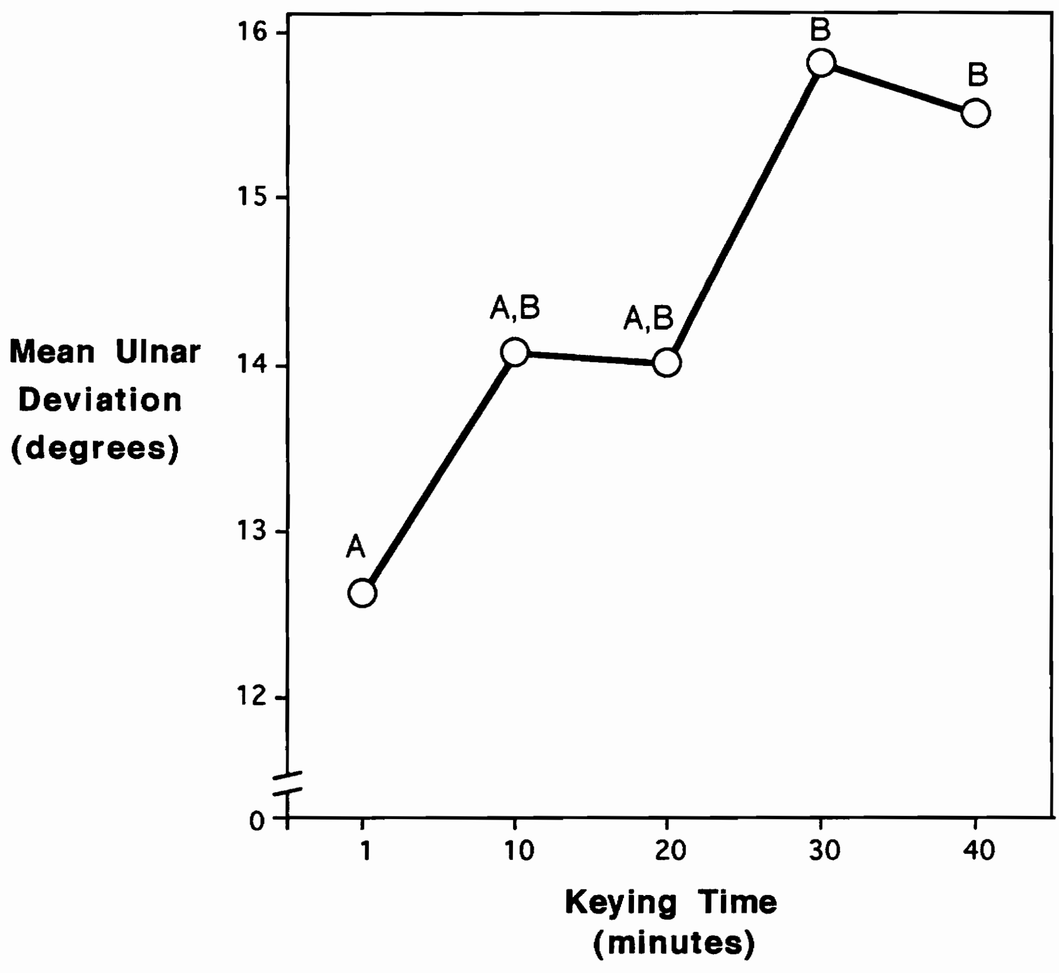



**Figure 5.7.** The effect of Keying Time on ulnar deviation. Values with different letters indicate statistically significant differences ($p<.05$).

**Table 5.3**

ANOVA summary table for forearm pronation

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 19367.868 | 3873.574 | | | |
| Within Subjects | | | | | | |
| H | 2 | 3394.621 | 1697.310 | 1.895 | .2005 | .2131 |
| HxS | 10 | 8954.758 | 895.476 | | | |
| WS | 1 | 72885.918 | 72885.918 | 30.334 | .0027 | **.0027*** |
| WSxS | 5 | 12013.983 | 2402.797 | | | |
| BS | 1 | 158.530 | 158.30 | .139 | .7248 | .7248 |
| BSxS | 5 | 5713.913 | 1142.783 | | | |
| KT | 4 | 424.111 | 106.028 | 1.787 | .1711 | .2187 |
| KTxS | 20 | 1186.604 | 59.330 | | | |
| HxWS | 2 | 13791.320 | 6895.660 | 2.303 | .1504 | .1736 |
| HxWSxS | 10 | 29940.001 | 2994.000 | | | |
| HxBS | 2 | 307.130 | 153.565 | .561 | .5875 | .5497 |
| HxBSxS | 10 | 2736.106 | 273.611 | | | |
| WSxBS | 1 | 1093.610 | 1093.610 | .492 | .5145 | .5145 |
| WSxBSxS | 5 | 11123.508 | 2224.702 | | | |
| HxKT | 8 | 456.197 | 57.025 | .799 | .6067 | .4776 |
| HxKTxS | 40 | 2853.946 | 71.349 | | | |
| WSxKT | 4 | 405.374 | 101.344 | 1.173 | .3526 | .3484 |
| WSxKTxS | 20 | 1728.103 | 86.405 | | | |
| BSxKT | 4 | 285.634 | 71.409 | 2.049 | .1259 | .1885 |
| BSxKTxS | 20 | 696.906 | 34.845 | | | |
| HxWSxBS | 2 | 860.553 | 430.277 | .618 | .5585 | .4819 |
| HxWSxBSxS | 10 | 6964.923 | 696.492 | | | |
| HxWSxKT | 8 | 343.316 | 42.915 | 1.241 | .3014 | .3305 |
| HXWSxKTxS | 40 | 1383.525 | 34.588 | | | |
| HxBSxKT | 8 | 215.251 | 26.906 | .686 | .7012 | .5163 |
| HxBSxKTxS | 40 | 1568.890 | 39.222 | | | |
| WSxBSxKT | 4 | 77.719 | 19.430 | .539 | .7089 | .5752 |
| WSxBSxKTxS | 20 | 721.102 | 36.055 | | | |
| HxWSxBSxKT | 8 | 63.784 | 7.973 | .224 | .9845 | .8490 |
| HxWSxBSxKTxS | 40 | 1426.203 | 35.655 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

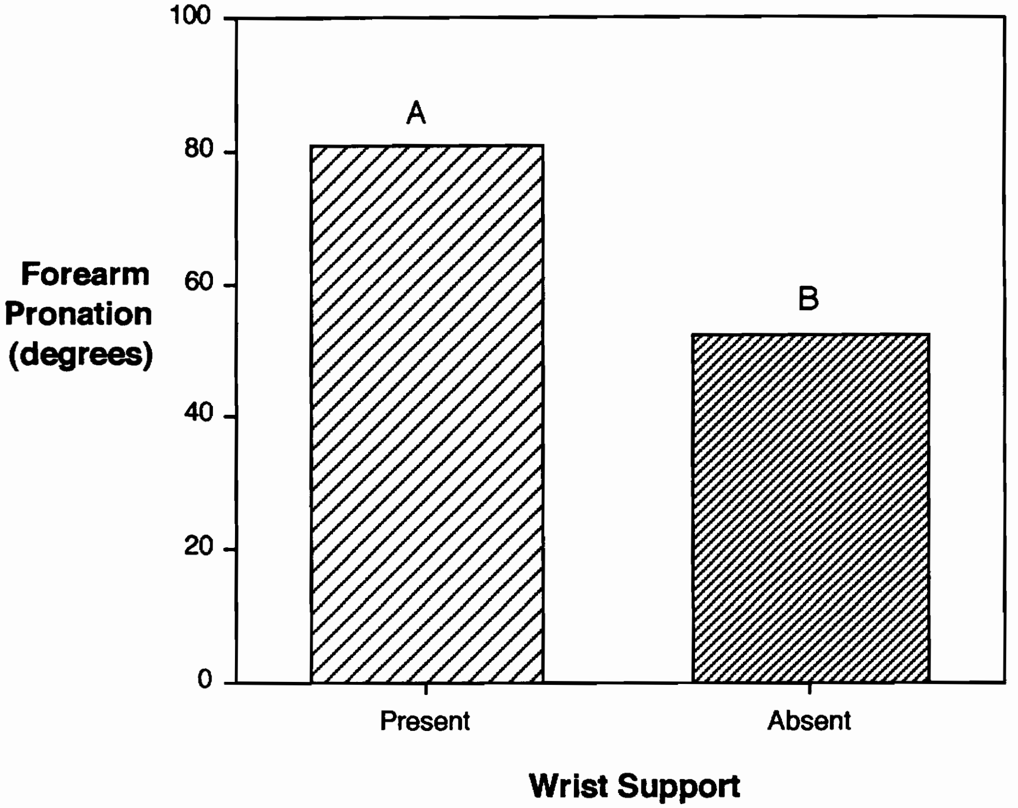



**Figure 5.8.** The effect of Wrist Support on forearm pronation. Values with different letters indicate statistically significant differences ($p<.05$).

**Table 5.4**

ANOVA summary table for shoulder abduction

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 853.561 | 170.712 | | | |
| Within Subjects | | | | | | |
| H | 2 | 152.469 | 76.235 | 2.999 | .0954 | .1426 |
| HxS | 10 | 254.183 | 25.418 | | | |
| WS | 1 | 41.006 | 41.006 | 2.666 | .1634 | .1634 |
| WSxS | 5 | 76.900 | 15.380 | | | |
| BS | 1 | 36.037 | 36.037 | .527 | .5005 | .5005 |
| BSxS | 5 | 341.966 | 68.393 | | | |
| KT | 4 | 5.782 | 1.446 | 1.340 | .2897 | .3045 |
| KTxS | 20 | 21.571 | 1.079 | | | |
| HxWS | 2 | 13.711 | 6.856 | 1.876 | .2033 | .2141 |
| HxWSxS | 10 | 36.542 | 3.654 | | | |
| HxBS | 2 | 12.829 | 6.414 | 2.243 | .1567 | .1881 |
| HxBSxS | 10 | 28.594 | 2.859 | | | |
| WSxBS | 1 | .685 | .685 | .399 | .5553 | .5553 |
| WSxBSxS | 5 | 2621.381 | 524.276 | | | |
| HxKT | 8 | 2.237 | .280 | .454 | .8805 | .5802 |
| HxKTxS | 40 | 24.627 | .616 | | | |
| WSxKT | 4 | 6.634 | 1.658 | 1.685 | .1929 | .2454 |
| WSxKTxS | 20 | 19.684 | .984 | | | |
| BSxKT | 4 | 2.889 | .722 | 1.614 | .2096 | .2518 |
| BSxKTxS | 20 | 8.949 | .447 | | | |
| HxWSxBS | 2 | 6.947 | 3.473 | .566 | .5851 | .5484 |
| HxWSxBSxS | 10 | 61.385 | 6.139 | | | |
| HxWSxKT | 8 | 9.423 | 1.178 | .881 | .5404 | .4220 |
| HXWSxKTxS | 40 | 53.547 | 1.336 | | | |
| HxBSxKT | 8 | 10.397 | 1.300 | 2.168 | .0512 | .1841 |
| HxBSxKTxS | 40 | 23.977 | .599 | | | |
| WSxBSxKT | 4 | 1.577 | .394 | .372 | .8261 | .6196 |
| WSxBSxKTxS | 20 | 21.219 | 1.061 | | | |
| HxWSxBSxKT | 8 | 5.802 | .725 | .834 | .5779 | .4368 |
| HxWSxBSxKTxS | 40 | 34.766 | .869 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

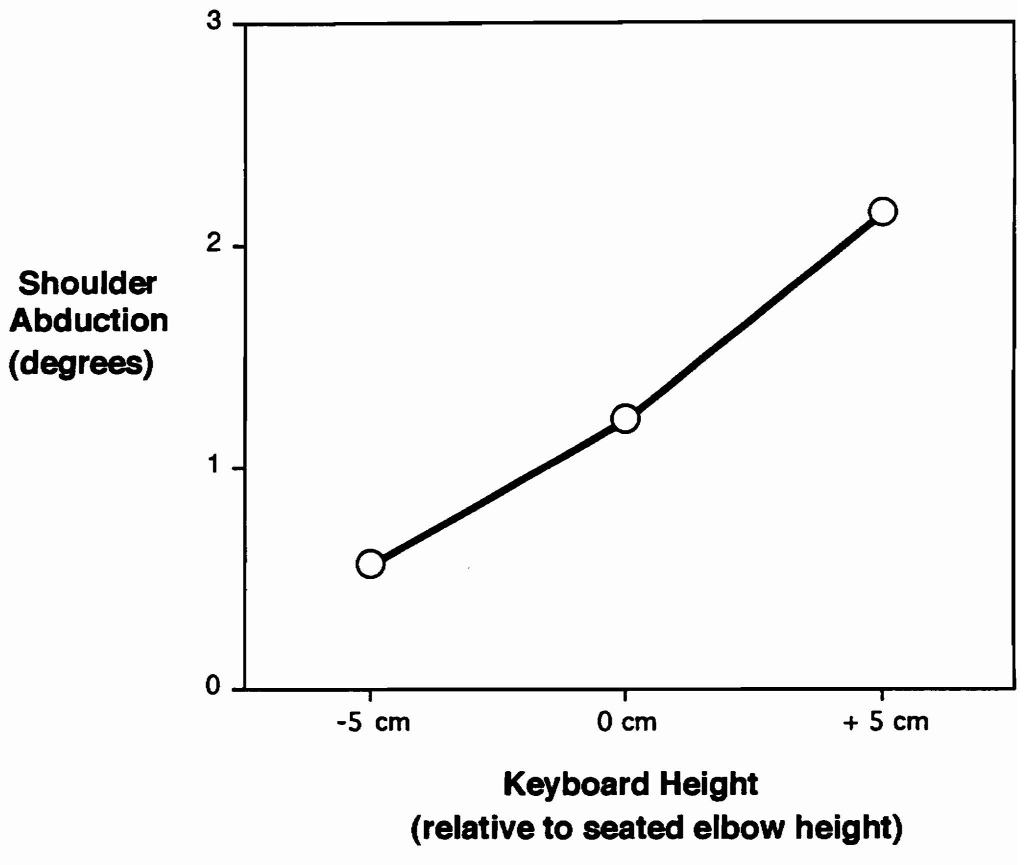



**Figure 5.9.** The non-significant effect of Keyboard Height on shoulder abduction.

**Table 5.5**
ANOVA summary table for MVC

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 1981.789 | 396.358 | | | |
| Within Subjects | | | | | | |
| H | 2 | 37.776 | 18.888 | .471 | .6374 | .6362 |
| HxS | 10 | 400.814 | 40.081 | | | |
| WS | 1 | 13.619 | 13.619 | .084 | .7842 | .7842 |
| WSxS | 5 | 815.476 | 163.095 | | | |
| BS | 1 | 494.068 | 494.068 | 3.400 | .1245 | .1245 |
| BSxS | 5 | 726.534 | 145.307 | | | |
| KT | 4 | 50.316 | 12.579 | 1.599 | .2135 | .2450 |
| KTxS | 20 | 157.343 | 7.867 | | | |
| HxWS | 2 | 184.191 | 92.095 | 1.654 | .2395 | .2447 |
| HxWSxS | 10 | 556.706 | 55.671 | | | |
| HxBS | 2 | 38.165 | 19.083 | 1.055 | .3838 | .3781 |
| HxBSxS | 10 | 180.810 | 18.081 | | | |
| WSxBS | 1 | 3.040 | 3.040 | .026 | .8783 | .8783 |
| WSxBSxS | 5 | 585.532 | 117.106 | | | |
| HxKT | 8 | 46.482 | 5.810 | 2.069 | .0623 | .1474 |
| HxKTxS | 40 | 112.333 | 2.808 | | | |
| WSxKT | 4 | 51.369 | 12.842 | 4.087 | .1140 | .1398 |
| WSxKTxS | 20 | 62.845 | 3.142 | | | |
| BSxKT | 4 | 33.264 | 8.316 | 2.504 | .0748 | .1395 |
| BSxKTxS | 20 | 66.424 | 3.321 | | | |
| HxWSxBS | 2 | 90.226 | 45.113 | 1.067 | .3801 | .3524 |
| HxWSxBSxS | 10 | 422.752 | 42.275 | | | |
| HxWSxKT | 8 | 33.683 | 4.210 | .758 | .6413 | .4955 |
| HXWSxKTxS | 40 | 222.325 | 5.558 | | | |
| HxBSxKT | 8 | 17.743 | 2.218 | .782 | .6208 | .5242 |
| HxBSxKTxS | 40 | 113.420 | 2.835 | | | |
| WSxBSxKT | 4 | 15.894 | 3.973 | 1.937 | .1435 | .1906 |
| WSxBSxKTxS | 20 | 41.031 | 2.052 | | | |
| HxWSxBSxKT | 8 | 18.690 | 2.336 | .840 | .5734 | .4815 |
| HxWSxBSxKTxS | 40 | 111.245 | 2.781 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

**Table 5.6**

ANOVA summary table for MPF

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 16315.318 | 3263.064 | | | |
| Within Subjects | | | | | | |
| H | 2 | 500.325 | 250.163 | .646 | .5446 | .5369 |
| HxS | 10 | 3871.753 | 387.175 | | | |
| WS | 1 | 124.303 | 124.303 | .513 | .5060 | .5060 |
| WSxS | 5 | 1212.320 | 242.464 | | | |
| BS | 1 | 2462.075 | 2462.075 | 1.143 | .3340 | .3340 |
| BSxS | 5 | 10773.671 | 2154.734 | | | |
| KT | 4 | 241.463 | 60.366 | 1.164 | .3563 | .3553 |
| KTxS | 20 | 1037.430 | 51.871 | | | |
| HxWS | 2 | 620.779 | 310.390 | 1.164 | .3512 | .3490 |
| HxWSxS | 10 | 2666.827 | 266.683 | | | |
| HxBS | 2 | 284.748 | 142.374 | .812 | .4713 | .4187 |
| HxBSxS | 10 | 1753.574 | 175.357 | | | |
| WSxBS | 1 | 236.293 | 236.293 | .360 | .5747 | .5747 |
| WSxBSxS | 5 | 3283.139 | 656.628 | | | |
| HxKT | 8 | 192.294 | 24.037 | .958 | .4820 | .4169 |
| HxKTxS | 40 | 1003.978 | 25.099 | | | |
| WSxKT | 4 | 308.137 | 77.034 | 2.681 | .0613 | .1066 |
| WSxKTxS | 20 | 574.634 | 28.732 | | | |
| BSxKT | 4 | 115.775 | 28.944 | 1.469 | .2487 | .2695 |
| BSxKTxS | 20 | 393.927 | 19.696 | | | |
| HxWSxBS | 2 | 743.212 | 371.606 | 3.662 | .0641 | .1104 |
| HxWSxBSxS | 10 | 1014.760 | 101.476 | | | |
| HxWSxKT | 8 | 443.771 | 55.471 | 1.771 | .1119 | .2067 |
| HXWSxKTxS | 40 | 1252.789 | 31.320 | | | |
| HxBSxKT | 8 | 83.682 | 10.460 | .580 | .7883 | .6817 |
| HxBSxKTxS | 40 | 721.723 | 18.043 | | | |
| WSxBSxKT | 4 | 142.743 | 35.686 | 2.349 | .0892 | .1322 |
| WSxBSxKTxS | 20 | 303.795 | 15.190 | | | |
| HxWSxBSxKT | 8 | 55.316 | 6.915 | .362 | .9344 | .7831 |
| HxWSxBSxKTxS | 40 | 764.251 | 19.106 | | | |

S=Subjects H=Keyboard Height WS=Wrist Support
BS=Body Side KT=Keying Time

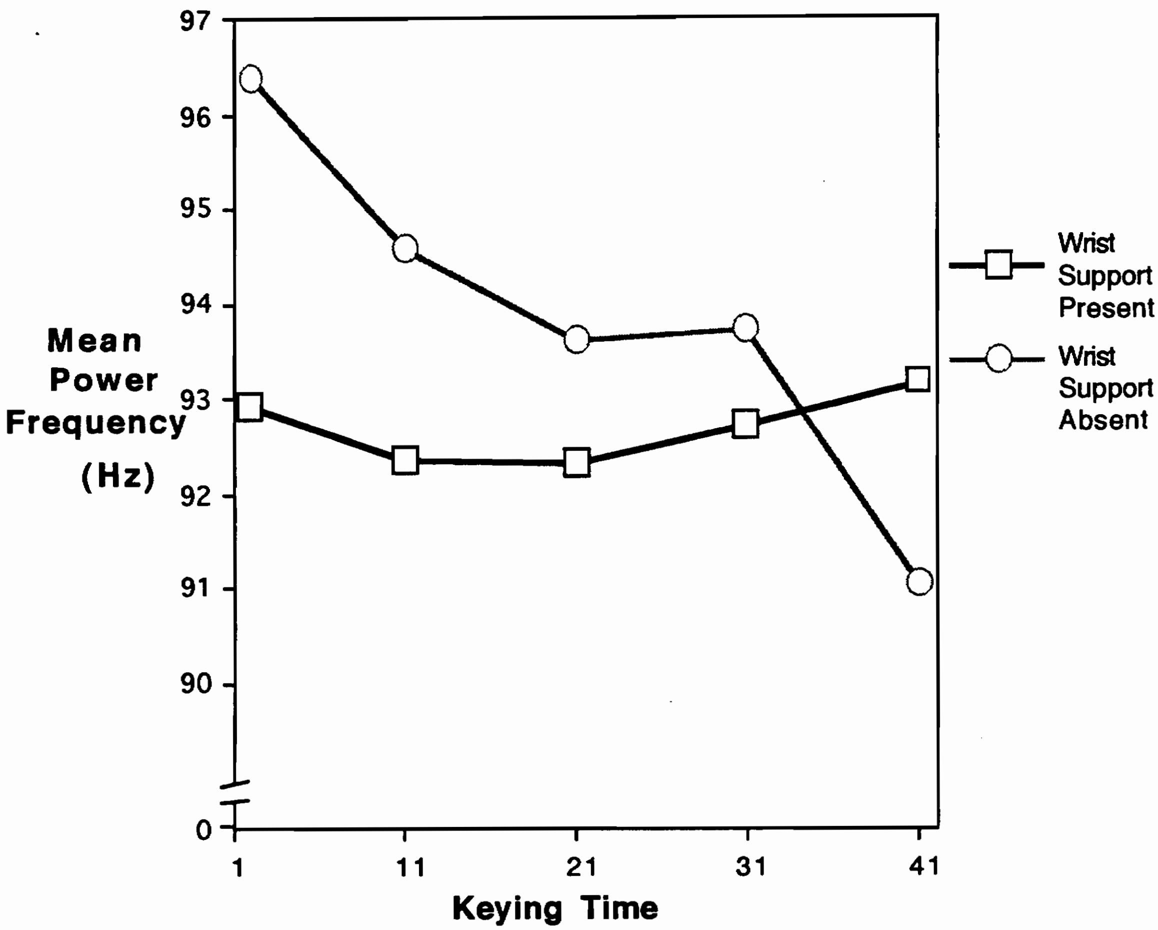



**Figure 5.10.** The non-significant Wrist Support x Keying Time interaction on MPF.

**Table 5.7**

ANOVA summary table for overall errors

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 8646.667 | 1729.333 | | | |
| Within Subjects | | | | | | |
| H | 2 | 275.167 | 137.583 | 1.293 | .3167 | .3087 |
| HxS | 10 | 1064.167 | 106.417 | | | |
| WS | 1 | 1.778 | 1.778 | .005 | .9477 | .9477 |
| WSxS | 5 | 1867.222 | 373.444 | | | |
| HxWS | 2 | 81.722 | 40.861 | .113 | .8943 | .8488 |
| HxWSxS | 10 | 3618.278 | 361.828 | | | |

S=Subjects
H=Keyboard Height
WS=Wrist Support

**Table 5.8**

ANOVA summary table for interval errors

| Source | df | SS | MS | F-Value | P-Value | G-G |
|---|---|---|---|---|---|---|
| Between Subjects | | | | | | |
| S | 5 | 183.244 | 36.649 | | | |
| Within Subjects | | | | | | |
| H | 2 | 2.878 | 1.439 | .471 | .6373 | .5883 |
| HxS | 10 | 30.522 | 3.052 | | | |
| WS | 1 | .200 | .200 | .024 | .8828 | .8828 |
| WSxS | 5 | 41.533 | 8.307 | | | |
| KT | 4 | 3.022 | .756 | .493 | .7409 | .6772 |
| KTxS | 20 | 30.644 | 1.532 | | | |
| HxWS | 2 | 1.633 | .817 | .059 | .9429 | .8643 |
| HxWSxS | 10 | 138.033 | 13.308 | | | |
| HxKT | 8 | 12.511 | 1.564 | 1.129 | .3656 | .3694 |
| HxKTxS | 40 | 55.422 | 1.386 | | | |
| WSxKT | 4 | 14.689 | 3.672 | 1.362 | .2823 | .3007 |
| WSxKTxS | 20 | 53.911 | 2.696 | | | |
| HxWSxKT | 8 | 8.644 | 1.081 | .512 | .8399 | .6651 |
| HXWSxKTxS | 40 | 84.356 | 2.109 | | | |

S=Subjects
H=Keyboard Height
WS=Wrist Support
KT=Keying Time

## 5.3 Descriptive and Non-parametric Statistical Analysis

### 5.3.1 Musculoskeletal Comfort Survey Results

Subjects tended to rate the comfort of their backs, necks, shoulders and upper arms as "comfortable", and rated the comfort of their forearms, wrists, hands, fingers as "slightly comfortable" before starting the keying task (see Tables 5.9 and 5.10). After the keying task, subjects tended to rate the comfort of their backs, necks, shoulders and upper arms as "slightly uncomfortable" to "neither comfortable or uncomfortable" regardless of Keyboard Height (see Table 9). Friedman two-way analysis of variance by ranks for the change in musculoskeletal comfort ratings due to the task showed that the effect of Keyboard Height was not significant (see Table 5.10). After the keying task, subjects tended to rate the comfort of their backs, necks, shoulders, arms, hands, and fingers as "neither comfortable or uncomfortable" to "slightly uncomfortable" when a wrist support was present, and rated the comfort of their backs, necks, shoulders, forearms and left wrist as "uncomfortable" to "slightly uncomfortable" when a wrist support was absent (see Table 5.11). For the change of musculoskeletal comfort ratings of the back, neck, shoulders, upper arms and lower arms, the Wilcoxin signed rank tests showed that the main effect of Wrist Support was significant ($p<.05$) (see Table 5.12). There was greater decrease in musculoskeletal comfort when a wrist support was absent than when a support was present (see Figure 5.11).

### 5.3.2 Keying Condition Preference Survey Results

Friedman two-way analysis of variance by ranks showed that there were significant differences ($p=.0311$) in preference rankings between the six different keyboarding conditions (see Table 5.13). The condition preferred

**Table 5.9**

Mean and median subjective ratings of musculoskeletal comfort before and after the keying task for the different keyboard heights*

| | Mean (median) Ratings | | | | | |
|---|---|---|---|---|---|---|
| | Keyboard +5 cm | | Keyboard 0 cm | | Keyboard -5cm | |
| Body Part | Before | After | Before | After | Before | After |
| Back | 6.00 (6) | 3.67 (3.5) | 6.00 (6) | 3.58 (3.5) | 5.92 (6) | 3.33 (3) |
| Neck | 5.83 (6) | 3.50 (3) | 5.83 (6) | 2.91 (3) | 5.75 (6) | 2.83 (2.5) |
| L. Shoulder | 5.58 (6) | 3.75(3) | 5.83 (6) | 3.50 (3) | 5.33 (6) | 3.33 (3.5) |
| L. Upper Arm | 5.91 (6) | 4.42 (4.5) | 6.08 (6) | 4.42 (4) | 5.67 (6) | 4.00 (4) |
| L. Forearm | 4.66 (5) | 3.17 (3) | 4.50 (4.5) | 3.17 (3) | 4.50 (4) | 3.08 (3) |
| L. Wrist | 5.08 (5.5) | 3.25 (3) | 4.92 (5) | 3.58 (3.5) | 4.75(4.5) | 3.58 (4) |
| L. Hand | 4.92 (5) | 3.42 (3) | 4.83 (4.5) | 3.42 (3) | 4.58 (4) | 3.42(3) |
| L. Fingers | 5.92 (6) | 3.83 (3.5) | 5.75 (6) | 4.50 (4.5) | 5.58 (6) | 3.58 (3.5) |
| R. Shoulder | 5.75 (6) | 3.83 (3) | 5.83 (6) | 3.58 (3) | 5.75 (6) | 3.50(3.5) |
| R. Upper Arm | 5.91 (6) | 4.50 (5) | 6.08 (6) | 4.42 (4) | 6.00 (6) | 4.08 (4) |
| R. Forearm | 4.67 (5) | 3.50 (3.5) | 4.41 (4.5) | 3.17 (3) | 4.67 (4.5) | 3.08 (3) |
| R. Wrist | 5.00 (5.5) | 3.92 (4) | 4.75 (5) | 3.67 (3.5) | 4.75(4) | 3.58 (4) |
| R. Hand | 4.83 (5) | 3.83 (4) | 4.83 (5) | 3.50 (3) | 4.67(4) | 3.50 (3.5) |
| R. Fingers | 5.75 (6) | 4.17 (4) | 5.67 (6) | 4.58 (4) | 5.50 (6) | 3.83 (4) |

*1=very uncomfortable, 2=uncomfortable, 3=slightly uncomfortable, 4=neither comfortable or uncomfortable, 5=slightly comfortable, 6=comfortable, and 7=very comfortable

**Table 5.10**

Summary of Friedman tests for the decrease in comfort ratings at different keyboard heights

| Body Part | Mean Decrease in Comfort Keyboard +5 cm | Mean Decrease in Comfort Keyboard 0 cm | Mean Decrease in Comfort Keyboard -5cm | P-value |
|---|---|---|---|---|
| Back | 2.333 | 2.417 | 2.577 | .9078 |
| Neck | 2.333 | 2.917 | 2.917 | .8139 |
| L. Shoulder | 1.833 | 2.333 | 2.000 | .7165 |
| L. Upper Arm | 1.500 | 1.667 | 1.667 | .8187 |
| L. Forearm | 1.500 | 1.333 | 1.417 | .9221 |
| L. Wrist | 1.833 | 1.333 | 1.167 | .1353 |
| L. Hand | 1.500 | 1.417 | 1.333 | .8948 |
| L. Fingers | 2.083 | 1.333 | 2.000 | .3679 |
| R. Shoulder | 1.917 | 2.250 | 2.250 | .8187 |
| R. Upper Arm | 1.417 | 1.500 | 1.917 | .5488 |
| R. Forearm | 1.167 | 1.250 | 1.583 | .6969 |
| R. Wrist | 1.083 | 1.083 | 1.167 | .7979 |
| R. Hand | 1.083 | 1.333 | 1.500 | .8318 |
| R. Fingers | 1.667 | 1.083 | 1.667 | .5719 |

**Table 5.11**

Mean and median subjective ratings of musculoskeletal comfort before and after the keying task when a support was present and absent*

| | Mean (median) Ratings | | | |
|---|---|---|---|---|
| | Support Present | | Support Absent | |
| Body Part | Before | After | Before | After |
| Back | 5.88 (6) | 4.27 (4) | 6.05 (6) | 2.78 (3) |
| Neck | 5.83 (6) | 3.72 (3.5) | 5.77 (6) | 2.44 (2.5) |
| L. Shoulder | 5.44 (6) | 4.16 (4) | 5.72 (6) | 2.89 (3) |
| L. Upper Arm | 5.88 (6) | 4.94 (5) | 5.89 (6) | 3.61 (3) |
| L. Forearm | 4.55 (4) | 4.00 (4) | 4.56 (5) | 2.28 (2) |
| L. Wrist | 4.83 (5) | 4.05 (4) | 5.00 (5.5) | 2.89 (3) |
| L. Hand | 4.61 (4) | 3.67 (3.5) | 4.94 (5.5) | 3.16 (3) |
| L. Fingers | 5.72(6) | 4.17 (4) | 5.78 (6) | 3.77 (3) |
| R. Shoulder | 5.67 (6) | 4.33 (4) | 5.89 (6) | 2.94 (3) |
| R. Upper Arm | 6.06 (6) | 5.00 (5) | 5.94 (6) | 3.67 (3.5) |
| R. Forearm | 4.56 (4.5) | 4.00 (4) | 4.61 (5) | 2.50 (2) |
| R. Wrist | 4.83 (5) | 4.17 (4) | 4.83 (5) | 3.28 (3) |
| R. Hand | 4.61 (4.5) | 3.72 (4) | 4.94 (5.5) | 3.50 (3) |
| R. Fingers | 5.56 (6) | 4.28 (4) | 5.72 (6) | 4.11 (4) |

*1=very uncomfortable, 2=uncomfortable, 3=slightly uncomfortable, 4=neither comfortable or uncomfortable, 5=slightly comfortable, 6=comfortable, and 7=very comfortable

**Table 5.12**

Summary of Wilcoxin signed rank tests for decrease in comfort ratings when the wrist support was present and absent

| Body Part | Mean Decrease in Comfort Support Present | Mean Decrease in Comfort Support Absent | P- value |
|---|---|---|---|
| Back | 1.611 | 3.271 | **.0165*** |
| Neck | 2.000 | 3.333 | **.0118*** |
| L. Shoulder | 1.278 | 2.833 | **.0113*** |
| L. Upper Arm | .944 | 2.278 | **.0036**** |
| L. Forearm | .556 | 2.278 | **.0030**** |
| L. Wrist | .778 | 2.111 | **.0066**** |
| L. Hand | .944 | 1.889 | **.0405*** |
| L. Fingers | 1.611 | 2.000 | .4955 |
| R. Shoulder | 1.333 | 2.944 | **.0077**** |
| R. Upper Arm | .833 | 2.278 | **.0047**** |
| R. Forearm | .556 | 2.111 | **.0039**** |
| R. Wrist | .667 | 1.556 | .0855 |
| R. Hand | .944 | 1.5 | .1657 |
| R. Fingers | 1.222 | 1.611 | .4179 |

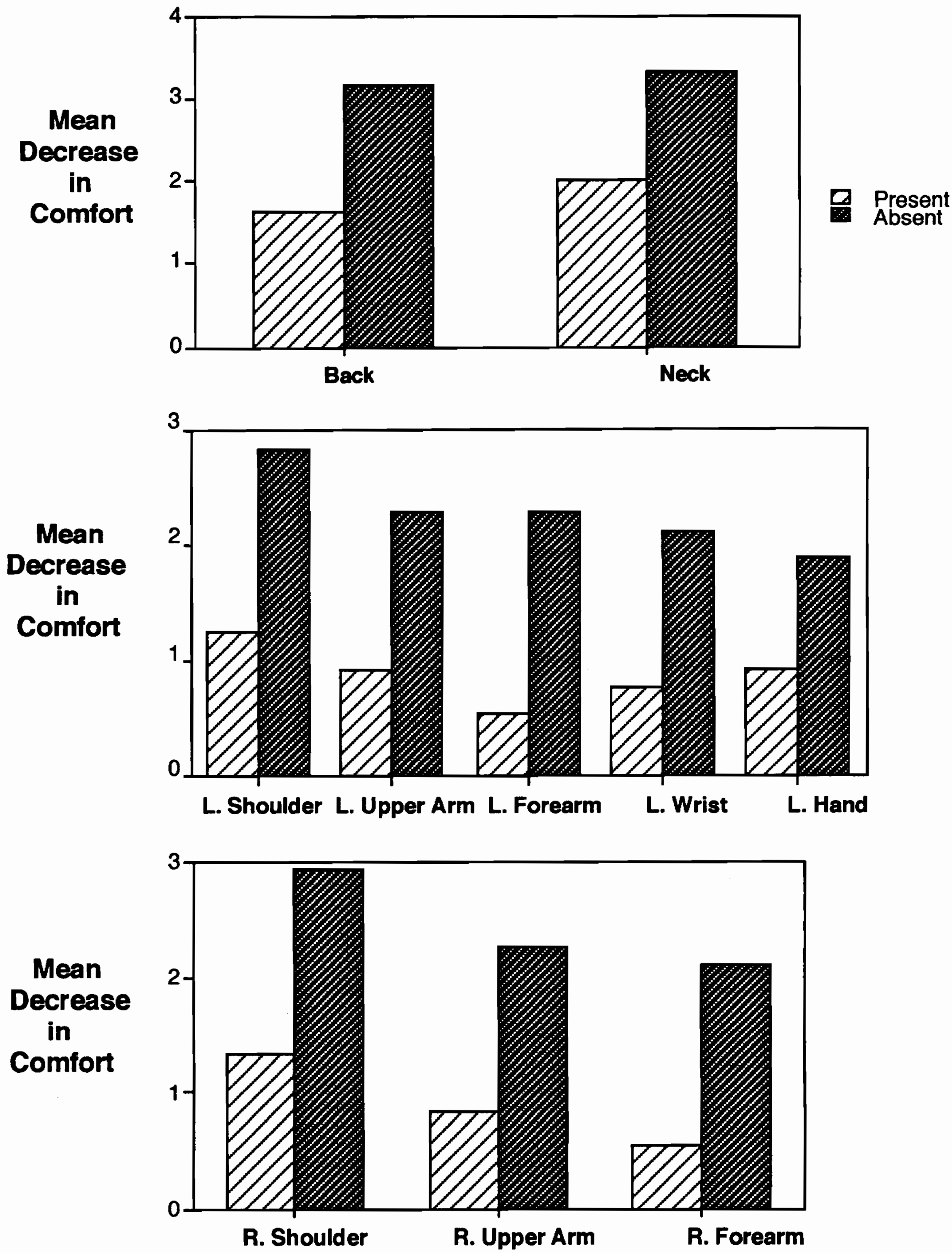



**Figure 5.11.** The significant effects ($p<.05$) of Wrist Support on the mean changes in comfort ratings (7 point comfort rating scale).

**Table 5.13**

Friedman two way analysis by ranks summary table for keying condition preference

| df | #samples | #cases | Chi-Squared | P-Value |
|---|---|---|---|---|
| 5 | 6 | 6 | 12.286 | **.0311*** |

most by the subjects was the condition of wrist support present and the keyboard located at elbow height. Preferred least was the condition of wrist support absent and the keyboard located 5 cm below elbow height. The three conditions in which a wrist support was present were preferred to the conditions in which the wrist support was absent. The mean rankings for each of the keying conditions are provided in Table 5.14. Multiple comparison tests of the mean ranks for the preference of each keying condition showed that the ranks for the condition of wrist support present and keyboard positioned at elbow height and the condition of wrist support absent and the keyboard positioned 5 cm below elbow height were significantly different ($p<.05$) (see Table 5.15).

### 5.6 Summary

- For wrist extension, the effects of Keyboard Height, Wrist Support and Keyboard Height x Keying Time were significant ($p<.05$).
- For ulnar deviation, the effects of Keyboard Height and Keying Time were significant ($p<.05$).
- For forearm pronation, the effect of Wrist Support was significant ($p<.01$).
- Mean EMG activity was 5.3 %MVC.
- No significant effects were found for EMG activity, MPF, shoulder abduction, over-all errors and interval errors.
- For the change in musculoskeletal comfort due to the keying task, the effect of keyboard height was not significant.
- For the change in musculoskeletal comfort for the back, neck, shoulders, upper arms, forearms, left wrist and left hand, the effect of Wrist Support was significant ($p<.05$).

**Table 5.14**

Mean Rankings of keying condition preference from 1 (most preferred) to 6 (least preferred)

| Condition | Description | Mean Ranking (1-6) |
|---|---|---|
| X1 | support present, keyboard 5 cm above elbow height | 2.667 |
| X2 | support present, keyboard at elbow height | 1.833* |
| X3 | support present, keyboard 5 cm below elbow height | 3.167 |
| X4 | support absent, keyboard 5 cm above elbow height | 4.333 |
| x5 | support absent, keyboard at elbow height | 3.833 |
| X6 | support absent, keyboard 5 cm below elbow height | 5.167** |

*most preferred

**least preferred

**Table 5.15**

Multiple comparisons tests of mean preference ranks for each keying condition

| Comparison | \|Difference between Means\| | Critical Value (p=.05) |
|---|---|---|
| \|X1-X2\| | 0.834 | 3.165 |
| \|X1-X3\| | 0.500 | 3.165 |
| \|X1-X4\| | 1.666 | 3.165 |
| \|X1-X5\| | 1.166 | 3.165 |
| \|X1-X6\| | 2.500 | 3.165 |
| \|X2-X3\| | 1.334 | 3.165 |
| \|X2-X4\| | 2.500 | 3.165 |
| \|X2-X5\| | 2.000 | 3.165 |
| \|X2-X6\| | **3.334*** | 3.165 |
| \|X3-X4\| | 1.166 | 3.165 |
| \|X3-X5\| | 0.666 | 3.165 |
| \|X3-X6\| | 2.000 | 3.165 |
| \|X4-X5\| | 0.500 | 3.165 |
| \|X4-X6\| | 0.834 | 3.165 |
| \|X5-X6\| | 1.334 | 3.165 |

*p<.05

# 6. DISCUSSION

## 6.1 Wrist Extension

Mean wrist extension for all keying tasks was 22 degrees. Other studies have shown similar results (Price et al., 1992; and Sauter and Schleifer, 1991). Because the degree of wrist extension may be related to the likelihood CTS, it is important to identify conditions which reduce wrist extension during keying activities.

The results of this study indicate that the use of a wrist support will reduce wrist extension during keying. Powers, Hedge and Martin (1992) concluded that use of full motion arm supports did not significantly reduce wrist extension during keying. However, in this study subjects' wrists (not forearms) were supported.

The results of this study also suggest that keyboard heights at or above seated elbow height may help reduce wrist extension. Jedrziewski (1992) did not find a significant main effect for keyboard height in spite of a larger range of heights tested, but this may be due to differences between the two studies. Jedrziewski (1993) tested both male and female subjects, using different keyboard slopes; subjects typed for 2 minutes in each condition, and did not use a wrist support. In this study, subjects used a keyboard having a positive 13 degree slope, were required to use a wrist support for one half of the conditions, and typed for 41 minutes during each condition.

## 6.2 Ulnar Deviation

In this study, mean ulnar deviation (14 degrees) was similar to that of Jedrziewski (1992) and of Sauter and Schleifer (1991). This suggests that the different experimental conditions did not have a large effect on ulnar deviation.

Ulnar deviation was slightly lower than that found by Price et al. (1989). Differences between the results of these studies might be due to differences between the electronic keyboard used by subjects in this study and the typewriter used by subjects in the study performed by Price et al. (1989).

The results of this study indicate that ulnar deviation is greater when the keyboard is positioned 5 cm above elbow height from when the keyboard is positioned at elbow height or 5 cm below elbow height. For ulnar deviation, Jedrziewski (1992) also found a similar effect.

### 6.3 Forearm Pronation

Average forearm pronation was 67 degrees and only the effect of Wrist Support was significant (p=.0027). Average forearm pronation was greater when a wrist support was present than when it was absent. The reason why wrist pronation increased with the presence of a wrist support is not clear. One possible explanation is that the subjects had to increase forearm pronation when the wrist support was present to avoid contact between the wrist monitors and wrist support.

### 6.4 Shoulder Abduction

Mean shoulder abduction (approximately 1.3 degrees) was similar to that of previous studies (Price et al., 1989; and Sauter and Schleifer, 1991). Price et al. (1989) found that for short-term observations shoulder abduction decreased with time. Although a similar trend was found in these data, the measurement technique used in this study may not have been sensitive to very small changes in shoulder abduction. The accuracy of the shoulder abduction measurement technique used in this study was not formally tested, but errors between 1 and 5 degrees are foreseeable. The very small change in shoulder abduction observed in this study may also be attributed to the relatively short duration of the keying task. Price et al. (1989) found changes in shoulder abduction over the course of a day, and the 41 minute keying period may not have been long enough to provoke large changes in shoulder abduction.

### 6.5 EMG Measurements

The mean EMG activity of the trapezius muscles during all conditions (5.3 %MVC) was similar to that found by Weber et al. (1984) and by Hagberg and Sundelin (1986). Although the muscular loading of the trapezius is relatively low during keying tasks, such static loading over long periods of time may be associated with musculoskeletal symptoms (Karwowski et al., 1990).

The effect of Wrist Support was expected to reduce the static loading and localized muscle fatigue of the trapezius muscle. In a similar study of 20 VDT operators, Weber et al. (1984) found that keyboard height and the presence of a wrist support affected EMG activity. In this study no significant effects were found for the mean EMG activity and MPF measurements. Sources of error in this study may be due to differences of subjects' skin conductivity on different days and small differences in electrode placement on different days. Additionally, some researchers have concluded that changes in MPF under low static loads may not provide reliable estimates of localized muscle fatigue (Redfern, 1992; and Wiker, 1991).

Nevertheless, for MPF, the trend of the Wrist Support x Keying Time interaction (p=.11) might suggest that MPF decreased over time when a wrist support was absent and remained constant when the support was present. Such a trend could suggest that the trapezius muscle may fatigue more rapidly during keyboard use when a wrist support is absent rather than when it is present.

### 6.6 Typing Performance

Subjects were able to perform the typing task accurately. Although relatively few typographical errors were made during the tasks, subjects reported that the keying task was challenging.

Although no significant effects were found for over-all errors, errors tended to increase with increasing keyboard height (means: 22 at -5 cm, 28 at 0 cm, and 29 at +5 cm). The potential effect of keyboard height on keying performance should be investigated further.

### 6.7 Localized Musculoskeletal Comfort

The results of the survey clearly show that the wrist support helped reduce the musculoskeletal discomfort of the upper extremities, neck and back. For the change of ratings of musculoskeletal comfort due to the keying task, the effect of Keyboard Height was not significant. The change in muscular loading of the neck, shoulders and upper arms due to postural changes might have been small due to the relatively small range of keyboard heights (10 cm) tested in this study.

Although ratings have been used in other studies examining the association between VDT workstation characteristics and musculoskeletal discomfort (Gallimore and Brown, 1993; Sauter, Schleifer and Knutson, 1991; Shute and Starr, 1984; and Lu and Aghazadeh, 1993), the rating scale used in this study has not been fully tested and validated. Therefore, there may be problems with the definitions and/or numerical scaling in this survey, and it's validity for measuring musculoskeletal discomfort should be explored in the future. In spite of the survey's potential problems, increases in musculoskeletal discomfort caused by the absence of a wrist support were found. From these results, it appears that wrist supports should be used to reduce musculoskeletal discomfort of the upper extremities, neck and back.

### 6.8 Keying Condition Preference

Subjects preferred the conditions in which a wrist support was present and the keyboard was at or above seated elbow height. Preferred most was the condition of the keyboard positioned at elbow height and the wrist support present. This condition was associated with the most neutral wrist posture and least reported musculoskeletal discomfort. The least preferred condition was when the keyboard was positioned below elbow height and the wrist support was absent.

### 6.9 General Recommendations

When determining the general recommendations, the effects of Keyboard Height, Wrist Support and Keying Time on the measures of wrist position, reported changes in musculoskeletal comfort and preferred keying condition were considered. The recommendations may help reduce the risk of musculoskeletal injury for VDT operators who perform keying tasks similar to the one studied in this experiment.

There are two major recommendations:

1. Wrist supports should be used to reduce wrist extension and reduce musculoskeletal discomfort experienced during keying tasks.
2. Keyboard heights should be at seated elbow height to reduce wrist extension and ulnar deviation. Keyboard heights below seated elbow height should be avoided.

## 6.10 Limitations

The results of the experiment were limited in the following ways:

- The wrist monitors may have inhibited normal wrist posture during keying activities. Although the measures of wrist extension and ulnar deviation agreed with previous studies, forearm pronation may have been affected by the presence of the wrist monitors; particularly when the wrist support was present.
- In this experiment, subjects were required to sit erect on a horizontal seat pan, look toward the CRT screen, keep both feet flat on the floor, and type without breaks during the keying tasks. People do not normally maintain this posture during typical keying activities. The results of this study may not be generalizeable to different keying activities.
- Only one keyboard (having a positive 13 degree slope) was used in this experiment. Keyboard slope has been found to affect wrist posture (Jedrziewski, 1992). Therefore, the recommendations of this study are intended for keyboards similar to the one used in this experiment.

## 6.11 Future Research

As a result of the conclusions and limitations of this study, three areas for future research are suggested:

- The effect of frequency and length of rest breaks on changes in musculoskeletal comfort during keying tasks.
- The effect of keyboard height and presence or absence of a wrist support on wrist posture and changes in musculoskeletal comfort when subjects assume more typical keying postures (e.g., subject is allowed

to lean back, cross legs, and adjust the horizontal distance of the keyboard).

- The validity of reported changes in musculoskeletal comfort for predicting muscular fatigue.

# 7. REFERENCES

ANSI HFS 100-1988 (1988). American national standard for human factors engineering of visual display terminal workstations. Santa Monica, CA: Human Factors Society.

Armstrong, T. J., and Chaffin, D. B. (1979). Some biomechanical aspects of the carpal tunnel. Journal of Biomechanics, 12, 567-570.

Arndt, R. (1983). Working posture and musculoskeletal problems of video display terminal operators - review and reappraisal. American Industrial Hygiene Association Journal, 44(6), 437-446.

Basamajian, J. V., and De Luca, C. J. (1985). Muscles Alive. Their Functions Revealed by Electromyography. Baltimore: Williams and Wilkins.

Bendix, T., and Jessen, F. (1986). Wrist support during typing - a controlled, electromyographic study. Applied Ergonomics, 17(3), 162-168.

Bammer, G. (1988). The prevalence of work-related neck and upper limb disorders among office workers in 7 countries - a pilot study. In Proceedings of the International Conference on Ergonomics, Occupational Safety and Health and the Environment (pp. 297-305). Beijing, China: The Chinese Society of Metals/Australian Darling Downs Institute of Advanced Education.

Brogmus, G., and Marco, R. (1991). Cumulative trauma disorders of the upper extremities: the magnitude of the problem in the U.S. industry. In W. Karwowski and J. W. Yates (Ed.), Advances in Industrial Ergonomics and Safety III (pp. 95-101). London, England: Taylor and Francis.

Brunnstrom, S., Lehmkuhl, L. K., Smith, L. K. (1989). Brunnstrom's Clinical Kinesiology (4th edition). Philadelphia, PA: F. A. Davis Company.

Cannon, L. J., Bernacki, E. J., and Walter, S. D. (1981). Personal and occupational factors associated with carpal tunnel syndrome. Journal of Occupational Medicine, 23 (4), 255-258.

Carpi, J. (1989). Keystroker's Cramp. PC Magazine, 237.

Corlett, E. and Bishop, R. (1976). A technique for assessing postural discomfort. Ergonomics, 19(2), 175-182.

Cushman, W. H. (1984). Data entry performance and operator preferences for various keyboard heights. In E. Grandjean (Ed.), Ergonomics and Health in Modern Offices (pp. 495-506). London, England: Taylor and Francis.

Erdelyi, A., Sihvonen, T., Helin, P., and Hanninen, O. (1988). Shoulder strain in keyboard workers and its alleviation by arm supports. International Archives of Occupational and Environmental Health, 60, 119-124.

Fries, A. C., and Clayton, D. (1975). Timed Writings about Careers (2nd edition). Cincinnati, OH: South-Western.

Gallimore, J., and Brown, M. (1993). Effectiveness of the C-Sharp: reducing ergonomics problems at VDTs. Applied Ergonomics, 24(5), 327-336.

Gardner, W. and Osburn, W., (1973). Structure of the Human Body (2nd ed.). Philadelphia, PA: Saunders.

Gengel, S., Washburn, J. M. III, and Wick, J. (1991). Carpal tunnel syndrome prevention: a case study. In W. Karwowski and J. W. Yates (Ed.), Advances in Industrial Ergonomics and Safety III (pp. 117-120). New York: Taylor and Francis.

Grandjean, E. (1984). Postural problems at office machine work stations (introductory paper). In E. Grandjean (Ed.), Ergonomics and Health in Modern Offices (pp. 445-455). London, England: Taylor and Francis.

Green, R. A., Briggs, C. A. (1989). Anthropometric dimensions and overuse injury among Australian keyboard operators. Journal of Occupational Medicine, 31(9), 747-750.

Hagberg, M. and Sundelin, G. (1986). Discomfort and load on the upper trapezius muscle when operating a word processor. Ergonomics, 29(12), 1637-1645.

Hahn, K., Chin, D., Ma, P., and Rebello, S. (1991). Cumulative trauma disorder reductions in the industrial workplace: a systems approach. In W. Karwowski and J. W. Yates (Eds.), Advances in Industrial Ergonomics and Safety III (pp. 147-154). London, England: Taylor and Francis.

Hoyt, W. R. (1984). Carpal tunnel syndrome: analysis and prevention. Professional Safety, November, 16-21.

Jedrziewski, M. (1992) Wrist posture as a function of keyboard height and slope. Unpublished master thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Johnson, K. (1985). Analytical report on the causes an prevention's of carpal tunnel syndrome. Professional Safety, October, 48-51.

Kapit, W., and Elson, L. (1977). The Anatomy Coloring Book. New York, NY: Harper and Row.

Karwowski, W., Noland, S., Eberts, R. and Salvendy, G. (1990). Effects of keying method, image preview and work/rest schedule on posture of the remote bar coding operators. In Proceedings of the Human Factors Society 34th

Annual Meeting (pp. 738-742). Santa Monica, CA: Human Factors Society.

Knave, B. G., Wibom, R. I., Voss, M., Hedstrom, L. D., and Bergovist, U. O. V. (1985). Work with display terminals among office employees. Scandinavian Journal of Work Environment and Health, 11, 457-466.

Kroemer, K. H. E. (1989). Cumulative trauma disorders: their recognition and ergonomics measures to avoid them. Applied Ergonomics, 20(4), 274-280.

Kroemer, K. H. E., Kroemer, H. J., and Kroemer-Ebert, K. E. (1986). Engineering Physiology: Physiologic Bases of Human Factors/Ergonomics. New York, NY: Elsevier.

Lamb, R. and Hobart, D. (1992). Anatomic and physiologic basis for surface electromyography. In G. Soderberg (Ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives (pp. 5-22). Cincinnati, OH: U. S. Department of Human Services.

Landau, B. R. (1976). Essential Human Anatomy and Physiology. Glenview, IL: Foresman and Company.

Langley, L., and Christensen, J. B. (1978). Structure and Function of the Human Body. Minneapolis, MN: Burgess.

Leeson, C. R., and Leeson, T. S. (1989). Human Structure. Toronto, Ontario: B.C. Decker.

LeVeau, B. and Andersson, G. B. J. (1992). Output forms: data analysis and applications interpretation of the electromyographic signal. In G. Soderberg (Ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives (pp. 69-102). Cincinnati, OH: U. S. Department of Human Services.

Linton, S. and Kanwendo, K. (1989). Risk factors in the psychological work environment for neck and shoulder pain in secretaries. Journal of Occupational Medicine, 31(7), 609-613.

Low, I. (1990). Musculoskeletal complaints keyboard operators. Journal of Occupational Health and Safety, 6(3), 205-211.

Lyon, B. K. (1992). Video display terminal ergonomics. Professional Safety, June, 32-39.

Lu, H. and Aghazadeh, F. (1993). VDT positions: effect on performance and comfort. In Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society (pp. 397-400). Santa Monica, CA: Human Factors and Ergonomics Society.

Manuele, F. A. (1991) Workers' compensation cost control through ergonomics, Professional Safety, December, 27-32.

Marras, W. (1992). Applications of electromyography in ergonomics. In G. Soderberg (Ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives (pp. 121-143). Cincinnati, OH: U. S. Department of Human Services.

McClintic, J. (1975). Physiology of the Human Body. New York, NY: Wiley.

Ong, C. N. (1984). VDT work place design and physical fatigue: a case study in Singapore. In E. Grandjean (Ed.), Ergonomics and Health in Modern Offices (pp. 484-494). London, England: Taylor and Francis.

Pagnanelli, D. M. (1989). To your health: light at the end of the carpal tunnel. Nation's Business, August, 69.

Powers, J. R., Hedge, A., and Martin, M. G. (1992). Effects of full motion arm supports and a negative sloped keyboard support system on hand-wrist posture while keyboarding. In Proceedings of the Human Factors Society 36th Annual Meeting (pp. 796-800). Santa Monica, CA: Human Factors Society.

Price, D. L., Fayzmehr, F., and Beaton, R. (1989). Field observations on the ergonomics of typewriting. In Kurt Landau and Walter Rohmert (Ed.), Recent Developments in Job Analysis, 199-206.

Putz-Anderson, V. (Ed.). (1988). Cumulative trauma disorders: a manual for musculoskeletal diseases of the upper limbs. Bristol, PA: Taylor and Francis.

Redfern, M. (1992). Functional muscle: effects on electromyographic output. In G. Soderberg (Ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives (pp. 103-120). Cincinnati, OH: U. S. Department of Human Services.

Rockwell, J. R. (1992). Characteristics of muscle co-contraction during isometric tracking. Unpublished masters thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Sauter, S. L., Chapman, L. J., Knutson, S. J., and Anderson, H. A. (1987). Applied Ergonomics, 18(3), 183-186.

Sauter, S. L., Schleifer, L. M., and Knutson, S. J. (1991). Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. Human Factors, 33(2), 151-167.

Schoenmarklin, R. W., and Marras, W. S. (1991). Quantification of wrist motion and cumulative trauma disorders in industry. In Proceedings of the Human Factors Society 35th Annual Meeting (pp. 838-842). Santa Monica, CA: Human Factors Society.

Shute, S. and Starr, S. (1984). Effects of adjustable furniture on VDT users. Human Factors, 26(2), 157-170.

Silverstein, B., Fine, L., and Armstrong, T. (1987). Occupational factors and carpal tunnel syndrome. American Journal of Industrial Medicine, 11, 343-358.

Sjogaard, G., Christensen, H., and Pedersen, M. B. (1991). In Proceedings of the Eleventh Congress of the International Ergonomics Association (pp. 123-125). London, England: Taylor and Francis.

Smith, M. (1987). Ergonomic problems dog VDT use. Occupational Hazards, December, 39-41.

Soderberg, G. L. (1992). Recording Techniques. In G. Soderberg (Ed.), Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives (pp. 44-68). Cincinnati, OH: U. S. Department of Human Services.

Stock, S. R. (1991). Workplace ergonomic factors and the development of musculoskeletal disorders of the neck and upper limbs: a meta-analysis. American Journal of Industrial Medicine, 19, 87-107.

Takala, E., Viikari-Juntura, E., Moneta, G. Saarenmaa, K., and Kaivanto, K. (1991). Predictors for the natural course of neck-shoulder symptoms and headache in light sedentary work. W. Karwowski and J. W. Yates (Ed.). In Advances in Industrial Ergonomics and Safety III (pp. 129-131). New York, NY: Taylor and Francis.

Weber, A., Sancin, E., and Grandjean, E. (1984). The effects of various keyboard heights on EMG and Physical Discomfort. In E. Grandjean (Ed.), Ergonomics and Health in Modern Offices (pp. 477-483). London, England:

Taylor and Francis.

Wiker (1986). Effects of relative hand location upon movement time and fatigue. Unpublished dissertation, University of Michigan, Ann Arbor, MI.

Woersted, M., Bjorklund, R. A., and Westgaard, R. H. (1991). Shoulder muscle tension induced by two VDU-based tasks of different complexity. Ergonomics, 34(2), 137-150.

# APPENDIX A: Pilot Study Results

Various wrist posture data, EMG data, subjective ratings of discomfort, and typing performance data were obtained from four subjects in five pilot tests to help ensure that the experimental apparatus and procedures were properly planned, and to provide insight for the experimental results. Selected results for the pilot tests appear in Figures A1-A10. The results of the pilot tests are outlined below.

Typing performance

Subjects usually had higher error rates in the experimental typing task than in the initial three minute typing test. Typically, a subject making 1 error per minute on the typing test could make up to 3 errors per minute in the typing task. Keying time did not seem to have a large effect on error rates (error rates were consisted throughout the typing task for each subject).

Regression Analysis of Wrist Calibration Values

During the wrist monitor calibration procedures voltages were recorded at different wrist deviations. A regression analysis provided linear equations which predicted angles from the voltages accurately ($R^2$ was consistently greater than .98). Figure A.1 shows a typical regression model predicting wrist deviation angle from voltages. The wrist deviation angles during the experimental sessions are calculated from the regression models.

Wrist Posture

During the pilot sessions in which subjects performed the typing task without a support above elbow height, wrist extension and ulnar deviation increased with time (See Figures A.2 and A.3). Some data suggest that pronation decreases during the course of the keying task (See Figure A.4).

EMG RMS Values

During pilot tests in which subjects performed the keying tasks only absolute RMS values of EMG activity were obtained. As expected, RMS values for trapezius muscle activity were smaller when a wrist support was used than when no support was used. RMS values did not appear to change over time (See Figure A.5).

MPF of the Power Spectrum

MPF values for the EMG power spectrum did not appear to be effected by time, the presence or absence of a wrist support, or keyboard height. The use of EMG spectral analysis for the small muscular exertions of the trapezius during the keying may not be sensitive to localized muscle fatigue. Figure A.6 depicts the power spectrum of a raw EMG signal obtained during a sampling period. Figure A.7 shows MPF values for the right and left trapezius for one subject during two experimental conditions.

Shoulder Abduction

The shoulder abduction angle was small (usually about 10 degrees). Time did not seem to have a large effect on shoulder abduction (See Figure A.8). Shoulder abduction angles obtained are estimated to be within 3 degrees of accuracy. Small changes in shoulder abduction are not expected to significantly affect wrist posture or EMG data; therefore this level of accuracy appears adequate.

Subjective Ratings of Comfort

Ratings of comfort after the typing task show that the shoulders, neck, and lower back have the greatest discomfort. Figure A.9 shows subjective ratings of localized comfort for a subject before and after performing a typing task without a wrist support and having the home row keys 5 cm above seated elbow height.

Body Posture and Procedures for MVC

A pilot test was conducted to determine which body posture and muscular exertion would produce the greatest muscular activity in the descending portion of the trapezius muscles. Numerous postures and efforts were attempted by two subjects and the condition which appeared to produce the most muscular activity required subjects to stand with the shoulder flexed 90 degrees, hold an anchored strap with the hand, and perform a maximum safe shoulder elevation. This condition, therefore, appears to be the best measure of MVC of the upper trapezius muscle. Figure A.10 shows mean RMS values for the right and left trapezius muscles during several of the conditions.

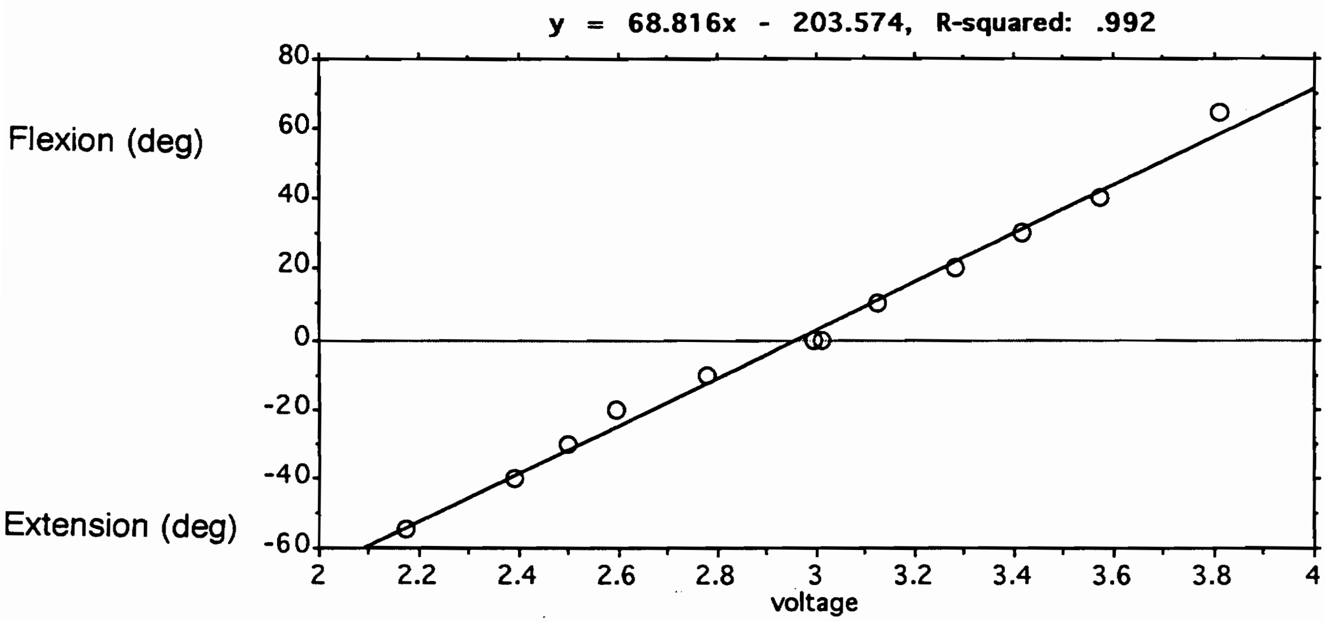



**Figure A1.** Regression model predicting wrist deviation angle from voltage.

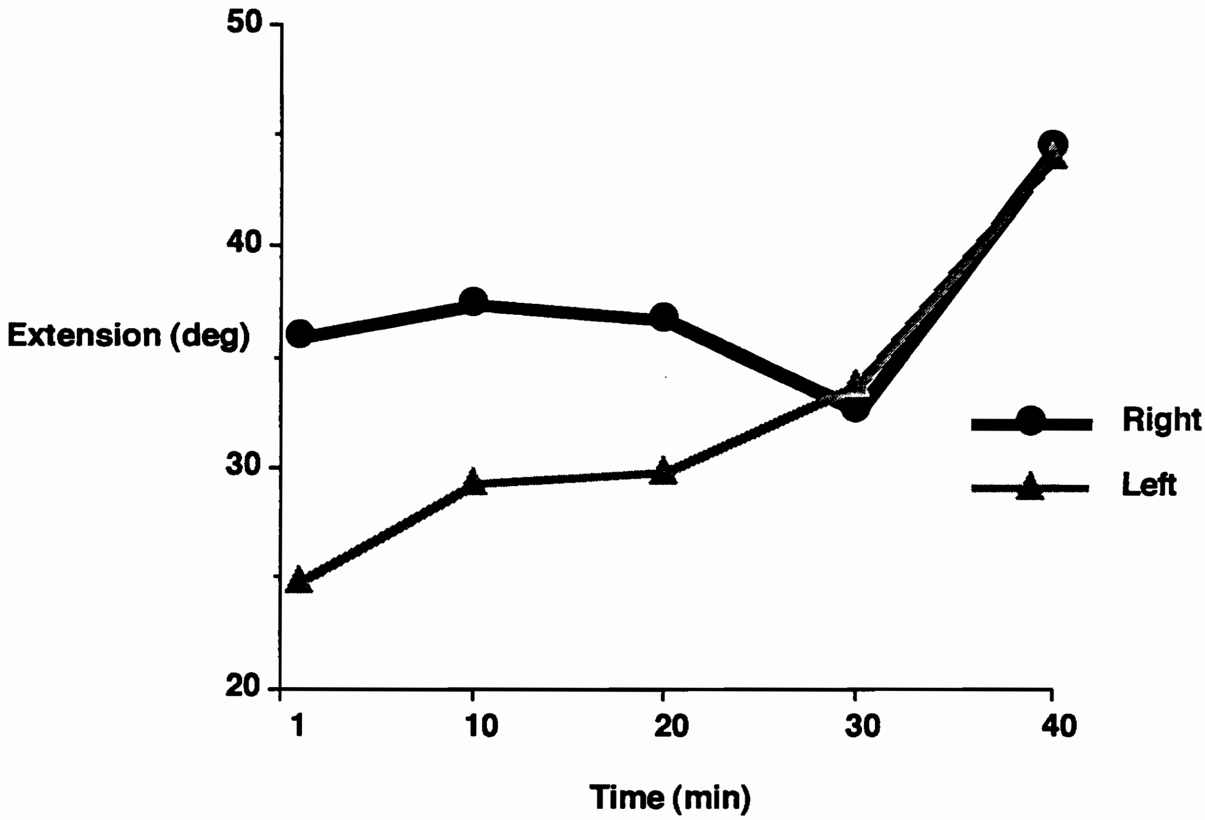



**Figure A2.** Right and left wrist extension as a function of keying time (wrist support absent; home row keys 5 cm above elbow height).

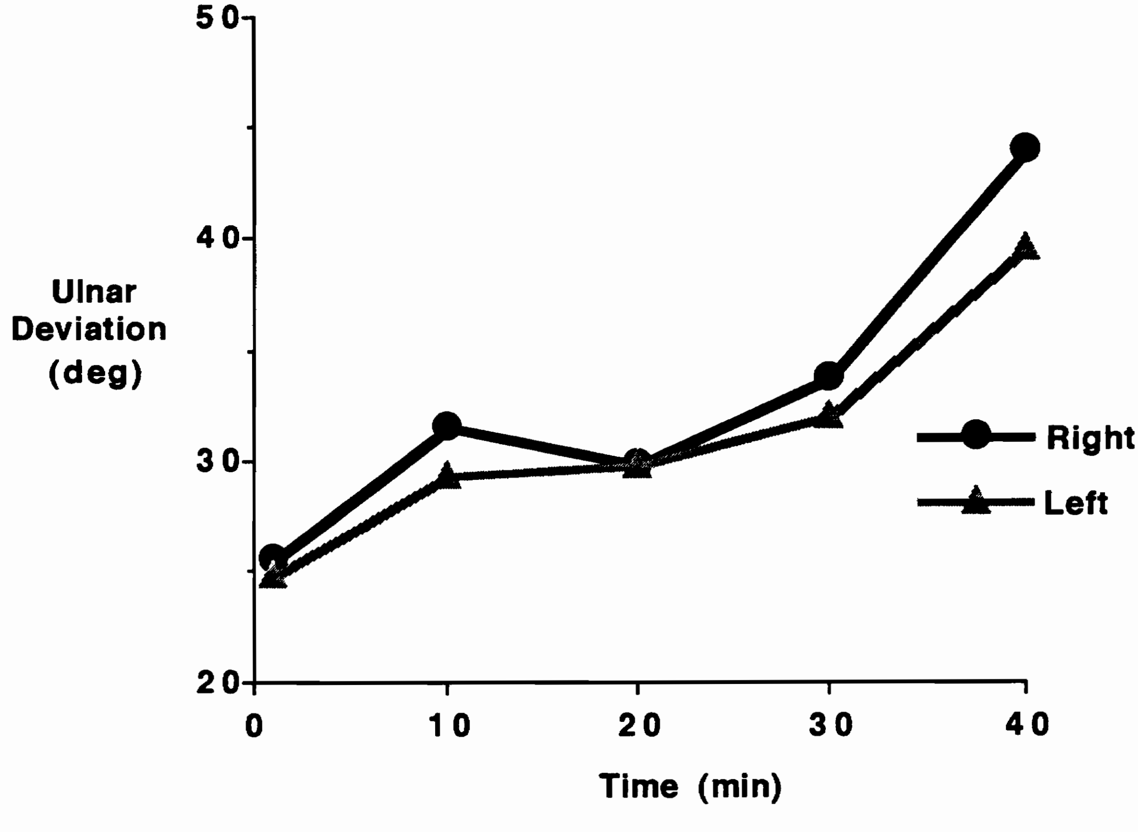



**Figure A3.** Right and left ulnar deviation as a function of keying time (wrist support absent; home row keys 5 cm above elbow height).

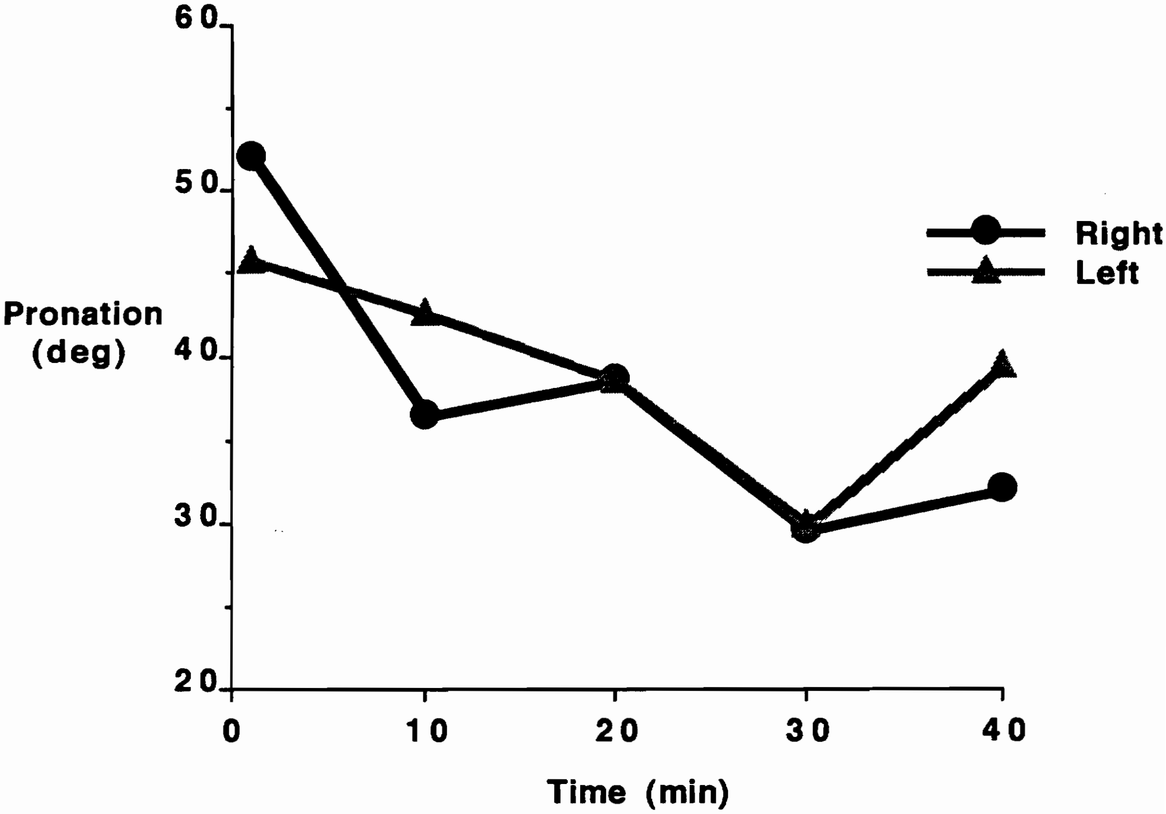



**Figure A4.** Right and left pronation as a function of time (wrist support absent; home row keys 5 cm above elbow height).

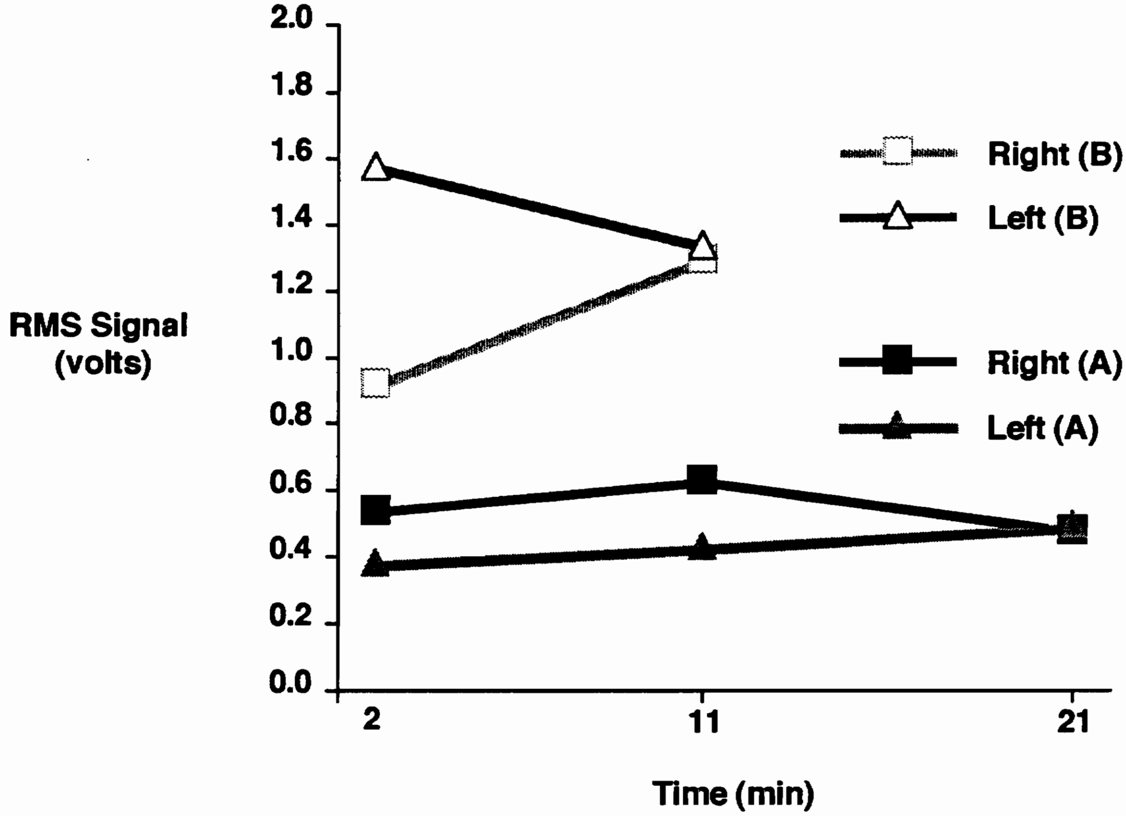
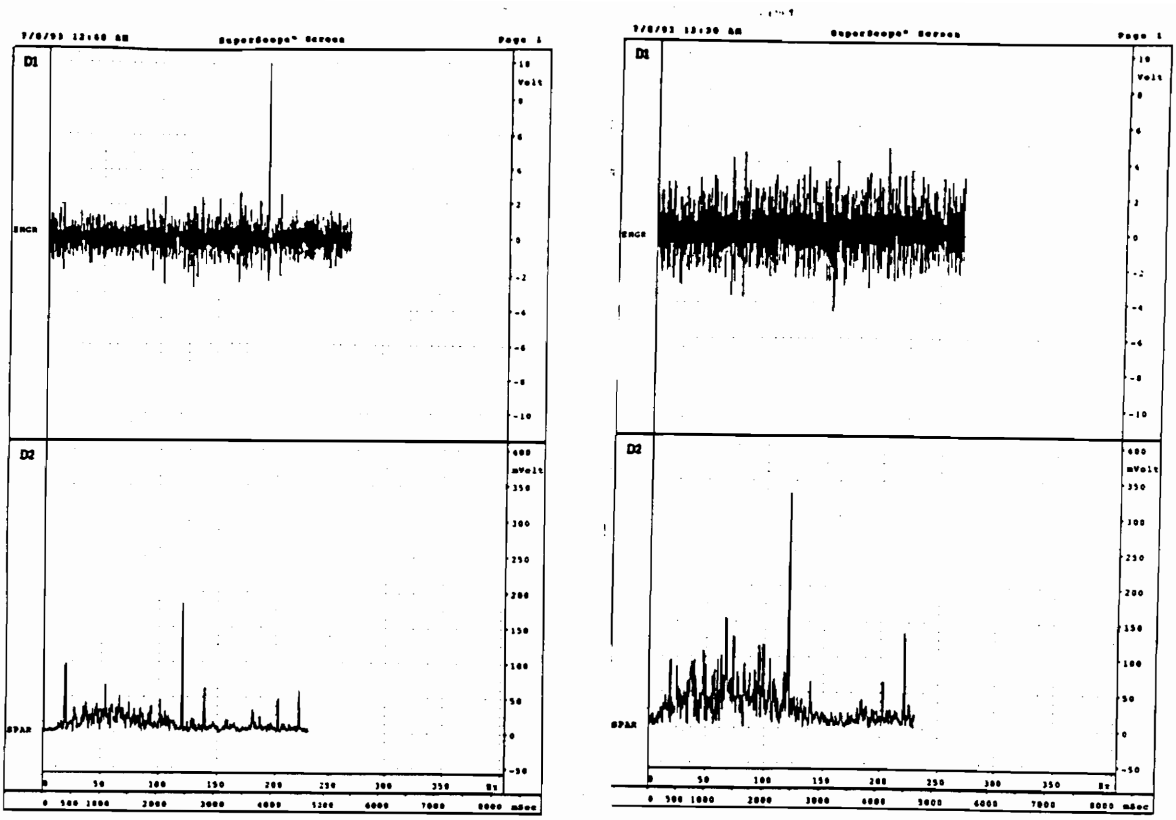



**Figure A5.** Right and left trapezius EMG RMS values for one subject in two conditions:

A) support present; home row keys 2.5 cm below elbow height
B) support absent; home row keys 2.5 cm above elbow height.



**A** **B**

**Figure A6.** Right and left trapezius EMG raw data and EMG frequency spectrum for one subject in two conditions after 11 Minutes of keying:

A) support present; home row keys 2.5 cm below elbow height
B) support absent; home row keys 2.5 cm above elbow height.

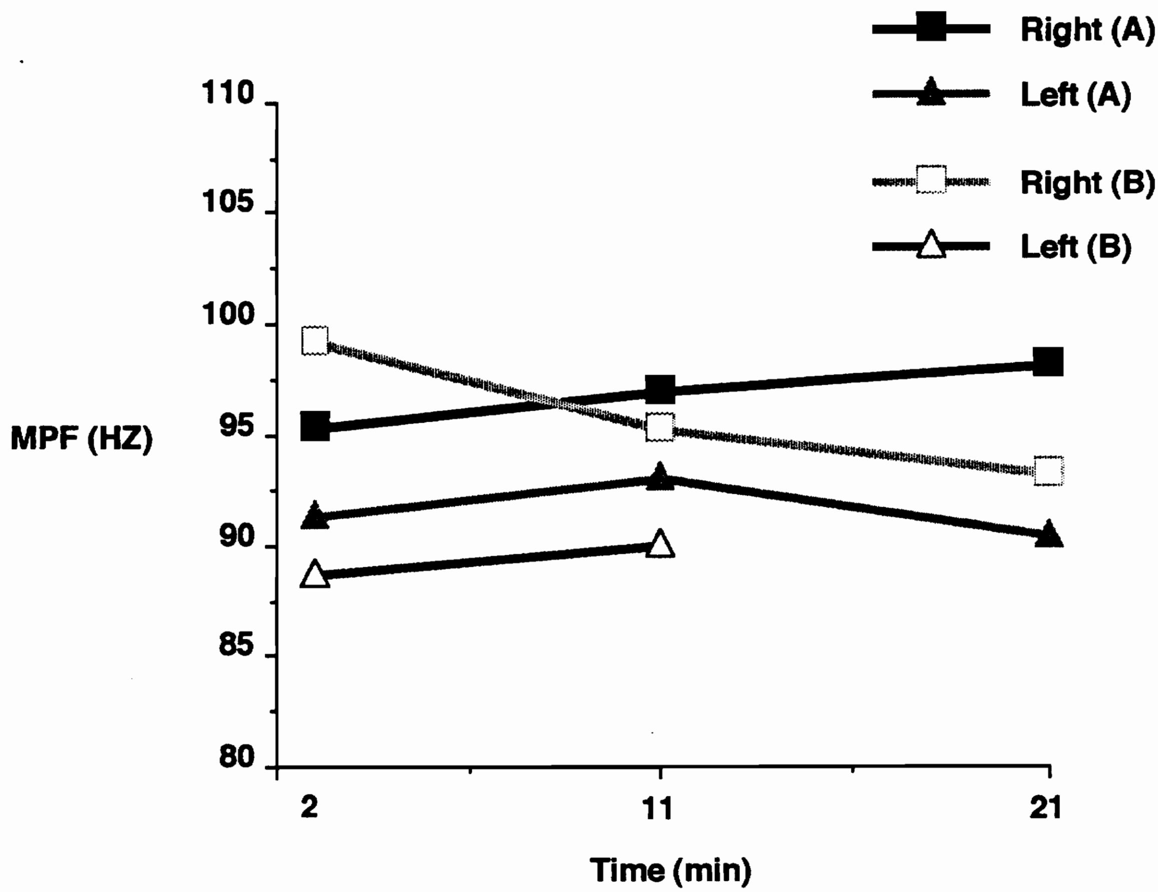



**Figure A7**. Right and left MPF as a function of time (support absent; home row keys 5 cm above elbow height).

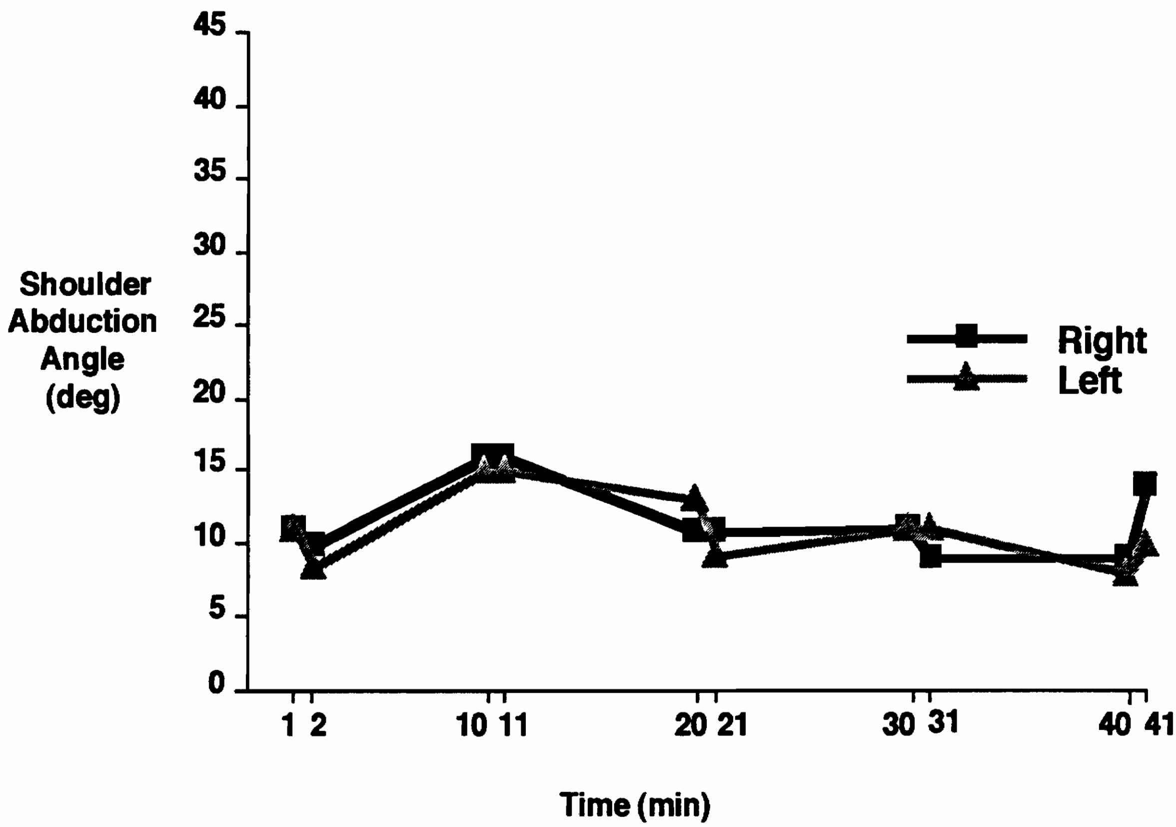



**Figure A8.** Right and left shoulder abduction as a function of time (support absent; home row keys 5 cm above elbow height).

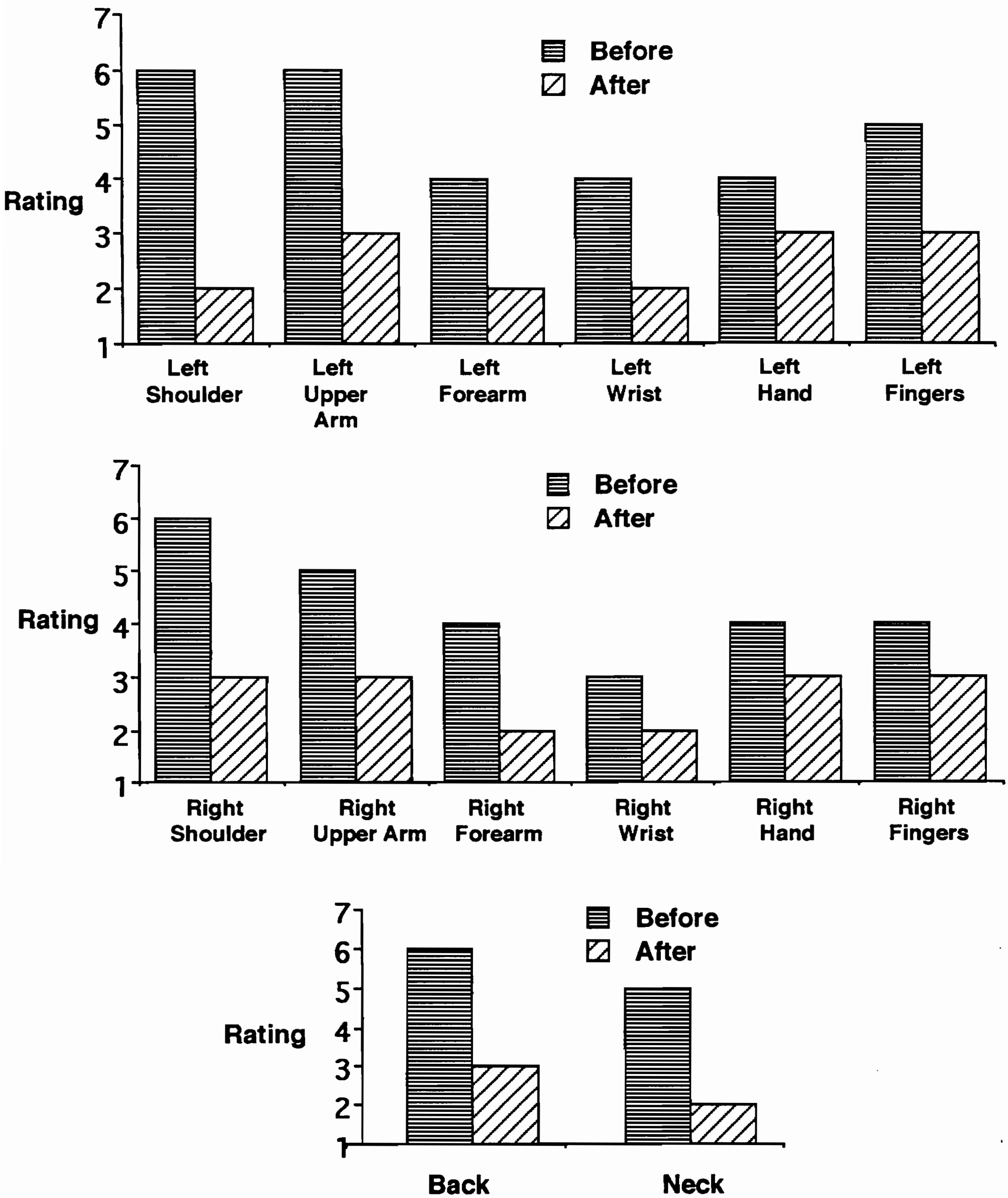



**Figure A9.** Subjective ratings of comfort before and after the keying task: 1 = very uncomfortable; 7 = very comfortable. (support absent; home row keys 5 cm above elbow height).

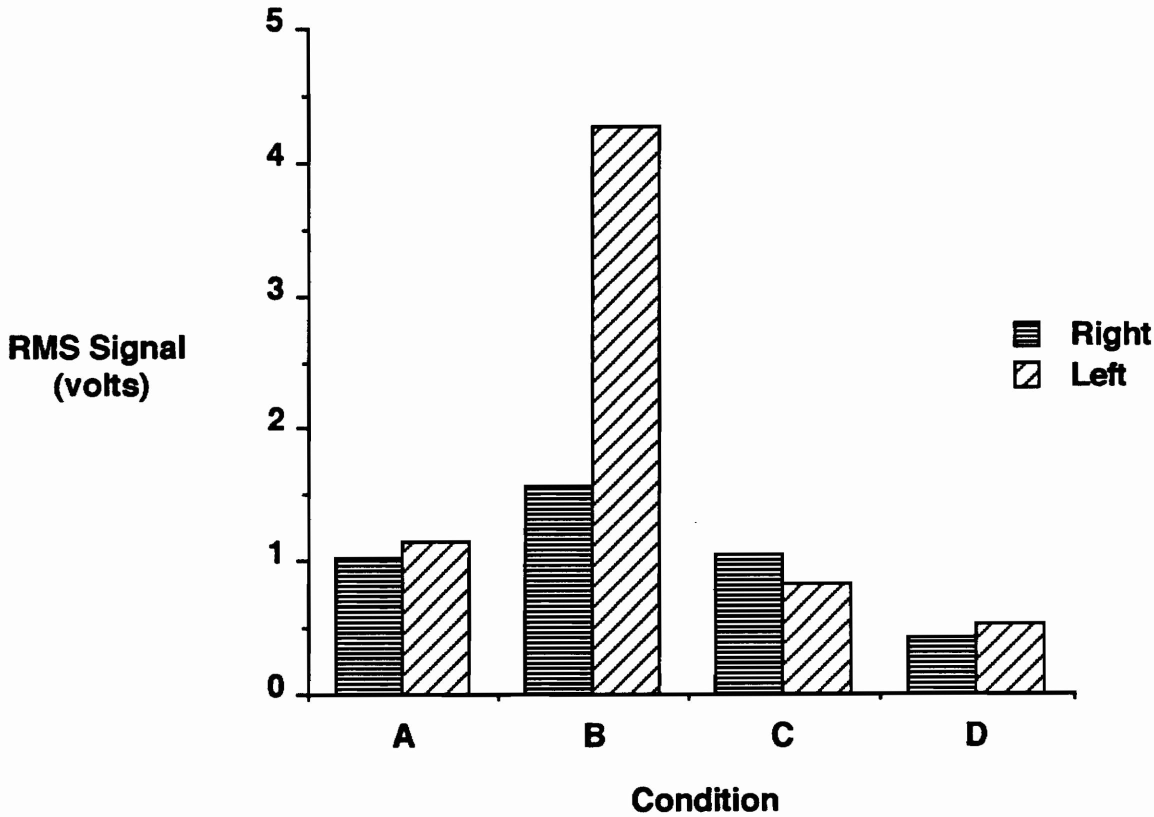



**Figure A10.** Right and left trapezius MVC RMS values under several different conditions:

A) anchored shoulder strap is placed around acromion process; subject performs maximum safe elevation
B) subject holds anchored strap in hand; has shoulder flexed 90 degrees; and performs maximum safe elevation
C) subject holds anchored strap in both hands at waist level; and performs maximum safe shoulder elevation
D) subject presses forehead against a fixed surface.

## APPENDIX B: Written Instructions for Experiment

## Keyboarding Study: Description and Subject Instructions

Thank you for participating in this study. This experiment is being conducted in the Environmental and Safety Laboratory of the Human Factors Engineering Center at Virginia Tech. It is being performed by Victor Paquet under the supervision of Dr. Kroemer, a professor in the Department of Industrial and Systems Engineering.

The major intent of this study is to examine how different keyboard heights and the presence (and absence) of a wrist support affect wrist posture and muscle activity of the shoulder during a keying task. If you agree to participate in this experiment you will be expected to attend six experimental sessions. Although you will only perform the actual keying task for approximately forty minutes during each experimental session, each session will take about 2 to 2.5 hours of your time. You will be paid $5.00 per hour for your participation and, upon completion of the six experimental session, you will receive an additional $10.00 bonus.

At the beginning of each experimental session you will be fitted with wrist monitors (these record wrist posture) and EMG surface electrodes (these record shoulder muscle activity). The wrist monitors will be attached to the wrists with Velcro straps and adhesive tape. Two electrodes will be placed on each trapezius muscle (near the location where the shoulder and neck meet), while one electrode will be attached to your earlobe.

After you have been fitted with the wrist monitors and electrodes, the measuring devices will be calibrated. During the calibration of the wrist monitors you will be required to bend and rotate your wrists at fixed intervals. During the calibration of the EMG electrodes, you will be connected to a device which measures force, and required to shrug each of your shoulders. It is important that you give your maximum safe effort during the shrugs.

Before you begin the typing task, the computer workstation will be adjusted to fit your body dimensions. The seat of the chair will be adjusted to enable you to place your feet flat on the floor while bending your knees 90 degrees. A padded reference bar will be adjusted so that it rests very lightly against your forehead. The computer screen will be adjusted so the top edge is no higher than seated ear height. They keyboard will be positioned so that the home row of keys is at one of three heights: 5 cm above seated elbow height (determined when your arms are down by your sides), at elbow height, and 5 cm below elbow height. A wrist support may or may not be attached to the surface that supports the keyboard. Each experimental session will have a different combination of keyboard height and the presence (or absence) of a wrist support. Thin reflective tape will also be placed on your shirt over your spinal column and on the backs of your arms. You will also be required to fill out a brief questionnaire concerning comfort.

During the keyboarding task, text will be displayed in a "window" on a computer screen and you will be required to type the text as it appears in the window. The text will be displayed at a fixed rate, and your typed text will be shown in a similar "window" below the display window on the computer screen. The typing tasks will take approximately 40 minutes to complete and will be videotaped. Your face will not appear on the videotape and the tape will be destroyed after the data analysis.

After you complete the typing task, the wrist monitors, electrodes, and reflective tape will be removed and you will be required to complete a brief questionnaire to indicate which muscles experienced discomfort or fatigue (if any).

The data from the experiment should be analyzed by September, 1993. The results will be made available to you at your request. The members of the research team are:

Victor Paquet, Graduate Student, ISE Department
Dr. K.H.E. Kroemer, Professor, ISE Department

If you have any questions or concerns about the way you have been treated during this experiment, please contact Janet Johnson, Acting Associate Provost/Research at 231-6077.

Your participation in this experiment is most appreciated. We hope you enjoy this experience.

## APPENDIX C: Informed Consent Form

**Keyboarding Study: Informed Consent**

This form constitutes informed consent by you to participate in this study. Please read it carefully and sign in the space provided below.

Your rights as a subject are:

1. It is your right as a subject to withdraw from this experiment at any time and for any reason.

2. You have the right to ask the researchers any questions regarding the experiment, and you should not sign this consent form until you fully understand the terms involved.

3. You have the right to review your data and withdraw it from the study if you so desire. Please inform the experimenter immediately of such a decision because the data will be recorded anonymously and cannot be tracked once the experiment is over.

4. You have the right to be informed of any risks or discomforts in this research. Although there is minimal risk associated with this experiment, you may experience some muscle discomfort or fatigue while performing the keying task. You may also feel some temporary redness or discomfort upon removal of the EMG electrodes and wrist monitors which will be attached to the shoulder and wrists with adhesive tape.

5. If you have any other questions regarding any aspect of the experiment, you should contact one of the researchers. If you have any concerns about the way the experiment is being conducted or the way you are being treated, you may contact Janet Johnson, Acting Associate Provost/Research at 231-6077.

Your participation is greatly appreciated and we hope that you will find the study interesting. Your signature below indicates that you have read this document, that your questions have been answered, and that you consent to participate in this study.

Signature: ______________________________ Date: ____________

Printed Name: ______________________________

Address: ______________________________

______________________________

## APPENDIX D: Subjective Assessment of Localized Comfort

## Musculoskeletal Comfort Survey

Consider the following descriptions:

Uncomfortable: hurt, sharp ache, dull ache, cramp, strain, numbness, tingling
Comfortable: the absence of discomfort; and relaxed, restful, or relieved feeling

Rate how each body part feels at this moment.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| **Very Uncomfortable** | **Uncomfortable** | **Slightly Uncomfortable** | **Neither Comfortable nor Uncomfortable** | **Slightly Comfortable** | **Comfortable** | **Very Comfortable** |

Back: _____

Neck: _____

| | | | |
|---|---|---|---|
| Left shoulder | _____ | Right shoulder | _____ |
| Left upper arm | _____ | Right upper arm | _____ |
| Left forearm | _____ | Right forearm | _____ |
| Left wrist | _____ | Right wrist | _____ |
| Left hand | _____ | Right hand | _____ |
| Left fingers | _____ | Right fingers | _____ |

Additional comments about the comfort or discomfort you felt during the keying task:

______________________________________________

______________________________________________

# VITA

Victor Leo Paquet III was born on February 14, 1969 in Malden, MA. While majoring in engineering psychology, he graduated with a B.S. degree from Tufts Univerity in May of 1991. He then attended Virginia Polytechnic Insitute and State University to pursue an M.S. degree in industrial and systems engineering (human factors and safety options). Between his first and second years at Virginia Tech he interned in the Loss Control Department of Chubb Group of Insurance Companies in Washington, D.C. He is currently a member of the Human Factors and Ergonomics Society and American Society of Safety Engineers, and is now pursuing a Sc.D. degree in work environment (ergonomics concentration) at the University of Massachusetts Lowell.

Victor L. Paquet

Victor Leo Paquet III