# Effects of Negatively Sloped Keyboard Wedges on User Performance and Perceptions

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## (ABSTRACT)

Of the studies that considered negatively sloped keyboards, results showed improved comfort and postural effects while typing on keyboards; however, few studies of negatively sloped keyboard angles and their resulting effects on objective physiological measures, psychological measures, and performance have been performed. The objective of this study was to quantify the effects of negative keyboard slopes on forearm muscle activity, wrist posture, key strike force, perceived discomfort, and performance to identify a negative keyboard angle or range of keyboard angles that minimizes exposure to hypothesized risk factors for hand/wrist work related musculoskeletal disorders.

Ten experienced typists (4 males and 6 females) participated in a laboratory study to compare keyboard slopes ranging from 7° to –30°, at 10° increments from 0° to –30°, using an experimental wedge designed for use with QWERTY keyboards. Repeatability was examined by requiring participants to complete the experiment in two test sessions one week apart. Dependent variable data was collected during 10 minute test sessions.

Wrist posture data revealed postural benefits for negative angles of 0° or greater compared to 7°. Specifically, the percentage of wrist movements within a neutral zone and percentage of wrist movements within ±5° and ±10° degrees increased as keyboard angle became more negative. EMG results were mixed with some variables supporting negative keyboard angles, while other results favored the standard keyboard configuration. Net typing speed supported the -10° keyboard angle, while other negative typing angles were comparable, if not better, than the standard. These findings showed that there was strong support for improved postural changes associated with negatively sloped keyboard wedges, though user perceptions favored the standard configuration.

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# CHAPTER I
# INTRODUCTION

## Background

The estimated costs associated with work related musculoskeletal disorders (WMSDs) range from 13 to 54 billion dollars annually (US Dept. of Health and Human Services, 2001). Research in the area of computer workstation design, most notably keyboard design and placement, has been driven by the growing number of cases of carpal tunnel syndrome (CTS) and similar WMSDs associated with their use. In 1999, there were 27,922 new CTS cases, an increase from 26,266 reported cases in 1998 (Figure I.1) (BLS, 2001). Repetitive motion injuries of the wrist have accounted for over 67% of the total number of repetitive motion injury cases for the upper extremities since 1992 (Figure I.2) (BLS, 2001). CTS cases have consistently accounted for over 50% of all repetitive motion injuries reported in the upper extremities for the same time span (BLS, 2001).

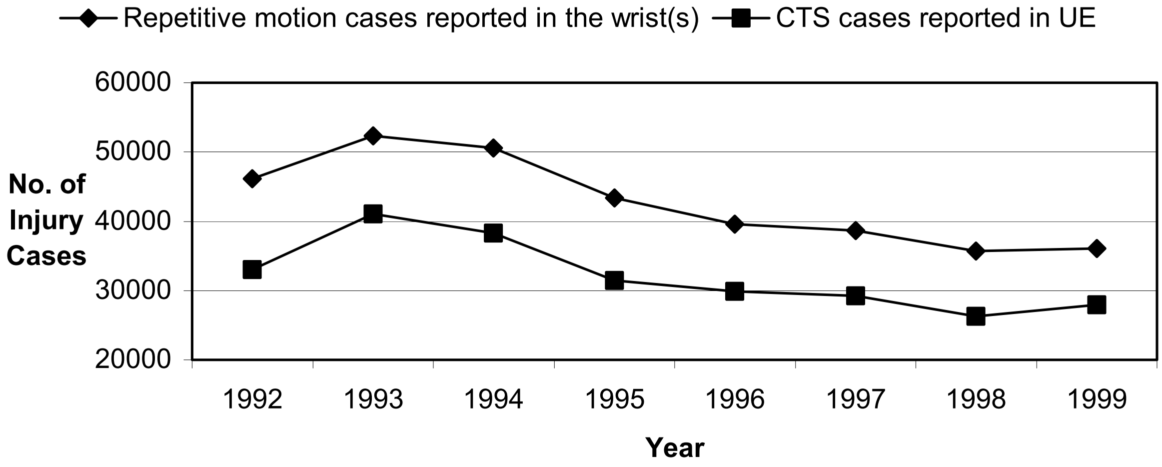

Figure I.1. Number of injury cases reported in the wrist(s) for CTS resulting in lost workdays (*data from* BLS, 2001)

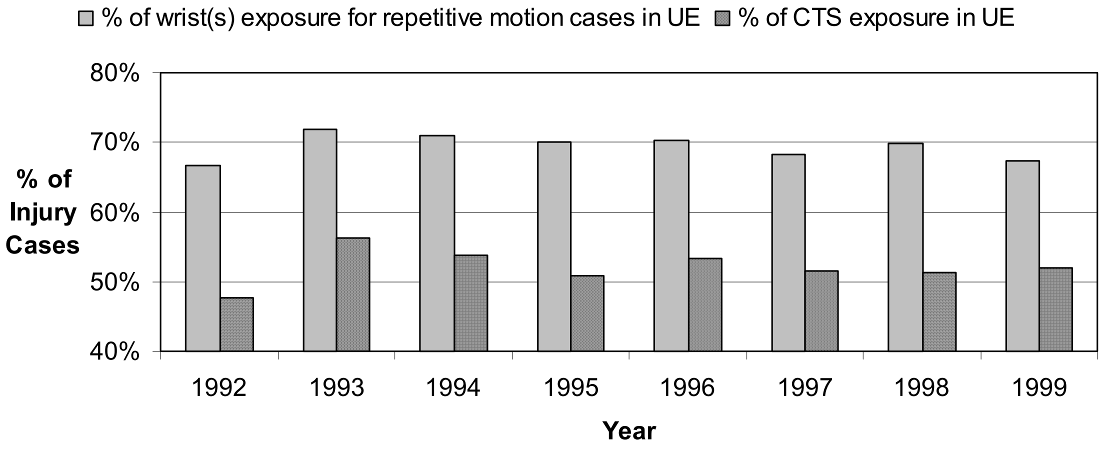

Figure I.2. Percentage of reported wrist and CTS cases of the UE resulting in lost work days (*data from* BLS, 2001)

Keyboard design research has focused on ulnar and radial wrist deviation, wrist extension, wrist support, forearm support, and shoulder and neck effects while using conventional keyboards, fixed and adjustable split-angle keyboards, natural or Kinesis™ keyboards, or more radical keyboard designs, such as the chair-mounted split keyboard and open or TONY™ keyboard. Wrist extension, or positively angled wrist and hand orientation, has become standard when discussing keyboard angles. This fact is eminent when considering the design of the conventional keyboard—each row, from bottom to top, is consecutively higher, resulting in a positively sloped keyboard face. This design forces keyboard users to conduct typing tasks predominantly with wrists, hands, and fingers extended. Only in the past decade has wrist flexion become a consideration for keyboard design in contrast to the accepted standard, said to be between 0° and a positive 25° slope (ANSI/HFS 100, 1988).

Few keyboards or keyboard apparatuses have features that achieve a zero- or negative-degree slope. The apparent advantage of a negatively sloped keyboard is to decrease the positive sloping of conventional keyboards, thus reducing wrist deviation, primarily wrist extension. Reducing wrist extension also minimizes static muscle exertions required to hold the hands over the keyboard during and following typing, since many users “float” their hands over the keyboard between bursts of typing.

## Statement of the Problem

Research has been conducted by Hedge (Hedge and Morimoto, 2001; Hedge et al., 1999; Hedge and Powers, 1995; Hedge et al., 1995; Hedge, 1994) using a keyboard tray that achieves a negative slope, called a negatively sloped keyboard support (NSKS) system or a downward-tilting (DT) keyboard tray. Hedge and Powers (1995) found that wrist extension was reduced significantly and none of the participants using the NSKS system extended their hands as severely as participants that used the conventional keyboard configuration. Hedge (1994) found that all workers in a field test of the NSKS system reported less discomfort during keying and 62.5% reported no pain or discomfort at all; thereby concluding the NSKS system reduced postural risks for all workers. Another study by Hedge et al. (1999) compared the DT keyboard tray system to two other conventional positively angled keyboard configurations using electrogoniometric wrist angle measurements. They found that when using the DT system, 67% of the typing movements were made with the wrist in a neutral zone (<15° extension, <30° flexion, <15° ulnar or radial deviation) compared to 42% for the conventional keyboard tray or desk.

Gilad and Harel (2000) recommended that a negative tilt of 10° in the sagittal plane might possibly improve the standard keyboard configuration. Although not documented, the negative design Gilad and Harel studied was subjectively evaluated as the most comfortable as compared to the flat design (standard keyboard configuration), Tony $^{\text{TM}}$, and apart (split) designs.

These studies provided compelling evidence to support research regarding negatively sloped keyboard systems for reducing musculoskeletal stresses. However, few negative slope angles and their resulting effects on objective physiological measures (such as muscle activity, wrist posture, etc.), psychological measures (such as perceived discomfort), and performance have been studied.

## Objective of the Study

The objective of this study was to quantify the effects of various negative keyboard slopes on forearm muscle activity, wrist posture, key strike force, perceived discomfort, and performance to identify a negative keyboard angle or range of keyboard angles that minimize exposure to hypothesized risk factors for hand and wrist WMSDs. It was also sought to determine if results were repeatable. A laboratory study was conducted to compare keyboard slopes ranging from 7° to –30°, at 10° increments from 0° to –30°, using an experimental wedge designed for use with current QWERTY keyboards.

It was hypothesized that keyboard angle would affect muscle activity, wrist posture, within a neutral zone, key strike forces, and reported discomfort in the forearms, wrists, and hands; while performance would remain consistent. It was also hypothesized that keyboard angles ≥ -30° would result in an increase in exposure to hypothesized risk factors for WMSDs of the hand/wrist (i.e. increased muscle activity, deviated wrist postures, etc.), increase reported discomfort and performance would decrease due to inability to view the keyboard and reach keys located on the periphery of the keyboard.

## Scope and Limitations of the Study

The scope of this study was limited to assessing the effects of different negative keyboard angles on muscle activity, wrist posture, key strike force, reported discomfort, and performance as compared to the standard QWERTY keyboard configuration (7° slope). Other factors, such as keyboard height, chair design parameters, and use of arm and wrist rests were not investigated. Research showed that these factors can influence upper extremity fatigue and discomfort (Duncan and Ferguson, 1974; Arndt, 1983; Andersson, 1987; Carter and Banister, 1994; Hedge and Powers, 1995; Albin, 1997; Marklin et al., 1997(a, b); Paul et al., 1996; Smith et al., 1998; Gilad and Harel, 2000). However, few negative keyboard angles have been investigated, and the range of keyboard angles minimizing exposure to WMSD risk factors need to be identified first.

Personality type and mental stress have been documented to affect muscle activation (Glasscock et al., 1999). These factors were not considered since the focus of this study was on the biomechanical aspects of typing, not psychophysical assessments. Additionally, studies quantifying the effect of psychophysical factors on the muscles of the forearm and hand were limited.

This study also focused on a single typing task. Other peripheral tasks, such as filing, writing, and other activities typically associated with typing positions were not evaluated. Further, the use of other input devices, such as the mouse, was not investigated.

# CHAPTER II

# LITERATURE REVIEW

## Effects of Keyboard Angle on Hand and Wrist Posture during Typing Tasks

A review of the literature revealed few articles investigating wrist flexion and the concept of negatively sloped keyboard systems. Stack (1987, 1988(a, b)) reported in an Australian field study that a negatively sloped keyboard design—slanting the keyboard away from the user resulting in leveling the angle of the wrists and fingers—has been a major improvement in addressing CTS problems in the Tasmanian public service.

Hedge (Hedge and Morimoto, 2001; Hedge et al., 1999; Hedge and Powers, 1995; Hedge et al., 1995; Hedge, 1994) has performed multiple studies on the NSKS system and DT keyboard platforms. Hedge and Powers (1995) and Powers and Hedge (1992) found the NSKS system significantly reduced wrist extension and participants did not report any negative reactions to using the NSKS system. Hedge et al. (1995) studied a preset tilt down (PT) system, similar to the NSKS system, and reported that 96% of users reported easy adjustability. Participants also indicated that the system and integrated palm rest resulted in comfortable typing positions. While using the PT system, 62.2% of typing movements were made with less than 20° of wrist extension, where 5.4% of wrist extension movements exceeded 25°, compared to 38.8% and 32.6% of wrist movements, respectively, for standard keyboard designs. After three weeks of field use, the PT system produced a number of postural benefits, such as increased “neutral zone” (±10° wrist flexion/extension) hand movements, reduced upper limb musculoskeletal discomfort as seen in self-ratings, and overall body posture improvement for seated work. DeKrom et al. (1990) found that the risk of CTS increased for wrist flexion *OR* extension, but if the wrist worked in combination of flexion and extension, there was no significant increased risk ratio. Hedge and Powers (1995) concluded that the reduction in wrist extension from use with their NSKS should lessen the risks of developing CTS.

Recently, Simoneau and Marklin (2001) analyzed wrist extension at five keyboard angles (+15°, +7.5°, 0°, -7.5°, and -15°) and at different keyboard heights. As the keyboard slope was changed from +15° to -15°, wrist extension decreased approximately 13°. It could be said that mean wrist extension decreased approximately 1° for every 2° of change in downward slope. The average negative slope angle participants selected for the keyboard platform was -12°, resulting in a keyboard slope close to 0°.

Even in situations where the wrist is extended, lower wrist extension angles associated with negative keyboard slopes are theoretically beneficial with respect to etiology. Gilad and Harel (2000) found that the negative angle of the keyboard they studied provided a more natural positioning of the hand while keying and decreased muscle strain in the arms as measured by EMG. When using a negatively sloped keyboard at approximately 10°, the hands moved within a neutral zone (<15° extension, <30° flexion, <15° ulnar or radial deviation) 67% of the time as compared to 42% of the time for other keyboard arrangements (Hedge and Morimoto, 2001). Rempel et al. (1995) found that when the angle of the keyboard was sloped -2.6° at the home row, wrist extension, ulnar deviation, and forearm pronation were closer to a neutral position. Consequently, sloping the keyboard negatively also resulted in increased ulnar deviation of both wrists, which may diminish its benefits. However, Marras and Schoenmarklin (1991) and Schoenmarklin and Marras (1993) have stated that wrist extension and flexion pose a greater risk of injury for CTS than does radial or ulnar deviation. Gilad and Harel (2000) also suggested that wrist strain associated with keyboards was primarily due to wrist extension, not ulnar deviation.

These improvements in achieving a neutral posture are supported by Rose (1991) who recorded from a compilation of participants a completely relaxed posture of the forearm and hand, which showed the fingers curled greatly inwards toward the palm. In this relaxed state, the finger posture was extremely flexed. Rose found that operating a conventional keyboard required the fingers to be extended rather than flexed, forcing the fingers to work at approximately 75% of their full range of motion Rose described. Typing at such angles prohibits the fingers from operating efficiently. A negatively sloped keyboard may allow the hand and fingers to assume a posture closely resembling the relaxed posture Rose documented. Neutral wrist postures are of benefit also when considering pathophysiological mechanisms of CTS, such as carpal tunnel pressure.

### Interrelation of Keyboard Angle, Key Strike Force, and Carpal Tunnel Pressure

Increased carpal tunnel pressure (CTP) has been implicated as a causal factor for CTS by resulting in compressive forces on the median nerve from surrounding tissues. Gelberman et al. (1984) found that fluids in the palm of the hand flow freely with the hands in neutral-to-moderate extension (<20°) or flexion (<20°). Weiss et al. (1995) found that extreme extension and flexion of the wrist elevated CTP. It has been shown that brief exposure to a CTP of 30 mm Hg in animals is sufficient to affect nerve functioning for prolonged periods of time (Lundborg et al., 1983). Rempel et al. (1997) found that CTP levels approached this critical value (30 mm Hg) when passively extending the wrist 30° (Table II.1). For discrete, passive wrist movements, mean CTP values were lowest at 15° of flexion, and increased as the wrist was flexed or extended around this value. However, CTP values for wrist flexion were less than corresponding values for wrist extension. This finding supports that of Brain et al. (1947), who found wrist extension raised CTP more so than wrist flexion in cadavers. Further, fingertip forces significantly affect mean CTP values. Under the conditions of Rempel et al.'s (1997) experiment, finger force had a greater effect on CTP than did wrist angle. Rempel et al. (1997) found the relationship between CTP and fingertip load could be estimed with a second-order polynomial for the neutral posture.

Table II.1. Mean carpal tunnel pressures in mmHg for varying fingertip force of 15 healthy participants (*data from* Rempel et al., 1997)

| Wrist angle | Fingertip force (N) | | | |
|---|---|---|---|---|
| | 0 | 6 | 9 | 12 |
| 45° of extension | 36.0 ± 4.3 | 63.9 ± 8.0 | 70.8 ± 10.4 | 73.7 ± 10.8 |
| 30° of extension | 27.7 ± 4.9 | 53.5 ± 5.6 | 61.6 ± 7.1 | 62.3 ± 6.8 |
| 15° of extension | 18.5 ± 3.9 | 41.1 ± 5.6 | 50.8 ± 6.4 | 52.7 ± 6.2 |
| Neutral | 19.7 ± 3.0 | 44.6 ± 6.4 | 53.1 ± 6.1 | 56.5 ± 7.9 |
| 15° of flexion | 16.9 ± 2.8 | 42.4 ± 9.5 | 51.4 ± 9.7 | 54.5 ± 10.0 |
| 30° of flexion | 18.8 ± 4.2 | 32.9 ± 5.5 | 41.4 ± 5.9 | 43.7 ± 7.1 |
| 45° of flexion | 26.6 ± 3.6 | 41.5 ± 5.4 | 44.0 ± 6.8 | 46.3 ± 8.4 |

Studies have also identified postures (flexion/extension, radial/ulnar deviation, forearm pronation/supination) associated with the lowest CTP values. Weiss et al. (1995) found that the average position of the wrist for the lowest CTP was 2° ± 9° of extension and 2° ± 6° of ulnar deviation. Similarly, Rempel et al. (1992) found CTP to be lowest with the hand in 3.5° ± 5.9° of wrist flexion, 5.0° ± 7.1° ulnar deviation, and 45° of metacarpophalangeal flexion. When considering forearm pronation/supination, Hedge (1994) found CTP was lowest with the hand in 2° of flexion, 3° of ulnar deviation, and pronated. Gilad and Harel (2000) stated that CTP was lowest with the hand in a natural working posture of up to 15° wrist extension, less than 20° wrist flexion, and moderate ulnar deviation. Considering these findings, it would appear that minimizing extension or flexion could reduce CTP during keying.

Implications of these findings in relation to typing tasks are meaningful. Average wrist extension angles while typing have been reported to be between 13° and 33° (Hedge and Powers, 1995; Honan et al., 1996; Honan et al., 1995; Sommerich and Marras, 1994). Rempel and Horie (1994) found the lowest CTP occurred at 0° or 15° of wrist extension. They advocated that wrist extension angle was a strong determinant of CTP, and suggested minimizing wrist extension during typing.

Additionally, specifications for key activation forces of most keyboards fall between 0.2 N and 0.9 N (Rose, 1991), although the ANSI/HFS standard specified a larger range of key activation force from 0.25 N to 1.5 N (ANSI/HFS 100, 1988). Relaxed finger weights range from 0.3 N to 1.2 N, which often outweigh key activation forces, causing potential accidental activation (Rose, 1991). Force requirements for key activation do not reflect the actual exertions of keyboard operators when keying (Radwin, 1997). Studies have shown that key strike force exceeded the necessary key activation force (Armstrong et al., 1994; Feuerstein et al., 1994). Peak force during keying has been measured to be as much as 2.5 to 4.6 times the required activation force (Armstrong et al., 1994; Feuerstein et al., 1994; Martin et al., 1994). In extreme wrist extension, greater finger forces and higher CTP result for higher key strike forces (Table II.1). CTP values also increased for extreme wrist flexion, although not as severely.

### Effect of Keyboard Angle on Recorded Muscle Activity during Typing Tasks

Muscle activity during typing tasks has also been studied. Martin et al. (1998) studied the reliability of methods to quantify muscle load for keyboard work and concluded surface electromyography (EMG) measurements reliably represented the activity of the extensor carpi ulnaris (ECU), extensor indices proprius (EIP), extensor digitorum communis (EDC), flexor digitorum communis (FDC) and flexor carpi radialis (FCR) muscles. They found the FCU and ECU muscles could be considered the primary muscles used in typing tasks.

Gilad and Harel (2000) assessed muscle activity of the forearm and shoulder using EMG measurements for a negatively sloped keyboard system; however, it was unclear what angles were investigated. Surface electrodes were placed over the flexor carpi ulnaris (FCU), extensor carpi ulnaris (ECU), deltoid, and trapezius. They found that EMG measurements for average effort of the FCU when typing on a negative sloped keyboard were 36% less when compared with the average effort on the Tony$^{TM}$ keyboard design and 58% less than the split keyboard design. Results for the average effort of the ECU with the negative design were found to be 28% less than the average effort for the Tony$^{TM}$ keyboard.

## Effects of Keyboard Height on Operator Discomfort during Typing Tasks

Placing the keyboard above elbow height can increase upper-extremity discomfort (Bergqvist et al., 1995; Faucett and Rempel, 1994; Life and Pheasant, 1984; Sauter et al., 1991). Only one study was found that explicitly investigated the influence of keyboard height while using a negatively sloped keyboard system. Simoneau and Marklin (2001) studied the effects of negative keyboard sloping while adjusting the keyboard above, even with, and below elbow height. Results showed that if the elbow and wrist were placed at equal heights with the keyboard negatively sloped 7.5° or 15°, wrist extension would average 15° or less. This configuration adheres to the suggested standard (ANSI/HFS 100, 1988).

## Effects of Wrist Rest Usage during Typing Tasks

Wrist and palm rests act as a resting place for the wrist and hands; however, identified benefits associated with wrist rest use are varied. Albin (1997) found that wrist rests promoted a more neutral wrist posture by reducing wrist extension angles. Additionally, participants perceived that conditions with a wrist rest were significantly more comfortable than conditions without a wrist rest. Smith et al. (1998) found that participants using a wrist rest reported feeling more in control of their typing and when not using a wrist rest reported more pain in the front of their shoulders and on the outside of their elbows/forearms.

Rose (1991) identified a possible explanation for increased discomfort when not using a wrist rest. He discovered that finger extensor muscles could not be relaxed when typing had ceased because the weight of the hand or fingers normally outweighs key activation forces. Extensor muscles were therefore required to exert constant static contractions to retain fingers in typing-ready postures (Rose, 1991). Hedge and Powers (1995) found that the broad palm rest used with the NSKS supported the hands while typing, allowing the hands to rest and type simultaneously without the wrist being fully pronated. This broad palm rest supported the majority of weight of the hand, substantially decreasing the amount of weight placed directly on the keys and nullifying any accidental activation of keys from resting the hands on the keys. A negatively sloped keyboard may provide improved conditions for resting the hands while typing by facilitating the natural hand and finger posture observed by Rose (1991) and reducing static loading on the extensor muscles.

The use of wrist rests has also been implicated as a potential contributor to hand and wrist WMSD development. CTP was found to increase by over 120% when using a wrist rest or resting wrists on a work surface while keying (Hedge, 1994). Paul and Menon (1994) stated that contoured wrist pads actually focused pressure over the carpal tunnel, but floating the hands over a resting surface while typing significantly decreased CTP (Horie et al., 1993; Albin, 1997). Parsons (1991) tested nine different wrist rests and found that none of the forty participants found any wrist rest beneficial, and 10% reported increased discomfort when using a wrist rest with a traditional (positively sloped) keyboard.

Wrist rest usage with negatively sloped keyboard systems was found to affect observed wrist extension angles (Simoneau and Marklin, 2001). Wrist rests were either separate from the keyboard system (Figure II.1) or integrated with the keyboard system (Figure II.2). Separate wrist rests did not follow the tilt of the keyboard, and as the keyboard was sloped downward, the hand was kept farther away from the keyboard. Integrated wrist rests remained horizontal with the keyboard platform for every tilt angle, allowing the hand to follow the keyboard tilt. The type of wrist rest, separate or integrated, affected the location of the wrist's pivot point (used to measure wrist angles). Simoneau and Marklin (2001) believed the difference in the wrist pivot point was responsible for a discrepancy of 10° in measured wrist extension when compared to a Hedge and Powers (1995) study. Both studies investigated the use of wrist rests with a negatively sloped keyboard system, though maximum negative angles were slightly different [–15° in Simoneau and Marklin (2001), –12° ± 0.4° in Hedge and Powers (1995)]. Simoneau and Marklin (2001) suggested that future negative slope keyboard studies should take into consideration the relationship between keyboard heights and wrist rest heights because both affected wrist extension.

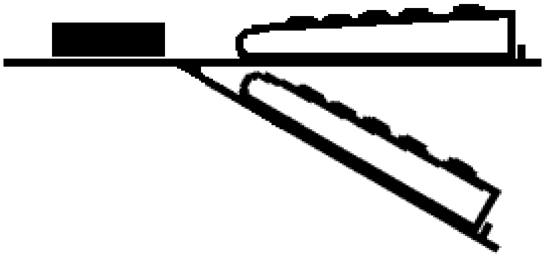

Figure II.1. Negatively sloped keyboard with a separate wrist rest

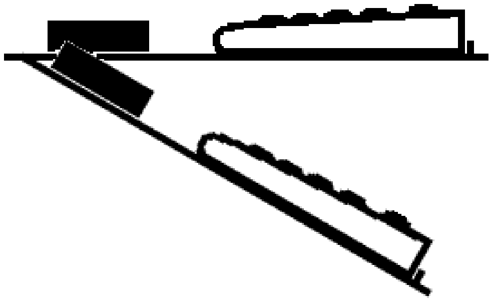

Figure II.2. Negatively sloped keyboard with an integrated wrist rest

### Typing Task Performance on the Negative Sloped Keyboard

Varying results were also found between negative and standard keyboard designs when considering typing performance measures. Hedge (1995) found that 91% of users reported improved work throughput when using a negative sloped keyboard. Typing quality was also found to improve 27% when using the negative design versus the standard configuration (Gilad and Harel, 2000). Simoneau and Marklin (2001) found no significant differences in mean typing speed, or in mean typing accuracy across the five slope conditions (+15°, +7.5°, 0°, -7.5°, and -15°) they studied. Similarly, Hedge and Powers (1995) found no significant difference in errors or in cumulative typing time between the standard keyboard configuration and the negative sloped keyboard.

### Summary

Negatively sloped keyboard systems have come under light scrutiny within the past decade as a possible improvement upon the standard of a positively sloped keyboard. They have been documented to reduce the percentage of wrist postures outside of a neutral zone, produced full-body postural benefits, received positive reactions from participants using them, and have improved work output (Hedge et al., 1995; Hedge, 1994).

Literature revealed a slowly growing recognition for use of negatively sloped keyboards; however, additional research was still needed. Few field and laboratory studies have been conducted primarily exploring negative sloped keyboards, and only one study compared electromyography results across four types of keyboard *designs*, not negative keyboard angles. No studies have investigated key strike force with the use of negatively sloped keyboards, and few negative keyboard angles have been studied.

# CHAPTER III
# METHODOLOGY

## Experimental Design

A laboratory study was conducted to attain the stated objectives. A within-participant design was used to test for the effects of keyboard angle, as well as day, order, subject, gender, and side on wrist postures, forearm muscle activity, key strike force, self-reporting of discomfort for specific areas of the upper extremity, and typing task performance. Order of exposure to keyboard angle was balanced using a Latin square design (Table III.1).

Table III.1. Balanced Latin square order of exposure to experimental keyboard angle

| | Keyboard angle | | | | |
|---|---|---|---|---|---|
| Participant | 7° | 0° | -10° | -20° | -30° |
| 1 | 3 | 4 | 5 | 2 | 1 |
| 2 | 4 | 5 | 1 | 3 | 2 |
| 3 | 5 | 1 | 2 | 4 | 3 |
| 4 | 1 | 2 | 3 | 5 | 4 |
| 5 | 2 | 3 | 4 | 1 | 5 |
| 6 | 1 | 2 | 5 | 4 | 3 |
| 7 | 2 | 3 | 1 | 5 | 4 |
| 8 | 3 | 4 | 2 | 1 | 5 |
| 9 | 4 | 5 | 3 | 2 | 1 |
| 10 | 5 | 1 | 4 | 3 | 2 |

## Dependent Variables

Five dependent variables—four objective measures and one subjective measure—were investigated. Objective measures included electrogoniometric measured wrist postures, EMG of the forearm muscles, key strike force measurements, and performance (i.e. typing speed, accuracy, types and numbers of errors made). The subjective measure was a self-reported postural discomfort questionnaire (SPDQ) with exit questions completed after each experimental condition. Discomfort was quantified using the Corlett postural discomfort scale (Corlett and Bishop, 1976).

### Electrogoniometric Measurements

A bi-axial electrogoniometer (SG65, Biometrics, Gwent, UK) was used to measure wrist flexion/extension (FE) and radioulnar (RU) deviation. The SG65 outputted signals of ±2.3 mV to a battery-operated data logger outputting signals of 0-1.28 V. A straight line was drawn from the third metacarpal along the forearm to facilitate goniometer fitting. Goniometers were attached while the hand and forearm were in a neutral position [arm resting at the participant's side, elbow flexed 90°, wrist straight, and hand pronated to minimize crosstalk (Bucholz and Wellman, 1997)]. The distal end of the goniometer was affixed along the drawn line using double-sided tape. The participant extended the wrists completely, with help from the experimenter, and the proximal end of the goniometer was affixed to the forearm along the straight line. Cloth tape was placed over the ends of the goniometer to ensure no displacement occurred during typing tasks. Loose wiring was taped and clipped to clothing, allowing for slack, to avoid any shifting of the goniometers during typing. Calibration of the goniometers occurred before data collection. Zero angles were set to represent neutral posture, and positive angles denoted wrist extension and ulnar deviation, while negative angles denoted wrist flexion and radial deviation.

All goniometric data was analyzed using DataLOG™ Software (Biometrics, Gwent, UK). Typing task data was software filtered and smoothed. Data unassociated with the typing task (i.e. reaching to turn the page, floating hands over the keys for an extended period of time without typing, etc.) was removed from analysis by using an IDENT switch to mark the times of such instances. These markers were easily noted in the program during data analysis, and time lengths were extracted from the data.

Mean FE and RU angles were calculated for the entire ten-minute testing period, minus the first and last ten seconds of the experimental condition. Additionally, the percentage of time spent within a neutral zone (<15° extension, <30° flexion, <15° ulnar or radial deviation) was calculated and values were compared across conditions (i.e. day, keyboard angle, order, subject, gender, side). Other intervals were also investigated for FE and RU deviations, including ±5° and ±10°.

Electromyography (EMG) Measurements

EMG measurements of the flexor carpi ulnaris (FCU) and extensor carpi ulnaris (ECU) of both arms were obtained using 10-millimeter, circular Ag/AgCl pregelled bipolar disposable electrodes. Prior to electrode application, the skin surface area was shaved, slightly abraded, and cleansed with alcohol to ensure minimal impedance. Electrodes for the FCU were located 3 cm medial to the ulna at a point one-third of the length of the forearm from the elbow crease (Perotto, 1994). Electrodes for the ECU were located one-third of the distance between the lateral epicondyle of the humerus and the olecranon process and the styloid process of the ulna (Soderberg, 1992). Interelectrode distance was set to 2.5 cm. Signals were transmitted through short (less than 30 cm) leads to preamplifiers (100 gain). The leads were secured to the arm with tape to reduce noise and minimize displacement during typing. EMG signals were hardware amplified, band-pass filtered (10-500 Hz), RMS converted (110 ms time constant), and AD converted. If electrodes lost adhesion or were moved during the experiment, the trial was re-run (Marras, 1990). The gain was set such that the RMS signal did not exceed 2-3 volts. Input impedance was measured using a standard voltmeter to ensure impedance was within acceptable levels (0-10 ohms).

After stabilization of the electrodes (15 minutes), resting and maximum voluntary contractions were obtained. Participants were instructed to sit with their arms in a posture representative of typing (elbows flexed at approximately 90°, palm downward, and wrists straight). Resting EMG measurements were recorded at 256 Hz for ten seconds with the participant’s hands in his or her lap or resting on a table. Three, five second maximum voluntary contractions (MVC) were collected for each muscle in both forearms independently while seated, with a one-minute rest period between each trial. Three types of MVC tests were performed: (1) handgrip strength test (overall forearm muscle activation test); (2) wrist flexion/extension tests (individual forearm muscle activation tests); and (3) hand-twisting test.

A number of studies have used handgrip strength tests to obtain MVC data for the forearm muscles. However, a study by Juul-Kristensen et al. (2002) showed that traditional handgrip strength tests using dynamometers underestimated MVC by an average of 34% for the participants tested. Twelve of the thirteen participants obtained maximum ECU EMG measurements during maximum wrist extension, and nine of thirteen participants obtained maximum FCU measurements during the handgrip strength test. Therefore, wrist flexion/extension tests isolate the FCU and ECU muscles better in some cases than conducting a handgrip strength test alone. For this study, all MVC tests were performed while participants were positioned with arms resting at their sides, elbows flexed at 90°, hands pronated, and wrists straight (representative of a typing posture). Handgrip strength was assessed using a dynamometer (Jamar Adjustable Dynamometer, Asimow Engineering Co.). The wrist flexion/extension MVC tests were performed using a stationary handle connected to an adjustable chain in the same posture described above. MVC for the FCU was obtained by requiring participants to perform a wrist flexion exertion, and for the ECU, during a wrist extension exertion. During each exertion, the experimenter held the upper limb in a consistent posture to reduce contributions from the upper arm and other supporting muscles. In the hand-twisting test, the participant was asked to twist a rod while seated, in the same posture as described above. This test was performed twice, alternating the direction of twisting for each hand. MVC tests were randomized across participants for the first test session, and the same sequence was used in the second test session to test repeatability.

The peak RMS EMG signal was identified for each trial using LabView Software (Barr et al., 2001), and the maximum value for all three trials was taken as the MVC for that test. Later, MVCs from each test were compared, and the maximum value was used as the $EMG_{maximal}$ value for that muscle for normalization of task EMG.

After completing all MVC tests, participants then performed a five-minute practice-typing task during which the EMG signal was monitored to ensure equipment was working properly. Task RMS EMG was sampled at 256 Hz using National Instruments AD bit card, and LabView software, which smoothed (10 Hz low pass filter) and stored data. This smoothed data was used to estimate normalized force levels using Equation III.1.

$$\frac{EMG_{observed} - EMG_{resting}}{EMG_{maximal} - EMG_{resting}} \qquad \text{(Equation III.1)}$$

Data unassociated with the typing task (i.e. reaching to turn the page, floating hands over the keys for an extended period of time without typing, etc.) was considered irrelevant and were removed from EMG data using a LabView program at the same times when irrelevant electrogoniometric data was removed. Means were calculated for the entire ten-minute testing period and at 30-second increments, minus the first and last ten seconds of the experimental condition. Processed data was expressed in terms of percent of maximum voluntary contraction and compared across conditions.

### Key Strike Force Measurements

Two 22.2 N (5 lbf) Model LBS Series load buttons (Interface, Scottsdale, AZ) were used to measure key strike forces. The load button was small and cylindrical, 3.05 mm (0.12 in.) in height and 9.65 mm (0.38 in.) in diameter. It had an accuracy of ±0.25% and its rated output was 2.0 mV/V. A 1.5 m (5 ft) integral cable connected the load button to a DMA Signal Conditioner/Amplifier. The manufacturer calibrated the amplifier to measure 0 VDC as 0 N (0 lbf) and 10 VDC as 22.2 N (5 lbf). The amplifier was connected to a National Instruments terminal block (SCB 100) for analysis with LabView Software. A Dell QuietKey$^{TM}$ keyboard was engineered to allow the load buttons to monitor one key for each hand without damaging the integrity of the keyboard's performance (Figure III.1). Participants were unaware which keys were being investigated. A metal plate inside the plastic keyboard casing held the circuit board against a plastic sheet of supporting rubber cones, connected to each key of the keyboard. The rubber cones forced the keys back to its resting state after a key was depressed and the circuit board, which is thin (<1 mm) and lightweight, had been activated. Along with a foam material, load buttons were housed underneath the key inside the foam and sandwiched between the metal plate and the circuit board. The foam kept the load button in place under the correct key and also allowed for a consistent and normal feel to the user for all the keys.

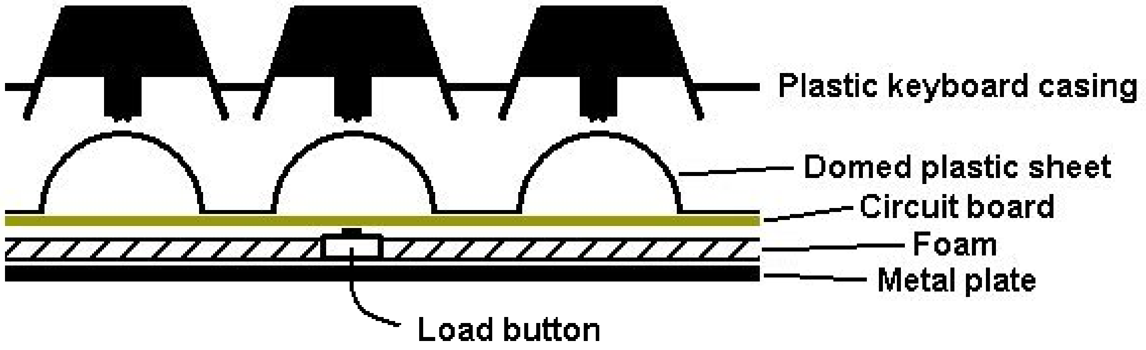

Figure III.1. Load button location inside keyboard

The load buttons measured any depressing of a key's rubber cone through the thin circuit board, thus measured the key strike force for the key. The keys that were considered for study were the 'E' key for the left hand and the 'N' key for the right hand. The 'E' key is a heavily used vowel, and appears in the 'Q' row above home row. The 'N' key is a commonly used consonant, and is located in the 'Z' row below the home row. Choosing these keys allowed for measurement of key strike forces where finger extension varied between the rows above and below the home row.

A LabView program was written to calculate peak values of each individual key strike force (KSF), and then averaged the peak values. Data from the load buttons was deciphered continuously for the ten-minute experiment. Three criteria were used to determine if a key strike force was made: (1) baseline, (2) threshold, and (3) width. The baseline value was determined so that any value below it was not considered part of a key strike force, or 'noise', and any value above the baseline was potentially a key strike force. To set the baseline, a pilot test was run at 1024 Hz, twice the frequency of the experiment. Data was collected continuously for four minutes, and 'E' key and 'N' key data was analyzed to find a maximum value, defined to be the maximum background noise in the absence of any key strikes. These values were manually inspected and adjusted to ensure all noise was removed and only potentially completed KSFs registered; moreover, 0.146 N for the 'E' key, and 0.093 N for the 'N' key, were used as the baseline for KSF consideration. Any data collected below these values was automatically discarded as noise.

The threshold value was used as a value that the key strike force must exceed in order to be considered a key strike force that activated the key successfully. This value was determined from another pilot test, run at 1024 Hz, where actual typing was done on the ‘E’ and ‘N’ keys. Light and hard tapping was done in rapid and slow motions, to test the range of the load button readings. Keys surrounding the ‘E’ and ‘N’ keys were also struck to see if there was any effect on the load buttons. This data was analyzed for peak values of successful key strike forces, which were found to be at 0.5-0.6 N. The threshold was set to 0.2 N for both keys, about half of these successful peak values. Any peak below this threshold value was assumed as noise or a partial key strike force that may not have activated the key successfully.

The width value was the number of consecutive data points above the baseline and the threshold that contributed a key strike force. This value was set at 50 samples, about one-half a full key strike force or 0.1 sec, for data collection at 512 Hz. Larger widths might reduce the apparent amplitudes by combining separate key strike forces together. Consequently, the number of data points from above the baseline and past the threshold, and back to the baseline, had to exceed 50 in order for the program to consider the strike as a key strike force, and accurately measure the amplitude. Data was rechecked visually after the LabView program had analyzed the data.

Data was collected at 512 Hz; contrary to the frequency of 250 Hz used in previous literature (Gerard et al., 1996; Gerard, Armstrong, Martin, Rempel, 2002; Gerard, Armstrong, Rempel, Woolley, 2002), and based on pilot study data. It was assumed that a peak value could never be accurately attained, but 1024 Hz, or three times the values used to collect key strike force data in previous literature, was sufficiently large to test for estimating peak values. Also, since capacity in the computer was limited, it was not conceivable, nor practical for data analysis purposes, to record data above 1024 Hz. A single key strike force for the ‘E’ key (‘N’ key not shown) was graphed for 1024 Hz, 512 Hz, and 256 Hz (Figure III.2, Figure III.3, and Figure III.4, respectively). Comparing the same key strike force at different frequencies showed that the larger frequencies more accurately represented the key strike force than did lower frequencies. The same key strike force peak for 1024 Hz and 512 Hz was estimated to be above 1.8 N, but was approximately 1.58 N for 256 Hz. These larger frequencies more accurately estimated peak values.  Judging from this initial result, 1024 Hz and 512 Hz better estimated peak key strike forces.

To further determine the best frequency regarding accurate key strike force representation, storage capacity, and time, means of key strike force peaks were calculated and graphed (Figure III.5).  If key strike force peaks were accurately estimated, then mean values would not change significantly as frequency decreased. Figure III.5 shows a significant drop in this estimation as frequency decreased for both keys.  Figure III.6 shows the percentage decrease in the estimation of the mean peak key strike forces for each incremental decrease in frequency.  The decrease was slight for the first incremental decrease to 512 Hz, but was much greater for lower frequencies.  When the sampling rate decreased from 1024 Hz to 512 Hz, there was a 2.3% and 1.7% decrease in the mean estimation of the peak values for key strike forces for the ‘N’ key and ‘E’ key, respectively.  When the sampling rate decreased from 512 Hz to 256 Hz, there was a 6.5% and 3.6% decrease, or a tripling of percentage decrease from 1024 Hz, in the estimation of mean key strike force peaks for the ‘N’ key and ‘E’ key, respectively.  This trend validated reasons to choose 512 Hz for sampling key strike force data. It was determined that to accurately estimate peak values for key strike forces in this experiment, 512 Hz was required.

The first and last ten seconds of data for the experimental condition were removed from analysis.  Means of key strike force peaks were presented in Newtons, and were calculated for the entire testing period for each key studied and compared across conditions.

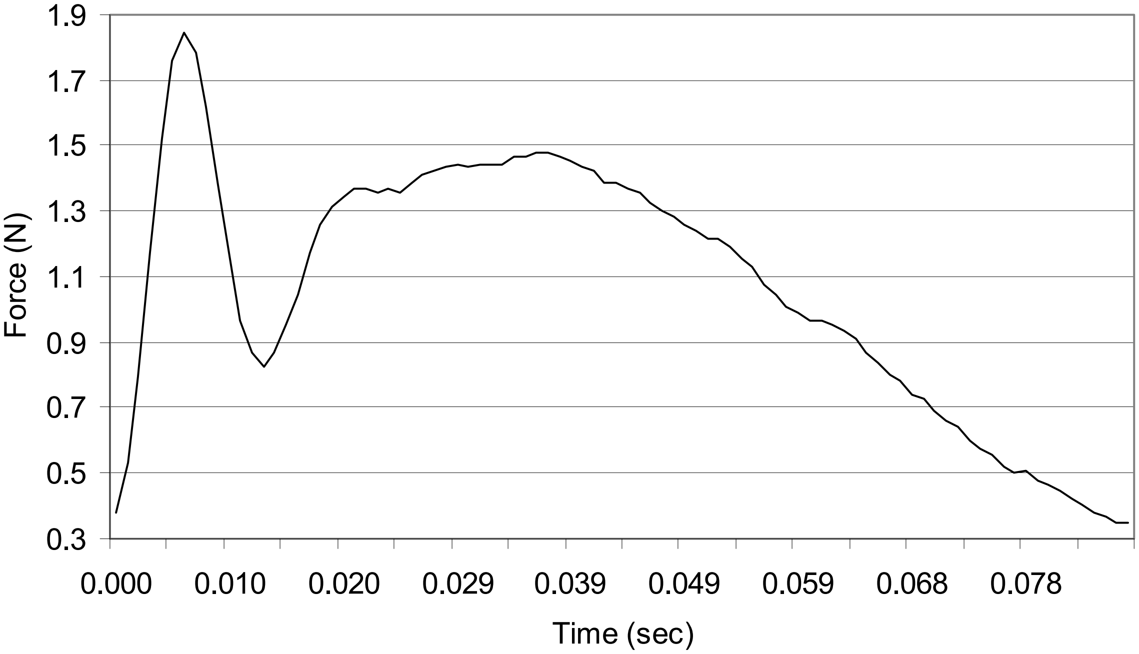

Figure III.2. Comparison of an ‘E’ key strike force at 1024 Hz

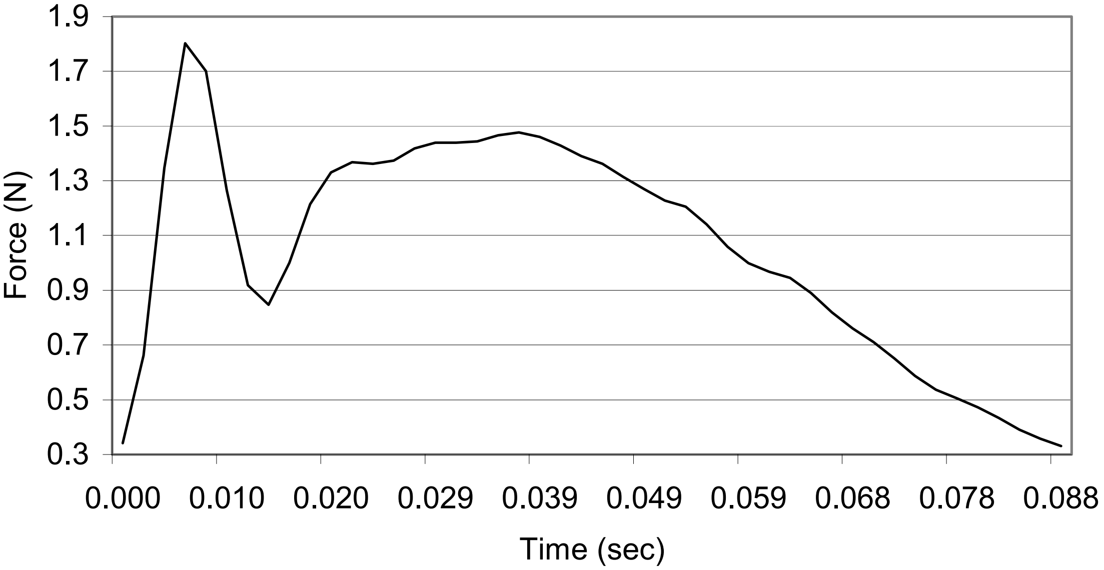

Figure III.3. Comparison of an ‘E’ key strike force at 512 Hz

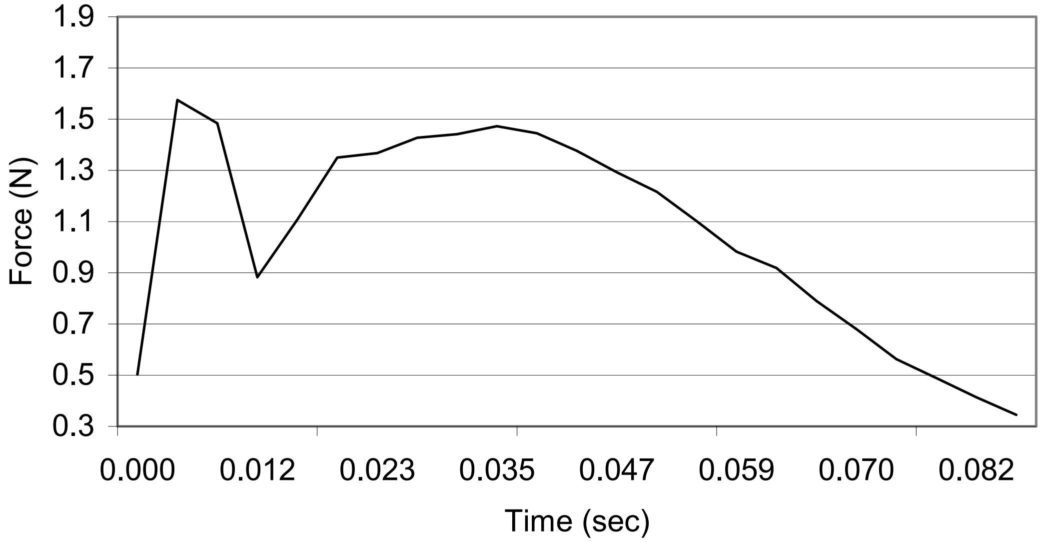

Figure III.4. Comparison of an ‘E’ key strike force at 256 Hz

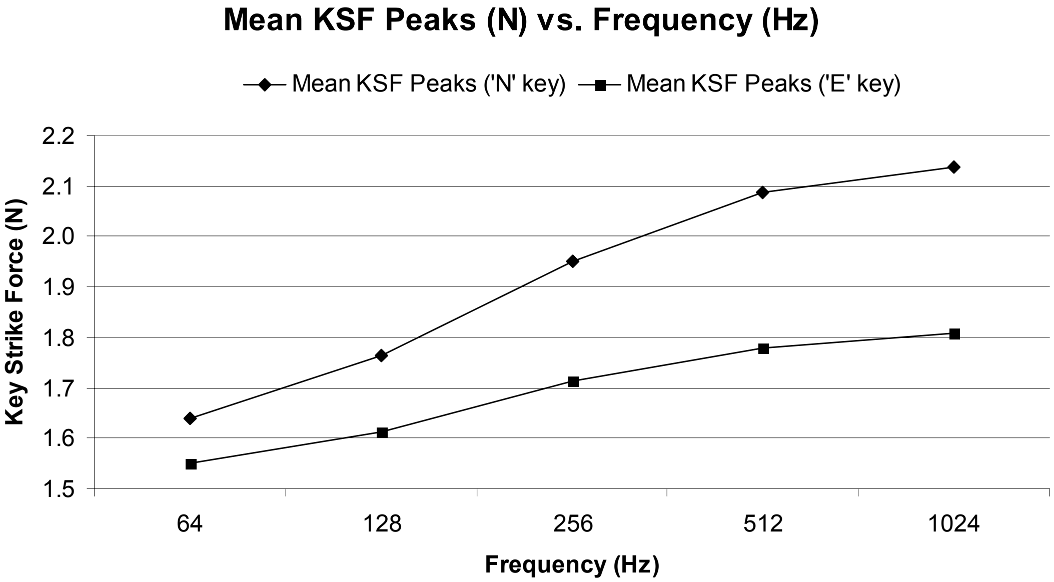

Figure III.5. Means of key strike force peaks compared at varying frequencies

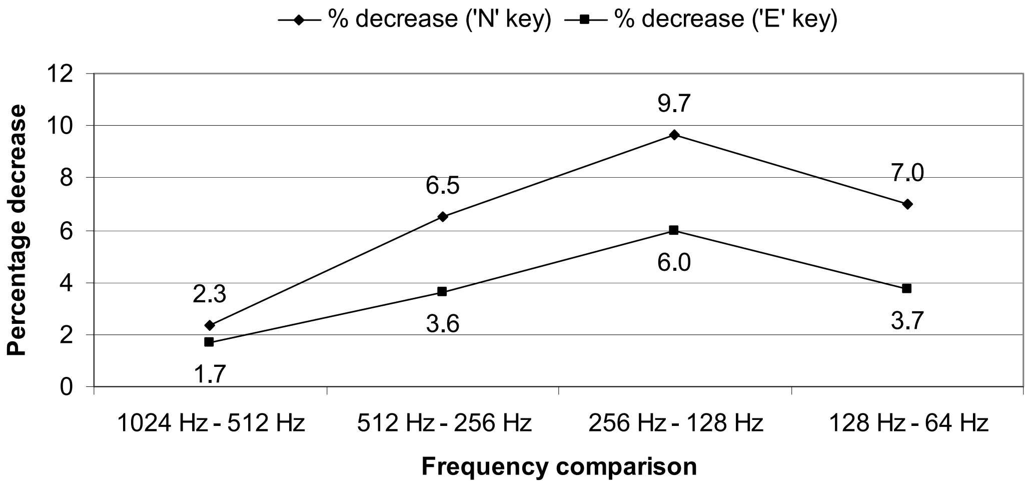

Figure III.6. Percentage decrease in estimation of mean key strike force peaks

Performance

SkillCheck typing test software (SkillCheck, Inc., Burlington, MA) was used to administer a pre-test typing task, practice-typing tasks, and test-typing tasks for all experimental conditions. The program provided text passages for participants to recreate. The task was limited to the computer screen. Performance measures calculated by the software (i.e. test duration, gross typing speed, number of errors, errors per minute, net typing speed, missing words, extra words, joined words, split words, and misspelled words) were automatically recorded for each condition in the form of reports. These reports were printed and specific performance measures were compared across conditions.

Self-reported Postural Discomfort Questionnaire (SPDQ)

The SPDQ with added exit questions (Appendix E) was completed after each experimental condition. The Corlett postural discomfort scale was used to assess a participant’s subjective feelings of discomfort following exposure to each keyboard angle. Participants indicated on a 7-point scale, ranging from 0 = extremely comfortable to 7 = extremely uncomfortable, the amount of discomfort they experienced for the forearm, wrist, palm, and fingers independently. Exit questions were asked, such as: “Compared to the standard keyboard configuration, the new typing angle was much easier, easier, about the same, harder, or much harder to use?”; “Did you reach the same level of typing speed and accuracy compared to the standard keyboard configuration?"; and at the end of the experiment, "Please rank each keyboard angle from best to worst". Participants were forced to rank order the keyboard angles from 1 = best to 5 = worst, where each keyboard angle received a different ranking.

Means, frequency counts, and other descriptive statistics were calculated for responses to the SPDQ and added exit questions, and were compared across day and keyboard angle. Friedman repeated measures ANOVA along with the SAS contrast method for post-hoc analysis was used to analyze the final ranking data.

## Independent Variable

The independent variable was keyboard angle. The natural positive sloping of the keyboard was estimated to be 7° between the keyboard support surface and the plane crossing the center of the keys in the 'Q' row and 'Z' row, defined as keyboard slope in ANSI/HFS 100-1988 (Figure III.7). Keyboard wedges were used to position the keyboard at 0°, -10°, -20°, and -30°; but the angle of 7° was presented naturally (i.e. no wedge present). For 0° keyboard angle (Figure III.8, Figure III.9, and Figure III.10), the wedge was designed at 7° to counteract the natural sloping of the keyboard for a net effect of 0°.

The keyboard wedge was a triangular prism spanning the entire width of a standard QWERTY keyboard. The wedge was constructed of four wood pieces—two triangular wedges for the sides, one flat board for the keyboard surface, and a wood block to secure the keyboard from slipping. Keyboard wedges achieved a negative slope in a different manner than did the DT, NSKS, or PT keyboard tray systems. In general, the wedge can be used on a tabletop desk or conventional keyboard tray. The wedge design allowed users to place the keyboard anywhere on its surface (forward, backward, lateral) to accommodate user preferences, varying hand sizes, and comfort zones. To prevent possible confounding effects of a perceived wrist rest, a fixed stop was used to prevent slipping while typing (Figure III.8) for all experimental conditions, thus minimizing the exposure of the top edge of the wedge.

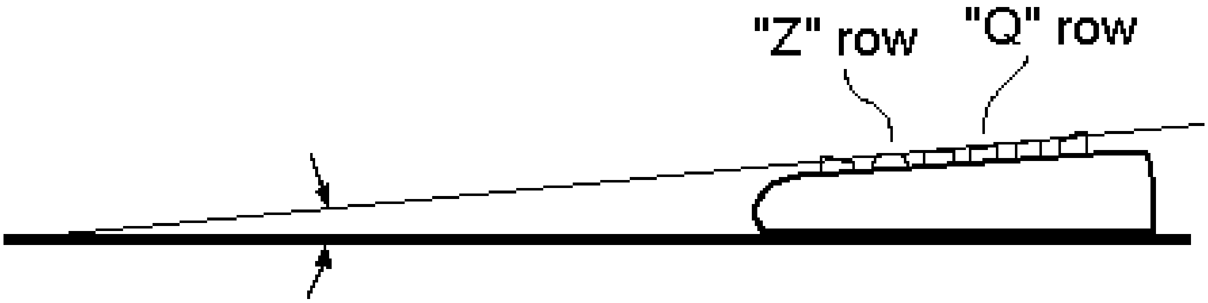

Figure III.7. Keyboard slope illustration

Figure III.8. Side view of experimental keyboard wedge (0°)

Figure III.9. Top view of experimental keyboard wedge (0°)

Figure III.10. Isometric view of experimental keyboard wedge (0°)

## Typing Task Description

A 17” monitor, standard QWERTY keyboard and Generation IV fully adjustable bi-level table (SIS Human Factor Technologies, Londonderry, NH) was used for the typing task. Typing tasks varied for each experimental condition. Text passages in the software package were adequate for the pre-test typing task, but another source—a technical communication textbook—was used to create practice- and test-typing tasks. Using varying text passages prevented participants from establishing a learning curve during the experiment. Passages were designed to last the duration of each experiment. No passage was ever completed prior to the completion of a test session. No numeric keypad and mouse activity was required for the task.

## Participants

Participants included ten experienced typists with a mean age of 22.1 years who spent at least 20 hours at a standard keyboard each week. Nine of the ten participants were right-handed. Participants used the ten-digit touch-typing method and typed a minimum of 45 words per minute. Potential participants were screened using the Nordic Questionnaire (Kuorinka et al., 1987) for current hand/wrist MSDs and other potential confounding disorders. Participants included in the study were those individuals responding negatively to, “Have you at any time, during the last 12 months, had trouble (ache, pain, discomfort) in the wrists or hands?” (Kuorinka et al., 1987). Participants also needed to have negative findings for at least one of Phalen’s and Tinel’s tests (Kuschner et al., 1992; Phalen, 1966) and report no symptomology (pain, numbness, or tingling) in the median nerve distribution of the hand (thumb, index, middle, and ring fingers, and palm) (Rempel et al., 1988). Detailed descriptions of Phalen's test and Tinel's test can be found in Appendix A and Appendix B, respectively. Participants exhibiting any signs of WMSDs, severe hand/wrist injury, arthritis, use of anti-inflammatory medication, or those that did not meet any of the criteria were excluded. Demographic information and anthropometric data were also collected (Van Cott and Kinkade, 1972), and are summarized in Appendix F.

## Procedure

Participants were required to attend a qualifying session, and upon qualification, complete two test sessions. In the qualifying session, potential participants received a verbal and written description of the project, it's objectives, and the procedures used, and were asked to complete informed consent documents approved through the Institutional Review Board for research involving human participants prior to any data collection (Appendix C). The Nordic questionnaire (Appendix D) and Phalen's and Tinel's tests were conducted to establish the absence of any WMSDs associated with the hands and wrists, thus determining whether or not the participant's health at the present moment qualified him/her for further participation in the experiment. A three-minute pre-test typing task was completed for assessing typing proficiency. Participants were required to have a net typing speed of 45 words per minute. For those participants meeting all inclusion criteria, demographic information (i.e. age, current employment, keyboarding habits, etc.) and anthropometric data (i.e. height, weight, etc.) were collected (Appendix F). Once inclusion in the experiment was determined, participants were scheduled for two test sessions at a later date. The two test sessions were completed at the same time of day on the same day of the week, one week apart, to assess repeatability of the experimental procedure and results.

While seated, EMG surface electrodes and electrogoniometers were fastened to the participant's forearm, wrists, and hands. Following calibration of the equipment and a fifteen-minute stabilization period, resting and MVC EMG data were collected.

Participants sat at the experimental computer workstation, which was adjusted so that the typing posture closely resembled the posture used by Hedge et al. (1999). The participant was seated in a chair with a backrest in an upright position. Rempel et al. (1997), Simoneau et al. (1999), and Marklin et al. (1999) advocated that placing the keyboard above elbow height increased upper-extremity discomfort; therefore, for the purposes of this study, the forearm was kept parallel to the floor, keeping an elbow angle of approximately 80° to 110°. Keyboard tray height was adjusted such that the elbow point was aligned with the wrist point, parallel to the floor. Chair height was adjusted so that the knees formed a 90° angle and the feet were flat on the floor. A foot rest was used, if necessary. Workstation parameters (keyboard height and chair height) were recorded.

The appropriate keyboard wedge was placed under the keyboard and a five-minute practice-typing task ensued to allow participants to become accustomed to the typing angle of the experimental condition. A five-minute rest period elapsed, and then participants completed a ten-minute typing task, followed by another five-minute rest period. During this second rest period, goniometer data was downloaded to the computer and the next keyboard wedge was set up. The SPDQ, with added exit questions, was then administered to assess the participant's perceived discomfort for the forearm, wrist, hand, and fingers for that keyboard angle. This procedure repeated for each experimental condition until all five had been completed. When the participant had finished all experimental conditions, electrodes and goniometers were removed, and the participant was compensated for their time. Protocols for the second test session were identical to the first. Participants followed the same balanced Latin square design for both test sessions. Total testing session time was 8.5 hours per participant.

## Statistical Data Analysis

Descriptive statistics (i.e. means, medians, standard deviations, frequency counts, etc.) were calculated for each dependent variable where appropriate. The Shapiro-Wilk's normality test was performed on all continuous variables to ensure assumptions pertaining to normality were met for subsequent analyses (Appendix G).

### One-way ANOVA

Three one-way repeated measures ANOVA models were used for data analysis. The first ANOVA model determined if differences between days existed for each dependent variable. For those dependent variables where no significance by day was identified, the data was pooled, and the second ANOVA model testing for differences in order was conducted on the aggregate data. For dependent variables where significance was found by day, data was not pooled, and the second ANOVA model was conducted. The third and final model tested for keyboard angle, gender, and subject differences, as well as the keyboard angle and gender interaction. ANOVA was also used to assess differences for each dependent variable by side. Tukey's HSD was used for post-hoc analysis for significant findings. The Friedman repeated measures ANOVA along with the SAS contrast method for post-hoc analysis was used to analyze final ranking data. Significant values were reported at $p < 0.05$.

### Linear Correlations by Day

Linear correlations (Pearson's or Spearman's Rho) were used to assess repeatability of each dependent variable depending upon normality of the continuous dependent variables. Critical values for Pearson's and Spearman's Rho correlation coefficients were used to determine significance, and was calculated based on sample size. All variables except MVC variables had samples of $N = 50$, thus critical values were $r_P^{CV} = 0.288$ (Fisher, 1973) for Pearson's correlations for normal data and $r_S^{CV} = 0.279$ (Zar, 1972) for Spearman's Rho correlations for non-normal data for $df = 48$ and $p < 0.05$. MVC variables had samples of $N = 10$ and data was normal, thus critical values were $r_P^{CV\text{-MVC}} = 0.632$ (Fisher, 1973) for $df = 8$ at the same $p$ level. Significance was found if correlations for either case exceeded critical values. Since the sample size differed for MVC variables, strong correlations were defined as $r_{Pearson}^{\text{MVC}} > 0.632$. Weak correlations were $r_{Pearson}^{\text{MVC}} < 0.632$. Strong correlations for remaining parametric and non-parametric variables were defined as values above or equal to 0.6, moderate correlations were defined as values from 0.279 to 0.599, and values below 0.279 were considered weak correlations. Correlation ranges were chosen based on where significance was found, while staying close to values used in common practice. Corresponding *p*-values were used to indicate the strength of these correlations.

Body Part Groupings

The SPDQ data consisted of ratings for various body parts. A one-way repeated measures ANOVA was conducted on body parts to determine significance among the ratings, and to assess if body parts could be grouped into logical body systems. Data was collected for ring and pinky fingers (RPs); the thumb, index, and middle fingers (TIMs); hand; wrist; and forearm for the left and right sides. Body parts were combined logically if there was no significance in the ratings found as a result of an ANOVA. For example, RPs and TIMs were compared first, since both were sets of fingers. If significance was not found for the left side and the right side for all keyboard angles and both days, the RPs and TIMs were combined into a body group. The logical body-grouping process continued until: (1) ratings showed significance between each body groups or parts; (2) ratings showed significance by keyboard angle; (3) body groups or parts showed significance by side; or (4) ratings showed significance by day. Keeping the same body groups allowed for day, keyboard angle, and side analyses, as well as linear correlations to test repeatability. After logical body systems were identified, ratings were normalized according to Equation IV.1.

$$\frac{\text{Sum score}}{\text{Maximum sum score}} \qquad \text{(Equation IV.1)}$$

Normalizing was necessary since summed body group ratings were likely to be greater than summed ratings of original body parts for the ten participants. The maximum response (MR) normalizing technique accounted for this discrepancy with a larger denominator when two body parts were grouped (14), or three body parts were grouped (21), and so forth. One-way repeated measures ANOVA were performed on these normalized values by day, keyboard angle, and side analyses. All discomfort data was treated as interval data, then analyzed as continuous data if summing and normalizing was necessary.

# CHAPTER IV

# RESULTS

Descriptive statistics for significant and non-significant variables by keyboard angle appear in Appendix J. Other descriptive statistics for significant findings are presented in the following sections (i.e., gender, side, etc.). A summary of the results for variables analyzed through repeated measures ANOVA are summarized in Table IV.1, Table IV.2, and Table IV.3. Only statistically significant results with descriptive statistics are presented in this section. Tables for post-hoc differences are presented in this section and all data are arranged by descending means. All F-ratios and p-values with Tukey HSD post-hoc q-values are tabulated and presented in Appendix H.

In general, most dependent variables were consistent across days, no order effects were found, and differences between participants were found for most variables. Significant day effects were found for normalized EMG values for the left FCU, and left and right ECU; left hand mean RU deviations, mean %RU deviations in the neutral zone, and mean %RU deviations within 10°; left hand and right hand mean %RU deviations within 5°; net typing speed, errors; missing words; misspelled words; and normalized left and right hand and forearm discomfort ratings. Insignificant results between participants were found for mean %FE deviations within 5°; day 2 left hand mean %RU deviations within 5°; right hand mean %FE deviations within 5°; day 2 missing words, combined extra-, joined-, and split-word (EJS) data; and self rating of keyboard usage difficulty as compared to the standard keyboard arrangement.

Table IV.1. Table of results for objective dependent variables

| Variable | Day | | Order | KA | Subject | Gender |
|---|---|---|---|---|---|---|
| Normalized EMG FCU - RH | N | | N | N | Y | Y |
| Normalized EMG ECU - RH | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | Y | N |
| Normalized EMG FCU - LH | Y | 1 | N | N | Y | N |
| | | 2 | N | Y | Y | N |
| Normalized EMG ECU - LH | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| MVC FCU - RH | N | | N/A | N/A | N/A | N/A |
| MVC ECU - RH | N | | N/A | N/A | N/A | N/A |
| MVC FCU - LH | N | | N/A | N/A | N/A | N/A |
| MVC ECU - LH | N | | N/A | N/A | N/A | N/A |
| Mean of KSF Peaks - E key | N | | N | N | Y | N |
| Mean of KSF Peaks - N key | N | | N | N | Y | N |
| Mean FE - LH | N | | N | Y | Y | N |
| Mean RU - LH | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | Y | N |
| % FE in Neutral Zone - LH | N | | N | Y | Y | N |
| % RU in Neutral Zone - LH | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | Y | N |
| Mean FE - RH | N | | N | Y | Y | N |
| Mean RU - RH | N | | N | Y | Y | N |
| % FE in Neutral Zone - RH | N | | N | Y | Y | N |
| % RU in Neutral Zone - RH | N | | N | Y | Y | N |
| % FE < 5 degrees - LH | N | | N | Y | N | N |
| %RU < 5 degrees - LH | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | N | N |
| % FE < 5 degrees - RH | N | | N | Y | N | N |
| %RU < 5 degrees - RH | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| %FE < 10 degrees - LH | N | | N | Y | Y | N |
| %RU < 10 degrees - LH | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | Y | N |
| %FE < 10 degrees - RH | N | | N | Y | Y | N |
| %RU < 10 degrees - RH | N | | N | N | Y | N |
| Net Typing Speed | Y | 1 | N | Y | Y | N |
| | | 2 | N | Y | Y | N |
| No. of Errors | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Missing Words | Y | 1 | N | N | Y | N |
| | | 2 | N | N | N | Y |
| Misspelled Words | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Combined EJS data | N | | N | N | N | N |

NOTE: EMG = electromyography, MVC = maximum voluntary contraction, FCU = flexor carpi ulnaris, ECU = extensor carpi ulnaris, RH = right hand, LH = left hand, KSF = key strike force, FE = flexion/extension, RU = radial/ulnar deviation, EJS = extra-, jointed-, and split-words

Table IV.2. Table of results for subjective dependent variables

| Variable | Day | | Order | KA | Subject | Gender |
|---|---|---|---|---|---|---|
| Normalized Left Hand Rating (SPDQ) (TIMs, RPs, Hand) | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Normalized Left Wrist Rating (SPDQ) | N | | N | N | Y | Y |
| Normalized Left Forearm Rating (SPDQ) | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Normalized Right Hand Rating (SPDQ) (TIMs, RPs, Hand) | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Normalized Right Wrist Rating (SPDQ) | N | | N | N | Y | Y |
| Normalized Right Forearm Rating (SPDQ) | Y | 1 | N | N | Y | N |
| | | 2 | N | N | Y | N |
| Self-rating | N | | N | Y | N | Y |

NOTE: SPDQ = Self-reported postural discomfort questionnaire; TIM = thumb, index, and middle fingers; RP = ring and pinky fingers

Table IV.3. Table of results by side

| Variable | Day | Side |
|---|---|---|
| Normalized EMG - FCU | 1 | N |
| | 2 | Y |
| Normalized EMG - ECU | 1 | N |
| | 2 | Y |
| MVC FCU | | N |
| MVC ECU | | N |
| Mean of KSF Peaks | | Y |
| Mean FE | | N |
| Mean RU | 1 | Y |
| | 2 | Y |
| % FE in Neutral Zone | | N |
| % RU in Neutral Zone | 1 | N |
| | 2 | Y |
| % FE < 5 degrees | | N |
| %RU < 5 degrees | 1 | N |
| | 2 | Y |
| %FE < 10 degrees | 1 | N |
| %RU < 10 degrees | 1 | N |
| | 2 | Y |
| Normalized Hand Rating (SPDQ) (TIMs, RPs, Hand) | 1 | N |
| | 2 | N |
| Normalized Wrist Rating (SPDQ) | | N |
| Normalized Forearm Rating (SPDQ) | 1 | N |
| | 2 | N |

NOTE: EMG = electromyography, MVC = maximum voluntary contraction, FCU = flexor carpi ulnaris, ECU = extensor carpi ulnaris, KSF = key strike force, FE = flexion/extension, RU = radial/ulnar deviation, SPDQ = Self-reported postural discomfort questionnaire

## Electrogoniometric Data

### Day

Left hand mean RU deviations, mean %RU deviations in the neutral zone, mean %RU deviations within 5°, and mean %RU deviations within 10° were significant by day. Left hand values for day 2 were significantly greater than day 1 for mean RU deviations (18.6° versus 15.6°). Day 1 was significantly greater than day 2 for mean left hand %RU deviations in the neutral zone (47.3° versus 32.7°), mean %RU deviations within 10° (25.9° versus 12.0°), and mean %RU deviations within 5° (8.9° versus 2.4°). Right hand mean %RU deviations within 5° were significantly greater on day 2 than day 1 (23.5° versus 12.9°).

### Keyboard Angle

#### *Left Hand*

All dependent variables were significant by keyboard angle (Table IV.4). The -30° keyboard angle showed the lowest mean FE deviations for the left hand ($\mu$=3.2°), which differed significantly from -20°, -10°, 0°, and 7°, though no difference was found between the 0° and 7° keyboard angles. The greatest mean percentage of left hand FE deviations in the neutral zone ($\mu$ =91.2%, $\sigma$ =13.24%) was found for the –30° keyboard angle, which differed significantly from -20°, -10°, 0°, and 7°, though no difference was found between the 0° and 7° keyboard angles. Similarly, -30° showed the greatest mean percentage of left hand FE deviations within 10° ($\mu$ =71.1%, $\sigma$ =23.57%) and within 5° ($\mu$ =40.5%, $\sigma$ =23.51%), and in both cases differed significantly from -20°, -10°, 0°, and 7°, though no difference was found between the -10°, 0°, and 7° keyboard angles.

The 7° keyboard angle showed the lowest mean RU deviations for both day 1 ($\mu$ =13.3°, $\sigma$ =7.81°) and day 2 ($\mu$ =14.8°, $\sigma$ =6.62°). On day 1, the 7° keyboard angle was different from -20° and -30°; and for day 2, it was different from -10°, -20°, and -30°. The greatest mean percentage of left hand RU deviations in the neutral zone was found for the 7° keyboard angle on day 1 ($\mu$ =59.5%, $\sigma$ =47.35%) and day 2 ($\mu$ =51.3%, $\sigma$

=44.24%). On day 1, the 7° keyboard angle was surprisingly similar to -10° ($\mu$=57.2%, $\sigma$=41.49%), but was different from 0°, -20°, and -30°. On day 2, the 7° keyboard angle was different from -10°, -20°, and -30°. The 7° keyboard angle resulted in the greatest mean percentage of left hand RU deviations within 10° on day 1 ($\mu$=39.56%, $\sigma$=38.79%) and day 2 ($\mu$=27.4%, $\sigma$=34.61%). For both days, the 7° keyboard angle was different from -10°, -20°, and -30°. The 7° keyboard angle also produced the greatest mean percentage of left hand RU deviations within 5° on day 1 ($\mu$=14.7%, $\sigma$=20.77%) and day 2 ($\mu$=7.2%, $\sigma$=12.34%). On day 1, the 7° keyboard angle was different from -10°, -20°, and -30°. On day 2, Tukey's HSD post-hoc analysis was inconclusive.

### *Right Hand*

All dependent variables were significant by keyboard angle except mean %RU deviations within 10°, and day 1 and day 2 mean %RU deviations within 5° (Table IV.5). The -30° keyboard angle resulted in the lowest mean FE deviations for the right hand ($\mu$=2.4°, $\sigma$=6.22°), which differed significantly from -20°, -10°, 0°, and 7°. All keyboard angles were significantly different from each other. The -30° keyboard resulted in the greatest mean percentage of right hand FE deviations in the neutral zone ($\mu$=94.4%, $\sigma$=10.4%), mean percentage of right hand FE deviations within 10° ($\mu$=77.0%, $\sigma$=17.6%), and mean percentage of right hand FE deviations within 5° ($\mu$=44.0%, $\sigma$=20.86%), which differed significantly from -20°, -10°, 0°, and 7°, though no difference was found between the -10°, 0°, and 7° keyboard angles.

The 7° keyboard angle produced the lowest right hand RU deviations ($\mu$=10.8°, $\sigma$=8.19°), and was similar to 0°($\mu$=12.2°, $\sigma$=8.47°), but both keyboard angles differed significantly from -10°, -20°, and -30°. The greatest mean percentage of right hand RU deviations in the neutral zone was found for the 7° keyboard angle ($\mu$=68.6%, $\sigma$=38.48%), which was similar to 0° ($\mu$=62.9%, $\sigma$=39.84%), but was different from -10°, -20°, and -30°.

Table IV.4. Left hand post-hoc differences for keyboard angle

| Left Hand | Mean (Standard Deviation) | | Day 1 and 2 | | | |
|---|---|---|---|---|---|---|
| Mean FE | 7°: | 30.8° (6.84°) | | | | D |
| | 0°: | 28.8° (6.87°) | | | | D |
| | -10°: | 21.5° (7.19°) | | | C | |
| | -20°: | 10.8° (6.66°) | | B | | |
| | -30°: | 3.2° (7.18°) | A | | | |
| %FE in NZ | -30°: | 91.2% (13.24%) | A | | | |
| | -20°: | 70.3% (28.94%) | | B | | |
| | -10°: | 25.3% (30.02%) | | | C | |
| | 0°: | 6.3% (13.06%) | | | | D |
| | 7°: | 3.0% (7.88%) | | | | D |
| %FE < 10° | -30°: | 71.1% (23.57%) | A | | | |
| | -20°: | 45.4% (32.05%) | | B | | |
| | -10°: | 11.0% (20.36%) | | | C | |
| | 0°: | 1.2% (3.14%) | | | C | D |
| | 7°: | 0.4% (1.29%) | | | C | D |
| %FE < 5° | -30°: | 40.5% (23.51%) | A | | | |
| | -20°: | 21.4% (25.06%) | | B | | |
| | -10°: | 3.0% (8.35%) | | | C | |
| | 0°: | 0.1% (0.21%) | | | C | D |
| | 7°: | 0.01% (0.04%) | | | C | D |

Table IV.4. Left hand post-hoc differences for keyboard angle (continued)

| Left Hand | Mean (Standard deviation) | | Day 1 | | | |
|---|---|---|---|---|---|---|
| Mean RU | -30°: | 19.7° (7.28°) | A | | | |
| | -20°: | 17.3° (6.92°) | A | B | | |
| | -10°: | 14.4° (7.65°) | | B | C | |
| | 0°: | 13.4° (7.94°) | | | C | D |
| | 7°: | 13.3° (7.81°) | | | C | D |
| %RU in NZ | 7°: | 59.5% (47.35%) | | B | C | D |
| | -10°: | 57.2% (41.49%) | | B | C | |
| | 0°: | 48.6% (44.22%) | A | B | C | D |
| | -20°: | 39.4% (40.0%) | A | B | | |
| | -30°: | 31.8% (37.7%) | A | | | |
| %RU < 10° | 7°: | 39.6% (38.79%) | | B | C | D |
| | 0°: | 34.2% (38.09%) | | B | C | D |
| | -10°: | 28.6% (28.72%) | A | B | C | |
| | -20°: | 18.2% (26.09%) | A | B | | |
| | -30°: | 9.1% (20.89% | A | | | |
| %RU < 5° | 7°: | 14.7% (20.77%) | | B | C | D |
| | 0°: | 13.3% (19.86%) | | B | C | D |
| | -10°: | 8.7% (16.41%) | A | B | C | |
| | -20°: | 4.9% (11.66%) | A | B | | |
| | -30°: | 3.2% (9.48%) | A | | | |
| **Left Hand** | **Mean (Standard deviation)** | | **Day 2** | | | |
| Mean RU | -30°: | 22.8° (6.21°) | A | | | |
| | -20°: | 21.4° (6.78°) | A | B | | |
| | -10°: | 18.0° (5.58°) | | | C | |
| | 0°: | 16.1° (6.26°) | | | C | D |
| | 7°: | 14.8° (6.62°) | | | | D |
| %RU in NZ | 7°: | 51.3% (44.24%) | | | C | D |
| | 0°: | 47.9% (42.33%) | | | C | D |
| | -10°: | 34.3% (35.44%) | | B | C | |
| | -20°: | 22.1% (31.14%) | A | B | | |
| | -30°: | 8.2% (10.19%) | A | | | |
| %RU < 10° | 7°: | 27.4% (34.61%) | | | | D |
| | 0°: | 20.4% (26.06%) | | B | C | D |
| | -10°: | 7.5% (9.28%) | A | B | C | |
| | -20°: | 4.2% (6.98%) | A | B | | |
| | -30°: | 0.6% (1.16%) | A | | | |
| %RU < 5° | 7°: | 7.2% (12.34%) | Tukey HSD post-hoc analysis inconclusive | | | |
| | 0°: | 3.9% (6.12%) | | | | |
| | -10°: | 0.9% (1.84%) | | | | |
| | -20°: | 0.2% (0.36%) | | | | |
| | -30°: | 0.04% (0.07%) | | | | |

Table IV.5. Right hand post-hoc differences for keyboard angle

| Right Hand | Mean (Standard deviation) | | Day 1 and 2 | | | | |
|---|---|---|---|---|---|---|---|
| Mean FE | 7°: | 34.0° (6.22°) | | | | | E |
| | 0°: | 28.7° (6.25°) | | | | D | |
| | -10°: | 20.8° (5.32°) | | | C | | |
| | -20°: | 11.3° (5.99°) | | B | | | |
| | -30°: | 2.4° (6.22°) | A | | | | |
| %FE in NZ | -30°: | 94.4% (10.4%) | A | | | | |
| | -20°: | 70.0% (29.2%) | | B | | | |
| | -10°: | 22.1% (18.61%) | | | C | | |
| | 0°: | 3.5% (5.07%) | | | | D | |
| | 7°: | 0.7% (1.41%) | | | | D | |
| %FE < 10° | -30°: | 77.0% (17.6%) | A | | | | |
| | -20°: | 45.0% (33.61%) | | B | | | |
| | -10°: | 5.4% (6.06%) | | | C | | |
| | 0°: | 0.6% (1.35%) | | | C | D | |
| | 7°: | 0.07% (0.18%) | | | C | D | |
| %FE < 5° | -30°: | 44.0% (20.86%) | A | | | | |
| | -20°: | 20.4% (21.89%) | | B | | | |
| | -10°: | 1.0% (1.40%) | | | C | | |
| | 0°: | 0.1% (0.38%) | | | C | D | |
| | 7°: | 0.02% (0.07%) | | | C | D | |
| Mean RU | -30°: | 17.0° (9.54°) | A | | | | |
| | -20°: | 14.7° (9.17°) | A | B | | | |
| | -10°: | 13.1° (9.10°) | A | B | C | | |
| | 0°: | 12.2° (8.47°) | | B | C | D | |
| | 7°: | 10.8° (8.19°) | | B | C | D | |
| %RU in NZ | 7°: | 68.6% (38.48%) | | B | C | D | |
| | 0°: | 62.9% (39.84%) | | B | C | D | |
| | -10°: | 54.5% (44.27%) | A | B | C | | |
| | -20°: | 45.3% (43.44%) | A | B | | | |
| | -30°: | 37.4% (43.89%) | A | | | | |

## KA by Gender Interaction

The keyboard angle by gender interaction was significant only for mean FE left hand deviations ($F(4,8) = 3.0585$, $p < 0.05$). Mean values decreased as keyboard angle decreased, but gender differences were noted at the -30° keyboard angle, where males ($\mu$ =7.69°, $\sigma$ =4.95°) were higher than females ($\mu$ =0.29°, $\sigma$ =7.05°) (Figure IV.1).

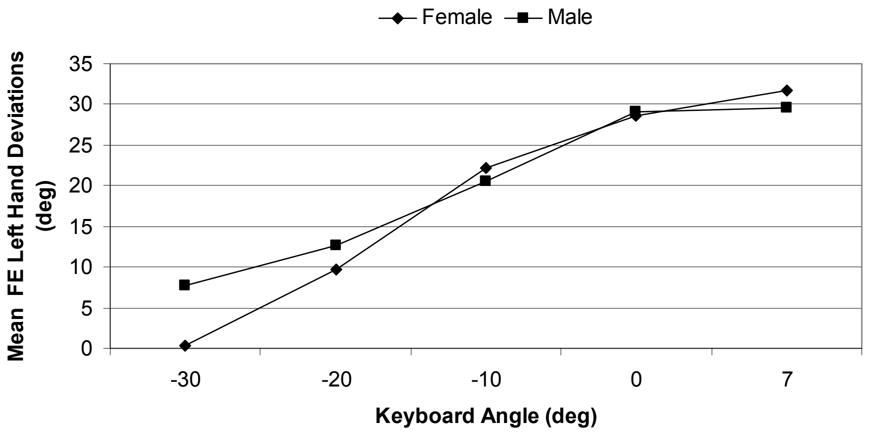

Figure IV.1. Mean FE left hand deviation KA by gender interaction

Side

Day 1 and day 2 mean RU deviations, and day 2 mean %RU deviations in the neutral zone, mean %RU deviations within 5°, and mean %RU deviations within 10° were significant by side. The left side was significantly greater than the right side for day 1 mean RU deviations (15.6° versus 12.8°) and day 2 mean RU deviations (18.6° versus 14.4°). The right side was significantly greater than the left side for day 2 mean %RU deviations in the neutral zone (49.1° versus 32.7°), day 2 mean %RU deviations within 10° (39.2° versus 12.0°), and mean %RU deviations within 5° (23.5° versus 2.4°).

## Electromyography Data

Graphs showing mean EMG values at 30-second intervals versus time for each of the four muscles for one participant appear in Appendix I for illustrative purposes only. The graphs depict fluctuations in muscle activity throughout the entire ten-minute test session; which were not seen in mean values.

Day

Normalized EMG values for the left arm FCU and ECU were significant by day. Day 1 values were significantly greater than day 2 values for the left arm FCU muscle (6.4% MVC versus 3.9% MVC) and left arm ECU muscle (11.9% MVC versus 9.1% MVC). Day 2 values were significantly greater than day 1 values for the right arm ECU muscle (12.0% MVC versus 11.1% MVC).

## Keyboard Angle and Gender

Day 2 normalized left arm FCU values and day 1 and day 2 normalized right arm ECU values were significant by keyboard angle (Table IV.6). The 7° keyboard angle required significantly less left arm FCU muscle activity than any other keyboard angle on day 2 of testing. On day 1, the 0° keyboard angle required significantly less right arm ECU muscle activity than the other keyboard angles. On day 2, each of the three negative keyboard angles required significantly less right arm ECU muscle activity than the 0° or the 7° keyboard angle, though no differences were found for muscle activity requirements among the negative angles.

Right arm normalized FCU values were significant by gender. FCU values for females (7.3% MVC) were significantly greater than males (4.5% MVC).

Table IV.6. EMG post-hoc differences for keyboard angle

| EMG Variable | Mean (Standard deviation) (%MVC) | | Day 1 | | | | |
|---|---|---|---|---|---|---|---|
| Right arm ECU | 7°: | 12.57% (3.54%) | A | | | | |
| | -10°: | 11.32% (3.02%) | A | B | | | |
| | -30°: | 10.94% (3.45%) | A | B | C | | |
| | -20°: | 10.78% (3.93%) | A | B | C | D | |
| | 0°: | 10.11% (4.28%) | | B | C | D | |
| **EMG Variable** | **Mean (Standard deviation) (%MVC)** | | **Day 2** | | | | |
| Right arm ECU | 7°: | 13.38% (4.9%) | A | | | | |
| | 0°: | 12.40% (4.49%) | A | B | | | |
| | -30°: | 11.56% (5.01%) | | B | C | | |
| | -10°: | 11.46% (5.17%) | | B | C | D | |
| | -20°: | 11.39% (4.77%) | | | C | D | |
| Left arm FCU | -20°: | 4.21% (2.88%) | -20: | A | | | |
| | -30°: | 4.08% (2.78%) | -30: | A | B | | |
| | -10°: | 4.05% (2.85%) | -10: | A | B | C | |
| | 0°: | 3.73% (2.49%) | 0: | A | B | C | D |
| | 7°: | 3.59% (2.17%) | 7: | | B | C | D |

## Side

Day 2 normalized FCU and ECU values were significant by side, where the right side was significantly greater than the left side for both values (FCU: 6.34% MVC versus 3.93% MVC; ECU: 12.04% MVC versus 9.07% MVC).

## Key Strike Force Data

Side

Mean key strike force was significantly greater for the “N” key than the “E” key (1.0682 N versus 1.0212 N).

## Performance Data

Day

Mean net typing speed, errors, missing words, and misspelled words were significant by day. Day 2 mean net typing speed was greater than day 1 (55.20 wpm versus 56.68 wpm). Day 1 mean values were greater than day 2 for errors (18.30 versus 14.56), missing words (1.24 versus 0.7), and misspelled words (15.82 versus 12.94). These findings suggest that participants traded off accuracy of the task for increased speed.

Keyboard Angle, Gender, and KA by Gender Interaction

Day 1 and day 2 mean net typing speed was significant by keyboard angle (Table IV.7). Day 2 missing words was significant by gender, where males (1.3) showed higher values than females (0.3). Day 1 mean net typing speed (*F*(4,8) = 3.6, *p* = 0.0156) showed significance in the KA by gender interaction (Figure IV.2).

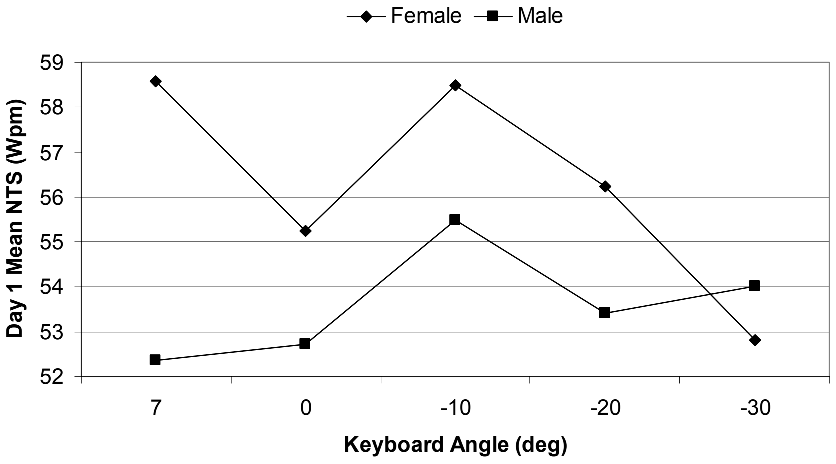

Figure IV.2. Day 1 mean net typing speed KA by gender interaction

Table IV.7. Net typing speed post-hoc differences for keyboard angle

| Performance Variable | Mean (Standard deviation) (Wpm) | | Day 1 | | | | |
|---|---|---|---|---|---|---|---|
| Net Typing Speed | -10°: | 57.29 (8.03) | -10°: | A | | | |
| | 7°: | 56.09 (9.22) | 7°: | A | B | | |
| | -20°: | 55.10 (7.39) | -20°: | A | B | C | |
| | 0°: | 54.24 (9.35) | 0°: | | B | C | D |
| | -30°: | 53.30 (8.25) | -30°: | | B | C | D |
| **Performance Variable** | **Mean (Standard deviation) (Wpm)** | | **Day 2** | | | | |
| Net Typing Speed | -10°: | 58.36 (8.47) | -10°: | A | | | |
| | -20°: | 58.00 (7.23) | -20°: | A | B | | |
| | 7°: | 56.68 (8.10) | 7°: | A | B | C | |
| | 0°: | 55.92 (9.05) | 0°: | A | B | C | D |
| | -30°: | 54.44 (6.55) | -30°: | | | C | D |

## Self-reported Postural Discomfort Questionnaire Data

### Self-reported Postural Discomfort Questionnaire (7-point scale)

After grouping body parts, one-way repeated measures ANOVA was conducted for discomfort ratings and self-ratings, and some variables showed significance by day, keyboard angle, subject, gender, and the KA by gender interaction.

### Day

Normalized discomfort values for the left hand (day 1: $\mu$=0.23 MR, $\sigma$=0.2 MR; day 2: $\mu$=0.19 MR, $\sigma$=0.17 MR), left forearm (day 1: $\mu$=0.32 MR, $\sigma$=0.27 MR; day 2: $\mu$=0.24 MR, $\sigma$=0.22 MR), right hand (day 1: $\mu$=0.23 MR, $\sigma$=0.19 MR ; day 2: $\mu$=0.18 MR, $\sigma$=0.18 MR), and right forearm (day 1: $\mu$=0.30 MR, $\sigma$= 0.28 MR; day 2: $\mu$=0.24 MR, $\sigma$=0.25 MR) showed significance by day. It is interesting to note that for each body part, discomfort rating decreased from day 1 to day 2.

### Keyboard Angle, Gender, and KA by Gender Interaction

Only self-rating of keyboard usage difficulty (compared to the standard 7°) was significant by keyboard angle. Self-rating, and normalized discomfort values for the left wrist and right wrist showed significance by gender. Males rated more discomfort for both the left wrist (males: $\mu$=0.41 MR, $\sigma$=0.21 MR; females: $\mu$=0.21 MR, $\sigma$=0.18 MR) and right wrist (males: $\mu$=0.41 MR, $\sigma$=0.21 MR; females: $\mu$=0.15 MR, $\sigma$=0.18 MR). Day 2 normalized discomfort values for both the left hand (*F*(4,8) = 3.132, *p* = 0.0278) and right hand (*F*(4,8) = 4.6, *p* = 0.0048), and normalized discomfort values for the right wrist (*F*(4,8) = 4.739, *p* = 0.0017) showed significance in KA by gender interaction, with males reporting more discomfort across keyboard angles (Figures IV.3, IV.4, and IV.5).

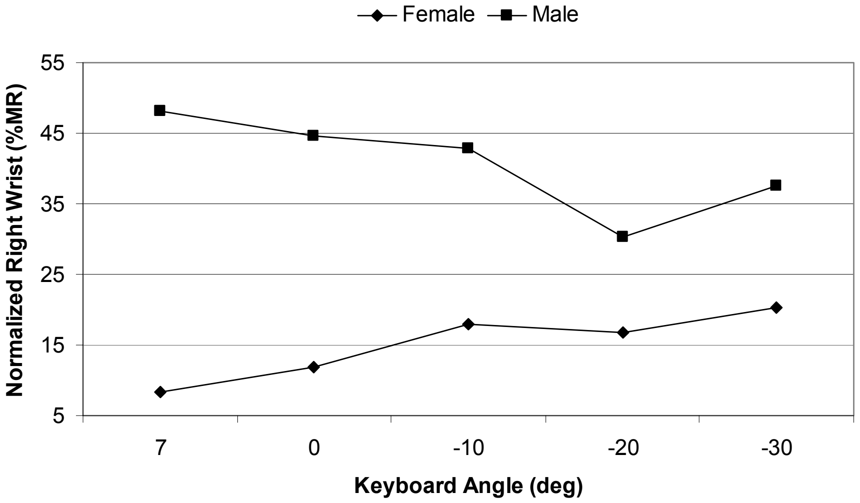

Figure IV.3. Normalized right wrist KA by gender interaction

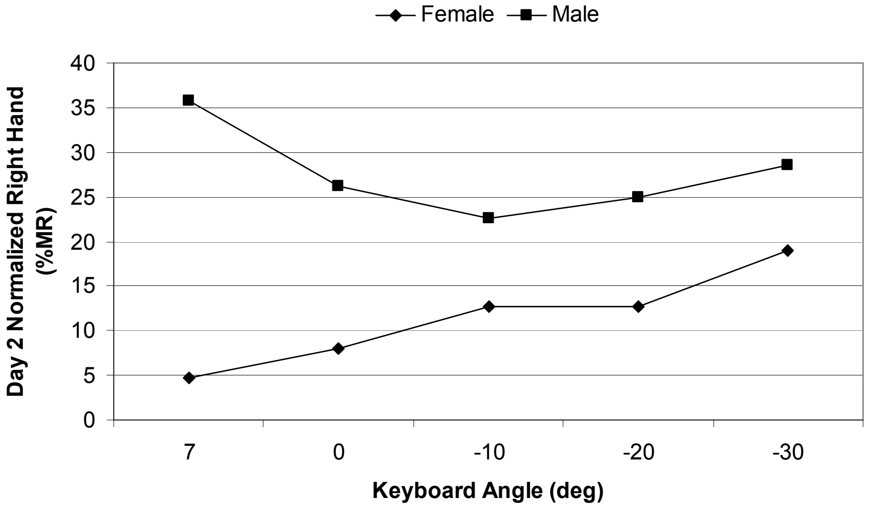

Figure IV.4. Day 2 normalized right hand KA by gender interaction

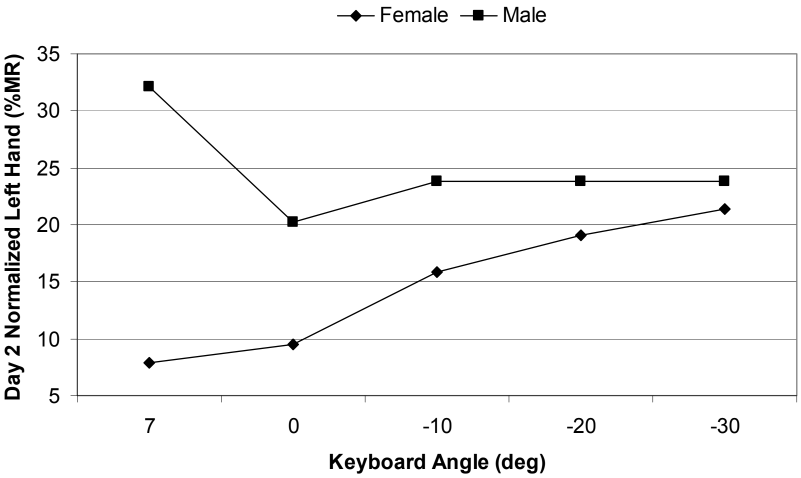

Figure IV.5. Day 2 normalized left hand KA by gender interaction

Exit Questions

Exit questions were added to the self reported postural discomfort questionnaire (SPDQ) to compare the non-standard keyboard angles to the standard including: (1) self-rating comparison; (2) estimated time for typing speed comparison; and (3) final ranking.

*Self-rating Comparison (5-point scale)*

Self-ratings of keyboard angle usage difficulty compared to the standard configuration were assessed using a 5-point scale in which participants rated each new keyboard angle against the standard 7° keyboard angle. Ratings ranged from 1= much harder to use to 5 = much easier to use. Self-ratings did not vary by day, indicating that participants self-rated the keyboard angles consistently for each day.

As can be seen from Figure IV.6, mean self-ratings decreased (or the level of difficulty for use increased) as the keyboard angle became more negative, and these ratings were found to be significant (Table IV.8). Minimum and maximum self-ratings received for each keyboard angle were approximately the same (Table IV.9), indicating that some participants perceived the usage of these keyboard angles to be comparable to the standard keyboard angle.

Self-rating was significant by gender. Males ($\mu$ =2.71, $\sigma$ =0.82) self-rated higher than females ($\mu$ =2.19, $\sigma$ =0.81), meaning males felt negative keyboard angles were easier to type on compared to the standard than females did.

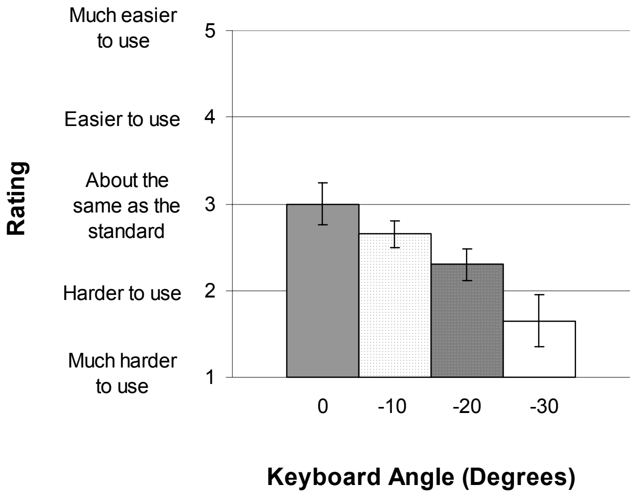

Figure IV.6. Mean self-rating of new keyboard angles compared to 7° keyboard angle (n=20)

Table IV.8. Self-rating post-hoc differences for keyboard angle

| Discomfort Variable | Mean (Standard deviation) | | Day 1 and 2 | | | |
|---|---|---|---|---|---|---|
| Self-rating | 0°: | 3.00 (0.73) | A | | | |
| | -10°: | 2.65 (0.49) | A | B | | |
| | -20°: | 2.30 (0.57) | | B | C | |
| | -30°: | 1.65 (0.93) | | | | D |

Table IV.9. Minimum and maximum values for mean self-rating of new keyboard angles compared to 7° keyboard angle

| Keyboard Angle | Minimum Value | Maximum Value |
|---|---|---|
| 0° | 2 | 4 |
| -10° | 2 | 3 |
| -20° | 1.5 | 3 |
| -30° | 1 | 4 |

*Estimated Time for Typing Speed Comparison*

Sixty percent of the population's responses indicated that they could reach the same level of typing speed and accuracy on *any* new keyboard angle when compared to their performance on the 7° keyboard angle. Participants were asked to estimate the amount of time they believed would be necessary to reach this performance level (Figure IV.7). Mean time estimates for new keyboard angles on day 1 fell roughly between 30-50 hours. Day 2, however, showed on average that less than 10 hours is needed to acclimate to -20°, but over 70 hours is needed to reach the same level at the -10° keyboard angle. From day 1 to day 2, estimated learning times decreased on average by 33% for 0°, 85% for -20°, and 55% for the -30° keyboard angle. For -10°, the learning time increased on average by 37%. In general, most participants felt confident they could learn to type on the new keyboard angles in a relatively short period of time (Table IV.10).

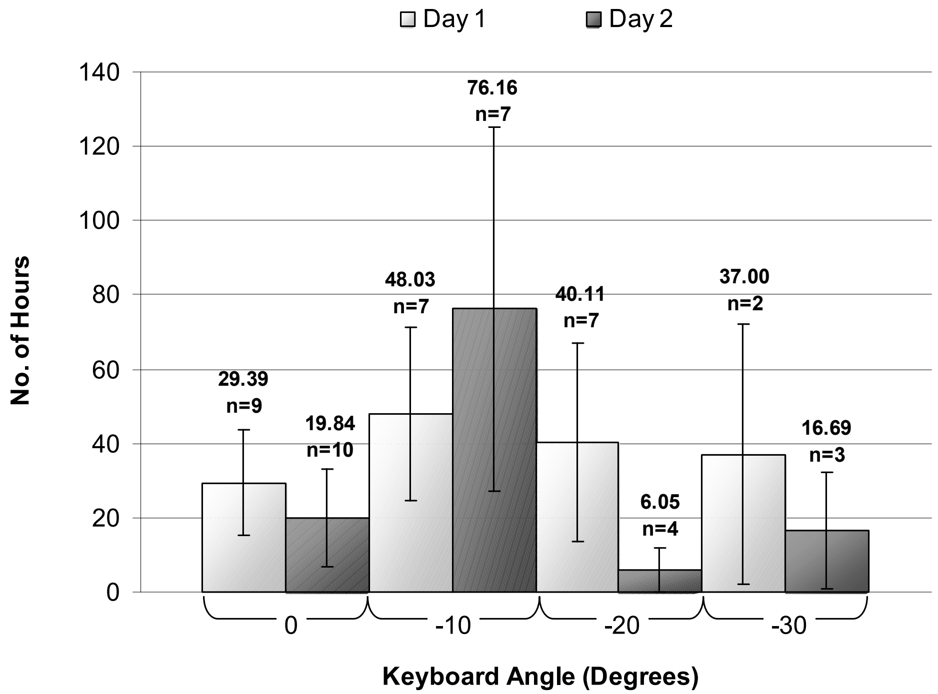

Figure IV.7. Mean time estimated to reach same typing speed compared to 7° keyboard angle by day (n=10)

Table IV.10. Means and standard deviations for estimated time of typing speed

| Day | Keyboard Angle | Mean (Standard deviation) (Hrs) |
|---|---|---|
| Day 1 | 0° | 29.39 (42.85) |
| | -10° | 48.03 (61.55) |
| | -20° | 40.11 (65.50) |
| | -30° | 37.00 (49.50) |
| Day 2 | 0° | 19.84 (41.71) |
| | -10° | 76.16 (129.81) |
| | -20° | 6.05 (11.96) |
| | -30° | 16.69 (27.13) |

### *Final Ranking*

Participants were forced to rank order the keyboard angles from 1 = best to 5 = worst. The Friedman test was generated for this repeated measures comparison. For both day 1 and day 2, there was a significant difference between the mean rankings (day 1: $F(4,36) = 7.48$, $p < 0.001$; day 2: $F(4,36) = 4.16$, $p < 0.01$), with most preferring the standard or 7° configuration. This result was expected since the final ranking was a forced ranking—only one ranking could be assigned to each keyboard angle.

### *Keyboard Angle and Gender*

Post-hoc differences by day were observed, while mean rankings were practically identical (Table IV.11). Day 1 mean rankings showed more differences between the final rankings among the keyboard angles, while day 2 rankings indicated that only the -30° keyboard angle was ranked significantly lower than all the other keyboard angles.

Gender differences were observed for day 2 rankings. The time by gender interaction for day 2 showed significance at $F(4, 32) = 3.28$, $p < 0.05$. The univariate test revealed a significant difference for the 7° keyboard angle between males and females ($F(1,9) = 10.82$, $p < 0.05$). Females ($\mu = 1.333$) showed a higher mean ranking than males ($\mu = 3.5$).

Table IV.11. Final ranking post-hoc differences for keyboard angle (best to worst)

| Day | Mean (Standard deviation) | | Post-hoc | | | |
|---|---|---|---|---|---|---|
| Day 1 | 7°: | 1.8 (1.03) | A | | | |
| | 0°: | 2.4 (1.35) | A | B | | |
| | -10°: | 2.8 (0.92) | | B | C | |
| | -20°: | 3.6 (0.97) | | | | D |
| | -30°: | 4.4 (1.35) | | | | D |
| Day 2 | 7°: | 2.2 (1.48) | A | | | |
| | 0°: | 2.3 (1.16) | A | | | |
| | -10°: | 2.7 (0.95) | A | | | |
| | -20°: | 3.5 (1.18) | A | | | |
| | -30°: | 4.3 (1.34) | | B | | |

## Linear Correlations by Day

Linear correlations were computed to assess repeatability across testing days (Table IV.12). Not counting MVC variables, Pearson's correlations were above 0.59, indicating a strong correlation between days. All MVC correlations were below 0.5. All nonparametric correlations were above 0.33 except for the left arm FCU muscle, which correlated at a value of 0.07. These variables were the only variables that did not show repeatability from day 1 to day 2. Thirteen percent of the correlations were weak, 19% were moderate, and 68% were strong.

Table IV.12. Table of linear correlations by day

**Parametric Correlations: Pearson's**

| Variable | Correlation (R) | P-value |
|---|---|---|
| Normalized EMG RH – FCU$^{\tau}$ | 0.5899 | 0.0000 |
| Mean RU - LH $^{\tau}$ | 0.6272 | 0.0000 |
| Mean FE - RH $^{\psi}$ | 0.9257 | 0.0000 |
| Net Typing Speed (NTS) $^{\psi}$ | 0.8978 | 0.0000 |
| MVC RH – FCU$^{\lambda}$ | 0.1974 | 0.5846 |
| MVC RH – ECU$^{\tau}$ | 0.4448 | 0.1978 |
| MVC LH – FCU$^{\tau}$ | 0.2803 | 0.4328 |
| MVC LH – ECU$^{\tau}$ | 0.4933 | 0.1474 |

**Nonparametric Correlations: Spearman's Rho**

| Variable | Spearman's Rho | Prob>\|Rho\| |
|---|---|---|
| Normalized EMG RH – ECU$^{\tau}$ | 0.5751 | <0.0001 |
| Normalized EMG LH – FCU$^{\lambda}$ | 0.0684 | 0.6370 |
| Normalized EMG LH – ECU$^{\tau}$ | 0.4262 | 0.0020 |
| Mean of KSF Peaks – 'E' key$^{\psi}$ | 0.9323 | <0.0001 |
| Mean of KSF Peaks – 'N' key$^{\psi}$ | 0.8898 | <0.0001 |
| %FE in Neutral Zone - LH$^{\psi}$ | 0.8740 | <0.0001 |
| %RU in Neutral Zone - LH$^{\tau}$ | 0.5633 | <0.0001 |
| Mean FE - LH$^{\psi}$ | 0.8652 | <0.0001 |
| Mean RU - RH $^{\psi}$ | 0.6354 | <0.0001 |
| %FE in Neutral Zone - RH$^{\psi}$ | 0.9335 | <0.0001 |
| %RU in Neutral Zone - RH$^{\psi}$ | 0.7211 | <0.0001 |
| %FE < 5 degrees - LH$^{\psi}$ | 0.8500 | <0.0001 |
| %RU < 5 degrees - LH$^{\psi}$ | 0.6345 | <0.0001 |
| %FE < 5 degrees - RH$^{\psi}$ | 0.9000 | <0.0001 |
| %RU < 5 degrees - RH$^{\tau}$ | 0.4764 | 0.0005 |
| %FE < 10 degrees - LH$^{\psi}$ | 0.8755 | <0.0001 |
| %RU < 10 degrees - LH$^{\psi}$ | 0.6380 | <0.0001 |
| %FE < 10 degrees - RH$^{\psi}$ | 0.9101 | <0.0001 |
| %RU < 10 degrees - RH$^{\psi}$ | 0.7303 | <0.0001 |
| Final Ranking$^{\psi}$ | 0.8300 | <0.0001 |
| No. of Errors$^{\psi}$ | 0.6396 | <0.0001 |
| Missing Words$^{\tau}$ | 0.4438 | 0.0012 |
| Extra, Joined, Split words (EJS)$^{\tau}$ | 0.3333 | 0.0180 |
| Misspelled Words$^{\psi}$ | 0.6635 | <0.0001 |
| Normalized Left Hand Rating (SPDQ)$^{\psi}$ (TIMs, RPs, Palm) | 0.8540 | <0.0001 |
| Normalized Left Wrist Rating (SPDQ)$^{\tau}$ | 0.5937 | <0.0001 |
| Normalized Left Forearm Rating (SPDQ)$^{\psi}$ | 0.7994 | <0.0001 |
| Normalized Right Hand Rating (SPDQ)$^{\psi}$ (TIMs, RPs, Palm) | 0.7917 | <0.0001 |
| Normalized Right Wrist Rating (SPDQ)$^{\psi}$ | 0.8408 | <0.0001 |
| Normalized Right Forearm Rating (SPDQ)$^{\psi}$ | 0.8443 | <0.0001 |
| Self-rating$^{\psi}$ | 0.7159 | <0.0001 |

$\lambda$ weak correlation ($r_S$, $r_P \leq 0.279$; $r_P^{MVC} < 0.632$)

$\tau$ moderate correlation ($0.279 < r_P, r_S < 0.632$)

$\psi$ strong correlation ($r_S, r_P, r_P^{MVC} \geq 0.632$)

# CHAPTER V
# DISCUSSION

The objective of this study was to identify a negative keyboard angle or range of keyboard angles that minimized exposure to hypothesized risk factors for hand/wrist work related musculoskeletal disorders. It was hypothesized that keyboard angle would have significant effects on muscle activity of the flexor and extensor carpi ulnaris muscles in the forearm, key strike force, wrist posture, and reported discomfort while performance remained consistent. It was further hypothesized that at a keyboard angle of –30°, the effects on all dependent variables would be negative. In general, the only hypotheses that were supported by this study for negative angles decreasing from 7° to -20° were: (1) wrist posture was within a neutral zone a greater percentage of the time with respect to FE deviations; but *not* RU deviations; and (2) performance remained consistent. Increased reported discomfort was the only hypothesis that was supported for the –30° keyboard angle.

## Wrist Posture

This study supported findings from Hedge et al. (1999) that found 67% of typing movements (both FE and RU deviations) made while using negatively sloped keyboards were within the neutral zone (<15° extension, <30° flexion, <15° ulnar or radial deviation). However, for both hands, this study found mean FE typing movements exceeded 70% and 90% within the same neutral zone for -20° and -30°, respectively, angles not studied in previous literature. The 7° and 0° keyboard angles yielded less than 7% of FE typing movements within the neutral zone. Mean FE percentages within tighter intervals than the neutral zone (<5° and <10°) were also noticeably greater for extreme negative keyboard angles. For mean percentages of FE deviations within 10°, -20° and -30° keyboard angles produced mean FE percentages above 45%, where the other keyboard angles were below 12%. For the tighter interval of within 5°, -20° and -30° keyboard angles produced values above 20%, far superior to the other keyboard angles (<3%). These results show benefit for the -20° and -30° keyboard angles regarding wrist posture, and are summarized in Figure V.1. Ideally, percentages of typing movements should be as close to the neutral position as possible to reduce risk of MSD development. The relationship of risk to typing posture is explained further in this section.

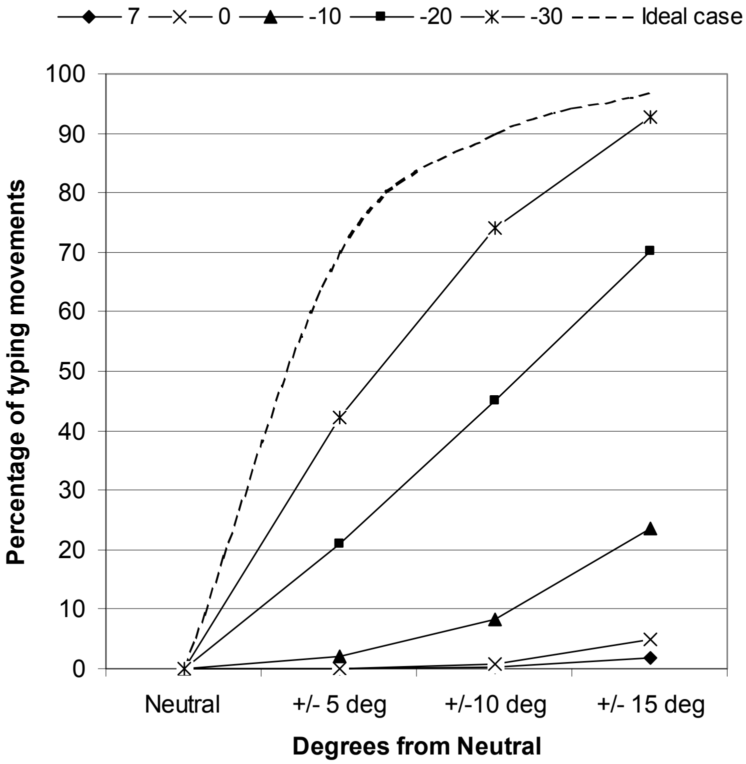

Figure V.1. Comparison of mean FE deviations within varying zones from neutral position

Maximum negative slopes that were studied herein (-20° and -30°) greatly exceeded slopes studied by Hedge and Powers (1995) (-12° ± 0.4°) and Simoneau and Marklin (2001) (-15°). Surprisingly, results from this study for the extreme negative angles were similar to results found in these two studies. Hedge and Powers (1995) found mean wrist extension at a keyboard slope of -12° ± 0.4° to be –1.2° ± 2.0°. Simoneau and Marklin (2001) found lowest mean wrist extension to be between 1-2° at a keyboard slope of -15° with wrists located *above* the elbows; but wrist extension for this same keyboard angle with the wrists *below* the elbows was between 15-17°. Mean wrist extension in this study was similar, between 2-3°, for the -30° keyboard angle. In addition to these negative slope contrasts, comparing the standard keyboard angle amongst the studies showed noticeable differences as well.

Mean wrist extension for the 7° keyboard angle studied herein was between 31-34°. These values agreed with aforementioned studies for average wrist extension for use with the standard keyboard configuration, although the values were on the higher end of the range. Hedge and Powers (1995) found wrist extension for a similar configuration to be 13.0° ± 2.2°, and Simoneau and Marklin (2001) found values between 8-10° for wrists located above the elbows and between 24-25° for wrists below the elbows on their 7.5° standard keyboard configuration. These values found by Hedge and Powers (1995) and Simoneau and Marklin (2001) where wrists were below the elbows were on the lower and middle ends, respectively, of the average range for wrist extension with the standard keyboard configuration. Although it was clear these studies showed benefits for using negatively sloped keyboards since mean wrist extension decreased as keyboard angle decreased, it was possible they underestimated potential wrist posture benefits. This finding was more obvious in this study when considering the percentage of FE typing movements within specified zones. These comparisons illustrate how dependent results were on typing posture, and these discrepancies may have been manifested in the use, or lack thereof, of a wrist rest.

The Hedge and Powers and Simoneau and Marklin studies used wrist rests, either integrated or separate. Simoneau and Marklin (2001) found that wrist extension decreased approximately 13° for a net change of 30° in keyboard slope, or a 1° decrease in wrist extension for 2° of change in downward slope. This study tested negative angles that were double what Simoneau and Marklin (2001) tested without a wrist rest, and found wrist extension decreased on average 30° resulting from a net change of 37°, or practically a 1° decrease in wrist extension for 1° of change in downward slope. Mean FE deviations at all five keyboard angles for both hands obtained in this study may be accredited to the absence of a wrist rest, because the lack of a wrist rest might allow upper extremity typing posture to vary. In hindsight, the absence of a wrist rest may have been a limitation. Mean FE deviations, however, still showed that greater negative angles benefit persons as deviated wrist postures are reduced while keying. Similar results were not as apparent for RU deviations.

Mean RU deviations in this study were found to be between 17-23° for the -30° keyboard angle. Values found in the studies by Hedge and Powers and Simoneau and Marklin were slightly lower for their respective maximum negative angles; but, results showed dependence on typing posture in the Simoneau and Marklin study. Simoneau and Marklin (2001) found mean RU deviations were lowest when wrists were *below* the elbows (as opposed to FE postures, presented earlier, which were lowest when wrists were located above the elbow). A separate wrist rest was used in that study. It is possible that different results may have been obtained if a wrist rest, separate or integrated, were used in the current study, to help keep the forearm parallel to the floor. These alternatives are a consideration for future research.

The impact of decreasing keyboard angle on radioulnar deviations was unexpected. Right hand mean RU deviations and mean %RU deviations within the neutral zone for negative angles were significantly lower compared to the flat and standard keyboard angles. Interestingly, side effects were noticed for all %RU deviations, with the right side greatly exceeding the left side. Higher right-hand values may have been caused by a primarily right-handed population or by more static postures associated with loading differences between the hands. The difference in right hand mean %RU deviations within the neutral zone between the 7° and -30° keyboard angles was 69% and 37%, respectively. Similar values were found for day 1 left hand mean %RU deviations within the neutral zone, but day 2 values were greatly varied (50% versus 8%). These results might be attributed to studying more extreme negative angles, unlike previous literature, or because of varying typing posture between the days.

Left side values were greater than right side values for mean RU deviations. Mean %RU deviations for the left hand within tighter intervals than the neutral zone (<5° and <10°) were significant by day and keyboard angle, and decreased from day 1 to day 2. This result across days contradicted results for the right hand, where no differences by day were noted, and both variables were not significant by keyboard angle. Mean left-hand RU deviations increased from day 1 to day 2 also, which is a basis for increased mean %RU deviations. Reasons for significant differences in left hand activity may be that the right-hand dominant population did not achieve the same level of comfort with the left hand at the typing angles, or, again, due to loading differences across the hands.

Discomfort ratings varied by day for left and right hands and forearms, but were not significant by side. All day 1 means were greater than day 2 means, indicating less discomfort was experienced as time elapsed. It was possible a higher level of discomfort was tolerated for the right hand and yielded fewer effects by day, unlike the left hand, which varied greatly in RU typing movements. The left hand is also known to be overloaded because of the layout of keys (Dvorak, 1936), and may have contributed to the significant findings for all left hand variables and this decrease within tighter intervals across days.

There were keyboard angle by gender interactions for day 2 normalized discomfort values for both the left and right hand, and normalized values for the right wrist. In general, normalized discomfort values for males were higher than females, and gradually converged as keyboard angle decreased. It would appear males were most comfortable at negative typing angles, where females were most comfortable at neutral or positive typing angles. It is possible that this finding is due to hand anthropometric differences, though this hypothesis was not tested.

### Performance Measures Compared with Discomfort

Most performance measures remained consistent across keyboard angle, but most were significant by day. All performance measures except extra-, jointed-, and split word (EJS) data were significant by day, and may have resulted from participant differences (Figures V.2 - V.5). For all performance measures other than typing speed, values decreased from day 1 to day 2. Participants may have felt more comfortable with the study after completing the first trial, and their familiarity with the text passages may have unavoidably led to better performance, even with a week in between experiments. On the other hand, this result could have established that negative keyboard angles were easily learned.

The -10° keyboard angle yielded the best mean net typing speeds, where 7° was second best on day 1 and -20° was second best on day 2 (Table V.I). Surprisingly, the -10° keyboard angle showed the largest mean values for all errors studied except missing words, despite having the largest mean net typing speed. All keyboard angles resulted in lower missing words than the standard on either day. In general, typing at negative angles yielded better or comparable results to the standard regarding number of errors, missing words, misspelled words, or extra-, joined-, and split-word errors, while significant differences were only found for net typing speed across keyboard angles. Gilad and Harel (2000), Simoneau and Marklin (2001), and Hedge and Powers (1995) found no significant differences in respective typing quality measures (i.e. mean typing accuracy, mean errors, cumulative typing time) for the negative angles they studied in comparison to the 7° keyboard angle. Contrary to the stated hypothesis, the extreme keyboard angles did not hinder participants from seeing or reaching keys consistently and accurately with two of the three top performing keying angles resulting at -10° and -20°. Although participants were very familiar with the standard keyboard configuration, these results showed evidence that participants could unknowingly succeed at typing on negative keyboard angles and were more accustomed to typing at these angles than they felt.

The differences in net typing speed should invariably be a result of differences in errors, since errors are directly related to a participant's net typing speed. This study produced results to show otherwise for keyboard angle differences. Day 1 and day 2 mean net typing speed showed the only significance by keyboard angle, and the KA by gender interaction showed significance on day 1. Females were more accurate than males, and participants typed their best at the -10° keyboard angle. While gender differences showed females outperforming males at the -20° keyboard angle, males outperformed females at the -30° keyboard angle. Participant differences, along with gender differences, may have contributed to these performance measure differences in keyboard angle because of varying hand size and differences in typing habits. Varying hand sizes could have lead to accidental key activations when a participant attempted to type certain words. Also, errors may originate from varying cognitive behaviors that lead to mistakes exclusive to that participant, which would result in lower typing speed.

Table V.1. Mean net typing speed

| Keyboard Angle | Minimum Value (Wpm) | Median Value (Wpm) | Maximum Value (Wpm) |
|---|---|---|---|
| 7° | 42.1 | 55.7 | 79.0 |
| 0° | 38.7 | 55.2 | 74.4 |
| -10° | 45.2 | 57.3 | 76.4 |
| -20° | 44.6 | 56.7 | 71.2 |
| -30° | 44.5 | 54.1 | 71.0 |

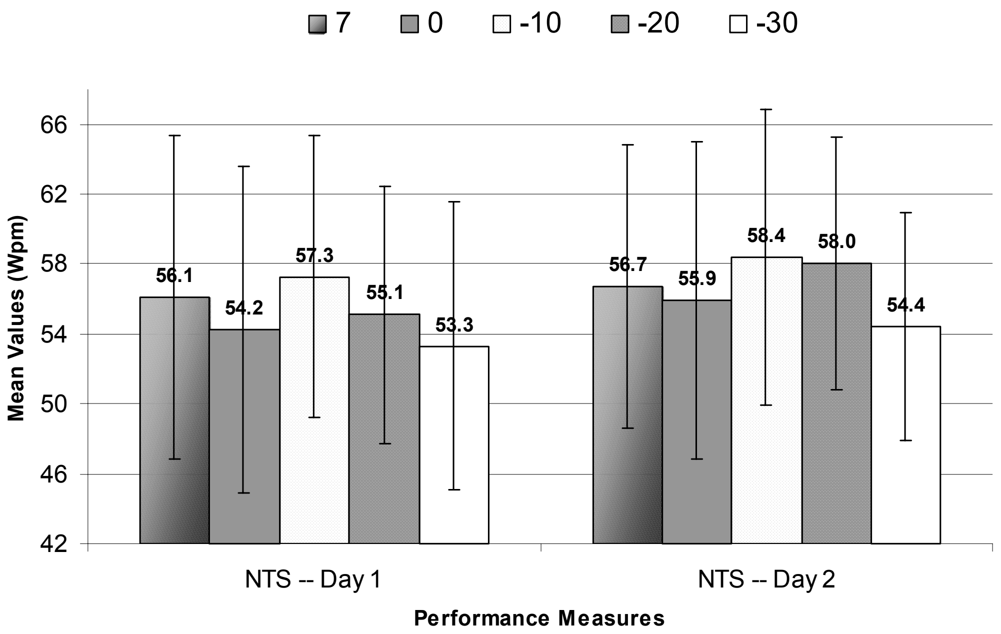

Figure V.2. Mean net typing speed by keyboard angle

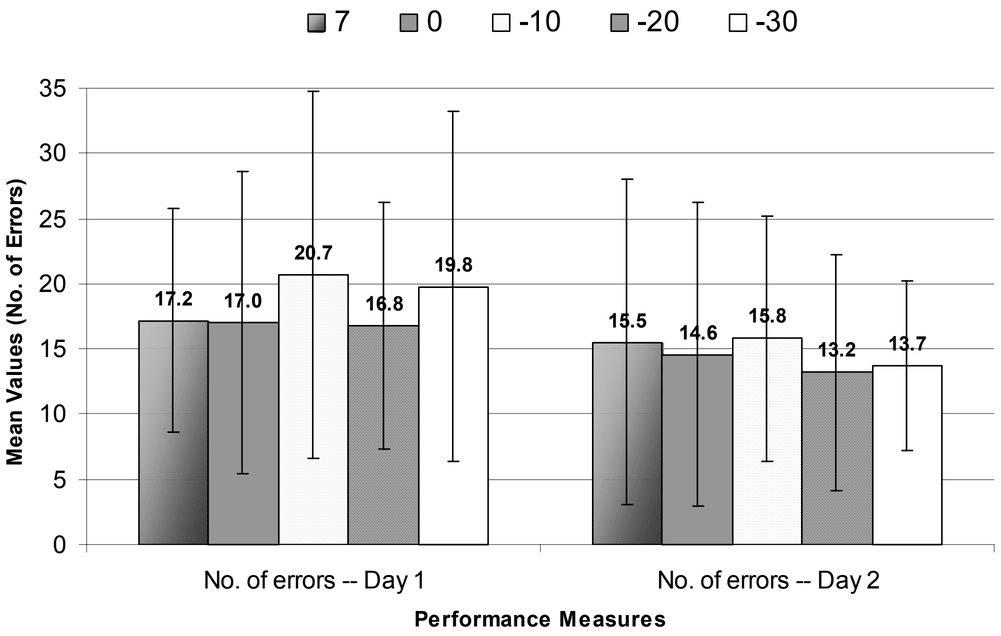

Figure V.3. Mean values for number of errors by keyboard angle

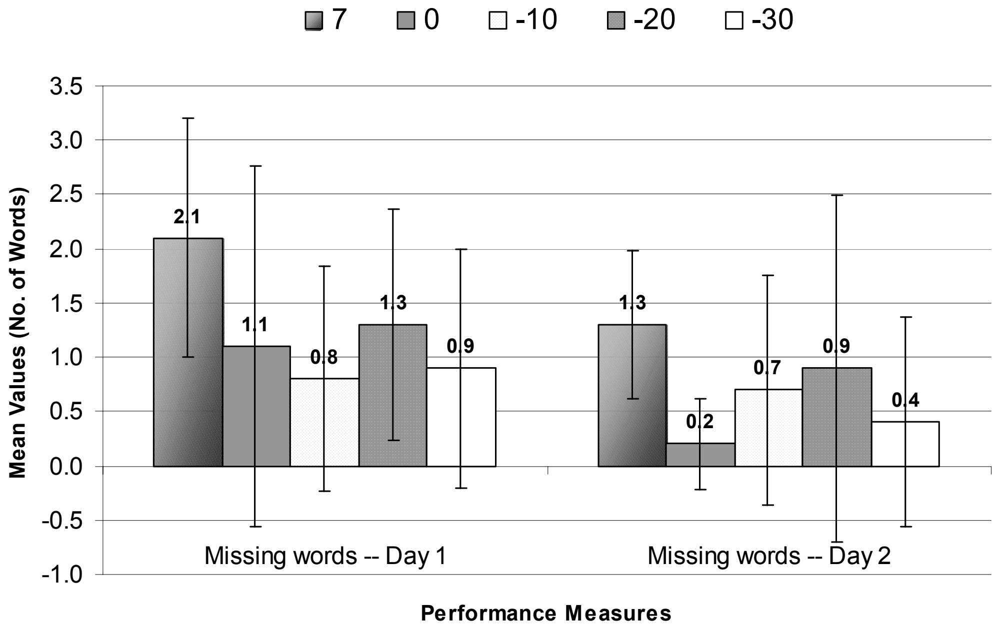

Figure V.4. Mean values for missing words by keyboard angle

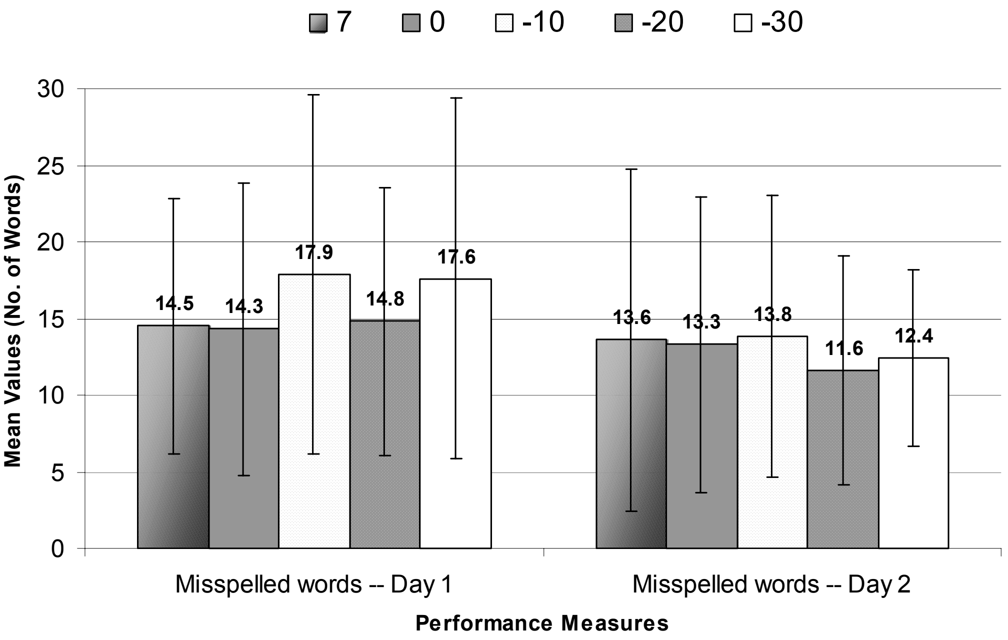

Figure V.5. Mean values for misspelled words by keyboard angle

Although performance measures varied to some extent, usability difficulty increased as keyboard angle decreased, though no other differences were found across keyboard angles for other subjective measures. Unlike previous studies, studying more extreme negative angles and more types of typing errors accounted for significant findings in performance measures.

The usability self-rating showed participants preferred the 7° and 0° to the -10°, -20°, or -30° successively, and there was no significance in the ratings by keyboard angle according to the 7-point discomfort rating; however, it was possible these ratings were confounded. All participants in this study were accustomed to the standard 7° keyboard configuration, and may have had a natural negative response to the negative typing angles, simply because they were different. This finding needs to be investigated following prolonged exposure to the negative angles to support or refute this confounding hypothesis.

Time estimates for reaching the same level of typing speed and performance as the standard configuration varied widely, and can be partially attributed to the varying number of responses. As was the case for both days, all or a majority of the participants were able to make time estimates for the 0° and -10° keyboard angles, while only three to four participants were able to make such estimates for the -20° or -30° keyboard angles. These results showed that a great amount of personal preference was associated with this measure. Some participants felt comfortable with the -30° keyboard angle, and gave short time estimates. Other participants felt extreme discomfort, thus gave longer time estimates to acclimate to the typing angle.

Final rankings were more widely varied on day 1 than day 2. Even though support was great for the flat and standard keyboard angles, final ranking comparison by day showed participants were more accustomed to the negative typing angles on day 2 than day 1, since rankings were only significant for the -30° keyboard angle on day 2. This result shows that given enough exposure, negative typing angles may be better received by users. Although there was a contradiction in objective and subjective results, discomfort decreased across days in this study, and may lead to general support for objective measure findings.

The findings in this study did not support results found by Hedge (1994) that a majority of workers reported less discomfort using negatively sloped keyboards. Participants in this study, however, were not professional typists, as they were in the Hedge study. This fact may have exemplified increases for discomfort in this study because typing was not a full-time task, and participants may not have adapted to the rigorousness of the typing tasks. Males gave a higher mean self-rating than females, so negative angles were less disruptive to their typing ability. Males also reported more discomfort in the left and right wrists than females, even though performance did not yield any gender differences except day 2 missing words, where males made more errors than females. These results may be been attributed to differences in typing habits or anthropometry. Overall, as keyboard slope decreased, participants rated more discomfort while typing.

### Electromyography

Muscle activity significantly increased in this study for right arm ECU means for the 7° keyboard angle and for left arm FCU means for the -20° keyboard angle (Figure V.6). For the right arm, the 7° keyboard angle yielded the highest ECU means of all the keyboard angles tested on both days. On day 1, it differed significantly only when compared with the lowest mean value at the 0° keyboard angle. On day 2, mean values were higher for the 0° keyboard angle, but the lowest means occurred at -20°, followed by the -10° and -30° keyboard angles. On day 1, the left arm FCU values yielded different results. First, the FCU mean values were much lower in comparison to the mean ECU values. The 7° keyboard angle had the lowest mean, and differed only from -20°, which had the highest mean. These contradicting results were interesting. On the one hand, these results showed benefits for the use of negative keyboard angles over the standard when considering the right arm; however, when considering the left arm, the standard yielded benefits over negative keyboard angles for one of the days.

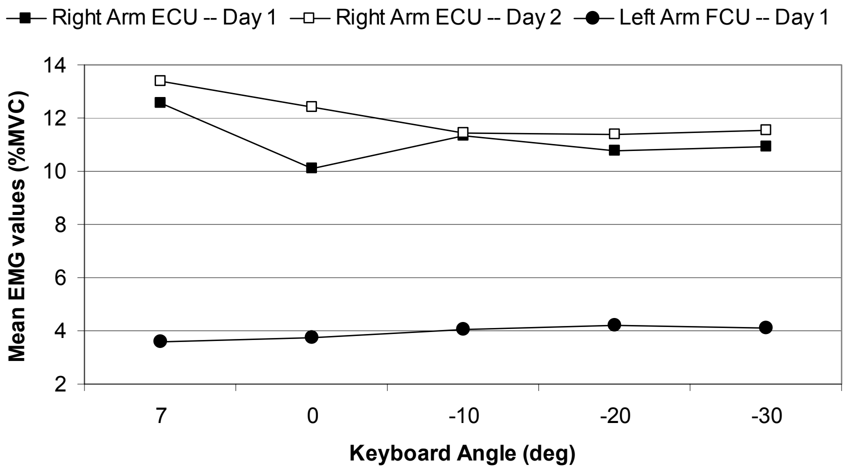

Figure V.6. Mean EMG value results comparison by muscle and day

It is known there is increased loading on the left hand due to the layout of keys, thus more muscle activity is presumed for the left arm; however, this study showed overall more loading on the right hand. One possible explanation is the fact the population was dominantly right-handed. As discussed later, key strike forces were significantly greater for the right hand than the left. These results may be possible causes for higher right side muscle activity. However, these explanations should result in higher side values for both days. Day 1 yielded no side differences, so discrepancies over days may be possibly explained by electrode placement. Moderately strong correlations of almost 0.6 resulted for right hand mean FCU and ECU values. Right hand and left hand MVCs may also have contributed to these significant differences for day 2 since these values correlated weakly or moderately at best, and were used to obtain normalized values for EMG variables. Another possible explanation is that static loading associated with loading differences between the hands may result in localized muscle fatigue of these muscles, increasing the number of muscle fibers recruited during the test session, thereby increasing the amplitude of the EMG signal. Fatigue was not specifically measured in this study, though it may be useful to look at this variable in future studies.

Right arm mean FCU values were significant by gender. FCU values for females were significantly greater than values for males. This result may be due to posture or anthropometry of females, but might be explained by other factors. First, three of four females were right-handed. More arm movement is required for more animated key strikes, where momentum of the hand striking the keys is heightened with help from the lower arm. For a largely right-handed population, the right hand could have been used more forcefully than usual, which resulted in higher key strike forces. It was possible that this increased loading of the right arm contributed to greater right arm muscle activity. Simply, though, this result could be due to an uneven gender population through speculation. Gilad and Harel (2000) studied females only while testing EMG for a negative keyboard angle, thus no comparisons for gender population with EMG results can be made with previous studies.

### Key Strike Force

Key strike force was not affected by keyboard angle. Figure V.7 shows relatively close trends in mean values for both keys by keyboard angle; moreover, “N” key strike forces were significantly greater than “E” key strike forces. There was a greater difference in the right index finger striking the ‘N; key below home row than the left middle finger striking the ‘E; key above the home row. These results could be attributed to the largely right-handed population, but it was more likely due to the location of the key. The right index finger is forced to curl a greater percentage of its range as Rose documented when striking the ‘N’ key *below* home row than any other finger extending for a key *above* home row. Negative keyboard angles yielded lower mean values than the standard for the “N” key, though this finding was not significant. These results may be attributed to the gradual decreasing of theta since the ‘N’ key became easier to strike as keyboard angle decreased. Interestingly, “E” key strike forces increased almost linearly except for a decrease at the -30° keyboard angle. These results may be due to the greater extension required for the left hand to strike the ‘E’ key, since it was above home row, and the possible subsequent lifting of the hand and arm to reach it, thus contributing heightened momentum to strike the key.

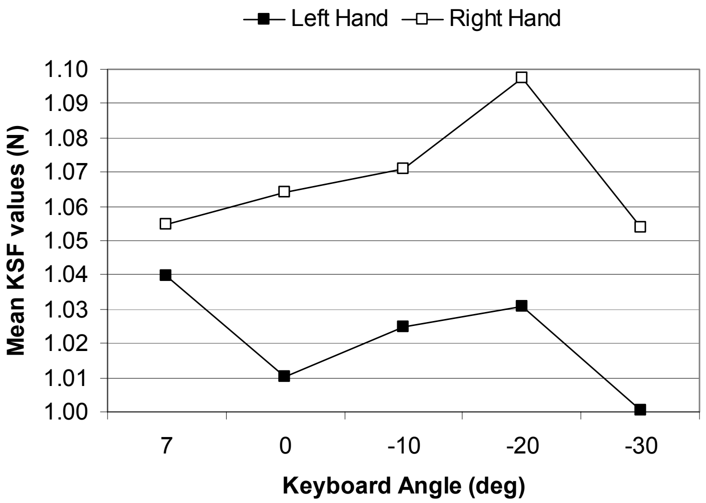

Figure V.7. Mean KSF value results comparison by side

### Repeatability of Results

For the most part, variables correlated extremely well by day. Most of the electrogoniometric data correlated strongly, as did key strike force, discomfort ratings, and most performance measures. However, repeatability was hard to achieve for certain electromyography variables.

There is a great deal of variability in collecting electromyography data. One source of variability was MVC, which are discussed later as a limitation in this study. Aside from MVC, only the left hand mean FCU value did not correlate by day. All other EMG values showed strong or moderate correlations by day. The FCU muscle was the harder of the two muscles to mark for electrode placement. It was possible that this, among other limitations discussed later, resulted in these correlations. This study reinforced that results obtained from experiments using electromyography protocol conducted once may not be completely accurate, and that a second trial, if possible, should be run to increase validity of results.

### Wrist Posture Plots Related to Risk

It is known that brief exposure to a CTP of 30 mmHg in animals is sufficient to affect nerve functioning for prolonged periods of time (Lundborg et al., 1983). CTP values could be considered predictors of risk, and are estimated as such by the plot in Figure V.8. CTP values for wrist flexion and extension up to 45° were calculated by Rempel et al. (1997), and a relationship between CTP and fingertip force was found to fit a second-order polynomial for the neutral posture. Mean FE deviations were averaged for the two hands, and are plotted with values shown for each keyboard angle against the risk curve estimated by CTP according to Rempel et al. (1997). As can be seen from the figure, higher potential risk associated with increased CTPs due to deviated wrist postures are associated with less negative keyboard angles. No true risk curve exists for deviated wrist postures, though this figure does illustrate meaningful potential benefits associated with using negatively sloped keyboard angles, as opposed to the standard configuration.

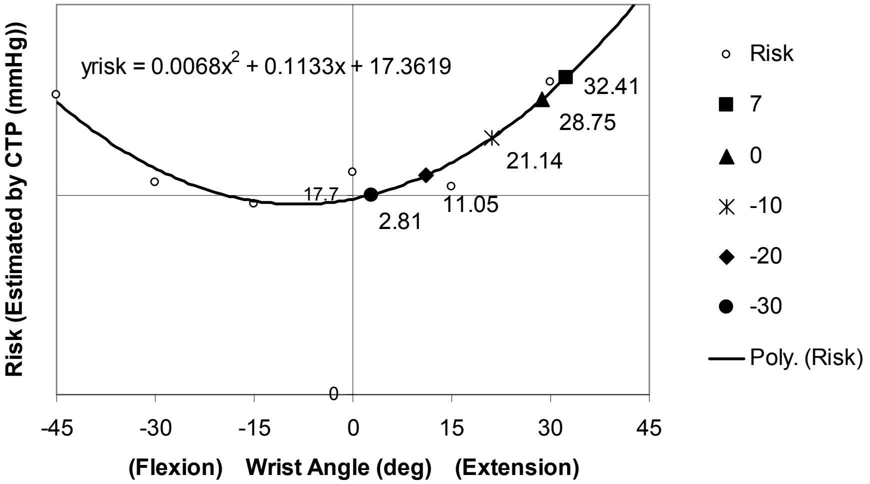

Figure V.8. Wrist posture related to risk, estimated by CTP (mmHg)

# CHAPTER VI

# CONCLUSION

This study sought to identify a negative keyboard angle, or range of angles, that minimized exposure to hypothesized hand and wrist WMSDs. Surprisingly, multiple objective and subjective measures revealed contradictory findings. Objective measures, such as wrist posture, favored negative angles of 0° or greater compared to 7°, and in some cases, heavily supported -20° and -30°. Certain EMG results supported negative angles, while other results favored the standard keyboard configuration. Net typing speed supported the -10° keyboard angle, while other negative typing angles were comparable, if not better, than the standard. However, other objective measures (i.e., key strike force) and the 7-point discomfort subjective rating showed no difference in the keyboard angles studied, whether positive or negative. However, it should be noted that discomfort ratings and all types of errors did decrease across two days of the study. Other subjective measures such as the 5-point self-rating, time estimates, and final rankings supported either 7° or a flat angle of 0°, but could have been a confounded result based on user preferences. It was evident from these results that one keyboard angle could not be identified, based on the multiple measures used and varying results. Personal preference could decide which angle was best based on subjective measures; however, this study concludes that a typing angle within the range of 0° to -30° provides objective postural benefits, reduced muscle activity in some cases, with improved or analogous typing performance when compared to the standard.

## Limitations

### Maximum Voluntary Contractions

Maximum voluntary contractions required for normalization of EMG data were a limitation in this study. This experiment was conducted twice on different days, and MVC values for the FCU muscle for both arms showed poor repeatability. The participant, experimenter, time of day, equipment, or electrode placement and application could have influenced these values. Electromyography data collection is affected by any of these factors. It was possible that any of these factors contributed to less accurate readings than could have been obtained.

### Electrode Placement

Electrode placement for the FCU muscle may have varied because markings made a week earlier were not readily apparent, possibly leading to weak correlations for some EMG variables. Over the week's time, it was possible the permanent marks had worn away from the usual flaking and washing of the skin. However, shaved areas were obvious in most cases, which facilitated similar electrode placement according to Perotto (1994) and Soderberg (1992).

### Typing posture

Many factors affected typing posture, making it a possible limitation in this study: (1) keyboard wedge design; (2) computer workstation; and (3) wrist rest.

#### *Keyboard Wedge Design*

Typing posture varied because of keyboard wedge design. The wedges used were made from wood to withstand multiple uses during the experiment over two weeks. Using this material made the wedges larger than if other materials were used, such as plastic or neoprene closed cell sponge or foam material. The larger wedges created some problems when the chair and the computer workstation needed to be adjusted for different participants. These effects were mainly postural, and can be attributed to limitations in the wedge design, as well as the computer workstation, which is explained hereafter.

#### *Computer Workstation*

In tandem with the keyboard wedge design, another limitation resulting in postural effects emanated from use of the computer workstation. The typing posture did not completely resemble the one that was intended for some extreme cases. When seating participants, the wrist point and elbow points at the ends of the ulna were used as reference marks to decipher if the forearm was parallel to the floor. Sometimes the wrist point was slightly above the elbow point. These cases where the forearm was not completely parallel with the floor can be attributed mainly to the limitations in adjusting seat height and keyboard tray height, but were magnified if the anthropometrics of the participant tested its limits. Chair, workstation, and postural values were recorded in day 1 experiments to accurately repeat experiments on day 2. Trying to recreate the same typing posture was difficult because of these limitations in adjusting the posture, and varying keyboard height, seat height, and other measures may have contributed to the varying results by day.

### *Wrist Rest*

In conjunction with keyboard wedge design and the computer workstation, lack of a wrist rest may have also affected typing posture. It was feared that a wrist rest would interfere with the natural movement of the hands while typing, and potential hazards with its use were forewarned by Simoneau and Marklin (2001). Hence, a wrist rest was removed from use in this study. Unknowingly, removal of a wrist rest may have contributed to a varied typing posture. Keeping the forearm parallel was difficult because of keyboard wedge design and adjusting chair and keyboard tray height, and the lack of a wrist rest may have exacerbated these limitations. Results showed discrepancies when compared with other studies, thus the absence of a wrist rest may have been a cause.

## Load Button Placement

Placement of the load button inside the keyboard may have been a limitation. Ideally, to most accurately measure a key strike force, a load button should be placed in direct contact with the finger. Accomplishing this task was impossible due to the size of the load button used, and because the anonymity of the load button's placement would have been compromised. To ensure the keyboard functioned properly, yet the participant's were unaware what keys were being studied, the load buttons were placed according to Figure III.1. Doing so placed the load button underneath a circuit board, a plastic-domed sheet, and the plastic keycap. Each of these components possibly experienced deformations during key strike forces, or absorbed part of the key strike forces, leading to potentially less accurate load button readings. However, since this same system was used for all conditions across day, keyboard angle, side, subject, and gender, the comparisons of the readings were consistent.

### Participants

Participants in this study were not professional typists. The sample population was also skewed, due to scheduling conflicts, where six participants were female and the remaining four were male. This inequality may have resulted in gender differences that may not have existed with equal gender populations. These may have been limitations in the study. However, studies by Gilad and Harel (2000); Simoneau and Marklin (2001); Hedge and Morimoto (2001); Hedge et al. (1999); Hedge and Powers (1995); Hedge et al. (1995); Hedge (1994); Powers and Hedge (1992); Gerard et al. (1996); Gerard, Armstrong, Martin, Rempel (2002); and Gerard, Armstrong, Rempel, Woolley, (2002) studied all or primarily female participants. These studies either made no mention of gender differences or were unable to identify gender differences due to study populations of mostly females. This study provided interesting gender differences unlike previous literature.

### Discomfort Variable

The discomfort variable in this study was potentially a confounding variable. The standard keyboard configuration has been widely used and accepted since the ANSI/HFES 100 –1988 standard. All participants in this study were accustomed to this standard configuration. It was possible there was a natural negative response by the participants to typing at angles different than the standard, simply because these angles were different. A longitudinal or longer terms study is needed to investigate this finding.

## Future Research

Use of a wrist rest with extreme negative angles should be explored further. It has been shown to affect typing posture, and may be a factor for finding an ideal negative typing angle. Simoneau and Marklin (2001) mentioned wrist extension angles may differ as much as 10° when a wrist rest is used. It would be beneficial to conduct similar studies using keyboard wedges testing angles up to -30°, perhaps at smaller increments, but with and without the use of a wrist rest. In addition, future studies should be aware that limitations in wedge design, computer workstation design, and wrist rests will affect typing posture, since participant anthropometry will be unknown; therefore, measures should be taken to ensure typing posture is consistent. It is possible to constrain the anthropometry in the study, but results may not be generalized to populations outside such constraints.

Results for this study only applied to use of a standard QWERTY keyboard. Future research could be conducted to determine if results for the same negative angles span different types of keyboards, such as for natural keyboards. Future projects may be able to determine full body postural effects for one or varying keyboard angle(s) on the QWERTY keyboard, but also for different types of keyboards.

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# APPENDIX A

## Phalen’s test

Having the participant flex the wrists completely for 60 seconds performs Phalen’s test. A positive test is one that yields numbness or paresthesias in the median nerve distribution (Kuschner et al., 1992; Phalen, 1966).

## APPENDIX B

### Tinel’s test

Tinel’s test is performed by firmly tapping three to ten times, with index and middle fingertips, over the median nerve at the level of the transverse carpal ligament. A positive test was one in which tingling was felt in the fingers in the median nerve distribution after each tap. A negative test was one which failed to result in sensation of tingling after any tap. If tingling occurred after one or two taps, the procedure was repeated for another three taps. No repeat were performed after this second test (Kuschner et al., 1992).

# APPENDIX C

## VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
## **Informed Consent for Participants in Research Projects**

Title of Project: Effects of a negatively sloped keyboard wedge design on user performance and perceptions

Investigator(s): Mitch Woods and Dr. Babski-Reeves

### I. Purpose

This laboratory study is designed to quantify the effects of various negative keyboard slopes ($0^o$, $-10^o$, $-20^o$, $-30^o$) on forearm muscle activity, wrist posture, key activation force, perceived discomfort, and performance for comparison with the standard keyboard slope ($7^o$). Additionally, the study is aimed at identifying a negative keyboard angle or range of keyboard angles that minimize risk for the development of hand and wrist work-related musculoskeletal disorders (WMSDs).

### II. Procedures

The study will require you to complete two test sessions: (1) the first session will quantify forearm muscle activity, wrist position, perceived discomfort, key activation force, and performance, and (2) the first session will be repeated one week later. Initially, I will provide you with a verbal description of the study and its objective, and copies of complete informed consent documents approved through the Institutional Review Board for research involving human participants. You will then be screened for current musculoskeletal injuries or illnesses by completing a questionnaire (Form B) and the performance of two screening tests for carpal tunnel syndrome, Phalen’s and Tinel’s tests. These procedures will be used to determine whether or not your health at the present moment qualifies you for further participation in the experiment. The questionnaire includes questions pertaining to your past hand and wrist injury profile and current hand/wrist pain or discomfort. Phalen’s test simply requires you to place your hands in a flexed position for 60 seconds after which I will ask you if you experienced any pain, numbness, or tingling in the palm, thumb, index, or middle fingers. Tinel’s test requires me to tap on your wrist with a reflex hammer 3 to 10 times. Again, I will ask you if you experienced any pain, numbness, or tingling in the palm, thumb, index, or middle fingers. If you answer ‘yes’ to both tests, you will be excluded from participation. Further you will be asked to estimate the number of hours you spend typing per week, complete a 3 minute typing test, and observed to ensure you type using the 10-digit method. Depending on your answers or performance you may be excluded from participation. You must currently type a minimum of 20 hours per week and type approximately 45 words per minute.

If you meet all of the above criteria, you will be asked to sit at the experimental computer workstation, which will be adjusted so that the forearms are parallel to the floor, elbows at roughly 70°-90°. Chair height will be adjusted so that the knees form a $90^o$ angle and the feet are flat on the floor (when necessary, a foot rest will be used). Workstation parameters (keyboard height, chair height, and monitor height) will be recorded.

Electromyography (EMG) surface electrodes will be fastened to both of your forearms over the extensor and flexor carpi ulnaris (ECU and FCU) muscles. These electrodes are self-adhesive and will in no way cause you harm. The area of the arm the electrodes are to be located may need to be shaved, lightly abraded, and cleansed with alcohol for good readings of your muscle activity. Electrogoniometers will also be fastened to your hands and wrists using double-sided tape. These devices will in no way cause you harm. You will place your arm flat on a table, palm down. One end of the goniometer will be attached on you hand over the bone for the middle finger. You will then bend your wrist backward with help from the experimenter and the other end of the goniometer will be attached to your forearm. I will then ask you to relax your arm and the goniometers will be calibrated. I will then ask you to move your wrist in a specific direction to set the positive and negative angles for wrist flexion/extension and radioulnar deviation. Following a 15-minute rest period I will then collect resting and maximum voluntary contraction (MVC) EMG data, followed by range of motion (ROM) measurements for the wrist. Resting EMG data will be collected for a 5 second period while your forearms are resting on a table. MVC for the ECU will require you to complete three, 5-second exertions, each separated by a 1-minute rest period, where you will attempt to move your hand toward the ceiling. MVC for the FCU will require you to complete three, 5-second exertions, each separated by a 1-minute rest period, while attempting to move your hand toward the floor. For the ROM measurements, you will asked to move your wrist in a specific direction as far as is comfortably possible and hold for 3 seconds.

The appropriate keyboard wedge ($7^o$, $0^o$, $-10^o$, $-20^o$, or $–30^o$) will be placed under the keyboard, and you will complete a 5-minute practice session to allow you to become accustomed to the typing angle of the experimental condition. You will then complete a 10-minute test session followed by a 5-minute rest period. During this rest period, electrogoniometer data will be downloaded to the computer and the next condition will be set up. The Corlett and Bishop scale and additional exit questions will be administered to assess your perceived discomfort for the forearm, wrist, and hand after each experimental condition. You will view the scale anchored to the table beside the monitor and verbally rate your discomfort for each body part on a 14-point scale (0= very comfortable to 14 = very uncomfortable). You will then complete another 5-minute practice session, and 10-minute test session for the next appropriate experimental condition, followed by a 5-minute rest period. This procedure will repeat until all five experimental conditions have been completed. When you’ve finished, electrodes and electrogoniometers will be removed, and you will be compensated for your time.

The second test session will take place at a subsequent date, preferably in one week’s time, and will be set before you leave the first session. The workstation will be repositioned according to the data obtained in the first session. The procedure will follow that described above in the first test session, with a 5-minute practice session, 10-minute testing session, and 5-minute rest period in between trials. When you finish, you will be compensated for your time.

The task will consist of typing passages presented to you through SkillCheck software. The software will also automatically record your typing speed and accuracy for each experimental condition. All data will be compared across keyboard angles for differences.

### III. Risks and Benefits

There is no risk associated with this study that would not be found in daily office activities. Temporary discomfort or fatigue in the hands, wrists, and/or forearms may result due to the unfamiliarity of typing at extreme angles; however, you are encouraged to discontinue usage of the equipment if you experience extreme discomfort. By participating in this study, you will be assisting the investigators in possibly identifying an ideal angle or range of angles for typing tasks on a standard QWERTY keyboard, which may reduce work-related musculoskeletal disorders in the hands, wrists and forearms associated with keyboard usage. One or more of the following may result: increased comfort for the upper extremity (hands and wrists primarily), increased awareness for proper computer workstation posture, less strenuous, and/or reduced risk for/to keyboard users associated with WMSD development.

### IV. Extent of Anonymity and Confidentiality

Your anonymity will be kept in the strictest of confidence. No names will appear on questionnaires, and a coding system will be used to associate your identity with questionnaire answers and data. All information will be collected in a file and locked when not being used. The list associating names with answers will be destroyed after one month of data collection. No videotaping, pictures, or audiotaping will occur during the experiment.

### V. Informed Consent

You will receive two informed consent forms to be signed before beginning the experiment; one copy will be for your records and the other copy will be obtained for the investigator's records.

### VI. Compensation

Compensation is offered for participating in this study, set at $7/hour, rounding to the quarter-hour if necessary.

### VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty or reason stated, and no penalty or withholding of compensation will occur for doing so.

### VIII. Approval of Research

The Department of Industrial and Systems Engineering has approved this research, as required, by the Institutional Review Board (IRB) for Research Involving Human Participants at Virginia Polytechnic Institute and State University.

### IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- To read and understand the aforementioned instructions
- To answer questions, questionnaires, etc. honestly and to the best of my ability
- To type as quickly, efficiently, naturally, and consistently as possible for each of the experimental conditions
- Be able to openly discuss (vocalize) any discomforts I experience during or in between typing tasks at the moment I experience them
- Be aware that I am free to ask questions at any point time

- To refrain from discussing any details of this experiment with others

## X. Participant's Permission

I have read and understand the Informed Consent and conditions of this research project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I reserve the right to withdraw at any time without penalty. I agree to abide by the rules of this project.

____________________________________________________________________
Participant’s Signature Date

________________________________________________
Printed Name

## Signature Page

I have read the description of this study and understand the nature of the research and my rights as a participant. I hereby consent to participate with the understanding that I may discontinue participation at any time if I choose to do so.

____________________________________________ ________________
Participant's Signature Date

The research team for this experiment includes Dr. Babski-Reeves and Mitch Woods. Team members may be contacted at the following address and phone number:

Dr. Babski-Reeves
Grado Department of Industrial and Systems Engineering
250 Durham Hall
Blacksburg, VA 24061
540.231.9093

Mitch Woods
Grado Department of Industrial and Systems Engineering
536E Whittemore Hall
Blacksburg, VA 24061
540.961.7270 (h)

In addition, if you have any detailed questions regarding your rights as participant in University Research, you may contact the following individual:

Dr. David Moore
IRB Chair
Assistant Vice Provost Research Compliance
Director, Animal Resources
CMV Phase II
Virginia Tech (0442)
Blacksburg, VA 24061
(540) 231-9359

**Form B**

## Nordic Questionnaire

Date: ____/____/____ (mm/dd/yy)

Start time: ____________ am / pm

End time: ____________ am / pm

CODE: ________________

Please answer the following questions, circling one of the following, where appropriate. You may skip any question you feel uncomfortable answering.

| | | | **To be answered only by those who have had trouble** | | | |
|---|---|---|---|---|---|---|
| Have you at any time during the last 12 months had trouble (ache, pain, discomfort) in: | | | Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble? | | Have you had trouble at any time during the last 7 days? | |
| Wrists: | | | | | | |
| 1. no | 2. yes, in right wrist<br>3. yes, in left wrist<br>4. yes, in both wrists | | 1. no | 2. yes | 1. no | 2. yes |
| Hands/fingers: | | | | | | |
| 1. no | 2. yes, in right hand/fingers<br>3. yes, in left hand/fingers<br>4. yes, in both hands/fingers | | 1. no | 2. yes | 1. no | 2. yes |

Please turn over

## Past Medical History

| | Left Hand | Right Hand |
|---|---|---|
| Fracture or break in hand/wrist? | 1. no | 2. yes |
| Have you ever been diagnosed by a physician with arthritis of the hand or wrist? | 1. no | 2. yes |
| Experience pain, numbness, or tingling in wrist, hands or fingers when typing? | 1. no | 2. yes |
| Have any condition that limits your ability to move/bend your wrist, hand, or fingers? i.e. (physical deformity, missing digit) | 1. no | 2. yes |

## Keyboard Usage

| | | | | |
|---|---|---|---|---|
| Do you type at a keyboard at work? | 1. no | 2. yes | | |
| • If 'yes', do you type . . . | 1. hourly | 2. daily | 3. weekly | 4. rarely |
| Do you type at a keyboard at home? | 1. no | 2. yes | | |
| • If 'yes', do you type . . . | 1. hourly | 2. daily | 3. weekly | 4. rarely |
| On average, how many hours a day do you type (including work and home)? | | | | ____ hrs |

| **Criterion Questionnaire** | | |
|---|---|---|
| Phalen's test? | Left<br>+ / - | Right<br>+ / - |
| Tinel's test? | Left<br>+ / - | Right<br>+ / - |
| Type with ten fingers? | 1. no | 2. yes |
| Types at least 45 wpm? | 1. no | 2. yes |

CODE: ________________

## Demographic Information

Age ________

| | | |
|---|---|---|
| Sex: | 1. female | 2. male |
| Dominant hand: | 1. right-handed | 2. left-handed |

Occupation: ____________________________________________

How long have you been employed at your current job? _____ yrs. _____ mos.

What keyboard do you use (home and work)? 1. standard flat 2. natural or comfort 3. Other

Please specify if Other':__________________________

Have you been previously employed in a job(s) that required significant amounts of keyboard usage? 1. no 2. yes

- If yes, how many years were you employed at that job(s). _____ yrs. _____ mos.

**Data Collection Form** **Code: ________**

## Anthropometric data

Shoulder to shoulder width: ___________ cm

Elbow to elbow width: ___________ cm

|  |  |  |
|---|---|---|
|  | Left | Right |
| Elbow to tip of finger: | ________ cm | ________ cm |
|  | Left | Right |
| Elbow to wrist: | ________ cm | ________ cm |
|  | Left | Right |
| Middle finger length: | ________ cm | ________ cm |
|  | Left | Right |
| Hand breadth tetracarpal: | ________ cm | ________ cm |

Height: ___________ m

Weight: ___________ kg

APPENDIX E

## Seat Measurements

CODE NO. ____________

Wedge angle 7° 0° -10° -20° -30°

Keyboard tray height ______________ " ______________ cm

Seat height ______________ " ______________ cm

Monitor height ______________ " ______________ cm

Elbow height ______________ " ______________ cm

Elbow angle ______________ deg

**Self-reported postural discomfort questionnaire with exit questions**

| | | | | | |
|---|---|---|---|---|---|
| Keyboard angle: | 7° | 0° | -10° | -20° | -30° |

| | |
|---|---|
| Palm | |
| Left | Right |
| 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable | 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable |
| Thumb, index, and middle fingers | |
| Left | Right |
| 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable | 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable |
| Ring and little fingers | |
| Left | Right |
| 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable | 0 1 2 3 4 5 6 7<br>Extremely comfortable<br>Extremely Uncomfortable |

| Wrist | |
|---|---|
| Left<br>0 1 2 3 4 5 6 7<br>Extremely comfortable — Extremely Uncomfortable | Right<br>0 1 2 3 4 5 6 7<br>Extremely comfortable — Extremely Uncomfortable |

| Forearm | |
|---|---|
| Left<br>0 1 2 3 4 5 6 7<br>Extremely comfortable — Extremely Uncomfortable | Right<br>0 1 2 3 4 5 6 7<br>Extremely comfortable — Extremely Uncomfortable |

Compared to the standard keyboard configuration, the new typing angle was:

1. much harder to use
2. harder to use
3. about the same as the standard
4. easier to use
5. much easier to use

Did you feel you could reach the same level of typing speed and accuracy as you would have with a standard keyboard configuration? 1. no 2. yes

- If ‘yes’, how long would it take?

_____ days

_____ hours

_____ minutes

Any discomfort or pain in the forearms, back, shoulders, neck, or other body part? 1. no 2. yes

- If ‘yes’, Where? (circle all that apply)

| | | |
|---|---|---|
| Neck | Right Shoulder | Left Shoulder |
| Upper Back | Middle Back | Lower Back |
| Right Forearm | Left Forearm | |
| Other (Please Specify): | | |

Please rank all five keyboard angles from best (1) to worst (5):

________ 7°

________ 0°

________ -10°

________ -20°

________ -30°

## APPENDIX F

## Participant Demographic Information

| | | |
|---|---|---|
| Shoulder breadth | 18.54 (in.) | 47.1 (cm) |
| Elbow-to-elbow breadth | 18.98 (in.) | 48.2 (cm) |
| **Hand breadth metacarpal** | | |
| Left | 3.23 (in.) | 8.2 (cm) |
| Right | 3.27 (in.) | 8.3 (cm) |
| **Forearm-hand length** | | |
| Left | 17.52 (in.) | 44.5 (cm) |
| Right | 17.64 (in.) | 44.8 (cm) |
| **Hand length** | | |
| Left | 7.17 (in.) | 18.2 (cm) |
| Right | 7.20 (in.) | 18.3 (cm) |
| **Elbow-to-wrist length** | | |
| Left | 10.35 (in.) | 26.3 (cm) |
| Right | 10.43 (in.) | 26.5 (cm) |
| **Middle finger length** | | |
| Left | 4.06 (in.) | 10.3 (cm) |
| Right | 4.02 (in.) | 10.2 (cm) |
| Height | 66.6 (in.) | 1.7 (m) |
| Weight | 169.7 (lbs.) | 77.0 (kg) |
| Age | 22.1 (yrs) | |

Mean values for anthropometric data and demographics

## APPENDIX G

## Shapiro-Wilk's Normality Test Results

| | Day | | Data Normal? | P-value |
|---|---|---|---|---|
| Normalized EMG RH - FCU | N | 1&2 | Y | 0.1213 |
| Normalized EMG RH - ECU | N | 1&2 | N | <0.0001 |
| Normalized EMG LH - FCU | Y | 1 | Y | 0.1044 |
| | | 2 | N | <0.0001 |
| Normalized EMG LH - ECU | Y | 1 | N | 0.0057 |
| | | 2 | N | 0.0001 |
| MVC RH - FCU | N | 1&2 | Y | 0.3564 |
| MVC RH - ECU | N | 1&2 | Y | 0.6863 |
| MVC LH - FCU | N | 1&2 | Y | 0.1757 |
| MVC LH - ECU | N | 1&2 | Y | 0.3473 |
| Mean KSF Peaks – 'E' key | N | 1&2 | N | <0.0001 |
| Mean KSF Peaks – 'N' key | N | 1&2 | N | <0.0001 |
| Mean FE - LH | N | 1&2 | N | 0.0064 |
| Mean RU - LH | Y | 1 | Y | 0.1205 |
| | | 2 | Y | 0.4099 |
| % FE in Neutral Zone - LH | N | 1&2 | N | 0 |
| % RU in Neutral Zone - LH | N | 1&2 | N | 0 |
| Mean FE - RH | N | 1&2 | Y | 0.0582 |
| Mean RU - RH | N | 1&2 | N | 0.0036 |
| % FE in Neutral Zone - RH | N | 1&2 | N | 0 |
| % RU in Neutral Zone - RH | N | 1&2 | N | 0 |
| % FE < 5 degrees - LH | N | 1&2 | N | 0 |
| %RU < 5 degrees - LH | Y | 1 | N | <0.0001 |
| | | 2 | N | 0 |
| %FE < 5 degrees - RH | N | 1&2 | N | 0 |
| %RU < 5 degrees - RH | N | 1&2 | N | 0 |
| %FE < 10 degrees - LH | N | 1&2 | N | 0 |
| %RU < 10 degrees - LH | Y | 1 | N | <0.0001 |
| | | 2 | N | <0.0001 |
| %FE < 10 degrees - RH | N | 1&2 | N | 0 |
| %RU < 10 degrees - RH | N | 1&2 | N | 0 |
| Net Typing Speed (NTS) | N | 1&2 | Y | 0.0617 |
| No. of Errors | N | 1&2 | N | <0.0001 |
| Missing Words | Y | 1 | N | <0.0001 |
| | | 2 | N | 0.0003 |
| Misspelled Words | N | 1&2 | N | <0.0001 |
| Extra, Joined, Split Words (EJS) | N | 1&2 | N | 0 |
| DS – Normalized Left Hand (TIMs, RPs, and Palm) | N | 1&2 | N | <0.0001 |
| DS – Normalized Left Wrist | N | 1&2 | N | <0.0001 |
| DS – Normalized Left Forearm | N | 1&2 | N | <0.0001 |
| DS – Normalized Right Hand (TIMs, RPs, and Palm) | N | 1&2 | N | <0.0001 |
| DS – Normalized Right Wrist | N | 1&2 | N | <0.0001 |
| DS – Normalized Right Forearm | N | 1&2 | N | 0 |
| Self-rating | N | 1&2 | N | <0.0001 |

APPENDIX H

## Table of F-ratios, P-values, and Tukey HSD Q-values for Significant Differences

| Objective Dependent Variable | Day | KA | | Gender |
|---|---|---|---|---|
| Normalized EMG FCU - RH | N | 1&2 | N | F(1,8) = 5.6846<br>p-value = 0.0443<br>Q = 2.306 |
| Normalized EMG ECU - RH | F(1,9) = 4.5145<br>p-value = 0.0364<br>Q = 1.987 | 1 | F(4,8) = 2.7446<br>p-value = 0.0454<br>Q = 2.889 | N |
| | | 2 | F(4,8) = 11.2394<br>p-value = <0.0001<br>Q = 2.889 | N |
| Normalized EMG FCU - LH | F(1,9) = 36.7793<br>p-value = < 0.0001<br>Q = 1.987 | 1 | N | N |
| | | 2 | F(4,8) = 3.1726<br>p-value = 0.0265<br>Q = 2.889 | N |
| Normalized EMG ECU - LH | F(1,9) = 53.0184<br>p-value = < 0.0001<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| MVC FCU - RH | N | 1&2 | N/A | N/A |
| MVC ECU - RH | N | 1&2 | N/A | N/A |
| MVC FCU - LH | N | 1&2 | N/A | N/A |
| MVC ECU - LH | N | 1&2 | N/A | N/A |
| Mean of KSF Peaks - E key | N | 1&2 | N | N |
| Mean of KSF Peaks - N key | N | 1&2 | N | N |
| Mean FE - LH | N | 1&2 | F(4,8) = 105.2783<br>p-value =<0.0001<br>Q = 2.789 | N |
| Mean RU - LH | F(1,9) = 10.2301<br>p-value = 0.0019<br>Q = 1.987 | 1 | F(4,8) = 9.2781<br>p-value = <0.0001<br>Q = 2.889 | N |
| | | 2 | F(4,8) = 22.8861<br>p-value = <0.0001<br>Q = 2.889 | N |
| % FE in Neutral Zone - LH | N | 1&2 | F(4,8) = 97.5473<br>p-value =<0.0001<br>Q = 2.789 | N |
| % RU in Neutral Zone - LH | F(1,9) = 5.9605<br>p-value = 0.0166<br>Q = 1.987 | 1 | F(4,8) = 3.8389<br>p-value = 0.0117<br>Q = 2.889 | N |
| | | 2 | F(4,8) = 9.5348<br>p-value = <0.0001<br>Q = 2.889 | N |

|  |  |  |  |  |
|---|---|---|---|---|
| Mean FE - RH | N | 1&2 | F(4,8) = 207.6429<br>p-value =<0.0001<br>Q = 2.789 | N |
| Mean RU - RH | N | 1&2 | F(4,8) = 4.4418<br>p-value = 0.0027<br>Q = 2.789 | N |
| % FE in Neutral Zone - RH | N | 1&2 | F(4,8) = 166.3606<br>p-value = <0.0001<br>Q = 2.789 | N |
| % RU in Neutral Zone - RH | N | 1&2 | F(4,8) = 4.2849<br>p-value = 0.0034<br>Q = 2.789 | N |
| % FE < 5 degrees - LH | N | 1&2 | F(4,8) = 25.8213<br>p-value = <0.0001<br>Q = 2.789 | N |
| %RU < 5 degrees - LH | F(1,9) = 9.572<br>p-value = 0.0026<br>Q = 1.987 | 1 | F(4,8) = 3.9359<br>p-value = 0.0104<br>Q = 2.889 | N |
|  |  | 2 | F(4,8) = 2.7178<br>p-value = 0.047<br>Q = 2.889 | N |
| % FE < 5 degrees - RH | N | 1&2 | F(4,8) = 40.0968<br>p-value = <0.0001<br>Q = 2.789 | N |
| %RU < 5 degrees - RH | F(1,9) = 6.8737<br>p-value = 0.0103<br>Q = 1.987 | 1 | N | N |
|  |  | 2 | N | N |
| %FE < 10 degrees - LH | N | 1&2 | F(4,8) = 55.3995<br>p-value = <0.0001<br>Q = 2.789 | N |
| %RU < 10 degrees - LH | F(1,9) = 9.0576<br>p-value = 0.0034<br>Q = 1.987 | 1 | F(4,8) = 5.697<br>p-value = 0.0014<br>Q = 2.889 | N |
|  |  | 2 | F(4,8) = 5.7958<br>p-value = 0.0013<br>Q = 2.889 | N |
| %FE < 10 degrees - RH | N | 1&2 | F(4,8) = 88.2052<br>p-value = <0.0001<br>Q = 2.789 | N |
| %RU < 10 degrees - RH | N | 1&2 | N | N |
| Net Typing Speed | F(1,9) = 6.4851<br>p-value = 0.0126<br>Q = 1.987 | 1 | F(4,8) = 4.0192<br>p-value = 0.0094<br>Q = 2.889 | N |
|  |  | 2 | F(4,8) = 4.6361<br>p-value = 0.0046<br>Q = 2.889 | N |
| No. of Errors | F(1,9) = 9.0157<br>p-value = 0.0035<br>Q = 1.987 | 1 | N | N |
|  |  | 2 | N | N |
| Missing Words | F(1,9) = 7.6864 | 1 | N | N |

| | | | | |
|---|---|---|---|---|
| | p-value = 0.0068<br>Q = 1.987 | 2 | N | F(1,8) = 10.7865<br>p-value = 0.0111<br>Q = 2.306 |
| Misspelled Words | F(1,9) = 7.3537<br>p-value = 0.008<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| Combined EJS data | N | 1&2 | N | N |

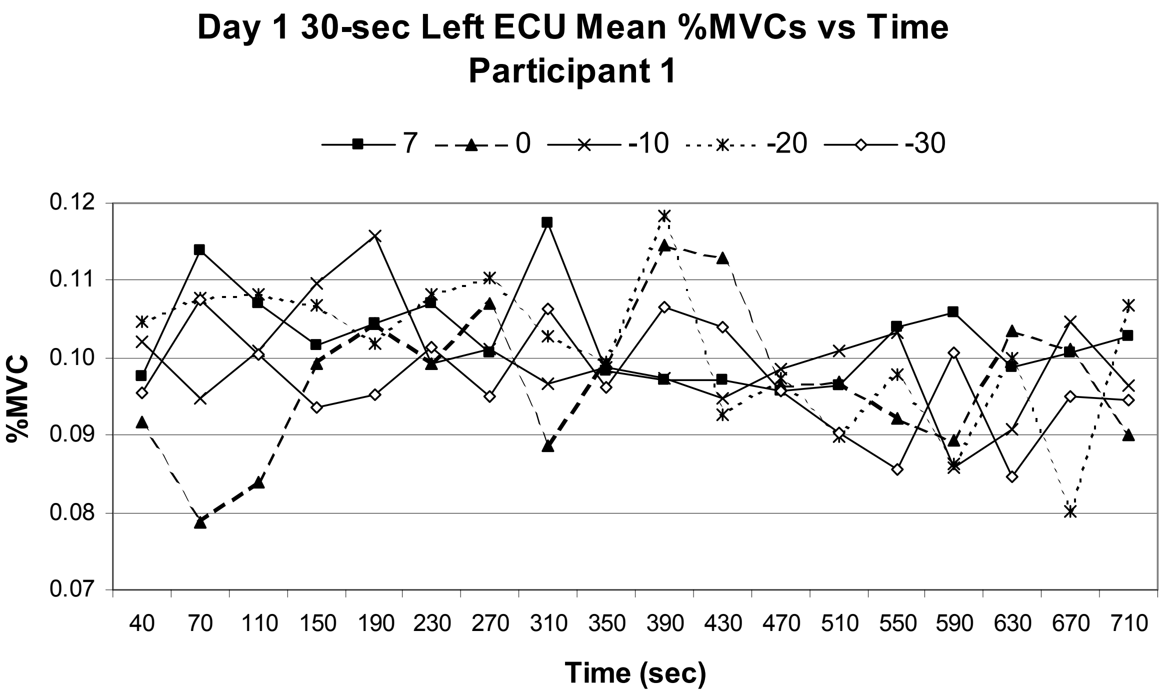
| Subjective Dependent Variable | Day | | KA | Gender |
|---|---|---|---|---|
| Normalized Left Hand (TIMs, RPs, Hand) | F(1,9) = 4.5221<br>p-value = 0.0362<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| Normalized Left Wrist | N | 1&2 | N | F(1,8) = 6.2872<br>p-value = 0.0365<br>Q = 2.306 |
| Normalized Left Forearm | F(1,9) = 10.1765<br>p-value = 0.0020<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| Normalized Right Hand (TIMs, RPs, Hand) | F(1,9) = 7.765<br>p-value = 0.0065<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| Normalized Right Wrist | N | 1&2 | N | F(1,8) = 5.1271<br>p-value = 0.0535<br>Q = 2.306 |
| Normalized Right Forearm | F(1,9) = 6.4048<br>p-value = 0.0131<br>Q = 1.987 | 1 | N | N |
| | | 2 | N | N |
| Self-rating | N | 1&2 | F(4,8) = 14.0601<br>p-value = <0.0001<br>Q = 2.638 | F(1,8) = 9.5669<br>p-value = 0.0148<br>Q = 2.306 |

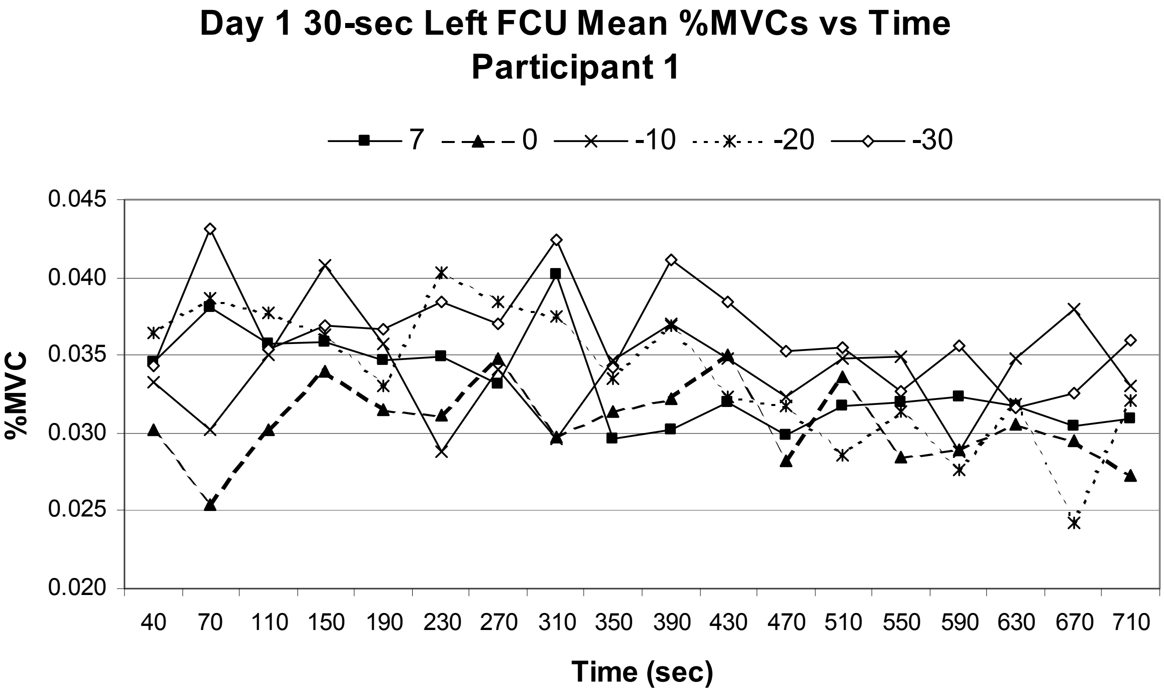
| Objective Dependent Variable | Day | Side |
|---|---|---|
| Normalized EMG - FCU | 1 | N |
| | 2 | F(1,9) = 104.59<br>p-value = <0.0001<br>Q = 1.987 |
| Normalized EMG - ECU | 1 | N |
| | 2 | F(1,9) = 31.407<br>p-value = <0.0001<br>Q = 1.987 |
| MVC FCU | 1&2 | N |
| MVC ECU | 1&2 | N |
| Mean of KSF Peaks | 1&2 | F(1,9) = 14.526<br>p-value = 0.0002<br>Q = 1.987 |
| Mean FE | 1&2 | N |

| | | |
|---|---|---|
| Mean RU | 1 | F(1,9) = 6.2289<br>p-value = 0.0144<br>Q = 1.987 |
| | 2 | F(1,9) = 10.14<br>p-value = 0.002<br>Q = 1.987 |
| % FE in Neutral Zone | 1&2 | N |
| % RU in Neutral Zone | 1 | N |
| | 2 | F(1,9) = 6.5148<br>p-value = 0.0124<br>Q = 1.987 |
| % FE < 5 degrees | 1&2 | N |
| %RU < 5 degrees | 1 | N |
| | 2 | F(1,9) = 28.293<br>p-value = <0.0001<br>Q = 1.987 |
| %FE < 10 degrees | 1&2 | N |
| %RU < 10 degrees | 1 | N |
| | 2 | F(1,9) = 25.568<br>p-value = <0.0001<br>Q = 1.987 |
| Normalized Hand (TIMs, RPs, Hand) | 1 | N |
| | 2 | N |
| Normalized Wrist | 1&2 | N |
| Normalized Forearm | 1 | N |
| | 2 | N |

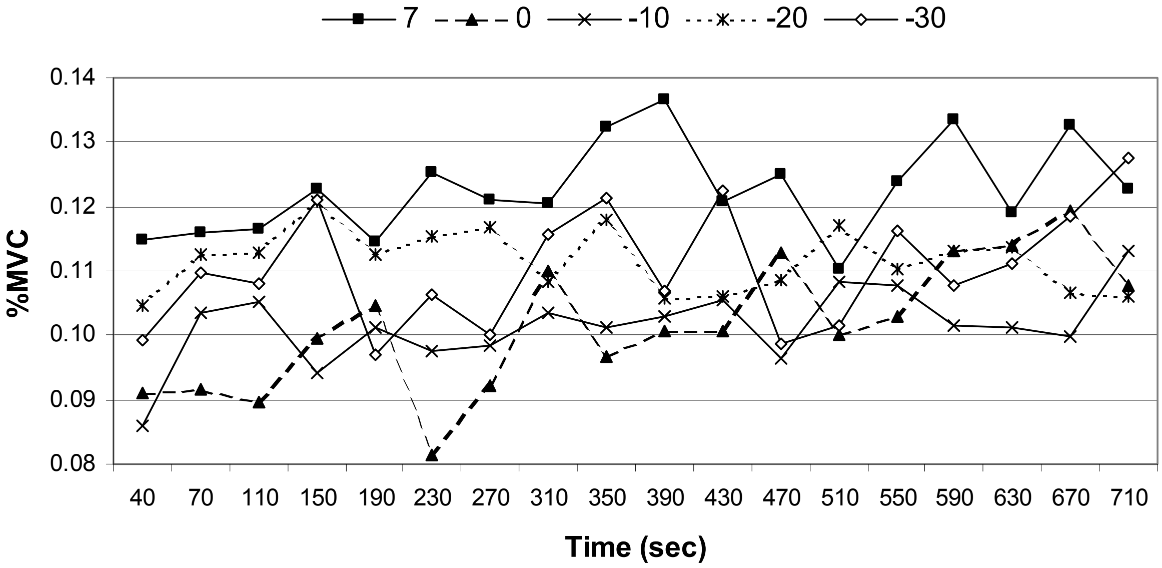
# APPENDIX I

## 30-second Mean %MVC Graphs

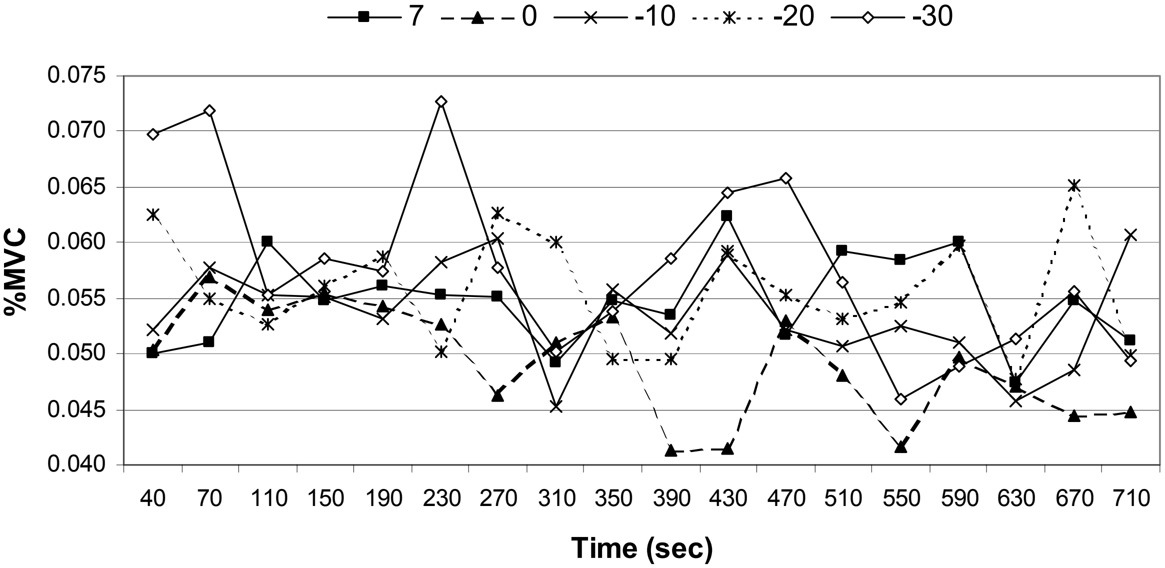




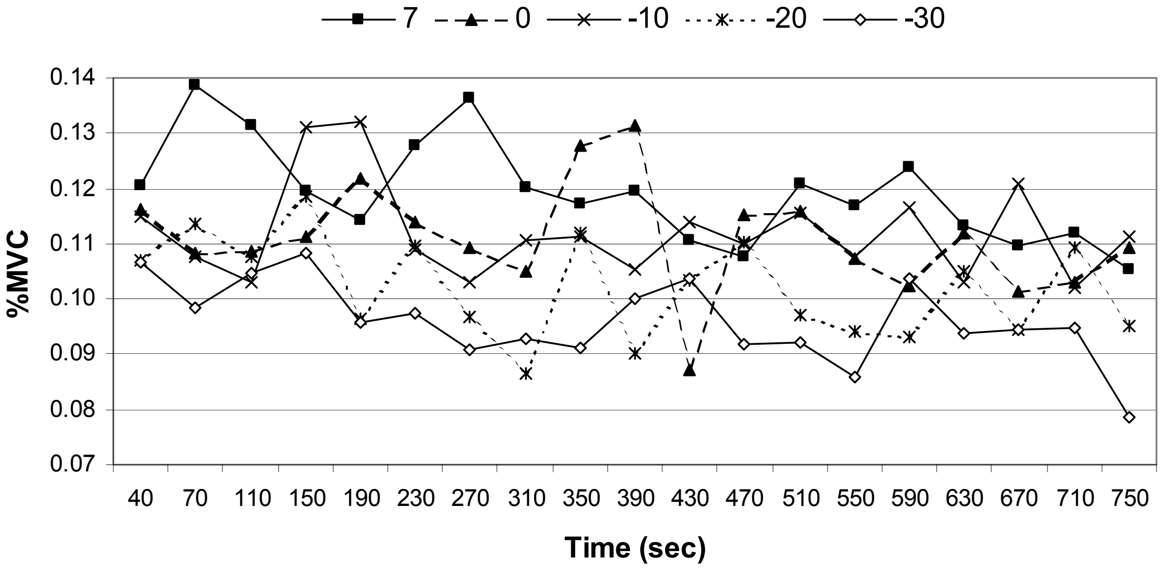
## Day 1 30-sec Right ECU Mean %MVCs vs Time Participant 1



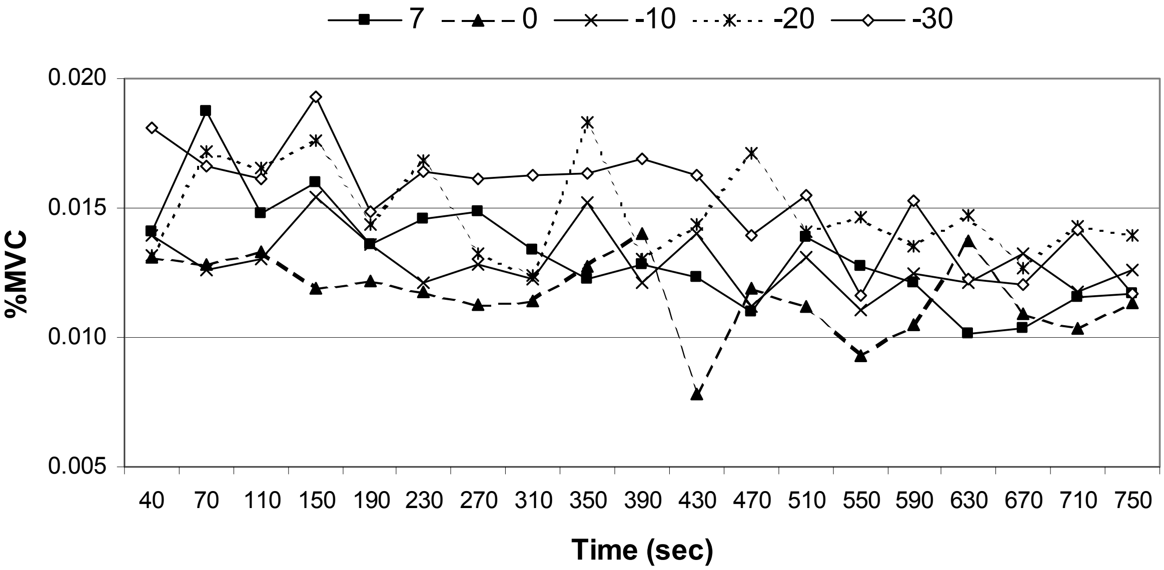
## Day 1 30-sec Right FCU Mean %MVCs vs Time Participant 1



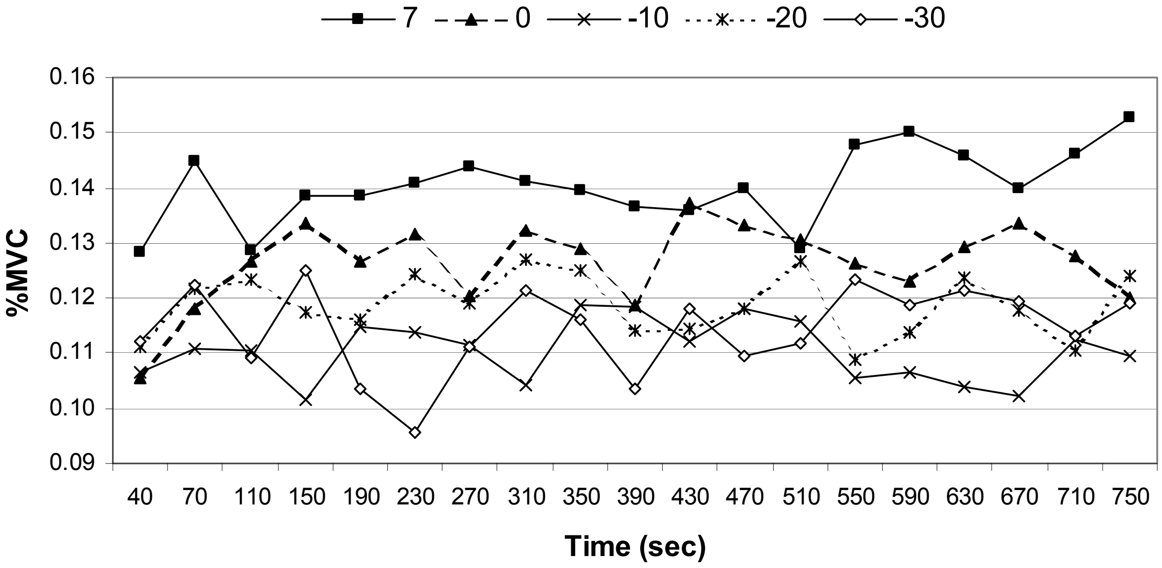
Day 2 30-sec Left ECU Mean %MVCs vs Time
Participant 1



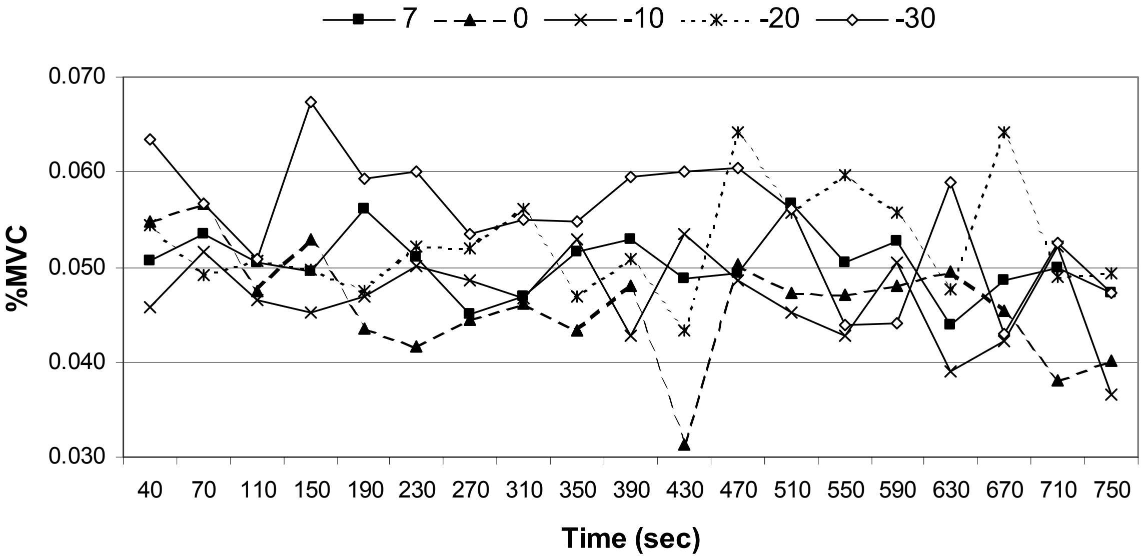
Day 2 30-sec Left FCU Mean %MVCs vs Time
Participant 1



Day 2 30-sec Right ECU Mean %MVCs vs Time
Participant 1



Day 2 30-sec Right FCU Mean %MVCs vs Time
Participant 1



# APPENDIX J

## Descriptive statistics for significant and non-significant variables by keyboard angle

### Electrogoniometric Data

| Left Hand | Mean (Standard Deviation) |
|---|---|
| Mean FE Day 1 and 2 | 7°: 30.8° (6.84°) |
| | 0°: 28.8° (6.87°) |
| | -10°: 21.5° (7.19°) |
| | -20°: 10.8° (6.66°) |
| | -30°: 3.2° (7.18°) |
| Mean RU Day 1 | -30°: 19.7° (7.28°) |
| | -20°: 17.3° (6.92°) |
| | -10°: 14.4° (7.65°) |
| | 0°: 13.4° (7.94°) |
| | 7°: 13.3° (7.81°) |
| Mean RU Day 2 | -30°: 22.8° (6.21°) |
| | -20°: 21.4° (6.78°) |
| | -10°: 18.0° (5.58°) |
| | 0°: 16.1° (6.26°) |
| | 7°: 14.8° (6.62°) |
| %FE in NZ Day 1 and 2 | -30°: 91.2% (13.24%) |
| | -20°: 70.3% (28.94%) |
| | -10°: 25.3% (30.02%) |
| | 0°: 6.3% (13.06%) |
| | 7°: 3.0% (7.88%) |
| %RU in NZ Day 1 | 7°: 59.5% (47.35%) |
| | -10°: 57.2% (41.49%) |
| | 0°: 48.6% (44.22%) |
| | -20°: 39.4% (40.0%) |
| | -30°: 31.8% (37.7%) |
| %RU in NZ Day 2 | 7°: 51.3% (44.24%) |
| | 0°: 47.9% (42.33%) |
| | -10°: 34.3% (35.44%) |
| | -20°: 22.1% (31.14%) |
| | -30°: 8.2% (10.19%) |
| %FE < 10° Day 1 and 2 | -30°: 71.1% (23.57%) |
| | -20°: 45.4% (32.05%) |
| | -10°: 11.0% (20.36%) |
| | 0°: 1.2% (3.14%) |
| | 7°: 0.4% (1.29%) |

|  |  |  |
|---|---|---|
| %RU < 10°<br>Day 1 | 7°: | 39.6% (38.79%) |
|  | 0°: | 34.2% (38.09%) |
|  | -10°: | 28.6% (28.72%) |
|  | -20°: | 18.2% (26.09%) |
|  | -30°: | 9.1% (20.89% |
| %RU < 10°<br>Day 2 | 7°: | 27.4% (34.61%) |
|  | 0°: | 20.4% (26.06%) |
|  | -10°: | 7.5% (9.28%) |
|  | -20°: | 4.2% (6.98%) |
|  | -30°: | 0.6% (1.16%) |
| %FE < 5°<br>Day 1 and 2 | -30°: | 40.5% (23.51%) |
|  | -20°: | 21.4% (25.06%) |
|  | -10°: | 3.0% (8.35%) |
|  | 0°: | 0.1% (0.21%) |
|  | 7°: | 0.01% (0.04%) |
| %RU < 5°<br>Day 1 | 7°: | 14.7% (20.77%) |
|  | 0°: | 13.3% (19.86%) |
|  | -10°: | 8.7% (16.41%) |
|  | -20°: | 4.9% (11.66%) |
|  | -30°: | 3.2% (9.48%) |
| %RU < 5°<br>Day 2 | 7°: | 7.2% (12.34%) |
|  | 0°: | 3.9% (6.12%) |
|  | -10°: | 0.9% (1.84%) |
|  | -20°: | 0.2% (0.36%) |
|  | -30°: | 0.04% (0.07%) |

| Right Hand | Mean (Standard deviation) |  |
|---|---|---|
| Mean FE<br>Day 1 and 2 | 7°: | 34.0° (6.22°) |
|  | 0°: | 28.7° (6.25°) |
|  | -10°: | 20.8° (5.32°) |
|  | -20°: | 11.3° (5.99°) |
|  | -30°: | 2.4° (6.22°) |
| Mean RU<br>Day 1 and 2 | -30°: | 17.0° (9.54°) |
|  | -20°: | 14.7° (9.17°) |
|  | -10°: | 13.1° (9.10°) |
|  | 0°: | 12.2° (8.47°) |
|  | 7°: | 10.8° (8.19°) |
| %FE in NZ<br>Day 1 and 2 | -30°: | 94.4% (10.4%) |
|  | -20°: | 70.0% (29.2%) |
|  | -10°: | 22.1% (18.61%) |
|  | 0°: | 3.5% (5.07%) |
|  | 7°: | 0.7% (1.41%) |
| %RU in NZ<br>Day 1 and 2 | 7°: | 68.6% (38.48%) |
|  | 0°: | 62.9% (39.84%) |
|  | -10°: | 54.5% (44.27%) |
|  | -20°: | 45.3% (43.44%) |
|  | -30°: | 37.4% (43.89%) |

|  |  |  |
|---|---|---|
| %FE < 10°<br>Day 1 and 2 | -30°: | 77.0% (17.6%) |
|  | -20°: | 45.0% (33.61%) |
|  | -10°: | 5.4% (6.06%) |
|  | 0°: | 0.6% (1.35%) |
|  | 7°: | 0.07% (0.18%) |
| %RU < 10°<br>Day 1 and 2 | 7°: | 50.3% (42.61%) |
|  | 0°: | 43.0% (43.14%) |
|  | -10°: | 35.8% (41.73%) |
|  | -20°: | 31.4% (41.86%) |
|  | -30°: | 28.2% (41.31%) |
| %FE < 5°<br>Day 1 and 2 | -30°: | 44.0% (20.86%) |
|  | -20°: | 20.4% (21.89%) |
|  | -10°: | 1.0% (1.40%) |
|  | 0°: | 0.1% (0.38%) |
|  | 7°: | 0.02% (0.07%) |
| %RU < 5°<br>Day 1 | 7°: | 21.3% (32.23%) |
|  | -10°: | 11.5% (22.28%) |
|  | 0°: | 11.3% (16.71%) |
|  | -20°: | 10.8% (29.24%) |
|  | -30°: | 9.8% (28.02%) |
| %RU < 5°<br>Day 2 | 7°: | 24.3% (36.74%) |
|  | 0°: | 24.3% (38.23%) |
|  | -10°: | 24.1% (40.36%) |
|  | -20°: | 24.0% (39.19%) |
|  | -30°: | 20.9% (36.81%) |

### Electromyography Data

|  |  | Mean (Standard deviation) (%MVC) |
|---|---|---|
| Right arm FCU<br>Day 1 and 2 | -30°: | 6.6215% (2.75%) |
|  | -20°: | 6.2775% 2.67%) |
|  | 7°: | 6.1225% (2.35%) |
|  | -10°: | 6.0345% (2.50%) |
|  | 0°: | 5.8275% (2.22%) |
| Right arm ECU<br>Day 1 | 7°: | 12.57% (3.54%) |
|  | -10°: | 11.32% (3.02%) |
|  | -30°: | 10.94% (3.45%) |
|  | -20°: | 10.78% (3.93%) |
|  | 0°: | 10.11% (4.28%) |
| Right arm ECU<br>Day 2 | 7°: | 13.38% (4.9%) |
|  | 0°: | 12.40% (4.49%) |
|  | -30°: | 11.56% (5.01%) |
|  | -10°: | 11.46% (5.17%) |
|  | -20°: | 11.39% (4.77%) |

| | | |
|---|---|---|
| Left arm FCU<br>Day 1 | -10°: | 6.883% (3.02%) |
| | -30°: | 6.472% (2.81%) |
| | -20°: | 6.394% (2.82%) |
| | 7°: | 6.34% (2.78%) |
| | 0°: | 5.985% (2.58%) |
| Left arm FCU<br>Day 2 | -20°: | 4.21% (2.88%) |
| | -30°: | 4.08% (2.78%) |
| | -10°: | 4.05% (2.85%) |
| | 0°: | 3.73% (2.49%) |
| | 7°: | 3.59% (2.17%) |
| Left arm ECU<br>Day 1 | 7°: | 12.403% (4.19%) |
| | -10°: | 12.174% (3.35%) |
| | 0°: | 12.059% (3.80%) |
| | -30°: | 11.587% (3.99%) |
| | -20°: | 11.468% (2.94%) |
| Left arm ECU<br>Day 2 | 0°: | 9.441% (2.74%) |
| | 7°: | 9.42% (3.15%) |
| | -10°: | 9.38% (2.65%) |
| | -20°: | 8.745% (2.69%) |
| | -30°: | 8.347% (2.49%) |

## Key Strike Force Data

| | | Mean (Standard deviation) (N) |
|---|---|---|
| Mean of KSF Peaks – 'E' key<br>Day 1 and 2 | 7° | 1.039825 (0.220733) |
| | -20° | 1.030715 (0.223692) |
| | -10° | 1.024595 (0.238809) |
| | 0° | 1.010135 (0.222018) |
| | -30° | 1.000565 (0.22248) |
| Mean of KSF Peaks – 'N' key<br>Day 1 and 2 | -20° | 1.097545 (0.253774) |
| | -10° | 1.07074 (0.243232) |
| | 0° | 1.063965 (0.21794) |
| | 7° | 1.05474 (0.22056) |
| | -30° | 1.05384 (0.217805) |

## Performance Data

| | | Mean (Standard deviation) (Wpm) |
|---|---|---|
| Net Typing Speed<br>Day 1 | -10°: | 57.29 (8.03) |
| | 7°: | 56.09 (9.22) |
| | -20°: | 55.10 (7.39) |
| | 0°: | 54.24 (9.35) |
| | -30°: | 53.30 (8.25) |

| | | |
|---|---|---|
| Net Typing Speed Day 2 | -10°: | 58.36 (8.47) |
| | -20°: | 58.00 (7.23) |
| | 7°: | 56.68 (8.10) |
| | 0°: | 55.92 (9.05) |
| | -30°: | 54.44 (6.55) |
| No. of Errors Day 1 | -10°: | 20.7 (14.07) |
| | -30°: | 19.8 (13.47) |
| | 7°: | 17.2 (8.57) |
| | 0°: | 17.0 (11.61) |
| | -20°: | 16.8 (9.47) |
| No. of Errors Day 2 | -10°: | 15.8 (9.43) |
| | 7°: | 15.5 (12.46) |
| | 0°: | 14.6 (11.69) |
| | -30°: | 13.7 (6.49) |
| | -20°: | 13.2 (9.06) |
| Missing Words Day 1 | 7°: | 2.1 (1.10) |
| | -20°: | 1.3 (1.06) |
| | 0°: | 1.1 (1.66) |
| | -30°: | 0.9 (1.10) |
| | -10°: | 0.8 (1.03) |
| Missing Words Day 2 | 7°: | 1.3 (0.67) |
| | -20°: | 0.9 (1.59) |
| | -10°: | 0.7 (1.06) |
| | -30°: | 0.4 (0.96) |
| | 0°: | 0.2 (0.42) |
| Misspelled Words Day 1 | -10°: | 17.9 (11.70) |
| | -30°: | 17.6 (11.75) |
| | -20°: | 14.8 (8.76) |
| | 7°: | 14.5 (8.33) |
| | 0°: | 14.3 (9.57) |
| Misspelled Words Day 2 | -10°: | 13.8 (9.20) |
| | 7°: | 13.6 (11.16) |
| | 0°: | 13.3 (9.61) |
| | -30°: | 12.4 (5.74) |
| | -20°: | 11.6 (7.48) |
| Combined EJS data Day 1 and 2 | -30°: | 1.2 (1.609184) |
| | -10°: | 1.65 (1.899446) |
| | 0°: | 1.35 (2.007224) |
| | -20°: | 0.7 (0.864505) |
| | 7°: | 0.6 (0.994723) |

Self-Reported Discomfort Survey (SPDQ) Data

| | | Mean (Standard deviation) | |
|---|---|---|---|
| Self-rating Day 1 and 2 | 0°: | 3.00 (0.73) | |
| | -10°: | 2.65 (0.49) | |
| | -20°: | 2.30 (0.57) | |
| | -30°: | 1.65 (0.93) | |
| Estimated Time of Typing Speed Day 1 | 0° | 29.39 (42.85) | |
| | -10° | 48.03 (61.55) | |
| | -20° | 40.11 (65.50) | |
| | -30° | 37.00 (49.50) | |
| Estimated Time of Typing Speed Day 2 | 0° | 19.84 (41.71) | |
| | -10° | 76.16 (129.81) | |
| | -20° | 6.05 (11.96) | |
| | -30° | 16.69 (27.13) | |
| Final Ranking Day 1 (best to worst) | 7°: | 1.8 (1.03) | |
| | 0°: | 2.4 (1.35) | |
| | -10°: | 2.8 (0.92) | |
| | -20°: | 3.6 (0.97) | |
| | -30°: | 4.4 (1.35) | |
| Final Ranking Day 2 (best to worst) | 7°: | 2.2 (1.48) | |
| | 0°: | 2.3 (1.16) | |
| | -10°: | 2.7 (0.95) | |
| | -20°: | 3.5 (1.18) | |
| | -30°: | 4.3 (1.34) | |
| Normalized Left Hand (TIMs, RPs, Hand) Day 1 | -10°: | 0.25715 | (0.212022) |
| | -20°: | 0.25238 | (0.198302) |
| | -30°: | 0.24762 | (0.220831) |
| | 7°: | 0.20953 | (0.210821) |
| | 0°: | 0.18570 | (0.18974) |
| Normalized Left Hand (TIMs, RPs, Hand) Day 2 | -30°: | 0.22382 | (0.168068) |
| | -20°: | 0.20953 | (0.172717) |
| | -10°: | 0.19047 | (0.183751) |
| | 7°: | 0.17620 | (0.186548) |
| | 0°: | 0.13810 | (0.141003) |
| Normalized Left Wrist Day 1 and 2 | -20°: | 0.321435 | (0.253323) |
| | -10°: | 0.30001 | (0.178898) |
| | 0°: | 0.292865 | (0.219724) |
| | -30°: | 0.27145 | (0.201494) |
| | 7°: | 0.257145 | (0.220332) |
| Normalized Left Forearm Day 1 | -30°: | 0.35715 | (0.310409) |
| | -20°: | 0.35715 | (0.225867) |
| | -10°: | 0.35713 | (0.27968) |
| | 0°: | 0.28572 | (0.30117) |

| | | | |
|---|---|---|---|
| | 7°: | 0.24287 | (0.252434) |
| Normalized Left Forearm<br>Day 2 | -30°: | 0.30001 | (0.237602) |
| | -20°: | 0.27144 | (0.237612) |
| | 0°: | 0.22858 | (0.225376) |
| | -10°: | 0.21430 | (0.225864) |
| | 7°: | 0.18573 | (0.213489) |
| Normalized Right Hand<br>(TIMs, RPs, Hand)<br>Day 1 | -30°: | 0.26191 | (0.213237) |
| | -10°: | 0.23810 | (0.170964) |
| | -20°: | 0.23333 | (0.194979) |
| | 7°: | 0.21429 | (0.217926) |
| | 0°: | 0.19048 | (0.182381) |
| Normalized Right Hand<br>(TIMs, RPs, Hand)<br>Day 2 | -30°: | 0.22858 | (0.170672) |
| | -20°: | 0.17620 | (0.191859) |
| | 7°: | 0.17143 | (0.216717) |
| | -10°: | 0.16667 | (0.181336) |
| | 0°: | 0.15238 | (0.172131) |
| Normalized Right Wrist<br>Day 1 and 2 | -10°: | 0.278585 | (0.233937) |
| | -30°: | 0.271435 | (0.226582) |
| | 0°: | 0.250015 | (0.231169) |
| | 7°: | 0.24287 | (0.245695) |
| | -20°: | 0.22144 | (0.238476) |
| Normalized Right Forearm<br>Day 1 | -30°: | 0.35715 | (0.338386) |
| | 0°: | 0.30001 | (0.30453) |
| | -10°: | 0.30000 | (0.281303) |
| | -20°: | 0.28571 | (0.242798) |
| | 7°: | 0.25715 | (0.284116) |
| Normalized Right Forearm<br>Day 2 | -30°: | 0.30000 | (0.296981) |
| | -20°: | 0.24286 | (0.261253) |
| | -10°: | 0.22857 | (0.235212) |
| | 0°: | 0.21429 | (0.254211) |
| | 7°: | 0.21429 | (0.235692) |

# VITA

MITCHELL A. WOODS (*Effects of negatively sloped keyboard wedges on user performance and perceptions*) was born on September 5th, 1977, in Fairfax, Virginia. He received his Bachelor of Science degree in Industrial and Systems Engineering from Virginia Tech in May 2000. He continued directly into the Master of Science Human Factors Engineering and Ergonomics program in the same department, with a concentration in safety, in the Auditory Systems Laboratory. Mr. Woods was honored as the 2000 Kenneth J. Deurmier Safety Scholarship recipient, and became a more involved member of the Virginia Tech Student Section of the American Society of Safety Engineers (ASSE), serving as its President in 2001. While completing his coursework, Mr. Woods gained valuable teaching experience as a teaching assistant for Integrated Systems Design (ISE 5984). Mr. Woods was interested in negative sloped keyboard effects, and completed his thesis research work in the Industrial Ergonomics Laboratory with Dr. Kari Babski-Reeves.