Wrist and Forearm Posture from Typing on Split and Vertically Inclined Computer Keyboards

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A study was conducted on 90 experienced office workers to determine how commercially available alternative computer keyboards affected wrist and forearm posture. The alternative keyboards tested had the QWERTY layout of keys and were of three designs: split fixed angle, split adjustable angle, and vertically inclined (tilted or tented). When set up correctly, commercially available split keyboards reduced mean ulnar deviation of the right and left wrists from 12° to within 5° of a neutral position compared with a conventional keyboard. The finding that split keyboards place the wrist closer to a neutral posture in the radial/ulnar plane substantially reduces one occupational risk factor of work-related musculoskeletal disorders (WMSDs): ulnar deviation of the wrist. Applications of this research include commercially available computer keyboard designs that typists can use and ergonomists can recommend to their clients in order to minimize wrist ulnar deviation from typing.

INTRODUCTION

Many workers in the clerical sector, which has an employment base of more than 18 million in the U.S. (Statistical Abstract of the United States, 1992), use a computer keyboard during a majority of their working hours, resulting in 50 000 to 100 000 key strokes a day (40 words per minute [wpm] for 8 h). Within the last three decades of published literature, upper-extremity, work-related musculoskeletal disorders (WMSDs) have often been attributed to mechanical and electronic keyboard use (Bergqvist, 1995; Kroemer, 1972; Sauter, Schleifer, & Knutson, 1991). Thus it appears that the design of the keyboard is implicated in the etiology of upper extremity WMSDs among keyboard users for the following reasons: (a) The often-cited occupational risk factors of repetitive movements and deviated posture of the wrist in the flexion/extension and radial/ulnar planes are an inherent part of typing on a computer keyboard. (b) Cross-sectional studies have demonstrated a strong positive relationship between musculoskeletal discomfort and keyboard use (Bergqvist, 1995; Duncan & Ferguson, 1974; Sauter et al., 1991).

Conventional and Alternative Computer Keyboards

The conventional flat keyboard requires operators to hold their hands and forearms in a relatively awkward position. With this keyboard they must substantially pronate the forearms substantially in order to hold their palms almost horizontally. In addition, they must deviate both wrists in the ulnar direction in order to rest their fingers on the home keys, as shown in Figure 1. Most computer keyboard users also hold their wrists with some extension (Simoneau, Marklin, & Monroe, 1999).

Usually the design of alternative computer keyboards differs from that of conventional keyboards in the slant angle, slope, or tilt angle. A conventional keyboard has a slant angle of 0°, a slope ranging from 0° to 15°, and a tilt angle of 0° (see Figure 2). Several studies have investigated whether commercially available alternative keyboards place the wrist in

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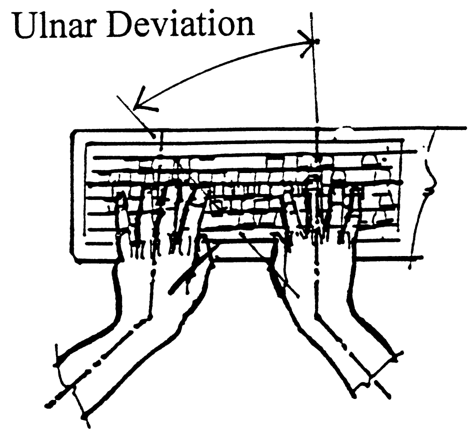

Figure 1. Top view of a conventional keyboard, which requires ulnar deviation of the wrist as well as pronation of the forearm.

a more neutral posture than conventional keyboards (Nakaseko, Grandjean, Hünting, & Gierer, 1985; Chen, et al. 1994; Honan, Serina, Tal, & Rempel, 1995; Honan, Jacobson, Tal, & Rempel, 1996). If a commercially available split keyboard has an opening angle of approximately 25° (12.5° slant angle), then wrist ulnar deviation is reduced to almost a neutral position in the radial/ulnar plane. The ulnar deviation for participants typing on a conventional keyboard is typically at least 10°. However, the studies that investigated alternative keyboards were limited in two ways. First, in those wrist posture studies in which practice time was stated, the participants were given only 3–30 min practice time. Second, the pronation/supination angle of the forearm was measured in only two of the studies that were part of our literature review (Honan, et al., 1995, 1996).

Alternative Keyboards and Wrist Posture

Unlike conventional keyboards, the goal of alternative keyboards is to position the wrist and forearm in a more neutral position when typing. Support for reducing deviated wrist and forearm postures while typing can be found in the biomechanical literature. Weiss, Gordon, Bloon, So, and Rempel (1995) used needle catheters to measure the effect of wrist position on pressure in the carpal tunnel. Wrist position was measured in both the radial/ulnar and flexion/extension planes. Compared to other angular intervals, the greatest number of the 20 participants recorded their lowest carpal tunnel pressure when the wrist was deviated in the ulnar plane over a range of 10°–15°. Compared with a neutral wrist posture, ulnar deviation of 10° does not increase carpal tunnel pressure, as supported by data from Rempel, Kier, Smutz, and Hargen (1997). Below 6 *N* and in the absence of fingertip loading, Rempel et al. (1997) found that the carpal tunnel pressure for 10° of ulnar deviation was 36.1 and 15.4 mm Hg, respectively, whereas the pressure for a neutral position in the ulnar plane was 44.6 and 19.7 mm Hg, respectively. At 20° ulnar deviation, the carpal tunnel pressure increased to 40.9 and 21.5 mm Hg for 6 *N* and no loading on the fingertips, respectively.

The effect of wrist extension was more evident on carpal tunnel pressure than the effect

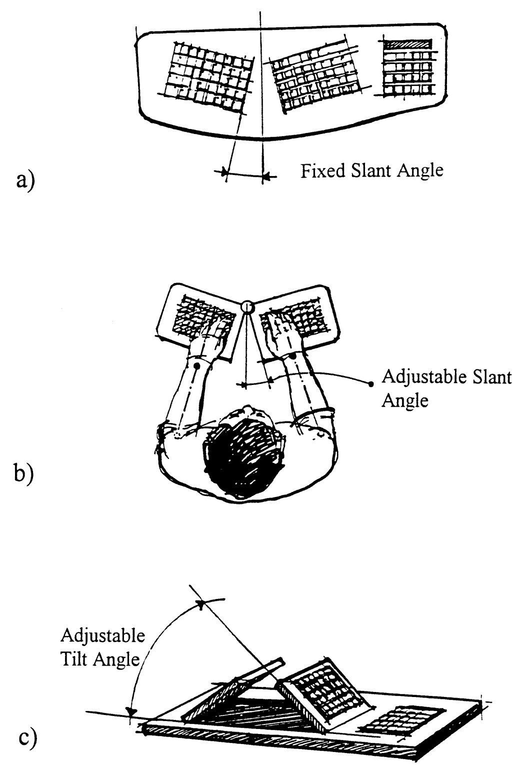

Figure 2. (a) Sketch of the commercially available split fixed-angle keyboard used in the study. (b) Sketch of the commercially available split adjustable-angle keyboard. (c) Sketch of the commercially available vertically inclined keyboard.

from ulnar deviation (Rempel et al., 1997). For 6 *N* and no loading on the fingertips, the carpal tunnel pressure increased from 41.1 and 18.5 mm Hg, respectively, at 15° wrist extension, to 53.5 and 27.7 mm Hg, respectively, at 30° wrist extension. Pressures as low as 20 mm Hg can result in damage to the neuron (possibly median nerve in the carpal tunnel), as demonstrated and reported by Dahlin and Lundborg (1990). Axonal transport decreased 75% when pressure applied to the vagus nerve of a rabbit increased from 10 to 20 mm Hg. When the pressure was increased to 30 mm Hg, the nerve showed marked morphological changes, such as displacement of the nucleus, and changes in the neuron's metabolism.

Although 10° of ulnar deviation of the wrist appears to have a negligible effect on carpal tunnel pressure, when compared with the neutral position, ulnar deviation increases the theoretical resultant forces exerted by the carpal bones and the carpal ligament against the flexor tendons passing through the carpal tunnel (Armstrong & Chaffin, 1979; Schoenmarklin & Marras, 1990). The increased resultant forces on the tendons and their sheaths can contribute to inflammation, possibly causing tenosynovitis or compression against the median nerve. Because wrist posture in the radial/ulnar and flexion/extension planes affects the biomechanics of occupational risk factors for WMSDs, the measurement of ulnar and extension wrist angles for participants typing on alternative keyboards is warranted.

Alternative Keyboards and Forearm Posture

The biomechanical relationship between forearm pronation/supination and WMSDs is hypothesized such that rotation of the forearm from its neutral position (hand with thumb pointing up) will cause the tendons to twist inside the carpal tunnel and possibly increase pressure on the median nerve. Rempel, Bach, Gordon, and So (1998) found that forearm pronation of 45° resulted in the lowest carpal tunnel pressure (10 mm Hg), which increased to 15–20 mm Hg at full pronation. Because typists typically pronate their wrists approximately 60° while typing on a conventional keyboard (Simoneau et al., 1999), and because pronation of the forearm is often cited as a major theoretical cause of physical pain and discomfort for conventional keyboard users (Zipp, Haider, Halpern, & Rohmert, 1983), measurement of forearm pronation could possibly enhance our understanding of the etiology of upper-extremity WMSDs afflicting keyboard users.

EXPERIMENTAL METHOD

Participants

All 90 participants were professional 10-digit touch typists who ranged in age from 21 to 58 years ($M = 37.8$; $SD = 9.34$) and who typed on a conventional computer keyboard a minimum of 2 h/day as part of their regular work duties. Participants were recruited from a variety of sources, including county government, hospitals, teaching institutions, and small to large corporations. They had extensive experience in jobs requiring typing ($M = 14.4$ years; $SD = 8.8$; range 2–45 years). Despite the authors' repeated attempts to recruit males, 88 of the 90 participants were female. All participants were healthy and asymptomatic of any acute or chronic musculoskeletal disorder or pain that could interfere with typing, and all participants were screened for carpal tunnel syndrome with a combination of subjective surveys, cutaneous sensory function exams, and Tinel's and Phalen's tests. The mean height and weight of the participants were 1.64 m ($SD = 0.07$) and 69.4 kg ($SD = 16.4$). There were no statistically significant differences in anthropometric dimensions among the keyboard participant groups, $F(2, 87) = 0.06$–0.84, $p > .43$.

Experimental Design

The experimental design had the following independent variables and respective levels: (a) keyboard (conventional, split fixed-angle, split adjustable-angle, and vertically inclined) and (b) hand (right vs. left). The data reported in this article are from participants typing only alphabetic text. Previous research has shown that wrist and forearm position are not significantly different between alphabetic and alphanumeric typing (Simoneau et al., 1999). The dependent variables were the following:

(a) mean, minimum, and maximum for radial/ulnar wrist angle; (b) mean, minimum, and maximum for flexion/extension wrist angle; and (c) mean, minimum, and maximum for pronation/supination forearm angle.

Of the 90 participants, 30 were randomly assigned to each of the three types of alternative keyboards. All participants were also tested while typing on the conventional keyboard to serve as their own control.

Computer Keyboards and Workstation

Participants were seated at a height-adjustable workstation that was adjusted to the criteria specified for visual display terminals (VDTs) in the American National Standard for Human Factors Engineering of Visual Display Terminal Workstations (ANSI-HFS-100-1988). The height of the keyboard tray was adjusted so participants' forearms were parallel to the floor and their elbow angle was approximately 90°. The height of the VDT was adjusted so the eye declination angle to the middle of the screen was 30°. The conventional keyboard used in this study was a high-quality QWERTY personal computer keyboard with spring-activated keys. The alternative keyboards, all of which were commercially available and had the QWERTY key layout, are illustrated in Figure 2.

Apparatus

Wrist monitors and pronation/supination devices designed and developed at the Biodynamics Laboratory at Ohio State University collected on-line position data of the radial/ulnar and flexion/extension angles of the right and left wrists and the pronation/supination positions of the right and left forearms (Marras & Schoenmarklin, 1993). Settings for pronation data were 0° when the thumb was pointed upward and 90° when the palm of the hand was parallel to the floor. Position data from the goniometric devices from the wrists and forearms were sampled at 300 Hz, fed into a 12-bit analog-to-digital converter, and stored on a personal computer. Additional details of the apparatus are provided in Simoneau et al. (1999).

Experimental Protocol

One of the three alternative keyboard types was assigned to each participant, who then typed on the assigned keyboard for at least 10 h at his or her workplace during a 1–2-week period prior to testing in the laboratory. At least 19 of the 30 participants assigned to each type of alternative keyboard practiced typing on the assigned keyboard for at least 20 h. We instructed the participants at their workplaces on how to use the keyboard. For the split adjustable-angle keyboard, the experimenters adjusted the keyboard halves to achieve a neutral position in the radial/ulnar plane. Participants were free to select the tilt angle of the vertically inclined keyboard.

On the day of laboratory testing, the wrist monitors and pronation/supination devices were attached to the participants' wrists and forearms and then calibrated. After calibration of the goniometers, four typing sessions of 8 min duration were performed – two on the alternative keyboard and two on the conventional keyboard. Participants typed primarily alphabetic characters from a seventh-grade social sciences text that contained very few numeric and special function keys. The presentation order of the keyboards was counterbalanced between the conventional and alternative types. Prior to testing of each keyboard, the participant practiced typing for 3 min. A 2-min rest period was required between typing sessions.

Typing Performance Data

The Typing Tutor 6.0 software (Kriya Systems, Inc., Sterling, VA) recorded the typing performance for each participant's 8-min typing sessions. The performance measures were typing speed (wpm), accuracy percentage, total characters typed, and total number of errors left in the document.

Kinematic Data

Kinematic data were collected for the conventional and alternative keyboard assigned to each participant. During each of the 8-min typing sessions, 5 samples of kinematic data of 30 s duration were collected, resulting in 10 30-s samples for the alternative keyboard and 10 30-s samples for the conventional keyboard. Mean angular positions for each participant for all three planes of movement were calculated as the average position in the plane of interest during the 300 s (10 samples × 30 s) of data collected for each keyboard. Maximum and minimum angular positions were calculated as the averages of the maxima and minima angular positions, respectively, from each of the 30-s sampling periods. Prior to analysis, raw data were filtered with a fourth-order 7-Hz Butterworth low-pass filter.

Statistical Analysis

The conditioned wrist and forearm data from all participants were pooled for statistical analysis. In order to determine differences between the conventional and alternative keyboards, a separate two-way, repeated-measures analysis of variance (ANOVA) was performed on each type of alternative keyboard. A mixed two-way ANOVA was performed to determine the differences in the dependent variables among the three alternative keyboard types.

RESULTS

Slant and Tilt Angles of the Alternative Keyboards

The slant angle of the split fixed-angle keyboard was 12.5° (25° opening angle). The halves of the split adjustable-angle keyboard were adjusted to each individual so that participants' wrists were aligned with their forearms, resulting in an approximately neutral radial/ulnar angle. The mean slant angle for all participants who typed on the split adjustable-angle keyboard was 10.5° (SD = 3.6; range 5°–20°).

The vertically inclined keyboard tended to rotate the keyboard halves apart while it was tilted upward, resulting in a small slant angle accompanying the tilt of the keyboard halves. Participants adjusted and selected their own tilt angles, resulting in a mean tilt angle of 32.8° (SD = 4.2; range 24.5°–42.0°) and 27.8° (SD = 4.3; range 19.3°–37.2°) for the left and right halves, respectively. The concomitant slant angle of the rotated keyboard halves was 7.0° (SD = 2.0; range 3.1°–11.3°).

Practice Time Typing on Alternative Keyboards

Participants in the three alternative keyboard groups were queried on how long they practiced before coming to the laboratory for testing. Participants reported an average of 25–29 h of practice in their offices. There was no significant difference in practice time among the three groups. Although all participants practiced at least 10 h, 61 of the 90 participants practiced at least 20 h but less than 40 h before testing.

Typing Performance

The mean typing speeds for participants typing on the vertically inclined, split adjustable-angle, and split fixed-angle keyboards were 54.1 wpm (SD = 9.0), 60.3 wpm (SD = 13.3), and 57.3 wpm (SD = 8.7), respectively. The mean typing speeds were 3–4 wpm less than those on the conventional keyboard for each respective group, F(1, 29) = 17.6–45.6, $p < .0002$. No statistically significant main effect was found in typing accuracy when each of the three alternative keyboards was compared with the conventional keyboard.

Wrist and Forearm Position

Vertically Inclined Keyboard. As shown in Tables 1 and 2, the vertically inclined keyboard significantly reduced the mean, maximum, and minimum wrist ulnar deviation angles compared with the conventional keyboard, $F(1, 29) = 218–233$, $p < .0001$. The mean wrist ulnar deviation angle was reduced approximately 12°, from 15.2° to 3.1° for the left wrist and 11.5° ulnar to 2.4° radial deviation for the right wrist. There were no significant differences in mean, maximum, and minimum wrist extension angles between the vertically inclined and conventional keyboards, as indicated in Tables 3 and 4, $F(1, 29) = 0.01–0.5$, $p > 0.47$. The mean extension angle for the left wrist was about 20°, which was 5° greater than the right wrist's mean extension angle, $F(1, 29) = 22.4$, $p < .0001$.

Compared with the conventional keyboard, the vertically inclined keyboard significantly reduced mean, maximum, and minimum forearm pronation angles, $F(1, 29) = 241–297$, $p < .0001$. As revealed in Tables 5 and 6, the vertically inclined keyboard required forearm pronation of about 40°, which was about 22° less pronation than for the conventional keyboard.

Split Adjustable-Angle Keyboard. As shown in Tables 1 and 2, the split adjustable-angle

TABLE 1: Mean, Maximum, and Minimum Wrist Ulnar Position in Degrees for Each Alternative Keyboard (Negative = Ulnar Deviation; Positive = Radial Deviation)

	Alternative Keyboard Designs		
	Vertically Inclined *n* = 30	Split Adjustable-Angle *n* = 30	Split Fixed-Angle *n* = 30
Left wrist			
Mean	–3.1 (7.8)	–5.7 (6.8)	–5.8 (9.8)
Maximum	–12.0 (7.4)	–14.9 (6.6)	–14.7 (9.8)
Minimum	6.7 (7.5)	5.1 (7.4)	4.3 (10.4)
Right wrist			
Mean	2.4 (7.3)	–2.5 (6.5)	1.2 (6.8)
Maximum	–14.2 (7.2)	–16.1 (7.1)	–13.7 (5.6)
Minimum	9.8 (6.9)	5.7 (5.8)	9.0 (7.6)

Note: Standard deviations appear in parentheses.

keyboard reduced mean, maximum, and minimum ulnar deviations by about 8° compared with the conventional keyboard. The mean ulnar angle decreased from 13.3° to 5.7° for the left wrist and from 10.7° to 2.5° for the right wrist. The differences in mean, maximum, and minimum ulnar deviation were statistically significant, $F(1, 29) = 137–146$, $p < .0001$. Although statistically significant, $F(1, 29) = 19.1–36.8$, $p < .001$, the decrease in mean, maximum, and minimum extension angles between the split adjustable-angle keyboard and the conventional keyboard was only 4°.

Split Fixed-Angle Keyboard. Compared with the conventional keyboard, the split fixed-angle keyboard reduced mean, maximum, and minimum ulnar deviation angles significantly, $F(1, 29) = 196–279$, $p < .0001$, by about 10° (mean left wrist, 16.5°–5.8°; mean right wrist, 7.9° ulnar – 1.2° radial). A frequency distribution of the mean ulnar deviation data for the 30 participants is shown in Figure 3. The conventional keyboard required approximately 4°–5° more mean, maximum, and minimum wrist extension than the split fixed-angle keyboard (left wrist mean, 22.6°–18.2°; right wrist mean, 17.6°–12.8°), $F(1, 29) = 12.7–20.2$, $p < .01$. The mean and minimum extension angles were greater for the left wrist than for the right wrist by 5°–9°, a significant difference, $F(1, 29) = 16.1–32.9$, $p < .001$.

TABLE 2: Mean, Maximum, and Minimum Wrist Ulnar Position in Degrees for the Conventional Keyboard (Negative = Ulnar Deviation; Positive = Radial Deviation)

	Conventional Keyboard		
	Vertically Inclined Keyboard Subgroup *n* = 30	Split Adjustable-Angle Keyboard Subgroup *n* = 30	Split Fixed-Angle Keyboard Subgroup *n* = 30
Left wrist			
Mean	–15.2 (6.3)	–13.3 (7.7)	–16.5 (8.8)
Maximum	–23.9 (5.5)	–21.6 (7.0)	–25.0 (8.2)
Minimum	–5.1 (7.1)	–3.4 (8.9)	–7.3 (10.5)
Right wrist			
Mean	–11.5 (7.3)	–10.7 (7.4)	–7.9 (6.7)
Maximum	–25.8 (6.0)	–24.5 (7.2)	–23.7 (4.7)
Minimum	–3.7 (7.1)	–2.8 (7.5)	–0.4 (9.0)

Note: Standard deviations appear in parentheses.

TABLE 3: Mean, Maximum, and Minimum Wrist Extension Position in Degrees for Each Alternative Keyboard Design (Negative = Wrist Extension; Positive = Wrist Flexion)

	Alternative Keyboard Designs		
	Vertically Inclined $n = 30$	Split Adjustable-Angle $n = 30$	Split Fixed-Angle $n = 30$
Left wrist			
Mean	–20.4 (5.5)	–16.9 (8.4)	–18.2 (8.6)
Maximum	–25.7 (5.7)	–22.3 (8.5)	–24.0 (9.1)
Minimum	–14.5 (6.3)	–9.9 (8.4)	–11.6 (9.3)
Right wrist			
Mean	–14.2 (7.4)	–14.1 (7.2)	–12.8 (5.7)
Maximum	–23.0 (8.1)	–23.3 (7.4)	–22.1 (6.2)
Minimum	–5.3 (7.7)	–3.4 (7.8)	–2.9 (6.7)

Note: Standard deviations appear in parentheses.

Comparison of the Three Alternative Keyboards. There was no statistically significant effect at the $p = .05$ level on mean ulnar and flexion positions among the three alternative keyboard designs, $F(2, 87) = 0.8–2.46$, $p = .09–.45$. There was, however, a significant main effect for alternative keyboard design on mean forearm pronation, $F(2, 87) = 58.6$, $p < .0001$. There was also a significant main effect for mean ulnar and wrist extension angles of the hands, $F(1, 87) = 38.1–42.9$, $p < .0001$. Across all three alternative keyboards, wrist radial/ulnar deviation for the right hand was nearly neutral as compared with 4°–5° of ulnar deviation for the left hand. The right wrist was extended about 5° less than the left hand(13° for the right and 18° for the left).

Variance of Wrist Motion within Participants

The standard deviations for the wrist and forearm movements in the ulnar, extension, and pronation planes were approximately 4.5°, 3.0°, and 3.5°, respectively, for all three alternative keyboards. There were no significant differences in variance between each alternative keyboard and the conventional keyboard.

DISCUSSION

Typing Performance

Participants were able to type about 3–4 wpm less with the alternative keyboards than with a conventional keyboard. This decrease

TABLE 4: Mean, Maximum, and Minimum Wrist Extension Position in Degrees for the Conventional Keyboard (Negative = Wrist Extension; Positive = Wrist Flexion)

	Conventional Keyboard		
	Vertically Inclined Keyboard Subgroup $n = 30$	Split Adjustable-Angle Keyboard Subgroup $n = 30$	Split Fixed-Angle Keyboard Subgroup $n = 30$
Left wrist			
Mean	–20.6 (7.2)	–20.4 (8.5)	–22.6 (10.4)
Maximum	–25.5 (7.2)	–25.5 (8.4)	–27.4 (10.6)
Minimum	–14.5 (6.9)	–13.7 (9.3)	–16.6 (10.6)
Right wrist			
Mean	–15.4 (7.2)	–17.9 (6.7)	–17.6 (8.1)
Maximum	–23.8 (7.8)	–26.2 (6.9)	–25.7 (8.9)
Minimum	–6.5 (7.6)	–7.6 (7.7)	–8.4 (8.9)

Note: Standard deviations appear in parentheses.

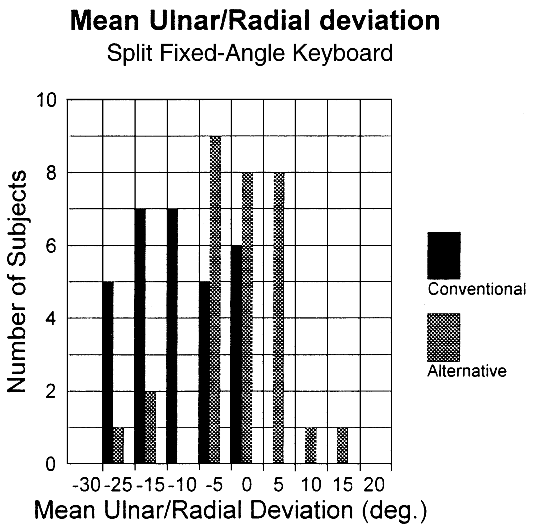

Figure 3. Frequency distribution of mean radial/ulnar deviation of the right wrist of the 30 participants who typed on the split fixed-angle keyboard.

represents a 5% reduction in typing speed, which may play a significant role in jobs in which typing speed is critical. It is not clear why there was a difference in typing speed in this study because other investigators have shown that accommodation to alternative keyboards requires only 2 h (Smith et al., 1998).

Magnitude of Practice Time

With respect to wrist position, participants are able to stabilize their wrist posture within 20 to 30 min of typing on an alternative keyboard. Honan et al. (1996) measured the wrist and forearm position of participants typing on alternative keyboards over a 4-h period and found no overall significant changes in wrist and forearm posture. The positions of the wrist and forearm measured in the first 20 min of typing were indicative of the postures during the 4-h period.

With respect to typing performance, Swanson, Galinsky, Cole, Pan, and Sauter (1997) found that experienced typists required about 5 h of typing on alternative keyboards in order to attain steady typing performance. However, Smith et al. (1998) found that participants can attain their normal typing speed after typing on a split adjustable-angle keyboard for 2 h or more. Recent published findings by Smith et al. (1998) indicate that the 10 h of practice in the present study is more than the minimum time required for participants to attain their normal typing speed on split keyboards. However, because vertically inclined keyboards were also tested in this study, 5 h of practice were necessary for those participants (Swanson et al., 1997). In summary, the 10 h of practice required in the present study is more than sufficient time for participants to overcome temporary disruptions to wrist posture and typing performance resulting from unfamiliarity with the keyboard.

TABLE 5: Mean, Maximum, and Minimum Forearm Pronation Position in Degrees for Each Alternative Keyboard Design

	Alternative Keyboard Designs		
	Vertically Inclined *n* = 25 for Left *n* = 29 for Right	Split Adjustable-Angle *n* = 24 for Left *n* = 27 for Right	Split Fixed-Angle *n* = 24 for Left *n* = 25 for Right
Left forearm			
Mean	41.8 (12.7)	60.0 (11.7)	61.9 (9.2)
Maximum	50.2 (13.6)	67.8 (12.1)	70.2 (10.5)
Minimum	33.7 (13.1)	53.0 (11.4)	53.4 (9.9)
Right forearm			
Mean	38.5 (8.9)	64.1 (9.0)	62.6 (6.9)
Maximum	46.2 (9.7)	70.7 (8.8)	69.7 (8.6)
Minimum	29.1 (9.0)	55.8 (10.8)	53.3 (7.1)

Notes: Standard deviations appear in parentheses. Data were not available from all participants, thereby resulting in sample sizes < 30.

TABLE 6: Mean, Maximum, and Minimum Forearm Pronation Position in Degrees for the Conventional Keyboard

	Conventional Keyboard		
	Vertically Inclined Keyboard Subgroup n = 25 for Left n = 29 for Right	Split Adjustable-Angle Keyboard Subgroup n = 24 for Left n = 27 for Right	Split Fixed-Angle Keyboard Subgroup n = 24 for Left n = 27 for Right
Left wrist			
Mean	62.4 (12.4)	59.5 (9.8)	64.7 (8.9)
Maximum	70.1 (11.8)	67.5 (9.5)	73.1 (9.1)
Minimum	54.9 (14.2)	52.6 (10.6)	56.3 (10.0)
Right wrist			
Mean	63.2 (7.6)	65.2 (8.6)	68.3 (8.1)
Maximum	68.9 (8.8)	72.0 (8.7)	75.1 (9.2)
Minimum	55.7 (9.7)	56.0 (11.0)	59.2 (11.2)

Note: Standard deviations appear in parentheses.

Wrist and Forearm Posture of Conventional and Alternative Keyboards

Conventional versus split keyboards. Compared with the conventional keyboard, the two split alternative keyboards reduced mean ulnar deviation substantially. The ulnar deviation results from this study agree well with those of Honan et al. (1996), who found that ulnar deviation of 20 experienced typists who typed on a split fixed-angle keyboard (with a slant angle of 12.5°) for 4 h ranged from neutral (0°) to 5°. The results from this study do not agree with an earlier study (Honan et al., 1995) that showed 5°–10° ulnar deviation from typing on a split keyboard with a fixed slant angle of 12.5°, nor do they agree with a study by Chen et al. (1994). In the latter study, the researchers measured the ulnar deviation for participants typing on a split adjustable-angle keyboard that was adjusted to a slant angle of 5°. The resulting mean ulnar deviation from typing on the split keyboard was 15°, which was no different from the ulnar deviation for the same participants typing on a conventional keyboard. The lack of a difference in ulnar deviation may result from the small slant angle of 5°.

Conventional versus vertically inclined keyboard. Compared with the conventional keyboard, the vertically inclined keyboard reduced forearm pronation substantially, as revealed in Tables 5 and 6. To our knowledge, no studies have been conducted that quantitatively measured the pronation angle of participants typing on vertically inclined keyboards. Therefore no comparisons can be made between the quantitative pronation angle results from this study and the literature. However, based on crude video analysis of a split adjustable-angle keyboard that had the capability of being vertically inclined, Smith et al. (1998) measured forearm pronation on a subjective Likert-type 5-point scale (0–4). Mean forearm pronation while using the vertically inclined keyboard was 2.33 (moderate pronation) compared with 3.94 (substantial pronation) for the conventional keyboard.

Wrist and Forearm Posture as a Function of Right and Left Hands

Whether the participants in this study were typing on conventional or alternative keyboards, they tended to place their left wrist in greater ulnar deviation and greater wrist extension than their right wrist. These results agree with those of Hedge and Powers (1995), who found that participants ulnarly deviated their left wrists 2° more than their right wrists when they typed on conventional and chair-mounted keyboards. The results for forearm pronation from typing on the conventional keyboard indicated that the right forearm was pronated approximately 1°–5° more than the left forearm.

The reasons for the differences in wrist and forearm posture between the two upper extremities are not fully understood. Perhaps typists pronate less and deviate ulnarly more with the left upper extremity than the right because they have to type more characters or special keys, such as the tab, with their left little finger than their right little finger, and it is easier to type these keys with reduced pronation and greater ulnar deviation. According to physiological findings from Zipp et al. (1983), less pronation in the upper extremity is advantageous to the health of the operator. However, whether the small difference of about 5° of pronation between the right and left forearms would result in an appreciable difference in health outcomes is questionable.

Biomechanical issues of wrist and forearm posture. The results from this study corroborate the findings by Hedge and Shaw (1996) and Honan et al. (1996) that split and vertically inclined keyboards, when used properly, reduce ulnar deviation to almost a neutral position. This reduction minimizes one of the occupational risk factors of WMSDs associated with typing – ulnar deviation. The finding from this study and others that conventional keyboards consistently require 10° or more of ulnar deviation could explain why typing on conventional keyboards has been problematic with respect to WMSDs. Theoretically as the wrist angle approaches neutral, the net reaction forces from the carpal bones and carpal ligament on the tendons and their sheaths decreases. Less net reaction force pressing against the sides of the tendons and their sheaths would theoretically decrease the incidence of tendinitis and tenosynovitis. However, the theoretical benefits of reduced ulnar deviation from alternative keyboard use are mitigated by carpal tunnel pressure studies that have shown an ulnar deviation of 10° does not increase pressure in the carpal tunnel compared with a neutral position (Rempel et al., 1997).

Although the beneficial effects of alternative keyboards are noteworthy for reducing wrist ulnar deviation and forearm pronation (vertically inclined keyboard only), these alternative keyboards did not substantially reduce wrist extension. Wrist extension had a greater effect than ulnar deviation on carpal tunnel pressure (Rempel et al., 1997). Further reductions of WMSD risk factors resulting from typing on alternative keyboards could be achieved by addressing wrist extension.

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