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Effect of Setup Configurations of Split Computer Keyboards on Wrist Angle

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Background and Purpose. Alternative computer keyboards whose halves can be slanted toward each other can reduce a risk factor (ulnar deviation) for work-related musculoskeletal disorders (WMSDs) affecting the upper limbs. Two questions that computer keyboard operators face when using keyboards that can be separated into halves (split keyboards) are: (1) At what angle should the keyboard halves be opened? and (2) At what distance apart should the keyboard halves be placed? The objective of this study was to investigate the effects of the opening angle and separation distance between halves of a split keyboard on wrist ulnar deviation and typing efficiency. **Methods.** Eleven experienced computer keyboard operators participated in this study and used a split keyboard that was set up in a conventional (nonsplit) format and also in 3 alternative configurations: (1) centers of keyboard halves were separated at 20-cm distance, (2) keyboard halves were separated half of the distance of shoulder width, and (3) keyboard halves were separated at shoulder width distance. **Results.** The 3 alternative configurations resulted in ulnar deviation of both wrists that were less than ulnar deviation from typing on a conventional setup. There were no differences in ulnar deviations among the 3 alternative configurations. **Discussion and Conclusion.** The results of this research provide physical therapists and ergonomists with a set of configurations of a split keyboard that they can recommend to their patients or clients. All of the alternative configurations of the split keyboard are beneficial in promoting a neutral wrist position, which theoretically would decrease exposure to WMSDs such as tenosynovitis in the wrist and carpal tunnel syndrome. [Marklin RW, Simoneau GG. Effect of setup configurations of split computer keyboards on wrist angle. *Phys Ther.* 2001;81:1038–1048.]

Key Words: *Computer keyboard, Split keyboard, Typing, Wrist angle.*

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Upper-extremity work-related musculoskeletal disorders (WMSDs), such as tenosynovitis in the wrist area, have been often attributed to mechanical and electronic keyboard use.[1,2] The design of the computer keyboard has been implicated in the etiology of upper-extremity WMSDs among keyboard users for the following 2 reasons: (1) the often-cited occupational risk factors of repetitive movements and deviated posture of the wrist in the flexion-extension and radioulnar planes[3] are an inherent part of typing on a computer keyboard, and (2) cross-sectional studies[1,2,4] have shown a strong positive relationship between musculoskeletal discomfort and keyboard use.

Individuals typing on a conventional computer keyboard typically type with an average of 10 and 15 degrees of ulnar deviation for the right and left wrists, respectively.[5] Compared with a conventional computer keyboard, split computer keyboards have been found to decrease ulnar deviation of the wrist to within 5 degrees of a neutral position while using the standard 10-digit "touch" method.[5–10] As shown in Figure 1, the typical split keyboard is one that has the alphabetic text divided into halves, and the halves are angled outward. The keyboard shown in Figure 1 has a fixed opening angle of 25 degrees between the halves, whereas other commercially available split keyboards offer the capability to adjust the opening angle and to separate the keyboard halves. In a previous study,[5] we demonstrated that typing on commercially available split fixed-angle or split adjustable-angle keyboards reduced ulnar deviation by at least 8 degrees compared with typing on a conventional keyboard (from 14.8° to 5.8° for the left wrist and from 9.3° to 1.8° for the right wrist). The fact that split keyboards place the wrist closer to a neutral posture in the radioulnar plane would reduce one occupational risk factor, namely wrist ulnar deviation, of WMSDs.[11]

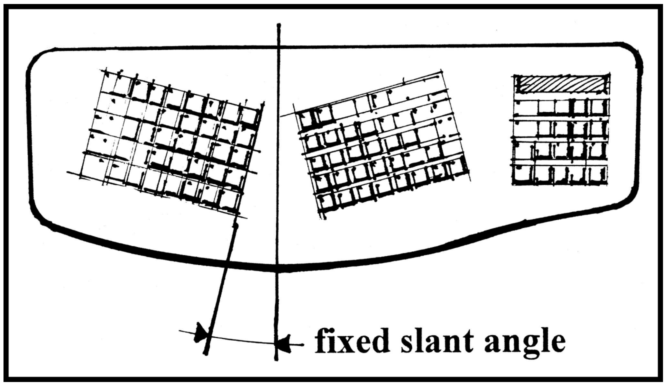

Figure 1.
Drawing of a typical split computer keyboard. This keyboard has a fixed opening angle of 25 degrees, resulting in a slant angle of 12.5 degrees for each keyboard half.

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Ulnar deviation theoretically increases the resultant forces exerted by the carpal bones and flexor retinaculum against the flexor tendons passing through the carpal tunnel.[12,13] The lateral forces on the tendons and their sheaths could contribute to inflammation, possibly causing tenosynovitis of the tendons passing through the carpal tunnel. Moderate to extreme wrist ulnar deviation has been shown to increase carpal tunnel pressure,[14] which could compress the median nerve and possibly cause carpal tunnel syndrome. In addition, epidemiological evidence linking wrist ulnar deviation and incidence of wrist discomfort from workers who are required to type for a substantial portion of the working day has been published in the literature.[2]

The split keyboards investigated in previous studies[5,7,9,10] had contiguous configurations. That is, the keyboard halves were connected either in a one-piece unit (split fixed-angle keyboard) or connected at a pivot point that rotated the halves (split adjustable-angle keyboard). However in many cases, the halves of split adjustable-angle keyboards can be separated and located at any distance (up to the length of the connecting cable) or angle between them. Even though the separation distance between the keyboard halves is constrained by the length of the cable connecting the halves, a user can still separate the keyboard halves at shoulder width distance. Whether a split keyboard with its halves separated and angled would produce the same beneficial reductions in ulnar deviation as found in our previous study[5] and in other studies[7,9,10] is unknown. When a split keyboard is separated, its keyboard halves can be oriented to promote a neutral wrist position based on the user's shoulder width and forearm length. However, whether users would actually type with a neutral wrist position if the halves were aligned to maintain a theoretically neutral position in various keyboard arrangements is unknown. Some users may be so accustomed to medially rotating their shoulders, which is the customary shoulder position when typing on a conventional keyboard or split keyboard with contiguous halves, that they may medially rotate (and consequently abduct) their shoulders to the same angle when the keyboard halves are separated halfway or at full shoulder width distance. If a user medially rotates and abducts the shoulders when the keyboard halves are not contiguous, this could nullify any reduction in wrist ulnar deviation and thereby defeat the purpose of providing the user with a variety of alternative arrangements of split keyboard halves.

When interventions are aimed at improving the health of office workers, we believe there needs to be consideration of the productivity of the worker. The most easily measured and readily available productivity measure for office workers using keyboards is typing speed. In our previous study of split keyboards,[5] we found typing speed on split keyboards to be, on average, 3 words per minute (5%) less than when the same user typed on a conventional keyboard. Results from another study of split and conventional keyboards[9] showed no difference in typing performance between the split and conventional keyboards of subjects who, up until the time of the study, did not have experience typing on a split keyboard. In another of our studies of alternative keyboard use,[15] we found no difference in typing speed and accuracy between keyboards that sloped downward (negatively) and conventionally sloped keyboards. Subjects practiced only 5 minutes on each keyboard slope. In summary, subjects readily adapted to split and sloped keyboards and did not show a decrement in performance as compared with when they used a conventional keyboard.

In addition to measuring typing performance, assessment of user comfort is another variable that provides insight into the overall effectiveness of keyboard designs. We recently published a study of keyboard use in which we measured user comfort with a 5-point Likert scale.[5] Other researchers of keyboard use have used the a National Institute for Occupational Safety and Health checklist[9] and the 10-point Borg scale[16] for assessing comfort or pain of individual body parts.

The objective of this study was to investigate whether keyboard users would type with a neutral wrist position in the radioulnar plane with a split keyboard whose halves were separated and angled in a manner designed to produce a theoretical neutral wrist position (based on the user's anthropometry). If more than one configuration of the separated keyboard halves, which are configured to promote a neutral position of the user's wrists based on his or her anthropometry, are found to reduce ulnar deviation compared with a conventional keyboard, then we believe a user could choose among several configurations of separation distance and opening angle between the keyboard halves. The application of this research to physical therapists and ergonomists is that, in order to promote a neutral wrist position, they could recommend configuration(s) of split computer keyboards to their patients or clients who are either symptomatic or asymptomatic of WMSDs affecting the wrist.

We tested 3 hypotheses. First, we hypothesized that ulnar deviation would be reduced when typing on separated and angled keyboards as compared with a conventional keyboard. Second, we hypothesized that various separated and angled keyboards adjusted to each subject's anthropometry would result in similar ulnar deviation angles when typing. Third, we hypothesized that separated and angled keyboards would not show a decrement in typing performance and assessment of user comfort compared with a conventional keyboard.

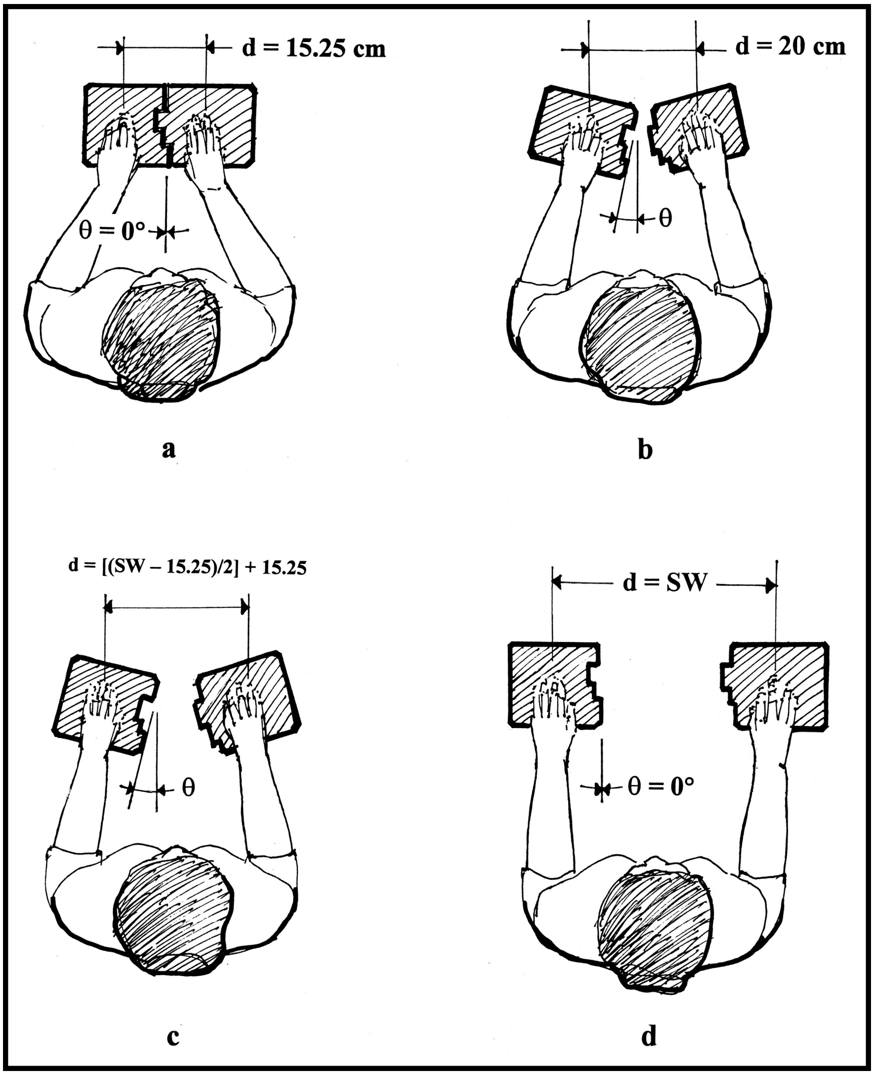

Figure 2.
Configurations of the split keyboard tested in this study: (a) (CV) Conventional setup of a computer keyboard. This figure shows the typical 10 to 15 degrees of wrist ulnar deviation that was measured while subjects were using a conventional keyboard; "d" corresponds to the distance between the centers of the 2 keyboard halves. (b) (S-20) Keyboards halves separated 20 cm, which resembles a setup where the halves are contiguous and connected at a pivot point. The keyboard halves were angled for each subject, based on the geometric relationship between shoulder width and forearm-hand length, to align the wrists at a neutral angle in the radioulnar plane. (c) (S-MID) Keyboard halves separated midway between setups CV and S-SW and angled for each subject to align the wrists at a neutral angle in the radioulnar plane. (d) (S-SW) Keyboard halves separated shoulder width (SW) distance.

Method

Subjects

Eleven typists were recruited from a temporary employment agency to participate in this study. All subjects, who were women and ranged in age from 18 to 40 years, were capable of typing at least 40 words per minute (wpm) using the 10-digit "touch" method (capable of typing accurately without looking at the keys). The ability of the subjects to type a minimum of 40 wpm was based on subject self-report when queried at the time of recruitment. This ability was subsequently confirmed by use of Typing Tutor 6.0 software* during a short typing practice session before data collection. The subjects' mean shoulder width was 37.85 cm (SD=1.64, range=33.0–39.9). The mean length of the right and left forearm-hand was 44.76 cm (SD=3.0, range=39.9–50.2).

At the time of recruitment, subjects were asked whether they were free of pain or discomfort related to typing. Based on answers to questions regarding health status of various body parts, subjects reported they were asymptomatic of musculoskeletal injury, pain, and discomfort that interfered with typing. Immediately prior to testing, subjects were asked questions about pain, tingling, and numbness in their upper extremities to confirm that they did not have symptoms of WMSDs related to typing. Furthermore, all subjects had negative outcomes for Phalen's and Tinel's tests for carpal tunnel syndrome. Phalen's and Tinel's tests have reported sensitivities of 71% and 44%, respectively, and specificities of 80% and 94%, respectively.[17,18] All subjects gave informed consent prior to participation in the study.

Experimental Design

A repeated-measures experimental design was used to determine the ulnar deviation angle from subjects typing on a split keyboard setup in the 4 configurations illustrated in Figure 2. The 4 levels of the independent variable (keyboard configuration) were the following:

1. Conventional (CV): The keyboard halves were set up the same way as a conventional keyboard. The slant angle, which is half of the opening angle, is 0 degrees for a conventional setup. The distance between the centers of the keyboard halves ("E" and "P" keys) was 15.25 cm.

2. Separated 20 cm (S-20): The centers of the keyboard halves were separated at a fixed distance of 20 cm, and the halves were angled to maintain a theoretical neutral position of the user's wrists in the radioulnar plane. This configuration minimized the separation distance (20 cm) but still allowed for free rotation of

* Kriya Systems Inc, Sterling, Va.

the keyboard halves in order to align the wrists in a neutral radioulnar position. The slant angles of both keyboard halves (θ) were calculated for each individual based on the geometric relationship between shoulder width and forearm-hand length that resulted in a theoretical neutral position of the wrists in the radioulnar plane. The slant angles of both keyboard halves were identical.

3. Separated midway (S-MID): The keyboard halves were separated halfway between the conventional setup (CV) and the configuration in which the halves were separated a shoulder width distance (S-SW). The keyboard halves were angled to maintain a theoretical neutral position of the user's right and left wrists in the radioulnar plane. The slant angles of both keyboard halves (θ) were calculated for each individual based on the geometric relationship between shoulder width and forearm-hand length that resulted in a theoretical neutral position of the wrists in the radioulnar plane. The slant angles of both keyboard halves were identical.

4. Separated shoulder width (S-SW): The keyboard halves were separated at a distance equal to the user's shoulder width, and the halves were parallel to each other, resulting in a theoretical neutral position of the user's wrists in the radioulnar plane.

The dependent variables for this study were the following:

1. Mean, maximum, and minimum ulnar deviations of the right and left wrists.

2. Typing speed (in words per minute) and accuracy. *Accuracy* was defined as the difference between the total number of characters typed and the total number of errors left in the document divided by the total number of characters.

3. Psychophysical assessment of discomfort level of the neck and back and right and left shoulders, arms, elbows, forearms, wrists, and hands by use of the 10-point Borg scale.[19]

The sample size of 11 subjects was based on calculations to ensure that the probability of a type I statistical error did not exceed .05 and that the statistical power (1 − type II error) was at least 0.8020. These calculations assumed a minimum effect size of 7.5 degrees and a standard deviation of 5 degrees for mean ulnar deviation angles. Our previous research[5] has shown that there is a difference in ulnar deviation of at least 7.5 degrees between typing on conventional and split keyboards.

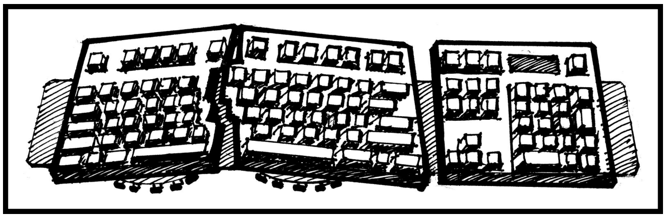

Figure 3.
The Comfort keyboard used in this study. The Comfort keyboard has 3 independent sections that can be separated.

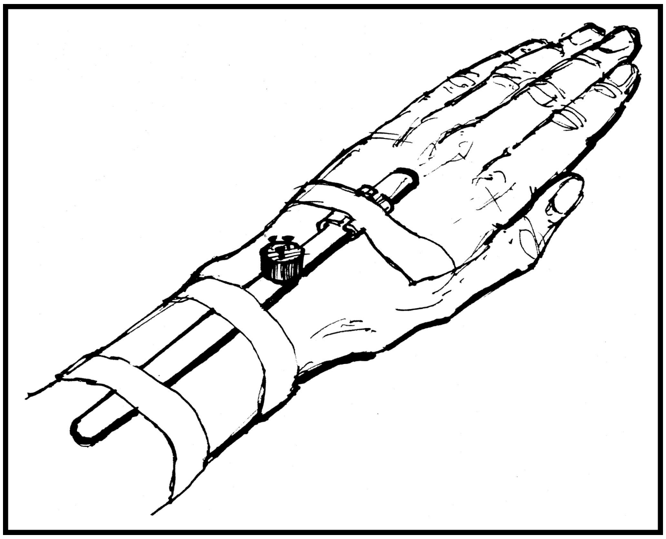

Figure 4.
Wrist monitor that measured wrist radial and ulnar deviation.

Apparatus

A Comfort keyboard,† which is shown in Figure 3, was set up in the 4 configurations illustrated in Figure 2. The Comfort keyboard has 3 independent sections—2 alphabetic and 1 numeric—that can be separated and oriented at any angle along a track. Because subjects typed primarily alphabetic text, only the 2 alphabetic sections of the Comfort keyboard were used in this study. The separation distance and angles of the Comfort keyboard halves were adjusted along the track by simply locking each half with a wheel. The "E" and "P" keys on the left and right halves, respectively, were defined as the center of each keyboard half because they were located at their respective geometric centers.

Wrist ulnar deviation was measured by use of a wrist goniometer developed at The Biodynamics Laboratory at The Ohio State University.[21] The goniometer, which is shown in Figure 4, consisted of 2 segments of thin, flexible metal joined by a rotary potentiometer. The metal segment on the dorsal side of the subject's forearm was taped to the skin with surgical-quality hypo-

† Health Care Keyboard Co, 12040-G W Feerick St, Wauwatosa, WI 53222.

allergenic tape, and the metal segment on the dorsal side of the subject's hand slid through a metal sheath. The metal sheath was then taped to the skin of the subject's hand. As one metal segment rotated with respect to the other, the potentiometer recorded the change in voltage, which was later converted to degrees of angular deviation. The potentiometer was placed on the center of the subject's wrist, which was defined as the palpable groove between the lunate and capitate bones.

Accuracy of the goniometer was within 1.5 degrees and repeatable to within 1.5 degrees in the radioulnar plane.[21] Accuracy was measured by comparing ulnar deviation angles between a video-based system and the goniometer. Each subject's wrist was calibrated for neutral position by placing her hand and forearm on a portable table, and the experimenter aligned the wrist in a neutral position in the radioulnar plane, which was defined as the alignment of the third metacarpophalangeal (MCP) joint, center of wrist (palpable groove between the lunate and capitate bones), and the lateral epicondyle.[22] Based on an earlier study,[5] intrarater reliability for positioning the wrist in neutral alignment was demonstrated by intraclass correlation coefficients (ICCs) of .87 and .81 for the left and right wrists, respectively.[23,24] In the current study, once the goniometers were in place on the subjects' hands, intertrial reliability for mean, maximum, and minimum measurements of ulnar deviation was demonstrated by ICCs of .99, .98, and .97, respectively. Intertrial reliability was established using the data from the 11 subjects participating in the study. The data for mean, maximum, and minimum wrist ulnar deviation for three 30-second typing trials were used for analysis.

Procedure

Subjects were given an initial briefing on the study and then asked to read and sign an approved consent form. The shoulder width (biacromial breadth) and forearm-hand length (tip of the olecranon process to tip of third digit) were measured using a standard rigid anthropometer.

After the shoulder width and forearm-hand length were measured, the experimenter calculated the slant angle (θ) of each keyboard half using the following equation:

$$\theta_{i,j} = \arcsin\left[(SW_i - d_j)/(2 \times FH_i)\right]$$

where $\theta_{i,j}$ represents the slant angle of each keyboard half of subject i for keyboard configuration j, d_j is the distance between centers of keyboard halves for keyboard configuration j, SW_i is the biacromial distance of subject i, and FH_i is the distance from the tip of olecranon process to the tip of third digit the hand of subject i. The slant angle is one half of the opening angle

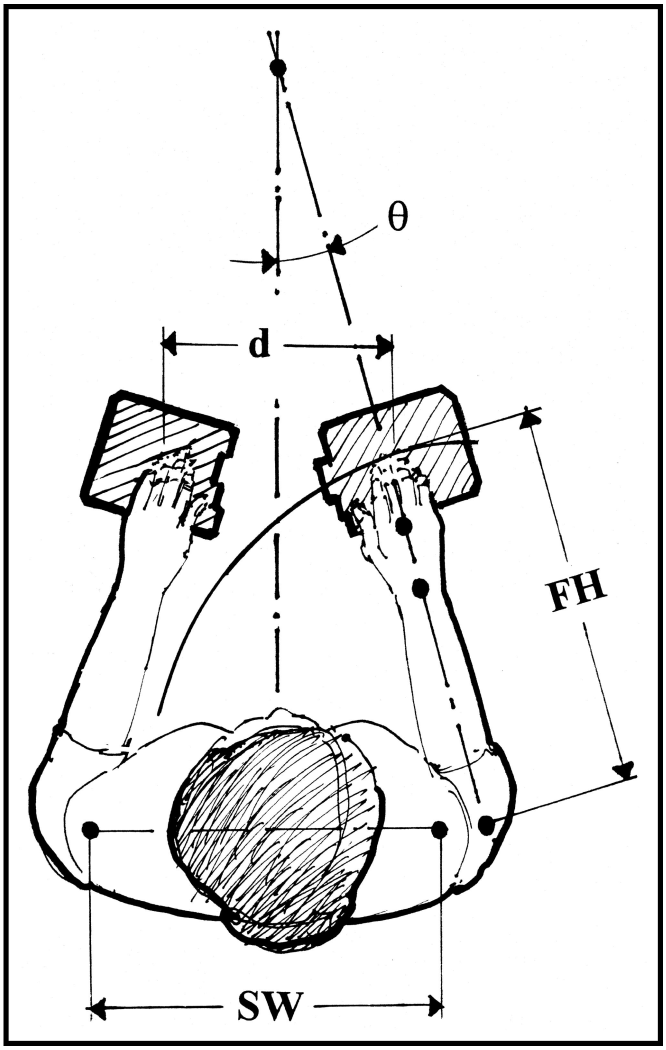

Figure 5.
Geometric model for establishing slant angle of each keyboard half. SW=shoulder width, FH=forearm-hand length, d=distance between the centers of both keyboard halves, θ=slant angle of each half of the keyboard.

of the keyboard. This equation was used to calculate the slant angle (θ) for the 2 conditions where the keyboard halves were separated 20 cm (S-20) and midway between shoulders (S-MID) by simply entering the distance (d) between the centers of keyboard halves. Figure 5 shows the geometric model that is the basis for calculating the slant angle.

Goniometers were attached to both the left and right wrists and were calibrated when the wrists were aligned at a neutral angle in the radioulnar plane, as described in the "Apparatus" section. The presentation order of the 4 keyboard configurations shown in Figure 2 was balanced and randomized using a Latin square table to minimize order and learning effects. The first keyboard configuration selected for the subject was set up in a computer workstation that followed the American National Standards Institute guidelines for computer

Table 1.
Mean, Maximum, and Minimum Wrist Ulnar Deviation (in Degrees) of the Four Keyboard Configurations[a]

	Conventional Setup						Keyboard Halves Separated 20 cm					
	Left			Right			Left			Right		
	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range
Mean ulnar deviation	18.9	6.8	7.9 to 29.6	14.2	6.9	2.1 to 25.2	7.4	7.1	−0.2 to 19.9	5.0	7.3	−5.5 to 19.2
Maximum ulnar deviation	28.6	4.7	23.6 to 35.3	29.6	8.0	10.6 to 40.5	18.7	8.9	7.8 to 27.6	19.5	8.6	4.5 to 29.3
Minimum ulnar deviation	8.0	8.9	−10.6 to 17.4	1.0	9.2	−20.7 to 13.6	−5.5	7.2	−18.4 to 6.0	−9.4	6.1	−16.2 to −1.0

[a] Radial deviation angles are expressed as negative values.

workstations (ANSI Standard No. 100-988).[25] The ANSI guidelines suggest a person sit upright in a high-quality ergonomic office chair with forearms parallel to the floor and feet touching the floor while typing. Before each keyboard configuration, the subject typed an 8th grade social science text for 20 minutes with Typing Tutor 6.0 software to familiarize herself with the keyboard setup. Then, the subject rested for 5 minutes and then typed for 5 minutes, during which three 30-second samples of wrist ulnar deviation data were collected with a 12-bit data acquisition system. The subject was not aware of the timing and duration of data collection. Immediately after the 5-minute test session, the subject completed Borg's 10-point psychophysical assessment of discomfort for respective body segments (neck, shoulder, back, right and left upper extremities, right and left elbows, right and left forearms, right and left wrists, and right and left hands). After another 5-minute rest period, the experimenter changed the keyboard setup for the next configuration, and the process was repeated for the remaining keyboard configurations. The subject typed different text with each of the 4 keyboard configurations.

Data Conditioning and Statistical Analysis

After the wrist ulnar deviation voltage data were converted to degrees, the angular data were filtered by a running average technique that was equivalent to a second-order, double-pass Butterworth filter with a cutoff frequency of 7 Hz. For each keyboard configuration of each subject, the mean, maximum, and minimum ulnar deviation from all three 30-second data files were averaged across the 3 trials. The mean data from each subject were then averaged across subjects. Typing speed (in words per minute) and typing accuracy (in percentages) were recorded by use of Typing Tutor 6.0 software for each 5-minute typing session. Because typing accuracy (in percentages) follows a binomial distribution rather than a normal distribution, the percentage data were transformed into normally distributed data with an arcsine function.

Wrist position data were analyzed with ANOVA and *post hoc* multiple-comparison tests. The psychophysical assessment of discomfort data were analyzed with the Kruskal-Wallis test because the 10-point Borg scale has an ordinal scale and thus is nonparametric. Typing speed and transformed typing accuracy were analyzed with an ANOVA. The *a priori* level of statistical significance was set at $P<.05$.

Results

Wrist Ulnar Deviation

As shown in Table 1 and Figure 6, mean wrist ulnar deviation of the 3 alternative keyboard configurations, which ranged from 7.0 to 8.5 degrees for the left wrist and from 2.7 to 5.0 degrees for the right wrist, did not vary. However, mean angular data from the 3 alternative configurations were less than the mean ulnar deviation from typing on the conventional keyboard (18.9° and 14.2° for the left and right wrists, respectively).

The maximum and minimum ulnar deviation data followed the same pattern as the mean ulnar deviation data in that they were not different among the 3 alternative configurations but were less than the conventional setup's maximal and minimal deviation data (Tab. 1, Figs. 7 and 8). While typing, wrist angular position ranged from approximately 18 to 20 degrees of ulnar deviation to 5 to 10 degrees of radial deviation for the 3 alternative keyboard configurations, whereas range of position for the conventional setup was approximately from neutral to 30 degrees of ulnar deviation.

Typing Performance

There was no difference in typing speed and accuracy among the 4 keyboard configurations, as indicated in Table 2. Mean typing speed ranged from 48.9 wpm when the keyboard halves were separated at shoulder width to 52.5 wpm for the conventional setup. In addition, typing accuracy did not vary, as demonstrated by the close range of 97.9% accuracy for the configuration separated half of

	Keyboard Halves Separated Half of Shoulder Width						Keyboard Halves Separated Shoulder Width					
	Left			Right			Left			Right		
	X̄	SD	Range	X̄	SD	Range	X̄	SD	Range	X̄	SD	Range
Mean ulnar deviation	7.0	5.5	−1.6 to 17.2	2.7	8.3	−8.6 to 16.2	8.5	6.2	0.8 to 22.6	3.5	6.9	−4.0 to 14.2
Maximum ulnar deviation	18.8	5.1	11.4 to 29.9	17.8	8.3	3.2 to 29.2	20.2	7.5	13.8 to 39.1	19.1	7.4	6.3 to 27.5
Minimum ulnar deviation	−6.5	6.9	−13.9 to 5.8	−11.5	6.1	−25.9 to −0.9	−4.6	6.5	−12.5 to 2.8	−11.3	7.3	−18.4 to 1.1

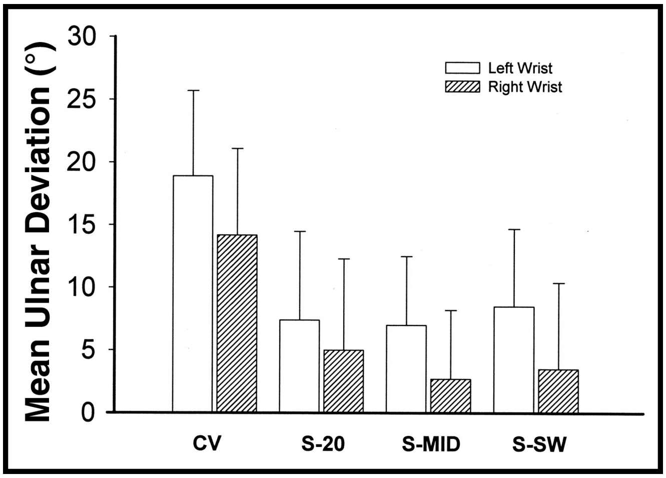

Figure 6.
Mean ulnar deviation of the left and right wrists for the 4 keyboard configurations. Bars represent 1 standard deviation. See Figure 2 caption for explanation of abbreviations of keyboard configurations.

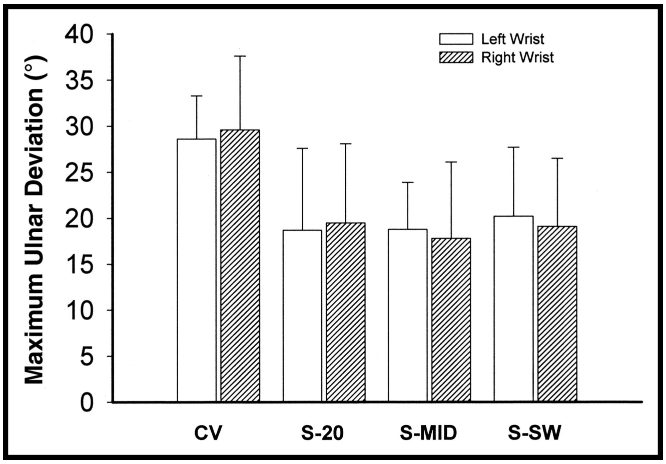

Figure 7.
Maximum wrist ulnar deviation of the left and right wrists for the 4 keyboard configurations. The values plotted are the averages of the maximum data across subjects. Bars represent 1 standard deviation. See Figure 2 caption for explanation of abbreviations of keyboard configurations.

shoulder width to 99.4% for the configuration where the halves were shoulder width apart.

Psychophysical Assessment of Discomfort

Except for the neck, there were no differences in psychophysical assessment of discomfort of the back and upper-extremity body segments. For all keyboard conditions, the mean Borg scale ratings of discomfort were generally less than 1.0 for the back and upper-extremity segments. For the neck, the mean assessment of discomfort for the conventional keyboard setup was greater than the mean ratings for the 3 alternative setups (0.92 for the conventional keyboard setup and 0.31–0.62 for the alternative configurations). The mean neck discomfort ratings for the 3 alternative configurations were not different from each other.

Discussion

The mean ulnar deviation data from this study agree well with the results from our previous study where we explored fixed-angle and adjustable-angle split keyboards.[5] In the present study, when the split keyboard was set up in the 3 alternative configurations to theoretically align the wrist in a neutral position, the resulting mean ulnar deviation was less than 9 degrees for the left wrist and 5 degrees for the right wrist. The comparable mean ulnar angles from our previous study were 6 degrees for the left wrist and 3 degrees for the right.[5] Mean ulnar deviation data from our present and previous studies have shown that when the split keyboard is set up correctly for an individual, it reduces mean ulnar deviation by approximately 10 degrees as compared with a conventional keyboard setup. Results from the present study show that the keyboard users did not medially rotate (and consequently abduct) the shoulder at their customary angle for typing with a conventional keyboard setup when the keyboard halves were separated half or full shoulder width distance. If users had carried a medially rotated shoulder position over to the alternative keyboard arrangements, then there would have been essentially no difference in wrist ulnar deviation between the conventional setup and configurations separating the keyboard halves. Findings from our study indicate that keyboard users respond to alternative arrangements of split key-

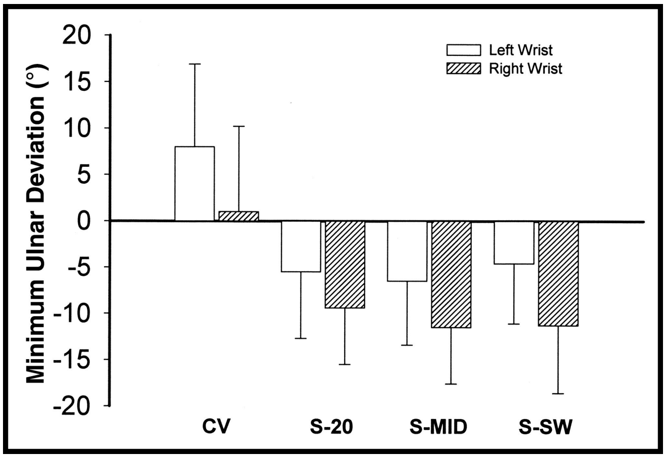

Figure 8.
Minimum wrist ulnar deviation of the left and right wrists for the 4 keyboard configurations. Ulnar deviation angles are plotted as positive, and radial deviation angles are plotted as negative. The values plotted are the averages of the minimum data across subjects. Bars represent 1 standard deviation. See Figure 2 caption for explanation of abbreviations of keyboard configurations.

board halves in a healthful manner by placing their wrists in a relatively neutral position in the radioulnar plane.

The results indicate that split keyboards, when set up properly, reduce wrist ulnar deviation to an angle relatively close to a neutral position. This effect would minimize one of the occupational risk factors of WMSDs associated with typing, namely, ulnar deviation. The finding from our study and other studies reported in the literature[7,8,26] that conventional keyboards consistently require about 10 degrees 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 a neutral angle in the radioulnar plane, the net reaction forces from the carpal bones on the tendons and their sheaths decrease.[12,13] Less net reaction force pressing against the sides of the tendons and their sheaths would theoretically reduce the likelihood of inflammation of the tendons and their sheaths, thereby diminishing the development of tendinitis and tenosynovitis. These lateral forces on the tendons and their sheaths may have been the reason why 13% of video display terminal operators complained of discomfort in the wrists from ulnarly deviated positions.[1]

In addition to the theoretical benefits of reduced ulnar deviation from alternative keyboards on the etiology of tenosynovitis and tendinitis, in vivo carpal tunnel pressure studies have shown that wrist ulnar deviation of 15 to 20 degrees increases pressure in the carpal tunnel compared with ulnar deviation of less than 10 degrees. While loading the fingertips with a 6-N force and no external force, carpal tunnel pressure for 10 degrees of wrist ulnar deviation was 36.1 and 15.4 mm Hg, respectively.[27] At 20 degrees of wrist ulnar deviation, the carpal tunnel pressure increased to 40.9 and 21.5 mm Hg, respectively, for a 6-N force and no loading on the fingertips.[27] In another in vivo carpal tunnel pressure study,[14] pressure in the carpal tunnel ranged from 15 to 25 mm Hg when the wrist was ulnarly deviated 10 degrees and the angle of the MCP joint ranged from 0 to 90 degrees. Pressure in the carpal tunnel increased to 25 to 40 mm Hg when the wrist was ulnarly deviated 20 degrees for the various MCP angles.

Because the mean wrist ulnar deviations from typing on the conventional keyboard were well over 10 degrees and closely approached 20 degrees (14.2° and 18.9° for the right and left wrists, respectively) and the mean ulnar deviations from typing on the 3 alternative keyboard setups were under 10 degrees (range=2.7°–8.5°), the median nerve passing through the carpal tunnel would be subject to greater pressure with a conventional keyboard setup. Carpal tunnel pressures with the wrist ulnarly deviated 20 degrees were greater than 20 mm Hg, even under various finger positions and loadings on the fingertips.[14,27] Pressures even as low as 20 mm Hg could result in damage to the median nerve, as demonstrated and reported by Dahlin and Lundborg.[28] Axonal transport decreased 75% when pressure applied to the vagus nerve of a rabbit increased from 10 to 20 mm Hg. When the pressure increased to 30 mm Hg, the nerve showed marked morphological changes, such as displacement of the nucleus and changes in the neuron's metabolism. An increase in carpal tunnel pressure from typing on a conventional keyboard setup, which results in wrist ulnar deviations of 15 degrees or more, could compress the median nerve to a level that slows conduction velocity. If the decrease in motor and sensory conduction velocity of the median nerve were severe enough, carpal tunnel syndrome could develop.

Of all the body parts that were assessed for comfort after the typing sessions, only the neck resulted in a increase in discomfort for the conventional keyboard setup compared with the 3 split keyboard configurations. However, the difference in mean discomfort ratings (0.92 for the conventional setup and 0.31–0.62 for the alternative configurations) were so small and less than 1 on the 10-point Borg scale that these results may not be of practical value or clinically relevant.

The overall lack of an effect on psychophysical assessment of discomfort may have been due to the short period of time that subjects were exposed to each keyboard configuration (25 minutes) or possibly the insensitivity of the 10-point Borg scale to tasks that require low levels of muscular effort. In a study of alternative keyboard designs, Swanson et al[16] found that overall ratings of discomfort on the 10-point Borg scale for subjects using conventional and alternative keyboards were approximately 1.0 over a 75-minute typing

Table 2.
Typing Speed and Accuracy From Typing on the Four Keyboard Configurations[a]

	Conventional Setup			Keyboard Halves Separated 20 cm			Keyboard Halves Separated Half of Shoulder Width			Keyboard Halves Separated Shoulder Width		
	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range	$\overline{X}$	SD	Range
Typing speed (wpm)	52.5	7.8	43–68	49.2	7.2	37–62	49.5	7.1	40–59	48.9	7.6	37–59
Typing accuracy (%)	99.1	1.9	94–100	98.4	3.1	89–100	97.9	3.1	93–100	99.4	1.4	95–100

[a] No differences were found among the 4 keyboards for either variable.

period. The assessment of discomfort increased slightly to 2.0 or lower after 5 hours of typing during one day. The slight increase in discomfort from typing for 5 hours in a day[16] and psychophysical results from our study suggest that the 10-point Borg scale may not be sensitive enough to elicit changes in discomfort for a task that involves low levels of muscular effort.

Statistical power was calculated *a priori* for ulnar deviation and not for typing speed or accuracy; however, statistical power was calculated *a posteriori* for typing speed based on the difference in mean typing speeds (3.6 wpm) across the 4 typing conditions and standard deviation (7.3 wpm) (Tab. 2). Although the resulting statistical power for typing speed was less than 30%, the difference of 3.6 wpm is only 6% of typing speed. Assuming that the 3 split keyboard configurations did not result in decrements in typing speed and accuracy compared with the conventional setup, then the 3 configurations of the split keyboard tested in this study appear to provide viable options for physical therapists and ergonomists for setting up computer keyboards so the user's wrists are relatively neutral in the radioulnar plane. Users of split adjustable-angle keyboards could separate the keyboard halves at shoulder width distance or angle them contiguously at the pivot point and still reduce ulnar deviation of both wrists by at least 10 degrees compared with a conventional keyboard. Although there may be differences in ulnar wrist angles among the 3 split configurations, we did not have the statistical power to elicit those differences due to the relatively small number of subjects in our study and the narrow difference of only 1.5 degrees in mean ulnar deviation among the 3 split keyboard configurations. We did have enough statistical power, however, to find differences in mean wrist ulnar deviation between the conventional keyboard and the 3 split keyboard configurations, because the sample size was calculated based on an effect of 7.5 degrees, which was less than the difference of 10 degrees in mean ulnar deviation between the conventional keyboard and the 3 alternative configurations. The 1.5-degree difference in mean wrist ulnar deviation across the 3 alternative keyboards is of little practical value.

Our recommendations regarding the setup of split keyboards are based on rotating the keyboard halves so that the user's wrists are aligned with the forearm, thereby promoting a neutral wrist position in the radioulnar plane. Physical therapists and ergonomists can provide their patients or clients with options for configuring the split keyboard to minimize ulnar deviation and theoretically reduce the exposure to WMSDs affecting the wrist. The configuration of a split keyboard can be tailored to the personal preferences of keyboard users or the anthropometric size and shape of the user while minimizing ulnar deviation. Whether the keyboard user has or does not have symptoms of WMSDs affecting the wrist, minimizing ulnar deviation from keyboard setup is theoretically beneficial to the user's occupational health.

Whether the subjects in this study were typing in the conventional setup or alternative configurations, they tended to place their left wrist in greater ulnar deviation than the right wrist. These results agree with our previous findings[5] and those of Hedge and Powers,[29] who found that subjects ulnarly deviated their left wrists 2 to 5 degrees more than their right wrists when they used conventional and split keyboards. The reasons for the differences in wrist position between the 2 upper extremities are not fully understood. Perhaps the reason keyboard users have more ulnar deviation with the left hand than with the right could be that they have to type more characters or special keys, such as the tab, with their left little finger than with their right little finger, and it is easier to type these keys with greater ulnar deviation.

Conclusion

Assuming that results from this laboratory study are generalizable to the field, our results show that users of split computer keyboards can set up the keyboard halves in a variety of configurations and still reduce ulnar deviation of both wrists by at least 10 degrees compared with a conventional keyboard. A user can separate the keyboard halves at shoulder width distance, connect and angle the keyboard halves at the pivot point, or achieve some configuration of separating and rotating the keyboard halves between the 2 extremes. These recommendations are valid only for keyboard users without symptoms of upper-limb WMSDs and when the user rotates the keyboard halves so that the wrist is aligned with the forearm in the radioulnar plane, thereby promoting a neutral wrist position. The configuration of a split keyboard can be tailored to the personal preferences of the keyboard user or the user's anthropometric size while minimizing ulnar deviation, which theoretically would reduce exposure to carpal tunnel syndrome and tenosynovitis in the wrist. In the clinic, physical therapists can provide their patients with options for selecting and configuring a computer keyboard to prevent WMSDs (based on biomechanical theory) and possibly relieve symptoms of WMSDs. In the field, physical therapists now have guidelines on healthful keyboard configurations that they can use to conduct evaluations of computer keyboard workstations. Evaluation of workstations and subsequent intervention is an important, and expanding, role of physical therapists, and this article provides practical information to physical therapists on the setup of computer keyboards for their patients. A future research topic that would aid physical therapists is whether the 4 setups of split computer keyboards tested in this study can produce relatively neutral wrist alignment for people with either mild symptoms of WMSDs associated with using a keyboard or more severe, diagnosed cases of WMSDs and most importantly whether, in a prospective study, pain and injuries can be reduced by using the configuration we suggest. Ultimately, a prospective study could be implemented to determine whether the incidence and severity of WMSDs can be reduced by the alternative keyboard configuration tested in this study.

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