Design of computer keyboards no longer is limited to the flat keyboards that are typically shipped with personal computers. Keyboards now exist that are split into halves and these halves can be slanted away from each other (creating a triangle between the halves), sloped downward toward the visual display terminal, tilted upward like a tent, or simply separated. These design features are intended to alleviate discomfort and possible musculoskeletal disorders that have been suggested to be associated with the extensive use of conventional computer keyboards. The geometry of conventional keyboards requires the wrists to be in 10° to 15° of ulnar deviation and 20° of extension and the forearms to be nearly fully pronated while typing. A review of the available experimental data collected on 10-digit touch typists indicates that (1) keyboards with a slant angle (half of the opening angle) of 10° to 12.5° or keyboards with halves separated to approximately shoulder width are both effective in placing the wrist in near neutral (0°) ulnar/radial deviation when typing, (2) wrist extension can be reduced to near neutral (0°) when a keyboard with a negative slope of 7.5° is used, contingent on the wrist rest also sloping with the keyboard, and (3) tilting the keyboard halves 20° to 30° is effective in reducing forearm pronation to approximately 45°. These studies also indicate that experienced 10-digit touch typists readily adapt (within 10 minutes) to these individual alternative keyboard features, and can type with approximately the same speed and accuracy as with the conventional keyboard. While placing the wrist and forearm in a more neutral position could, in theory, reduce the incidence of musculoskeletal disorders, randomized controlled trials are necessary before strong recommendations can be made on the effectiveness of alternative keyboards for the prevention and/or treatment of musculoskeletal disorders. In the absence of these randomized controlled trials, the information in this article provides preliminary guidance to clinicians in their evaluation of computer keyboards and workstations and their recommendations to patients.

Key Words: alternative computer keyboard, office ergonomics, slant angle, slope angle, tilt angle

Computers are ubiquitous in our society, with 100 million estimated to be in use in the United States in 2000. Except for rare cases, every computer has a keyboard for text and data entry. The occupational risk factors of distal upper extremity musculoskeletal disorders (MSDs), such as carpal tunnel syndrome (CTS) and wrist tenosynovitis, are thought to be due to excessive use (up to 100 000 keystrokes per day) and the deviated wrist posture noted while typing. This paper will explore how the design components of a conventional computer keyboard could contribute to MSDs and how alternative keyboard designs could reduce, in theory, the risk of MSDs.

**KEYBOARD USAGE AND MSDs**

An extensive review of the literature on the association between keyboard usage and prevalence of MSDs determined that the prevalence of keyboard-related MSDs among computer users, based on symptoms or physical examination findings, ranged from 9% to 50%, as compared with 4.5% to 17% among reference groups who were exposed to low levels of or no keyboard work. Compared to reference groups, the odds ratios for keyboard-related MSDs among computer users ranged from 0.5 to 9.9 for the neck and shoulder region, and from 0.7 to 10.1 for the hand, wrist, or elbow. Although most of the studies reviewed by Tittiranonda et al had limitations of comparisons across groups at a single period and were based on self-reported health measures, the odds ratios and prevalence of upper extremity MSDs of computer users, as compared with findings for reference groups, suggest that computer keyboards may contribute to MSDs affecting the neck and upper extremities.
In contrast to the data grouping all MSDs together, the prevalence of CTS among computer keyboard users has been the subject of more specific objective investigations. In a cross-sectional study of 314 employees who used a computer frequently at a medical facility, 3.5% of the employees had CTS confirmed by nerve conduction studies, which was similar to the prevalence of 2.7% for electrophysiologically confirmed CTS from a sample of 3000 people from a population of 170,000 in southern Sweden. In another study, 82% of 9480 members of a professional technicians’ trade union of computer users participated in a study in which the prevalence of CTS was measured at the start of the study and 1 year later. The researchers found that between 1.4% and 4.8% of the respondents had possible CTS based on a screening questionnaire and clinical interview. The incidence of new or aggravated symptoms of possible CTS was 5.5% over the 1-year period. There was an association between use of a mouse device for more than 20 hours per week and possible CTS, but no association between computer keyboard use and possible CTS. The researchers concluded that the occurrence of possible CTS among these computer users was low and that computer use did not pose a severe occupational hazard for developing symptoms of CTS.

Although these last 2 studies suggest that computer keyboard use may not lead to CTS, there is some recent evidence that intensive computer keyboard usage may contribute to other MSDs affecting the upper extremity and neck/shoulder region. In a prospective study of 632 newly hired employees who used a computer at least 15 hours per week, researchers tracked the incidence of hand/arm and neck/shoulder symptoms for 12 months via daily diaries recorded by participants and verification of symptoms from clinical examinations. The total incidence rate of hand/arm disorders was 21.1 per 100 person-years of exposure. Of the total incidence rate of 21.1, the most frequently occurring hand/arm disorder was extensor tendonitis (dorsal compartments 1 through 6 of the wrist), with an incidence rate of 14.7. Digital flexor tendonitis was the second most frequently occurring with an incidence rate of 8.7. The incidence rate of neck/shoulder disorders confirmed by clinical examination was 35 per 100 person-years after 12 months of occupational exposure. The neck/shoulder disorders included radicular pain syndrome, somatic pain syndrome, rotator cuff tendonitis, and bicipital tendonitis.

In summary, while the epidemiologic data may not demonstrate a clear association between keyboard use and the incidence of CTS, the recent data reported by Gerr and his colleagues, along with the results of earlier epidemiologic studies, suggest that computer keyboard usage greater than 15 hours per week can contribute to MSDs affecting the upper extremity, shoulder, and neck region.

### CONVENTIONAL COMPUTER KEYBOARDS

The conventional computer keyboard, often referred to as a QWERTY keyboard, is easily recognizable, based on its rectangular design and classic arrangement of alphabetic and numeric keys. QWERTY refers to the general layout of the alphabetic keys and is derived from the arrangement of the 6 keys at the left end of the upper row of the keyboard. This key layout dates back to the advent of the first commercial typewriter, which was credited to Christopher Latham Sholes in 1873. Despite attempts to inculcate other keyboard arrangements into the mainstream of computer keyboard design, most notably by Dr August Dvorak, the overwhelming majority of modern keyboards, both conventional and alternative, have the QWERTY layout of keys. Keyboards with the QWERTY layout, therefore, will be the focus of this paper.

The conventional flat computer keyboard requires the operator to hold the hands and forearms in a relatively awkward position. Because of the keyboard’s horizontal plane orientation, near end range forearm pronation is required so that the palm of the hands can be nearly parallel to the horizontal plane of the keys. In addition, the relative large width of the body, combined with the need for the hands to be near each other to place the fingers on the home keys while typing, mandate that both wrists be deviated in the ulnar direction, as shown in Figure 1. While individual variation does exists among clerical workers, 10-digit touch typists (defined as those who can type accurately with 10 digits without looking at the keys), using a conventional keyboard, place their right and left wrists in approximately 10° and 15° of ulnar deviation, respectively. Most keyboard users

![FIGURE 1. Top view of a conventional computer keyboard, which requires ulnar deviation of the wrists as well as pronation of the forearms.](image-url)
typing on a conventional keyboard also hold their wrists with an extended wrist posture of approximately 20°.26

DESIGN OF ALTERNATIVE COMPUTER KEYBOARDS

Although there are many designs of alternative computer keyboards on the market, the predominant feature of many of these designs is related to splitting the conventional QWERTY layout of keys into 2 halves (Figure 2). In most cases, the alphabetic segment of keys will be split down the middle, along a break line formed by the 7, Y, H, and N keys, which are in the right half.

The angles that the halves of a split keyboard form to the keyboard’s orthogonal axes are shown in Figures 2 and 3. The slant angle is half of the horizontal opening angle of a split keyboard (Figure 2); the slope angle, which is the angle of the plane of keys on the keyboard (not the base of the keyboard), is either angled upward, horizontally, or downward towards the visual display terminal (Figure 3A); and the tilt angle is the angle that each half forms to the horizontal plane along the keyboard’s longitudinal axis (Figure 3B). While a slope angle can be incorporated without splitting the keyboard in 2 halves, incorporation of a slant or tilt angle requires division of the keyboard. Another possible feature of split keyboards is the separation of the 2 keyboard halves (Figure 4).

The typical conventional keyboard illustrated in Figure 1 has a slant angle of 0°, a slope angle ranging from 0° to 15° (depending on the manufacturer), and a tilt angle of 0°. With conventional keyboards, only the slope angle is adjustable to some extent. Depending on the manufacturer, the slope angle can be increased by raising the rear legs (nearest the visual display terminal) located under the keyboard, or decreased if the front legs, located closer to the operator, are raised. In addition, the slope of the keyboard may be adjusted by tilting the work surface under the keyboard.

The fixed-angle split keyboard depicted in Figure 2A has a slant angle of approximately 12.5° (total opening angle between halves of 25°), and the slant angle of the adjustable-angle split keyboard in Figure 2B can range from 0°, which is the configuration of a conventional keyboard, to 22.5° (45° opening angle). Any combination of slant, tilt, and slope angles can be incorporated into a keyboard, as illustrated in Figure 5. Commercially available alternative keyboards may be designed to be “fixed,” as the keyboard illustrated in Figure 2A, which typically has a 12.5° slant angle, a 6° slope angle, and a 7° tilt angle (the last 2 angles are not visible in Figure 2A). Other alternative keyboards may be adjustable in 1 or more planes, increasing the choices of keyboard angles.

FIGURE 2. Sketch of a fixed-angle split keyboard (A) and an adjustable-angle split keyboard (B). Reprinted with permission from Human Factors 2001;43(1/4). Copyright 2001 by the Human Factors and Ergonomic Society. All rights reserved.

FIGURE 3. Slope (A) and tilt (B) angles of a computer keyboard. Reprinted with permission from Human Factors 2001;43(1/4). Copyright 2001 by the Human Factors and Ergonomic Society. All rights reserved.
configuration for the user. However, the multiple choices for a user may come at the expense of confusion and/or frustration regarding an optimal configuration.

Alternative computer keyboard designs are intended to reduce the incidence of MSDs by positioning the wrists and forearms in more neutral positions. It is specifically hypothesized that (1) incorporating a slant angle in the design of the keyboard will reduce wrist ulnar deviation, (2) incorporating a slope angle will reduce wrist extension, and (3) incorporating a tilt angle will reduce forearm pronation. In the next section of this paper, experimental data related to these hypotheses are synthesized.

EFFECTS OF ALTERNATIVE COMPUTER KEYBOARDS WHEN TYPING

In this section, the influence that various features of alternative computer keyboards have will be discussed, based on available data covering variables such as wrist and forearm posture, typing performance, comfort, and muscle activity of the forearm musculature. Techniques to measure wrist and forearm position and collect electromyographic (EMG) data vary among investigators, and it would be beyond the scope of this paper to discuss the approach used in each study. But, in our studies,16,18,24,25,26 joint position and EMG data were collected using lightweight, unobtrusive electrogoniometers and surface electrodes, respectively. In general, data were collected for 5 periods of 30-second duration for each keyboard condition. These 5 samples of 30 seconds were obtained during an uninterrupted 8-minute typing task, without the subject being aware of when data were collected within that 8-minute period. Our reported reliability, using intraclass correlation coefficients (ICCs), was greater than or equal to 0.90 for position data and greater than or equal to 0.94 for EMG data.24

Keyboards With a Slant Angle

Several studies have measured the amount of wrist ulnar deviation present when typing on keyboards with a slant angle, and evidence from these studies indicate that these keyboards place the wrist in a more neutral posture than a conventional keyboard.5,10,11,19,27 If a split keyboard has a slant angle of approximately 12.5° (25° opening angle), then wrist ulnar deviation is reduced to almost a neutral position (0°) in the radial/ulnar plane.5,10,11,19,27 In general, it appears that ulnar deviation at the wrist is reduced by nearly 1° for each degree of slant angle incorporated in the keyboard. These findings provide some justification to the use of a fixed 12.5° slant angle, given that the left and right wrists are in 15° and 10° of ulnar deviation, respectively, when typing on a conventional keyboard.26

The effect of a slant angle is illustrated by our own data collected on 30 10-digit touch typists who used a split keyboard with a slant angle of 12.5°.18 In this study, the mean wrist deviation angle while typing on the split keyboard was 1.2° of radial deviation for the right wrist and 5.8° of ulnar deviation for the left wrist (Figures 6 and 7). When typing on a conventional keyboard, these 30 individuals had an average of 7.9° of ulnar deviation on the right and 16.5° of ulnar deviation on the left. Therefore, the use of this particular split keyboard reduced mean ulnar deviation by 9.1° on the right and 10.7° on the left.

Similar results are illustrated in Figures 6 and 7 for another group of 30 10-digit touch typists who this time used a split keyboard whose slant angle was adjusted based on a visual estimate of a neutral wrist position when they placed their fingers on the home row of the keyboard. For these 30 subjects, the mean slant angle of the keyboard was 10.5° (SD, 3.6°; range, 5°-20°). Compared to a conventional keyboard, the mean ulnar deviation from typing on the adjustable slant angle keyboard was reduced from 10.7° to 2.5° for the right wrist and from 13.3° to 5.7° for the left wrist.18

FIGURE 4. A split keyboard separated at approximately shoulder-width distance.

FIGURE 5. Incorporation of slant (θ), tilt (α), and positive slope (β) angles in a computer keyboard. D is the distance between the halves of the keyboard.
FIGURE 6. Wrist ulnar deviation angle of the right wrist from typing on tilted, adjustable slant angle and fixed slant angle keyboards. Each subject typed on 1 alternative keyboard and the conventional keyboard. The top and bottom rows represent the wrist angle data from typing on the alternative keyboard and conventional keyboard, respectively. On each hand, the bold line represents the mean angle from the 30 subjects in that keyboard group. The light lines represent the minimum and maximum of the mean angle from the 30 subjects in the same keyboard group.

In this study, which required subjects to practice typing on the alternative keyboards several hours prior to the testing session, using the keyboards with a slant angle had only minimal impact on typing speed and accuracy. The mean typing speeds were 57.3 (SD, 8.7) and 60.3 (SD, 13.3) words per minute (wpm) for the fixed slant angle and adjustable slant angle keyboards, respectively, on which the typing speed was approximately 3 to 4 (5%) wpm less than that achieved on the conventional keyboard for each respective group. In addition, the keyboards with a slant angle were reviewed favorably with respect to comfort among the subjects, in particular the keyboard with the fixed slant angle. Subsequent studies indicate that as little as 6 minutes of practice are needed for experienced 10-digit touch typists to type at approximately the same speed on an alternative keyboard as on a conventional keyboard.

Compared to a conventional keyboard, typing on a keyboard with a slant angle did not result in a difference in general fatigue, general discomfort, or discomfort of the neck, shoulder, and upper extremities. However, Strasser et al reported a small but significant decrease in EMG activity of the upper trapezius and anterior deltoid when using a keyboard with a fixed slant angle.

Keyboards With Separated Halves

Another alternative that has been proposed to reduce or eliminate wrist ulnar deviation while typing is the separation of the 2 keyboard halves and moving the 2 halves away from each other without introducing a slant angle, as illustrated in Figure 4. With this design, the center of each half of the keyboard can be placed at approximately shoulder width, theoretically eliminating the need for ulnar deviation. Only limited data have been collected with this design, but it appears that separation of the keyboard halves in
this manner can be as effective as the introduction of a slant angle of 12.5°. Introduction of a slant angle or the separation of the keyboard does not have a significant influence on wrist extension and forearm pronation when typing.\textsuperscript{18}

\textbf{Keyboards With a Slope Angle}

Sloping a keyboard downward, as illustrated in Figure 3A, has the effect of reducing wrist extension angle. Hedge and Powers\textsuperscript{9} studied 12 office workers who self-adjusted the slope angle of a platform that supported a conventional keyboard with an integrated palm rest. The mean self-selected slope angle of the keyboard platform was $-12°$, which resulted in a keyboard slope close to $0°$. Wrist extension angle of the users averaged $13°$ with the conventional keyboard supported on a horizontal platform, while wrist angle averaged $1°$ of flexion with the platform sloped in a negative direction.\textsuperscript{9} Keyboards adjusted with a negative slope were also investigated in a corporate office in Phoenix, AZ.\textsuperscript{8} In the control group, 15 people typed on a conventional keyboard placed on a desktop or keyboard tray, and in the test group, 23 subjects typed on a keyboard tilted downward on a desktop or keyboard tray (the keyboard used in this study had a preset tiltdown mechanism and its slope angle was not reported). Wrist extension angle for the control group averaged $19.4°$, while wrist extension for the group who typed on the negatively sloped keyboards averaged $10.7°$.

The slope angle of the keyboards tested in the previous 2 studies\textsuperscript{8,9} was adjusted by the individual subject or preset to only 1 angle. In addition, it was not clear from the 2 studies by Hedge and his colleagues\textsuperscript{8,9} whether the height of the keyboard in

\textbf{FIGURE 7.} Wrist ulnar deviation angle of the left wrist from typing on tilted, adjustable slant angle and fixed slant angle keyboards.\textsuperscript{18} Each subject typed on 1 alternative keyboard and the conventional keyboard. The top and bottom rows represent the wrist angle data from typing on the alternative keyboard and conventional keyboard, respectively. On each hand, the bold line represents the mean angle from the 30 subjects in that keyboard group. The light lines represent the minimum and maximum of the mean angle from the 30 subjects in the same keyboard group.
relation to elbow height was well controlled. This is a critical consideration because a change in wrist extension angle can also be accomplished by adjusting the height of the keyboard support surface, which modifies the height of the wrist in comparison to the elbow. In response to these limitations, we conducted a study that investigated whether there was a systematic effect of (1) keyboard slope angle and (2) keyboard height (relative to the elbow) on wrist extension angle.25

In this study, as keyboard slope angle was adjusted downward 30° from +15° to −15° in 7.5° increments, mean wrist extension for both wrists decreased monotonically from 21.7° for the +15° slope to 8.8° in the −15° slope condition (Figure 8).25 Post hoc analysis showed that mean wrist extension angles for all 5 slope conditions were significantly different from each other. It should be noted that the 30° change in slope angle of the keyboard resulted in 12.9° reduction in wrist extension angle, a slightly less than 1:2 ratio. While it was not measured, more finger flexion was observed as the keyboard was sloped progressively more downward, partially reducing the need for the wrist to move into flexion to reach the keys. It must also be noted that these data must be interpreted in relation to the fact that the wrist rest used to guide wrist height was fixed in the horizontal plane and not on the same plane as the keyboard (Figure 8). Our more recent work clearly indicates a greater influence of the slope angle on wrist extension when the wrist rest is integrated into, and on, the same plane as the keyboard.24 It is also of interest that as the keyboard is adjusted with a progressively greater slope angle, a decrease in wrist extension is accompanied by a small increase in wrist ulnar deviation.24,25 While small, this increase in ulnar deviation should be considered in the design of alternative keyboards.

As shown in Table 1, mean wrist extension angles also varied significantly across the 3 wrist heights, ranging from a mean greater than 20° when typing with the wrists 4 cm below the elbows to approximately 7° with the wrists 5 cm above the elbows. An extreme wrist extension angle in excess of 27° was noted when the keyboard was sloped +15° and positioned 4 cm below the elbows. Based on those data, while adjusting keyboard height upward may initially be viewed as a viable alternative to reduce wrist extension, this option should be considered with due caution, given that several studies have shown that typing on a keyboard elevated higher than the elbow causes pain and discomfort in the neck, shoulder, and arm regions.6,14,22

In a more recent study investigating the influence of keyboard slope,24 the wrist rest was attached to and followed the slope of the keyboard, as opposed to remaining in the horizontal plane as used in our earlier study. In addition, EMG activity of selected wrist extensor and flexor muscles were monitored to determine the impact of changing the wrist position on muscular activity levels.

Similar to our earlier results,25 progressively sloping the keyboard downward led to a change in wrist position from approximately 13° of extension at a slope of +7.5° to 3° of wrist flexion at a slope of −15°.24 This represents a change of wrist angle of approximately 16°, compared to a change in keyboard slope of 22.5° (approximately a 2:3 ratio). A near neutral wrist position of 2° of wrist extension was measured with the −7.5° slope angle. This is noteworthy, given the fact that the participants considered the keyboard with a −7.5° slope as comfortable to use as the conventional keyboard, which was not the case for the keyboard with a −15° slope.

In this study,24 EMG activity of the extensor carpi ulnaris (ECU), flexor carpi ulnaris (FCU), and flexor carpi radialis (FCR) were also monitored. The level of EMG activation of the ECU expressed as a percentage of maximal voluntary contraction (MVC) was similar for the left and right sides. The mean 50th percentile amplitude probability distribution function (APDF) of the ECU decreased from approximately...
13.5% MVC to 11.5% MVC as the keyboard slope was changed from 7.5° to –15°. Compared to the ECU, the effect of keyboard slope on percent MVC of the FCU and FCR was less or nonexistent. The exact consequence of a reduction of 2% MVC in the activity level of the ECU is not clear, but could possibly be meaningful, particularly for those who type for extended periods of time. At a minimum, this latest work establishes that bringing the wrist near a more neutral position while typing does not increase the activity level of the related musculature—a positive finding in itself.

In the 2 studies that investigated the influence of keyboard slope and keyboard height, typing performance did not vary significantly when compared to typing on a conventional keyboard, despite the subjects (10-digit typists) being given less than 10 minutes to practice each keyboard configuration. Although typing speed did not suffer, the subjects expressed the fact that a slope of –15° was less comfortable than the other 4 slope conditions (15°, 7.5°, 0°, and –7.5°). We are not aware of any data reporting on the influence of changing the slope angle of the keyboard on the neck and shoulder region.

Keyboard With a Tilt Angle

We measured forearm pronation angle of users typing on a keyboard with a tilt angle as depicted in Figure 3B. The tilt angle of the keyboard was adjustable and subjects were free to select the angle. The subjects tilted the left and right keyboard halves an average of 27.8° (SD, 4.2°) and 32.8° (SD, 4.3°), respectively. The keyboard with the tilt angle required forearm pronation angle of approximately 40°, which was about 22° less forearm pronation than when typing on the conventional keyboard.

To our knowledge, this is the only study that measured quantitatively pronation angle of the forearm while users typed on a keyboard with a tilt angle. However, Smith et al investigated forearm pronation angle of subjects typing on a split keyboard that had the capability of being tilted. The experimenters subjectively recorded pronation angle with a Likert-type 5-point scale (0-4) based on crude video analysis. Mean forearm pronation while using the keyboard with a tilt angle was 2.33 (moderate pronation), compared to 3.94 (substantial pronation) for the conventional keyboard.

In our study of keyboards with a tilt angle, typing performance among the subjects, who were all 10-digit touch typists, was slightly less for the keyboard with a tilt angle (mean ± SD typing speed, 54.1 ± 9.0 wpm) versus the conventional keyboard (mean ± SD, 59.0 ± 12.1 wpm). The keyboard with a tilt angle was also not viewed as favorably as the conventional keyboard in regard to comfort. The subjective assessment of comfort showed a bipolar distribution—either the subjects felt the keyboard with the tilt angle was less comfortable than the conventional keyboard or vice versa. Very few subjects indicated a lack of preference between the conventional and tilted keyboards. It must be noted that introducing a tilt angle to a keyboard not only reduces the need for forearm pronation, but also reduces the need for ulnar deviation. In our study, introducing a tilt angle of approximately 30° effectively placed the wrists in approximately 5° of radial deviation but had only minimal effect on wrist extension.

SUGGESTED USE OF ALTERNATIVE COMPUTER KEYBOARDS

All of the results from the studies reviewed in the literature and reported in this article were obtained from subjects who were 10-digit typists and are defined as having the skill to type accurately with all fingers and thumbs without looking at the keys. This was a planned limitation of these studies. To our knowledge, the percentage of computer keyboard users who type with less than 10 digits is not known, but anecdotal observations of offices indicate that the percentage is substantial. Thus, the findings reported in this article may not apply to users who type with

### Table 1. Mean (SD) wrist extension angles (in degrees) for the left and right wrists as a function of keyboard height, keyboard slope, and hand.

<table>
<thead>
<tr>
<th></th>
<th>Wrists Above Elbows¹</th>
<th></th>
<th>Wrists Even With Elbows</th>
<th></th>
<th>Wrists Below Elbows²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left (n = 10)</td>
<td>Right (n = 10)</td>
<td>Left (n = 10)</td>
<td>Right (n = 10)</td>
<td>Left (n = 10)</td>
</tr>
<tr>
<td>+15.0° slope</td>
<td>15.4 (2.8)</td>
<td>12.4 (3.3)</td>
<td>22.5 (2.9)</td>
<td>21.8 (2.7)</td>
<td>29.0 (2.3)</td>
</tr>
<tr>
<td>+7.5° slope</td>
<td>10.7 (2.9)</td>
<td>8.4 (3.6)</td>
<td>18.5 (3.0)</td>
<td>20.0 (3.0)</td>
<td>24.9 (2.5)</td>
</tr>
<tr>
<td>0.0° slope</td>
<td>7.9 (2.6)</td>
<td>6.6 (3.4)</td>
<td>16.3 (3.2)</td>
<td>18.4 (2.8)</td>
<td>22.2 (2.6)</td>
</tr>
<tr>
<td>–7.5° slope</td>
<td>4.5 (2.8)</td>
<td>2.9 (3.6)</td>
<td>12.7 (2.9)</td>
<td>14.7 (3.4)</td>
<td>19.8 (3.2)</td>
</tr>
<tr>
<td>–15.0° slope</td>
<td>1.9 (2.4)</td>
<td>1.0 (3.7)</td>
<td>7.8 (2.9)</td>
<td>9.9 (3.5)</td>
<td>17.0 (3.0)</td>
</tr>
</tbody>
</table>

¹ Wrist was 5 cm above the elbow.
² Wrist was 4 cm below the elbow.
In the absence of epidemiological prospective studies and additional clinical trials, current advice on the use of alternative keyboards must be based on biomechanical factors related to how the wrist position affects (1) carpal tunnel pressure, (2) reaction forces on the tendons crossing the wrist, and (3) EMG activity level of the musculature of the upper extremities. In addition, the impact of the alternative keyboard on comfort, productivity, and symptoms of each individual must be considered. When assessing whether an alternative keyboard should be recommended, clinicians should carefully take into consideration the postural benefits of specific keyboard features that relate to their patient’s diagnosis, functional limitations, and pain or discomfort patterns.

**Keyboards With a Slant Angle**

The premise of keyboards with a slant angle is that they reduce ulnar deviation, and several studies have shown that they perform as intended (Table 2). The reduction of ulnar deviation to almost a neutral position is beneficial biomechanically because, as the wrist angle approaches neutral, biomechanical modeling indicates that the net reaction forces from the carpal bones and carpal ligament on the tendons and their sheaths decrease. Less net reaction force pressing against the sides of the tendons and their sheaths would theoretically decrease the incidence of tenosynovitis of the wrist and finger flexor/extensor tendons.

Reducing ulnar deviation from 10° to 15° when using a conventional keyboard to a more neutral position when using an alternative keyboard may have only minimal influence on carpal tunnel pressure. Studies on carpal tunnel pressure performed on healthy subjects have shown that ulnar deviation of 10°, which is approximately the ulnar deviation angle from typing on a conventional keyboard, does not increase pressure in the carpal tunnel, as compared...
to the neutral position.\textsuperscript{21} It is possible that the effect of reducing wrist ulnar deviation from 10° to 15° to a neutral position could be meaningful in individuals with CTS; but this is currently not known because, to our knowledge, no data on carpal tunnel pressure and ulnar deviation are available on individuals with CTS.

We have found that keyboards with a slant angle are very well received by typists.\textsuperscript{18} Users learn the postural premise of these keyboards quickly and can adapt their wrist posture easily.\textsuperscript{10,16}

**Keyboards With Separated Halves**

If the halves of a split keyboard can be separated, then the clinician has a few options of setting up the keyboard so the user can type with minimal ulnar deviation (Table 2).\textsuperscript{10} The halves could be placed at shoulder width distance without a slant angle, or at a closer distance and angled in line with the longitudinal axes of the forearms (using the necessary slant angle). The possibility of a near infinite combination of separation distances and slant angles to position the wrist in a more neutral position in the radial/ulnar deviation plane is appealing from the perspective of providing options to the therapist and users. But, this appeal may be mitigated by the fact that many individuals may want to be presented with a single setting for their keyboard (eg, a fixed slant angle, a fixed separation distance, or a fixed combination of both).

**Keyboards With a Slope Angle**

Most conventional keyboards have a built-in slope of 6° to 7° for the plane of the keys when the keyboard is placed on a horizontal surface and the rear legs under the base of the keyboard are not elevated. Sloping the keyboard downward from the built-in slope decreases wrist extension by approximately 1° for every 2° the keyboard is sloped downward if the wrist rest is left in the horizontal plane,\textsuperscript{25} or 2° for every 3° of change in slope if the wrist rest is on the same plane as the keyboard.\textsuperscript{24} In the latter study,\textsuperscript{21} a negative slope angle of 7.5° led to a near neutral wrist extension angle during typing (Table 2). Biomechanically, a more neutral wrist position reduces the net reaction forces between the tendons and the surrounding ligamentous and osseous structures of the wrist.\textsuperscript{2,23}

Based on carpal tunnel pressure studies, wrist extension angles closer to neutral are believed to be beneficial with respect to etiology of nerve conduction injuries affecting the wrist.\textsuperscript{12,21} Wrist extension angles greater than 15° could result in more pressure against the median nerve, and thus could contribute to the development or perpetuation of CTS. Therefore, typing with a wrist position close to an anatomically neutral position (0°) could minimize pressure in the carpal tunnel, and this could possibly be of greatest benefit for individuals with a diagnosis of CTS. Furthermore, we have recently established that the benefit of a more neutral wrist position—from typing on a keyboard with a negative slope—did not come at the expense of an increase in the EMG activity of the ECU, FCU, and FCR.\textsuperscript{24}

Clinicians are urged to keep the keyboard sloped no greater than 7.5° and, if possible, to slope the keyboard at an angle between 0° and −7.5°. However, one must be careful not to slope the keyboard downward too much, because subjects who were 10-digit touch typists rated the −15° keyboard slope angle less favorably than slope angles from 7.5° to −7.5°. A range of keyboard slope angles that may work well for many users is between 0° (or horizontal) and −7.5°, in that this range of angles brings the mean wrist extension angle to near neutral and is well accepted by the users. An adjustable keyboard tray, either built-in or attached to office furniture, may be one feasible method to position the keyboard keys horizontally or angled slightly downward.

---

**TABLE 2. Summary of keyboard features leading to a more neutral wrist and forearm posture. The theoretical benefits of a more neutral 0° wrist position include a reduction in reaction forces of the tendons crossing the wrist and a reduction in carpal tunnel pressure, especially in individuals with carpal tunnel syndrome.**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slant angle of 12.5°</td>
<td>• Places the wrist in near neutral position in the radial/ulnar plane</td>
</tr>
<tr>
<td>Separation distance equal to shoulder width</td>
<td>• Minimal influence on wrist extension and forearm pronation</td>
</tr>
<tr>
<td>Slope angle of −7.5° (wrist rest integrated into keyboard)</td>
<td>• Places the wrist in near neutral position in the radial/ulnar plane</td>
</tr>
<tr>
<td>Tilt angle of 20° to 30°</td>
<td>• Minimal influence on wrist extension and forearm pronation</td>
</tr>
<tr>
<td>Slant angle</td>
<td>• Places the wrist in near neutral position in the flexion/extension plane</td>
</tr>
<tr>
<td>Separation distance</td>
<td>• Increases wrist ulnar deviation by a few degrees</td>
</tr>
<tr>
<td>Tilt angle</td>
<td>• No apparent influence on forearm pronation</td>
</tr>
<tr>
<td>Slant angle</td>
<td>• Reduces the electromyographic activity of the extensor carpi ulnaris slightly</td>
</tr>
<tr>
<td>Separation distance</td>
<td>• Reduces forearm pronation to approximately 40° to 45° (from 60° to 65°)</td>
</tr>
<tr>
<td>Tilt angle</td>
<td>• Reduces ulnar deviation to near neutral</td>
</tr>
<tr>
<td>Slant angle</td>
<td>• Minimal influence on wrist extension</td>
</tr>
</tbody>
</table>

**CLINICAL COMMENTARY**
Keyboards With a Tilt Angle

The premise underlying the concept of tilted keyboards is that they reduce forearm pronation angle (Table 2). Test data showed that computer keyboards that are tilted at an angle of approximately 30° reduce forearm pronation angle to about 40°, a decrease of approximately 20°.15 Carpal tunnel pressure has been measured to be lowest at a pronation angle of 45°, which was recommended as the pronation angle for repetitive, hand-intensive tasks and for splinting to minimize carpal tunnel pressure.20 However, keyboards tilted 30° may have limited acceptance among computer users. Half of the subjects in a study of tilted keyboards rated them unfavorably.17,18 However, a user who has CTS and is symptomatic of other MSDs or has severe distal upper extremity pain may be motivated enough to overcome these obstacles and use a tilted keyboard.

From a practical perspective, keyboards tilted approximately 30° place the hands higher above the work surface than conventional or keyboards with a slant angle; thus the work surface will need to be lowered to maintain the same posture of the forearms (relative height of wrists versus the elbows) as that of the forearms when typing on a conventional keyboard. It must also be noted that keyboards with a tilt angle have the added benefit of reducing wrist ulnar deviation while typing.18

Workstation Factors

Adjustments of the slant, tilt, and slope angles of a computer keyboard are not the only factors that affect wrist posture of users. Other workstation factors, such as the height of the chair and the height of the keyboard support, along with the horizontal placement of the keyboard, can affect wrist posture. Placement of the keyboard not directly in front of the user could increase ulnar deviation and forearm pronation. In one study, placing the keyboard at a height above the elbows and sloping the keyboard downward 15° resulted in wrist extension closest to neutral25 (Table 1). Although typing with the keyboard placed higher than the elbow may be theoretically beneficial to the wrist joint, several studies have shown that typing on a keyboard elevated higher than the elbow causes pain and discomfort in the neck, shoulder, and arm region.5,14,22 A practical alternative to raising the keyboard above the elbow to minimize wrist extension is to place the keyboard level with the elbows and slope the keyboard horizontally or 7.5° downward. This arrangement of keyboard height and slope should enable typists to maintain wrist extension angles of 15° or less.

Future Work

A summary of suggested future work is provided in Table 3.

TABLE 3. Summary of suggested future work.

<table>
<thead>
<tr>
<th>Work</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future experimental work incorporating more than 1 alternative feature in the keyboard design</td>
<td></td>
</tr>
<tr>
<td>Extend the experimental work to systematically study the effect of alternative keyboard design on the shoulder and neck region</td>
<td></td>
</tr>
<tr>
<td>Extend the experimental work to individuals who are not 10-digit touch typists</td>
<td></td>
</tr>
<tr>
<td>Perform randomized controlled trials on individuals with musculoskeletal disorders attributed to the use of computer keyboards</td>
<td></td>
</tr>
<tr>
<td>Perform epidemiological studies comparing incidence of musculoskeletal disorders in individuals who use alternative computer keyboards and those who use conventional keyboards</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION

Despite the fact that more recent studies have shed some doubt on the relationship between keyboard usage and the development of CTS specifically, there seems to be sufficient evidence in the literature that extensive use of computer keyboards could lead to MSDs affecting the neck and upper extremities. Some of those MSDs affecting the distal region of the upper extremities could be related to the deviated forearm and wrist posture required for typing. Compared to a conventional computer keyboard, keyboards that have design features incorporating a tilt, a slant, or a negative slope angle have been shown to be successful in placing the wrist and forearm in a more neutral position, and users can relatively easily adapt their wrist and forearm posture to the postural premise of the respective keyboards. In addition, users can type at normal or near normal speed. Unfortunately, the effectiveness of alternative keyboards in either preventing or reducing the incidence of MSDs is not known. Similarly, there is very little available evidence on the effectiveness of alternative keyboards as an intervention for existing musculoskeletal disorders, which warrants future investigations.

REFERENCES


