The Effect of Three Alternative Keyboard Designs on Forearm Pronation, Wrist Extension, and Ulnar Deviation: A Meta-Analysis

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The growth of computer keyboard use in the workplace is believed to be one important determinant of the increased prevalence of work-related musculoskeletal disorders of the upper extremity (MSD-UE). One possible contributing factor to the development of MSD-UE is the flat standard keyboard, which places the forearm and wrist in biomechanically awkward postures. This meta-analysis examines the efficacy of three alternative keyboard designs, adjustable slope (AS), split fixed-angle (FA), and adjustable open-tented (AT), in reducing forearm pronation, wrist extension, and ulnar deviation. Analyses of pooled effect size from six studies indicated that the AT had a large effect on pronation ($r = 0.85$) and ulnar deviation whereas the FA had a large effect only on ulnar deviation ($r = 0.79$). The AS was found to have a large effect ($r = 0.66$) on wrist extension. The FA had a moderate effect on pronation ($r = 0.33$) and wrist extension ($r = 0.30$). None of these keyboards were found to have a significant effect on all three postures. This meta-analysis has implications for clinicians by providing objective information that may assist with the selection of an alternative keyboard that best reduces an identified problematic posture.


In the past 2 decades, the United States has experienced rapid growth in computer use in the workplace. Use of computers in the workplace has increased from 67.4 million (36%) in 1993 to 92.2 million (47.1%) in 1997 (Newburger, 1999). In 2001, the Bureau of Labor Statistics reported that 72.3 million people at work used a computer, accounting for 53.5% of total employment (Bureau of Labor Statistics, 2002a). Studies have suggested that there is an increased incidence of musculoskeletal disorders of the upper extremity (MSD-UE) in computer users (Bergqvist, Wolgast, Nilsson, & Voss, 1995; Gerr et al., 2002; Hales et al., 1994) although the national incidence of MSD-UE among computer users is unknown. However, the overall incidence of MSD-UE has been steadily rising and has been estimated to be 70% of all occupational illnesses (Bureau of Labor Statistics, 2002b). This suggests that computer-related MSD-UE is likely to be on the rise as well.

This has significant connotations for the occupational therapy professional. The ability to use computers without discomfort or injury is important not only for the completion of workplace tasks but also in meaningful leisure and daily tasks. One in eight adults used the Internet to perform job-related tasks at home and 21% of children used the Internet to perform school-related tasks (Newburger, 1999). Computer use can increase the independence of persons with disabilities. Persons who have difficulty leaving their home can use the computer to order groceries, pay bills, shop, research health-related questions, obtain the news, and catch up with old friends and/or make new ones (Gordon, Capell, & Madhok, 2002; Kaye, 2000). Pain and irritation secondary to MSD-UE interferes with this task completion, decreasing productivity in the workplace, limiting participation in leisure activity, and for some decreasing independence with daily task completion.

One hypothesized pathomechanism of MSD-UE, also referred to as cumulative trauma disorders or repetitive strain injuries, is repeated or sustained exertions of the body while in biomechanically awkward postures. The postures of the forearm and wrist assumed during use of the flat, horizontal design of the conventional
QWERTY keyboard is considered to be problematic by many (Swanson, Galinsky, Cole, Pan, & Sauter, 1997; Zecevic, Miller, & Harburn, 2000). Simoneau and Marklin (2001) have reported that keyboard users maintain their forearms in 60° of pronation and their wrists in 20° of extension in order to keep their hands parallel to the surface of the flat conventional keyboard and ready to strike the keys. Additionally, some keyboard users maintain their hands close together on a standard keyboard while slightly abducting their upper arms, leading to a posture exceeding 20° of ulnar deviation (Serina, Tāl, & Rempel, 1999). Marklin, Simoneau, and Monroe (1999) reported that standard keyboard users assumed postures between 75.1° to 60° of elbow flexion, 6.5° to 27.4° of wrist extension.

These awkward postures are believed to lead to elevated pressure inside the carpal tunnel and to strain muscle structures (Luchetti, Schoenhuber, & Nathan, 1998). Researchers have reported that pressure inside the carpal tunnel is elevated when the wrist is extended (Serina et al., 1999; Simoneau & Marklin, 2001), ulnarly deviated (Serina et al.), or the forearm is pronated past 45° (Rempel, Bach, Levinsohn, & Gordon, 1996). For example, pressure inside the carpal tunnel has been demonstrated to increase from an average of 29.8 mm Hg at 15° of wrist extension to an average of 40.3 mm Hg at 30° of extension (Marklin et al.). When the wrist is ulnarly deviated to 10° or more, forces exerted by the carpal bones and carpal ligaments against the flexor tendons increase, contributing to inflammation with repetitive use (Marklin et al., 1999). The inflammation resulting from these deviated wrist postures can cause increased pressure on nerves, blood vessels, and tendons passing through the carpal tunnel (Smith et al., 1998). This can cause ischemia and flexor tendon synovial tissue edema, which may lead to pressure on the median nerve, nerve block, and to development of carpal tunnel syndrome and other MSD-UE (Rempel et al., 1996; Werner & Andary, 2002).

In recent years, alterations to the standard keyboard that reduce if not eliminate the need to assume awkward postures of the hand and forearms have been developed and are believed to increase comfort and decrease musculoskeletal injury (Hedge, Morimoto, & McCrobie, 1999; Nelson, Treaster, & Marras, 2000; Simoneau & Marklin, 2001), although no studies, to date, have shown that they do reduce the occurrence of MSD-UE. These proposed designs include splitting the keyboard in half (Smith et al., 1998), laterally tenting keyboard halves (Zecevic et al., 2000), and altering the tilt in the positive or negative direction (Hedge & Powers, 1995; Simoneau & Marklin, 2001). Single studies using a randomized control design have been conducted to describe the effect of alternative keyboards designs on awkward postures (Swanson et al., 1997; Tittiranonda, Rempel, Armstrong, & Burastero, 1999; Zecevic et al.). Although the results of these studies have reported favorable results, no systematic review of these studies has been completed to compare and contrast the keyboards efficacy in reducing different wrist postures. This meta-analysis of these studies provides therapists with a clear, objective description of the overall results and clarifies the differences and similarities between the keyboards.

The effect of alternative keyboards on posture is an important clinical issue when determining if a client would benefit from an alternate keyboard and which alternative keyboard to prescribe. The object of this review was to determine whether alternative keyboard designs promote better postures of the forearms and wrists during computer keyboard use. This meta-analysis provides clinicians with information about the different effect that three common alternative keyboards have on awkward postures of the wrist and forearm, thus assisting them in making appropriate keyboard recommendations to clients.

Method
Criteria for Selecting Studies for Review

This meta-analysis examined the effect of alternate keyboard use on the postures of clients without MSD-UE or other disorders of the upper extremity. Therefore, studies including persons with MSD-UE, acute trauma, inflammatory disease, neurological disease, or neoplasm were excluded. Studies were selected whose target population included at least 10 total asymptomatic adult computer users. Both laboratory and clinically based randomized controlled trials comparing a standard flat keyboard with (a) a split fixed-angle keyboard design (FA); (b) an adjustable open-tented keyboard (AT); and (c) an adjustable slope keyboard (AS), adjusted in the positive (keys tilted toward the user) and negative (keys tilted away from the user) directions were included (see Table 1). Outcome measures investigated included ulnar deviation angle, wrist extension angle, and forearm pronation angle.

Search Strategy for Identification of Studies

An extensive search of MEDLINE (1966 to present), PEDro—the Physiotherapy Evidence Database, CINAHL (1982 to present), ISI Web of Knowledge, PubMed, O’Treeker, and Cochrane Database of Systematic Reviews was undertaken. Reference lists of retrieved articles were also searched for additional articles as well as a personal collection of articles. The literature search strategy was not limited to studies published in peer-reviewed journals. An
in-depth search via Internet search engines to identify unpublished work and/or ongoing projects of relevance from credible resources was used to identify if there were unpublished studies that might be included. Main search key words entered for computerized database searches included cumulative trauma disorders, repetitive strain injury, ergonomics, keyboards, posture, musculoskeletal disorders and injuries, fatigue, pain, visual display units, computer terminal, and human engineering.

Methods of the Review

Titles and abstracts were identified by electronic database search, and a reviewer scrutinized hand searches. Studies thought relevant by the reviewer were retrieved for full-text review. A total of 17 articles were identified and retrieved. Each article was examined and those that met the following inclusion criteria were included: (1) asymptomatic sample population greater than or equal to 10; (2) randomization of participants to keyboard condition (standard or alternative) or randomized order of keyboard presentation; (3) clear description of types of keyboard designs included; (4) comparison of the effect of an AS keyboard, FA keyboard, and/or AT keyboard to a standard flat keyboard for forearm pronation, wrist ulnar deviation, and/or wrist extension; and (5) adequate information for the calculation of an effect size ($r$). Ten studies met these inclusion criteria.

Methodological Quality Assessment

Studies meeting the above inclusion criteria were further assessed for methodological quality. Each article was rated using a criterion-based checklist by the second author (EC). Areas addressed on this checklist were those identified in the literature on reporting quality. They included overall study design, sample descriptions such as size, inclusion or exclusion criteria, retention and equality of groups, clear definitions of instruments and interventions, and appropriate and detailed statistical analyses. Study design was defined using the hierarchy proposed by Moore, McQuay, and Gray (1995) for critiquing quality of evidence. Descriptions of the sample relate to internal and external validity issues, and are included in many checklists (Greenhalgh, 1997; Maher, Sherrington, Herbert, Moseley, & Elkins, 2003; Moher, Schulz, & Altman, 2001; Sackett, Straus, Richardson, Rosenberg, & Haynes, 2000; Verhagen et al., 1998). Although not all checklists on research quality examine the clarity of definition of outcome measures and interventions, the reliability of measures and the ability to replicate therapy interventions provides information on the quality of the intervention as well as the reliability and validity of the measurement tools (Law et al., 1998). Statistical analyses have also been identified as an area of concern, particularly in the effort to interpret results. The inclusion of central tendency and variability data in particular has been highlighted as important to article quality (Maher et al., 2003; Verhagen et al.).

Items on the list were scored ranging from zero to 2 depending on how well the article met the methodological criteria. The maximum score that could be achieved on the assessment was a 22. The criteria used in this methodological quality review were as follows: (1) clear description of purpose or aim of study; (2) explanation of pre-intervention screening response such as the number of returned mailed questionnaires compared to total questionnaires mailed; (3) clear description of statistical analysis; (4) randomized controlled study versus nonrandomized control study; (5) clear exclusion/inclusion criteria; (6) greater than 20 participants; (7) groups equated at baseline; (8) a clear description of keyboards examined; (9) blinding of participants and/or assessors; (10) attrition at follow-up(s); and (11) a clear definition and explanation of investigated outcome measures. Studies with a quality assessment score of 17 or higher were included in the meta-analysis (see Table 2). A rating of 17 ensured that the article included greater than 75% of the specified criteria considered necessary for a high-quality

### Table 1. Description of Keyboard Dimensions

<table>
<thead>
<tr>
<th>Type of keyboard</th>
<th>Abbreviation</th>
<th>Description</th>
<th>Lateral inclination (degrees)</th>
<th>Opening angle (degrees)</th>
<th>Frontal tilt (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>none</td>
<td>Flat horizontally oriented keyboard with QWERTY arrangement.</td>
<td>0</td>
<td>0</td>
<td>0–15</td>
</tr>
<tr>
<td>Split fixed-angle</td>
<td>FA</td>
<td>Keyboard is split down the “center.” The “center” keys are fixed higher than the “outside” keys and the top row keys are fixed closer together at the center than the bottom row keys. Keyboard has a split down the “center” and is constructed to allow the height of the “center” keys to adjust upward and the bottom row keys to adjust outward (&quot;tented&quot;).</td>
<td>10</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Adjustable open-tented</td>
<td>AT</td>
<td>Keyboard can tilt toward (+ direction) or away from (- direction) the keyboarder.</td>
<td>42</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Adjustable slope</td>
<td>AS</td>
<td>Keyboard has a split down the “center.” The “center” keys are fixed higher than the “outside” keys and the top row keys are fixed closer together at the center than the bottom row keys. Keyboard has a split down the “center” and is constructed to allow the height of the “center” keys to adjust upward and the bottom row keys to adjust outward (&quot;tented&quot;).</td>
<td>0</td>
<td>0</td>
<td>-(+)15–(+)15</td>
</tr>
</tbody>
</table>

Note. Lateral inclination—tilt angle in the coronal plane corresponding to pronation/supination movement of forearm; opening angle—split angle between the two halves of a keyboard in the transverse plane corresponding to ulnar and radial deviation movement of the wrist; frontal tilt—angle in the sagittal plane corresponding to flexion and extension movement of the wrist.
research article. Initially 10 studies were identified for further review, after quality assessment, 6 studies remained (see reference list for studies excluded after quality assessment). This provided an overall population of 182 participants.

Data Analysis

Descriptive statistics for all the studies were extracted. These included both article characteristics (e.g., date of publication, language) and participant characteristics. In order to compare the effects between alternative keyboards from the selected studies, the appropriate statistics (means, t statistic, F ratio, X²) were extracted from the selected articles and converted into correlation effect sizes (r) (Hedge & Powers, 1995; Marklin et al., 1999; Simoneau & Marklin, 2001; Smith et al., 1998; Szeto & Ng, 2000; Zecevic et al., 2000). The correlation effect size r was then transformed into its corresponding Fisher-r. The Fisher-r for each correlation effects size was used to calculate all mean effect sizes. Each mean correlation effect size was adjusted based on the sample size of each study by transforming each correlation effect size into its corresponding Fisher-r, multiplying the Fisher-r of each study by the inverse of the variance of each study, summing those results together, and dividing by the sum of the inverse of the variances of each study. The weighted correlation effect size was translated back to an unbiased effect size r for reporting results and this weighted correlation was also used to calculate a 95% confidence interval (CI) around the mean to provide an estimate of the variability of r and to test whether r was statistically different from zero. The calculated effect sizes were considered small if .10 ≥ r ≥ .29, moderate if .30 ≥ r ≥ .49, and large if r ≥ .50 (Cohen, 1988). A homogeneity statistic, Q, was also calculated for the overall effect of each alternative keyboard on forearm pronation, wrist ulnar deviation, and wrist extension. The homogeneity statistic has an approximate chi-square distribution with k-1 degrees of freedom, where k is the number of effect sizes and is used to determine whether the various effect sizes included in the analysis that are averaged into a mean value all estimate the same population effect size (Lipsey & Wilson, 2000). If Q was greater than the critical value of chi-square, then the variability of the effect size was larger than would be expected from sampling error and therefore each effect size does not approximate a common population mean (Lipsey & Wilson). Some studies examined more than one keyboard or posture of interest.

Results

Publication Characteristics

Table 2 presents the characteristics of the selected articles. In the six studies, 93% of the participants were female. Mean age of all participants was 27.7 years. The majority of the participants were employed in positions requiring extensive use of a computer keyboard and were considered to be expert computer keyboard operators. The average number of hours of computer use was 3.6 hours per day. In all six studies, participants were excluded if they were symptomatic of MSD-UE.

Intervention Characteristics

In all six studies the order of keyboard presentation was randomized allowing participants to act as their own control (Table 2). Content of the keyboarding task varied from strictly alphabetic text to a combination of alphabetic and alphanumeric. Two studies employed the use of Typing Tutor 6.0 software to provide typing text as well as to record keyboarding performance information (Marklin et al., 1999; Simoneau & Marklin, 2001). Information pertaining to acclimation period, rest period duration, and data collection instruments is presented in Table 2.
**Effect of Alternative Keyboards on Forearm Pronation**

Two studies measured the effect of two alternative keyboards (FA and AT keyboards) on forearm pronation (Marklin et al., 1999; Zecevic et al., 2000). A single study examined forearm pronation posture resulting from the use of an FA keyboard (Zecevic et al.). Although a moderate correlation effect size ($r = 0.33$) was found, this result was nonsignificant (95% CI = -0.21, 0.87, $p < 0.08$) (see Table 3). Two studies examined forearm pronation while keyboarding on an AT keyboard (Marklin et al., 1999; Zecevic et al.). The AT keyboard had a large effect on reducing forearm pronation ($r = 0.85$) (95% CI = 0.65, 1.05, $p < 0.05$) when compared to the standard flat keyboard (see Table 2). When the overall effect of both the FA keyboard and the AT keyboard on forearm pronation were pooled and analyzed a large effect ($r = 0.82$) (95% CI = 0.64, 1.00) ($Q = 0.10$) on decreasing forearm pronation angle was revealed ($p < 0.05$) (see Table 3).

**Effect of Alternative Keyboards on Ulnar Deviation Posture**

Ulnar deviation postures during alternative keyboard use as compared to the standard flat keyboard were examined in five studies (Marklin et al., 1999; Simoneau & Marklin, 2001; Smith et al., 1998; Szeto & Ng, 2000; Zecevic et al., 2000). Three studies measured the effect of an FA keyboard on ulnar deviation compared to a standard keyboard (Marklin et al.; Szeto & Ng; Zecevic et al.). Examination of the combined effect reveals that use of the FA keyboard had a large effect in reducing ulnar deviation posture ($r = 0.79$) (95% CI = 0.60, 0.98) as compared to the flat standard keyboard (see Table 3).

The effect of an AT keyboard versus a standard flat keyboard on ulnar deviation was analyzed in three studies (Marklin et al., 1999; Smith et al., 1998; Zecevic et al., 2000). As displayed in Table 3, the AT keyboard had a large effect on reducing ulnar deviation angle ($r = 0.77$) (95% CI = 0.59, 0.95) as compared to the standard flat keyboard.

Only one study investigated the effect of altering the slope of a keyboard on ulnar deviation posture compared to a standard keyboard (Simoneau & Marklin, 2001). Ulnar deviation of the wrists was examined with the AS keyboard set first at a positive tilt angle of 7.5° and then with the AS keyboard set at a positive tilt angle of 15°. Ulnar deviation of the wrists was also examined with the AS keyboard adjusted to two predetermined negative tilt angles of first, a negative 7.5° and second, a negative 15°. When the AS keyboard was set at an inclined positive tilt angle of 7.5° or 15°, the ulnar deviation angle of the wrist was closer to neutral than when the AS keyboard was set at either of the two negative inclined tilt angles. Statistical analysis revealed that an increasing positive tilt of a keyboard had a small effect on ulnar deviation ($r = 0.04$) compared to the standard flat keyboard. This result was not significant (95% CI = –0.23, 0.32) (see Figure 1). When the tilt of the AS keyboard was decreased in a negative

<table>
<thead>
<tr>
<th>Keyboard</th>
<th>Study</th>
<th>Study ES ($r$)</th>
<th>Total ES ($r$)</th>
<th>95% CI</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pronation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>Zecevic et al., 2000</td>
<td>0.33</td>
<td>0.33</td>
<td>-0.21, 0.87</td>
<td>0.08</td>
</tr>
<tr>
<td>AT</td>
<td>Marklin et al., 1999</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zecevic et al., 2000</td>
<td>0.80</td>
<td>0.85</td>
<td>0.65, 1.07</td>
<td>0.0003</td>
</tr>
<tr>
<td>Total effect of FA and AT keyboard</td>
<td><strong>0.82</strong></td>
<td></td>
<td>0.64, 1.00</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Ulnar deviation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS (+ direction)</td>
<td>Simoneau et al., 2001</td>
<td>0.05</td>
<td>0.04</td>
<td>-0.23, 0.31</td>
<td>0.0003</td>
</tr>
<tr>
<td>AS (- direction)</td>
<td>Simoneau et al., 2001</td>
<td>0.17</td>
<td>0.16</td>
<td>-0.11, 0.44</td>
<td>0.0003</td>
</tr>
<tr>
<td>FA</td>
<td>Marklin et al., 1999</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Szeto &amp; Ng, 2000</td>
<td>0.44</td>
<td>0.79</td>
<td>0.60, 0.98</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>Zecevic et al., 2000</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>AT</td>
<td>Marklin et al., 1999</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smith et al., 1998</td>
<td>0.34</td>
<td>0.77</td>
<td>0.59, 0.95</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>Zecevic et al., 2000</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total effect of AS, FA, and AT keyboards</td>
<td><strong>0.42</strong></td>
<td></td>
<td>0.26, 0.58</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Wrist extension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS (+ direction)</td>
<td>Simoneau et al., 2001</td>
<td>0.51</td>
<td>0.51</td>
<td>0.11, 0.91</td>
<td>0.0025</td>
</tr>
<tr>
<td>AS (- direction)</td>
<td>Simoneau et al., 2001</td>
<td>0.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hedge &amp; Powers, 1995</td>
<td>0.90</td>
<td>0.74</td>
<td>0.41, 1.07</td>
<td>0.00087</td>
</tr>
<tr>
<td>AT</td>
<td>Zecevic et al., 2000</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marklin et al., 1999</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>Marklin et al., 1999</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Szeto &amp; Ng, 2000</td>
<td>0.39</td>
<td>0.30</td>
<td>0.11, 0.49</td>
<td>0.0113</td>
</tr>
<tr>
<td></td>
<td>Zecevic et al., 2000</td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total effect of AS and FA keyboards</td>
<td><strong>0.52</strong></td>
<td></td>
<td>0.17, 0.87</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

Note. **Indicates pooled effect of the listed alternative keyboards; AS = adjustable slope; AT = adjustable open-tented; ES = effect size; FA = split fixed-angle.
direction, ulnar deviation angle assumed by the subject increased 16% \((r = 0.16)\) when compared to ulnar deviation postures present during the use of a standard keyboard. However, like the result for increasing the tilt of the AS keyboard in the positive direction, this result was nonsignificant (95% CI = –0.11, 0.44) (see Figure 1). Overall, the pooled effect of the three alternative keyboards on ulnar deviation suggests that the use of an alternative keyboard has a large effect on reducing ulnar deviation \((r = 0.42)\) (95% CI = 0.26, 0.58) (homogeneity, \(p < 0.05\)) compared to the standard keyboard. Statistical homogeneity was observed among the results for the effect of the FA, AT, and AS keyboard on ulnar deviation of the wrists \((Q = 0.00)\).

**Effect of Alternative Keyboards on Wrist Extension**

Wrist extension angle on alternative keyboards was measured in five studies (Hedge & Powers, 1995; Marklin et al., 1999; Simoneau & Marklin, 2001; Szeto & Ng, 2000; Zecevic et al., 2000). Simoneau and Marklin specifically examined the effect of a positively tilt keyboard on wrist
extension angle compared to a standard flat keyboard. Statistical analysis of the results of this study demonstrates that wrist extension increases when the AS keyboard tilt was increased from 0° to a positive 7.5° and from 0° to a positive 15° ($r = .54$) (95% CI = 0.27, 0.81) (see Table 3).

The effect of increasing the negative tilt of the AS keyboard was evaluated by two studies (Hedge & Powers, 1995; Simoneau & Marklin, 2001). When the tilt angle of the keyboard was decreased from 0° to a tilt of negative 7.5° and a tilt of negative 15°, there was a large decrease in wrist extension angle ($r = .77$) (95% CI = 0.41, 1.13) compared to the standard flat keyboard (see Table 3).

Three studies measured the effect of an FA keyboard on wrist extension versus a standard keyboard (Marklin et al., 1999; Szeto & Ng, 2000; Zecevic et al., 2000). Evaluation of the effect of an FA keyboard revealed a moderate decrease in wrist extension angle ($r = 0.30$) (95% CI = 0.11, 0.49) compared to a standard flat keyboard (see Table 3). These results indicated that slight rotation and angulations of keyboard halves, as characteristic of the FA keyboard, have a moderate effect on wrist extension posture.

Two studies investigated the effect of an AT keyboard on reducing wrist extension compared to a standard flat keyboard (Marklin et al., 1999; Zecevic et al., 2000). The AT keyboard was found to reduce wrist extension ($r = 0.07$), however this result was small and lacked statistical significance (95% CI = −0.13, 0.27).

Overall, the alternative keyboards were found to have a large effect on wrist extension posture, generally positioning the wrist in a more neutral position ($r = 0.52$) (95% CI = 0.17, 0.87). Statistical homogeneity of the results was observed ($Q = −0.04$) ($p < 0.05$) indicating the dispersion of effect sizes from the studies estimate the same population effect size.

**Discussion**

The results of this meta-analysis provide evidence to substantiate claims that alternative design keyboards promote forearm and wrist postures closer to neutral position than standard flat keyboards. No previously identified work has provided a comprehensive review of the literature on the effect of keyboard design on forearm position. In this study three alternative keyboard designs were specifically investigated to determine their effect on wrist and forearm posture compared to a standard keyboard. The three keyboard designs included AS keyboards, FA keyboards, and AT keyboards. Figure 2 presents the overall reduction in each posture based on computer keyboard type.

Compared to the standard keyboard, the FA keyboard and the AT keyboard substantially reduced mean forearm pronation angle ($r = 0.72$, $p < 0.05$). Though both the FA keyboard and AT keyboard reduced forearm pronation, the AT keyboard was shown to be superior to the FA keyboard. The AT keyboard alone had a large effect ($r = 0.83$) on decreasing forearm pronation angle compared to the standard keyboard. The reason for a significant reduction in forearm pronation angle observed on the AT keyboard can be attributed to a fixed lateral inclination of the keyboard halves. This fixed lateral inclination, reported by Zecevic et al. (2000) to be approximately 42°, physically prevents keyboardists from pronating the forearm past 45°. The modest lateral inclination of 10° (Zecevic et al.) characteristic of the FA keyboard also decreased forearm pronation, but to a lesser extent than did the AT keyboard. As pressure inside the carpal tunnel increases as the forearm is pronated past 45° (Rempel et al., 1995) and keyboard users have been observed to sustain forearm posture of around 60° of pronation while using a standard flat keyboard (Simoneau & Marklin, 2001), the use of an AT keyboard and, to a lesser extent, the FA keyboard, may be effective at reducing awkward postures that potentially could lead to increases in carpal tunnel pressure and development of a MSD-UE.

Compared to the standard flat keyboard, the FA ($r = 0.56$) and AT ($r = 0.61$) keyboards profoundly reduced ulnar deviation posture, while the AS keyboard demonstrated a small ($r = 0.10$) but significant effect on ulnar deviation posture. When the tilt of the AS keyboard was increased in the positive direction, wrist ulnar deviation significantly decreased whereas the opposite effect was observed when the tilt of the AS keyboard was adjusted to an increased negative tilt. Both the FA and AT keyboard allow the hands to be spaced at a greater distance from each other during keyboarding and consequently promoting less abduction of the upper arms and allowing a more neutral wrist posture to be assumed by the keyboard user. The use...
of alternative keyboards that significantly decrease ulnar deviation angles, such as the FA and AT keyboard, may assist in reducing the forces acting on the biomechanical structures of the wrist and fingers as well as reducing the pressure in the carpal tunnel during keyboarding tasks.

The design of the flat standard keyboard may cause the user to assume a posture of excessive wrist extension in order to position the fingers for striking the appropriate keys. Results from the current study suggest the FA keyboard reduced wrist extension. The results also suggest that the AS keyboard positioned in the negative direction reduce wrist extension. When the tilt of the AS keyboard is increased in a positive direction, however, wrist extension increases along with the risk of MSD-UE. Clearly these results indicate that tilting the keyboard to a negative angle positions the wrist closer to a neutral extension posture. Compared to the standard keyboard the AT keyboard was found to have a small, nonsignificant effect on wrist extension ($r = 0.11$). The two halves of an AT keyboard are tented and rotated in a horizontal plane. Rather than specifically decreasing wrist extension angle, the set up of the AT keyboard changes the orientation of the of the hand compared to the standard flat keyboard (Zecevic et al., 2000) allowing for the hands to work in a more neutral wrist position but not requiring a neutral posture to use the keyboard. Therefore, some subjects may have maintained an excessive wrist extended posture while using the AT keyboard. Overall, the three alternative keyboard designs place the hand and forearm closer to a neutral extension position than the standard keyboard. However, the FA keyboard and AS keyboard adjusted in the negative direction place the hand in a more neutral wrist extension position than did the AT keyboard.

It is also important to note that in the study completed by Marklin et al. (1999) there were 10 hours of acclimation for the assigned alternative keyboard whereas the other studies analyzed allowed only 5 to 10 minutes of acclimation. The longer acclimation period would allow users sufficient time to overcome the unfamiliarity of wrist and forearm posture on the alternative keyboard and therefore resume prior level of typing performance on the standard keyboard. However, the increased familiarity with the alternative keyboard should not have had a substantial effect on wrist and forearm postures assumed when typing on the alternative keyboard compared to studies employing shorter periods of acclimation.

**Clinical Significance**

This current meta-analysis provides evidence that alternative keyboard designs decrease potentially harmful awkward postures typically assumed on a standard flat keyboard. If an occupational therapy practitioner is concerned about reducing a specific awkward posture, this study indicates the keyboard type that best reduces that posture. It is important for clinicians to understand the priority of each client. No single keyboard was superior for reducing all three awkward postures, so it is important that occupational therapy practitioners identify which posture appears to be causing the problem and select the keyboard that best reduces it. This knowledge could be used to identify which type of keyboard may increase participation in computer tasks that are limited by postural limitations secondary to disability. For example, a client may have reduced pronation secondary to a radial head fracture. Based on the results of this analysis, his or her therapist would probably recommend an adjustable open-tented angle keyboard as this design is the most successful for reducing the need to pronate while using a keyboard (see Figure 2).

Despite the ability of these keyboards to promote improved postures, it is important to note that these studies offer no evidence of a link between a specific keyboard design and alleviation of a specific MSD-UE condition or complaint. In other words, the use of an alternate keyboard may reduce or eliminate risky postures and may still not alleviate, reduce, or prevent symptoms of MSD-UE in clients. A comprehensive program that addresses additional elements of the computer workstation as well as the psychosocial environment may be necessary to help eliminate MSD-UE in computer users. However, armed with this information, occupational therapy practitioners can provide clients with evidence-based information to make choices as to which keyboard may be the best for that client, thus decreasing work and leisure time that might otherwise be lost to discomfort or disability.

**Limitations and Future Research**

This study provides information on only three alternative designs. Although additional alternative keyboard designs have been introduced on the market, they were not included in the present study as there was no literature available on their effects on reducing potentially harmful postures. These other alternative designs may provide benefits to the computer user that is not provided by the three investigated keyboards. A second limitation of the current study is its restriction to the effect of these three keyboard designs on only three potentially harmful postures; forearm pronation, ulnar deviation, and wrist extension. Associations may exist between MSD-UE and postures not included in the analysis such as arm abduction and neck angle. The present analysis is limited to a small number of studies and a limited number of effect sizes, however these effect sizes are
relatively large providing clinicians with some indication of the benefit of alternative keyboards.

When considering the information regarding alternative keyboards provided by the present meta-analysis, caution should taken due to limitations in the methods employed to gather and analyze the data. One limitation of this meta-analysis is there are no reliability values for the rating of the articles. A single rater reviewed articles on three separate occasions. Both authors then discussed the ratings of each article and a final decision was made concerning inclusion or exclusion of each article. No information on the degree of intrarater or interrater reliability was recorded. A more rigorous and systematic process of rating the articles might have enhanced article selection. In addition, the authors were not blinded to the results of each study prior to making the decision to accept or reject an article for inclusion. Removing the result section would help to ensure that the decision to include the article was based solely on the design and methods rather than the results.

Although this meta-analysis provides initial evidence that alternative keyboards reduce awkward postures, it, and the studies that comprise it, are only the first step in understanding and reducing MSD-UE related to computer use. These studies do not demonstrate that reducing awkward posture will actually reduce the incidence of MSD-UE in a computer-using population, nor do they examine the interaction between alternative keyboards and other environmental interventions, such as chair configuration. Further research is needed to understand how the environment, both physical and psychosocial, can be modified to enhance work performance and prevent work injury for computer users.

Conclusions

The rise in computer use has affected the complex relationships among individuals, the environments in which they function, and the occupations with which they become involved. Not only are computers increasingly common in the workplace, they are also a venue for work, school, and leisure to enter the home. The use of the Internet to fulfill daily occupations of many varied populations has led to increased use of the computer keyboard and potentially an increase in the occurrence of MSD-UE. Not only does MSD-UE decrease worker productivity but also for those who rely on the computer to perform important daily tasks, MSD-UE may make use of the computer painful and irritating and result in a decrease in independence and overall quality of life.

This study examined three alternative keyboards designs for their ability to reduce awkward postures associated with MSD-UE: forearm pronation, wrist extension, and ulnar deviation. Although each alternative keyboard demonstrated a moderate to large effect on at least one of the three investigated postures, none of the keyboards affected all three postures (see Figure 2). Although the AT keyboard had a large effect on reducing pronation of the forearm and wrist ulnar deviation, it had a small, non-significant effect on wrist extension, thus reducing two postural risk factors while maintaining another. Although the FA keyboard was shown to have a large effect on ulnar deviation and a moderate effect on wrist extension, a nonsignificant effect on pronation was observed. Wrist extension was decreased on the AS keyboard adjusted to a negative angle however the concurrent with this decreased wrist extension was an increased ulnar deviation. Studies indicating favorable results from the use of a single alternative keyboard on forearm pronation, wrist extension, and ulnar deviation are lacking in the literature. The high degree of variability from person to person while using a keyboard also makes it difficult to decrease awkward forearm pronation, wrist extension, and ulnar deviation solely through the selection of an alternative keyboard design. Additional research is needed to determine how specific keyboard features such as slope, tilt, and split angle interact with hand size, wrist and finger position, as well as keyboarding style to decrease biomechanically awkward postures while keyboarding. However, by decreasing biomechanically awkward postures while keyboarding through the prescription of an alternative keyboard, occupational therapy practitioners may play an important role in assisting computer users to maintain productivity, and promote functional independence. ▲

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