Workplace use of an adjustable keyboard: Adjustment preferences and effect on wrist posture

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Abstract:
An evaluation of an adjustable keyboard based on subjective preference and wrist joint motion during typing is presented. Thirty-five computer users used the adjustable split design keyboard for 7-14 days during their usual work and were instructed to adjust the keyboard to the opening angle they preferred. At the end of this period, three-dimensional motion analysis was performed to compare the distribution of wrist joint angles while subjects typed on a conventional keyboard and the adjustable keyboard adjusted to the subject's preferred angle. The results are discussed in detail.

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This study presents an evaluation of an adjustable keyboard based on subjective preference and wrist joint motion during typing. Thirty-five computer users used the adjustable split design keyboard for 7-14 days during their usual work and were instructed to adjust the keyboard to the opening angle they preferred. At the end of this period, three-dimensional motion analysis was performed to compare the distribution of wrist joint angles while subjects typed on a conventional keyboard and the adjustable keyboard adjusted to the subject's preferred angle. The mean preferred opening angle was 14 deg +/− 10. The mean ulnar deviation of the subjects who selected the opening angles between 21 and 28 deg (n = 12) decreased from 18 deg +/− 5 on the flat to 14 deg +/− 5 on the adjustable (p < 0.05), while those who selected 0 to 10 deg (n = 6) and 11 to 20 deg (n = 17) split angles showed no significant differences in ulnar deviation. Mean wrist extension on the adjustable keyboard was 17 deg +/− 5 and was significantly less than the 24 deg +/− 5 observed on the conventional keyboard and most likely due to the presence of palm support. On average, subjects reported that the adjustable keyboard was more comfortable (0.5 +/− 0.5) (worse = -1, same = 0, better = 1) in comparison with the conventional keyboard.

Keywords: adjustable keyboard, musculoskeletal disorders, user preference, wrist motion

Work-related neck and upper limb musculoskeletal disorders (MSDs) associated with computer use have been reported in the scientific literature worldwide.(1-5)

Specific work-related risk factors for MSDs include highly repetitive hand and finger movements, (6) forceful hand exertions," and awkward and static joint postures,(8,9) some of which are also present in computer work. When someone types on a keyboard, musculoskeletal symptoms or disorders may occur (1) when the shoulders are held in a static awkward position for a long period of time, (2) when the wrists are held in sustained nonneutral posture,(10,11) or (3) when the wrists are pressed against a sharp edge of the table or hard surface.
Attempts to reduce extreme wrist postures (ulnar deviation/wrist extension and forearm pronation) have been to modify the flat, linear keyboard design by splitting it into right and left halves adjusted to various angles. (12-14) Early studies based on subjective reporting of operator discomfort after brief exposures to new keyboard designs found that when ulnar deviation and pronation were reduced, such split designs could decrease operators' pain and discomfort in the neck and upper limb region. (13,14) Electromyographic studies conducted on split keyboard users also showed reduced electrical activities of the forearm as well as the neck and shoulder muscles. (15,16) In response to these findings, alternative keyboards have been designed and marketed to improve hand and forearm postures as well as comfort during typing. Performance, electromyographic analysis, and subjective preference data, based on short-term (1-3 day) use of these keyboards have demonstrated decreased electromyographic activities of the finger flexors and extensors and wrist flexors, (17) significant reduction in wrist extension and ulnar deviation, (18,19) and favorable ratings (20,21) in comparison with a conventional keyboard. To date, however, there have been no long-term studies on the effectiveness of split keyboards when used in workplace settings.

The objectives of this study were twofold. First, to determine computer user preference and comfort after 7-14 days of use of an adjustable keyboard in the workplace, and second, to assess at the end of the trial, dynamic wrist joint postures for subjects typing on the adjustable keyboard compared with typing on a conventional keyboard.

METHODS

Subjects

Thirty-five employees (22 females and 13 males) of the Lawrence Livermore National Laboratory who used the Macintosh computer for =>6 hours per day and had no prior history of hand/wrist injury or disorder participated in the study. Subjects were recruited via an electronic mail message that asked for volunteers to participate in the evaluation of several different ergonomic products. Subjects' mean age was 40 +/- 9 years (range: 24-55 years). Their mean height was 165 +/- 10 cm (range: 149-185 cm), and their mean weight was 75 +/- 19 kg (range: 56-124 kg). The mean typing speed measured during the typing tasks was 59 +/- 21 words per minute (wpm) (range: 32-83 wpm). None of the subjects reported having previous exposure to alternative geometry keyboards.

A split design keyboard that has been used with Macintosh computer is the Apple Adjustable Keyboard (Apple Computer, Inc., Cupertino, Calif.) The Apple Adjustable consists of two split halves separating the right and left hands and can be opened up to 28 deg laterally from the central hinge. A pair of retractable feet on the bottom of the keyboard allow a front-to-back slope of 7 deg. The intrinsic palm supports are detachable and can be snapped onto the front of the two halves. Function and numeric keys are located on an additional keypad that can be attached to the left or right side of the main alphabetic keyboard as shown in Figure 1.

Procedures

Subjective Preferences

At the time of distribution of the adjustable keyboard, subjects were instructed to adjust the opening angle to the angle that they perceived as most comfortable and continue to adjust it throughout the 7-14 day trial period. At the end of the trial, the opening angle selected was measured using a manual goniometer and whether retractable feet were used was recorded. Subjects rated the various keyboard characteristics using a categorical 5-point scale ranging from unfavorable (5) to favorable (1) ratings and
further compared the adjustable keyboard with their own conventional keyboard by giving a rating of worse (-1), same (0), or better (+1) than the conventional. These characteristics included (1) the feel of the keyboard, (2) awkwardness while typing, (3) keying force, (4) tiredness from typing, (5) aches/pain associated with using the keyboard, and (6) overall opinion of the keyboard.

**Wrist Motion Analysis**

**Experimental Design**

At the end of the keyboard trial, subjects participated in a laboratory-based typing experiment, where wrist angles (flexion/extension and ulnar/radial deviations) while typing on the conventional keyboard were measured and compared with the adjustable keyboard. The order of the keyboard testing was determined by a Latin square matrix to control for fatigue bias. A table that supported the keyboard was adjustable in height from 58 to 76 cm, and a chair was adjustable in height from 42 to 56 cm. The table height and chair were adjusted to allow each subject to assume their most preferred typing postures.

Each subject typed from an alphabetic text, using Typing Tutor 5 software (Kriya Systems, Inc., N.J.). The adjustable keyboard was configured to reflect the angle used during the subjects' trial period. No wrist or arm rests were provided, except those intrinsic to the adjustable keyboard. The typing test for each keyboard consisted of four typing sessions, lasting for 5 min each, followed by 1-min break after each session. Each typing session was designed to execute a specific series of alphabetic paragraphs, derived from textbook chapters and magazine articles. A 5-min break was given after completing all four sessions on a given keyboard. The wrist joint motion was recorded during the last minute of typing for each session. Wrist joint angles were sampled at 25 Hz. The experiment lasted for a total of 60 min.

**Apparatus**

The MacReflex Three-Dimensional Motion Analysis System (Qualysis, Inc., Saveladen, Sweden) was used to record wrist postures. The system consists of two infrared cameras and their respective video processors. The camera system detects reflective spherical markers attached to the subject's wrists and forearms and delivers their three-dimensional information about maker positions to the video processors. The video processors calculate the centroid of each marker and deliver marker coordinates to the Macintosh Quadra 840AV computer. The three dimensional position of each camera was determined at the beginning of the experiment, using a calibration reference frame containing six markers represented in x-, y-, and z-directions as shown in Figure 2. A method for establishing wrist orientation using inverse kinematics and expressing orientation with respect to the anatomic flexion/extension and radial/ulnar deviation axes was developed. Results obtained using this transduction/computational method were highly correlated with the motion measured in a mechanical wrist phantom \(r^2 > 0.99\)(22) as well as in human hands \(r^2 > 0.99\).(23)

**MacReflex System Set-Up**

On the right hand of each subject, three spherical markers (5 mm in diameter), mounted on a platform to represent three-dimensional marker coordinates, were placed 1 cm proximal to the third metacarpophalangeal joint. Another platform containing three additional markers was placed along the forearm as shown in Figure 3. To obtain three-dimensional information with high accuracy, the optical axes of the two cameras were set up at 90 deg. An infrared camera was mounted above the subject and the second camera was mounted to the right side of the subject, at keyboard level.

**Statistical Analyses**
Wrist posture data for each keyboard was averaged over the four 1-min sampling periods. The data analyses were performed using JMP Statistical Software 3.1.6 for the Macintosh (SAS Institute, Inc., Cary, N.C.). Kruskal-Wallis and Wilcoxon rank-sum nonparametric tests and post hoc Tukey-Kramer procedures were used to determine differences in subjective assessments for user groups, whereas paired t-tests and one within, one between repeated measure analysis of variance (ANOVA) were used to determine differences in typing wrist postures within four typing sessions and between two keyboard groups. Two-factor ANOVAs were used to examine the difference in wrist postures at various selected opening angles. P-values < 0.05 are considered statistically significant.

RESULTS

User Preferences

A histogram of preferred opening angles is shown in Figure 4. The opening angles selected ranged from 0-28 deg. Of the 35 subjects, 6 (17%) selected 0-10 deg. For 48% of the subjects (n = 17), the preferred angle fell within the range of 11-20 deg, and 12 (35%) selected 21-28 as their preferred opening angles. None of the subjects used the retractable feet to increase keyboard slope.

For the subjective evaluations, the subjects rated the adjustable keyboard by category and compared it with the conventional keyboard. Overall posture required during typing and tiredness and aches/pains caused by typing are summarized as comfort features (1 = very comfortable, 5 = painful), while feel and touch of the keys, keying force, ease of use, and effort required for typing are categorized as usability features (1 = favorable, 5 = unfavorable) (Table I). For all comfort and usability ratings, the adjustable keyboard received favorable mean scores. On the average, 27 subjects (77%) liked the feel (1.8 +/- 1.0) and 22 subjects (63%) liked the keying force (2.2 +/- 1.0) of the split keyboard. All 35 subjects experienced few to no aches and pains (1.3 +/- 0.9), while 19 (54%) subjects found the split keyboard easy to use (2.3 +/- 1.2). The mean overall scores were favorable for the adjustable keyboard (2.0 +/- 1.0).

The mean scores for each characteristic of the adjustable keyboard are further categorized into three subgroups, based on the range of split angles chosen by subjects for use (0-10 deg, 11-20 deg, and 21-28 deg) (Table II). Kruskal-Wallis nonparametric tests revealed no significant rating differences in overall postural requirements (p = 0.32), tiredness from typing (p = 0.21), aches and pains associated with typing (p = 0.31), key feel/touch (p = 0.09), keying force (p = 0.11), ease of use (p = 0.41), and effort required (p = 0.96) when the 0-10 deg, 11-20 deg, and 21-28 deg groups were compared. Overall keyboard rating, however, was significantly different among the three split angle groups (Kruskal-Wallis test, p = 0.05). A post hoc Tukey-Kramer procedure revealed that the 11-20 deg group rated the adjustable keyboard as significantly more favorable (1.8 +/- 0.9) than the 0-10O group (2.7 +/- 1.1) (p < 0.05). No significant rating differences were observed for other split angle group comparisons (p > 0.05).
Mean comparative ratings with 95% confidence limits between the adjustable and subjects' own conventional keyboards are shown in Figure 5. Mean ratings of -1 to -0.34, -0.33 to 0.33, and 0.34 to 1 correspond to "worse than the conventional keyboard," "same as the conventional keyboard," and "better than the conventional keyboard," respectively. In comparison with the conventional keyboard, subjects preferred the feel and touch of the adjustable keyboard (0.5 +/- 0.6), but rated the keying force as being the same (0.2 +/- 0.8). On average, the subjects felt that using the adjustable keyboard was significantly less tiring (0.5 +/- 0.5) and associated with more comfortable postures than the conventional keyboard (0.7 +/- 0.5). Using the split configuration was not thought to be more awkward (0.3 +/- 0.8), and fewer aches and pains (0.5 +/- 0.5) were experienced when using the adjustable keyboard. No subjects rated the adjustable keyboard as being worse than the conventional keyboard. Average overall assessment indicated that subjects rated the adjustable keyboard as better than the flat conventional keyboard (0.6 +/- 0.7).

Dynamic Wrist Postural Analysis

The distribution of the percentage of time spent typing in specific wrist angle intervals (extension intervals of 0-10 deg, 11-20 deg, 21-30 deg, 31-40 deg; ulnar deviation intervals of 0-10 deg, 11-20 deg, 21-30 deg, 31-40 deg; and radial deviation of 0-10 deg) for each keyboard was averaged over all subjects (1500 observations per subject for each typing session [60 sec x 25 Hz]) and for all four typing sessions. Repeated measures ANOVA (RANOVA) demonstrated no significant interaction between keyboard type and typing sessions (p = 0.51). No significant differences in mean wrist extensions between typing sessions were found for each keyboard (p = 0.12). Posture distributions indicated that, on average, subjects typed with their wrists extended. However, when typing on the adjustable keyboard the percentage time spent in extreme wrist extension of 31-50 deg was significantly reduced to 12% compared with 33% on the conventional keyboard (paired t-test, p < 0.05). The percentage of time spent in a more neutral range (wrist extension 0-15 deg) significantly increased from 5% on the conventional keyboard to 32% (p < 0.005) on the adjustable keyboard. Typing in moderate wrist extension between 16-30 deg was reduced slightly from 58% on the conventional keyboard to 48% on the adjustable keyboard (p = 0.11). Across all typing sessions, subjects typed in extreme wrist extensions between 15 deg and 36 deg on the flat keyboard, compared with 6 and 28 deg on the adjustable keyboard. A RANOVA model of mean wrist extensions, averaged over four typing sessions, showed a significantly decrease from 24 deg ( +/- 6) on the flat conventional keyboard to 17 deg ( +/- 6) on the adjustable keyboard (p = 0.0005).
The frequency histogram displaying the typing percentage time in radial/ulnar deviations for each keyboard over all typing sessions is presented in Figure 7. No significant difference in ulnar deviation between typing sessions was observed for either keyboard (RANOVA, p = 0.24). Wrist ulnar deviations >10 deg occurred for 65% of the time on the conventional keyboard compared with 45% of the time on the adjustable keyboard (paired t-test, p = 0.04). Extreme ulnar deviation (21-40 deg) was reduced from 18% of the time on the conventional keyboard to 7% on the adjustable keyboard (p = 0.07). The percentage of time spent in neutral to slight ulnar deviation (0-10 deg) was approximately the same for both keyboards (29 and 25% for the conventional keyboard and adjustable keyboard, respectively) (p = 0.62). When typing on the adjustable keyboard, subjects spent slightly but not significantly more time (8%) in radial deviation (1-10 deg) than on the conventional keyboard (2%) (p = 0.14).
To determine whether the selected range of opening angles on the adjustable keyboard can affect the differences in mean ulnar deviation between the two keyboards, subjects were trichotomized according to the range of opening angles they selected on the adjustable (0-10 deg, 11-20 deg, and 21-28 deg). The mean ulnar deviation over all typing sessions on the conventional and adjustable keyboards is presented as a function of three opening angle subgroups as shown in Figure 8. Two-way ANOVA revealed that the variable "split angle group" (p = 0.0007), but not "keyboard type" (p = 0.07) was a significant factor in determining mean ulnar deviation. A post hoc Tukey-Kramer procedure indicated that the average ulnar deviation on the conventional keyboard was significantly lower in the 0-10 deg group (n = 6) (7.7 +/- 3) than in the 11-20 deg (n = 17) (14.8 +/- 3) and 21-28 deg (n = 12) (18.0 +/- 5) split angle groups (p < 0.05). The interaction between keyboard and split angle group was also significant (p = 0.03). For the 2128 o split angle group, the mean ulnar deviation significantly decreased from 1B.0' (5) on the conventional keyboard to 14.1 deg ( +/- 5) on the adjustable keyboard (p < 0.05). No significant reduction in ulnar deviation was demonstrated between the two keyboards for the 0-10 deg (7.7 +/- 3 on the conventional versus 8.9 +/- 5 on the adjustable) and 11-20 deg (14.8 +/- 3 on the conventional versus 13.6 +/- 4 on the adjustable) split angle groups.

DISCUSSION

This study examined the effectiveness of the adjustable keyboard to reduce nonneutral wrist postures and, at the same time, increase long-term users' comfort without compromising ease of use in the workplace.

Subjective evaluations indicate that the adjustable keyboard was preferred over the conventional keyboard for its comfort and usability features. Subjects rated the adjustable keyboard as "better" than the conventional keyboard in all categories. No subjects rated the adjustable keyboard as less comfortable than its conventional counterpart. These findings are comparable with a short-term 4-hour laboratory study by Cakir.(20) In that study, 26 skilled typists rated the adjustable keyboard very favorably for its design and its impact on postural comfort and did not rate it as significantly worse than the conventional keyboard for its functionality. User preference and comfort results in the current study, however, differed from a 3-day laboratory study comparing three split geometry keyboards with a conventional keyboard.(24) Swanson et al.(24) reported no significant difference in discomfort and
fatigue ratings between the split geometry keyboards and a conventional keyboard in 50 healthy clerical workers, with 10 subjects assigned to each keyboard. The comfort rating differences may be attributable to the differences in keyboards tested and the design of the study. The subjects in Swanson's study typed continuously for 75 min at each work period before being given a 10-min break, while subjects in the current study were permitted to type on the adjustable keyboard at their usual work pace and workstation over 7 to 14 days. Furthermore, Swanson et al. used keyboards that were more dramatically different from the conventional than the Apple Adjustable keyboard. Whereas the angle of the split keyboard used in the current study can be opened only laterally from the central hinge, the two keyboards tested by Swanson et al. can also be adjusted to variable lateral inclination angles, and the third keyboard design consisted of two slightly inclined concave keypads.

Previous studies of alternative keyboards have examined static wrist typing postures with use of a manual goniometer.(11,14,25) The current study is unique in that dynamic wrist joint postures were measured using an opto-electronic system (Qualisys). With this system, marker positions were transduced in three-dimensional space and dynamic wrist angular positions were calculated from these coordinates. Continuous measurement of wrist angular deviation is advantageous in that it provides not only an accurate and cumulative distribution of wrist joint angles, but also records the extreme ranges of wrist motion. In contrast to previous studies, our subjects were given sufficient time (e.g., 7-14 days) to use and become familiar with the adjustable keyboard in their own work environment prior to undergoing postural analysis.

The results are for the right wrist only. Though it has been found that the left wrist position tends to be different from the right wrist (greater ulnar deviation), it is not known from this study whether the results for the left wrist will be the same as the reported positions for the right wrist. The findings suggest that the opening angles preferred by most subjects ranged from 11-20 deg. This is different from an earlier short-term laboratory study of split keyboards which reported that subjects preferred a split angle of 25 deg after typing for 45 min each on three keyboard settings: 0 o lateral inclination and 15 deg opening angle, 10 deg lateral inclination and 25 deg opening angle, and 10 deg lateral inclination and 35 deg opening angle.(14) The difference in opening angle preference may be due to the fact that subjects in this study were allowed to choose from a wider range of opening angles and were given more time (7-14 days) to adjust the opening angles at their own workstations. In the present study, the range at which the subjects selected their opening angle significantly affected the overall keyboard ratings as well as the changes in ulnar deviation between the conventional and adjustable keyboards. Subjects who selected larger opening angles (11-20 deg and 21-28 deg) gave a more favorable overall rating to the adjustable keyboard than those who chose opening angles between 0-10 deg. Among those who selected the highest range of opening angles (21-28 deg) on the adjustable keyboard, ulnar deviation significantly decreased from 18 deg on the conventional to 14 deg on the adjustable keyboard. A change in ulnar deviation among this group is comparable with Nakaseko's study,(15) which showed a significant decrease in ulnar deviation from 20 deg on a conventional keyboard to 10 deg on a
keyboard with a 25 deg fixed opening angle.

Interestingly, the typists who typed on a conventional keyboard with least ulnar deviations selected smallest opening angles (0-10 deg) on the adjustable keyboard, while those with largest ulnar deviation self-selected larger angles and had greater reduction in ulnar deviation. This suggests that with easy keyboard adjustability, typists will adjust to reduce posture extremes.

The conventional keyboard requires the wrist to deviate and forearm to pronate from neutral (Figure 9). The extent to which a conventional keyboard design can cause ulnar deviation may depend on the anthropometry of the users. Users whose shoulder or abdominal width exceeds the width of the keyboard alphabetic section may assume greater ulnar deviation when typing. In addition, extreme deviation of the wrist may be influenced by finger length. Users with relatively shorter fingers may find it necessary to deviate their wrist when using the keyboard. Although anthropometry was not measured in this study, it is possible that some of the study subjects may possess anthropometric characteristics that may influence the extent to which ulnar deviation is reduced when using a split geometry keyboard. Moreover, the subjects may be accustomed to deviating their wrists as a result of prolonged use of the conventional keyboard and a trial period of 7 to 14 days may not be sufficient for adjustments toward neutral to occur.

Prior studies have reported that transcribers with carpal tunnel syndrome or tendinitis typed in greater wrist extensions compared with controls(26) and that wrist extension was significantly reduced while typing on a conventional keyboard set on a negative sloped surface away from horizontal.(27) In the present study the subjects spent 12% of the time typing in extreme wrist extension (31-350) on the adjustable keyboard, a decrease from 33% observed on the conventional keyboard. Overall, the mean wrist extension decreased from 24o on the conventional to 170 on the adjustable keyboard. This decrease can probably be attributed to the use of palm rests, which are intrinsic to the adjustable
CONCLUSIONS

The study provides evidence that split keyboards can reduce posture-related risk factors associated with the development of MSDs. Keyboard users maintained more neutral wrist postures with the split keyboard than the conventional keyboard. In addition, users reported increased comfort and preferred the split keyboard over the conventional keyboard after 7 to 14 days of use in a workplace setting. While these keyboards may reduce some postural risk factors, they do not eliminate all risks. In an office environment, users may also be exposed to other risk factors such as repetitive and forceful exertions during keying as well as other stresses associated with their jobs (e.g., stressful postures during mouse use or telephone use, mechanical stress related to resting the hand/wrist on sharp table edges, sustained and repeated exertions during file handling). Additional studies of alternative workstations and work methods are necessary to assess how best to minimize exposure to multiple factors that may contribute to development of MSDs.

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