THE EFFECT OF KEYBOARD KEY SPACING ON PRODUCTIVITY, USABILITY, AND BIOMECHANICS IN TOUCH TYPISTS WITH LARGE HANDS

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International standards that specify the spacing between keys on a keyboard have been guided primarily by design convention. Experienced typists (N=37) with large hands typed on five keyboards with different horizontal and vertical key spacing (19x19, 18x19, 17x19, 16x19, and 17x17mm) while productivity, comfort ratings, left and right extensor carpi ulnaris (ECU) and flexor carpi ulnaris (FCU) muscle forces, and right and left wrist extension and ulnar deviation were recorded. Productivity and usability ratings were significantly worse for the 16x19 keyboard. There was a trend for muscle activity to increase in the left forearm and decrease in the right forearm with decreasing horizontal key spacing. There was also a trend for left wrist extension to increase and left ulnar deviation to decrease with decreasing horizontal key spacing. The study findings support key spacing on a keyboard between 17 and 19mm. These findings may influence keyboard standards and design of keyboards.

INTRODUCTION

As laptop computers have become smaller, some laptop designs have accommodated the smaller size by decreasing the spacing between keys. Advantages of a smaller keyboard include a smaller, lighter laptop and improved portability; reduced cost to manufacture; better usability for users with smaller hand sizes and shoulder widths; and reduced reach to the computer mouse (Rempel, 2007). However, the key spacing on the majority of laptop and desktop keyboards follows the national and international standards of 19 mm. Mini-keyboards, with key spacing less than the conventional 19 mm, are available on some netbooks and as specialty external keyboards.

The recommended center-to-center key spacing (e.g., key pitch) on keyboards is established by international (ISO) and American (ANSI/HFES) standards (ISO9241-410, 2008; ANSI/HFES 100, 2007). The current ISO and ANSI/HFES standards recommend that the horizontal and vertical distance between adjacent key centers (Figure 1) for keys in the alphanumeric and numeric zones, be 19 mm ± 1 mm. These recommendations are based on conventional industry practice and early research (Clare, 1976).

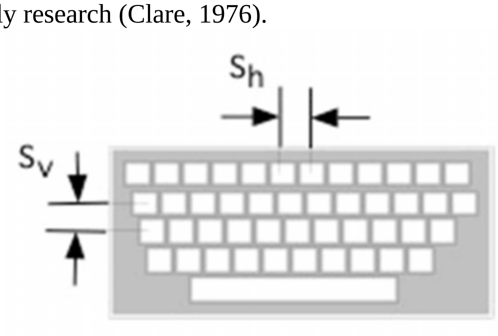

Figure 1. Vertical (S_v) and horizontal (S_h) key spacing on a conventional keyboard.

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The effect of key spacing on performance has been evaluated in only a few studies. A study from by Yoshitake in Japan evaluated the relationship between key spacing and typing performance on a conventional keyboard using key spacings of 19.7, 19.1, 16.0, 15.6, and 15.0 mm (1995). For subjects with small fingers (average middle finger length and width of 7.85 cm and 19.0 cm, respectively) there was no difference in performance between keyboards. However, for subjects with large fingers (average middle finger length and width of 8.48 cm and 22.4 cm, respectively) the performance decreased when the key spacing was 16.0 mm or less. The performance of the small-fingered group did not decrease even for the key spacing of 15.0 mm. Applying these results to North American and European populations may be problematic, because the 89th percentile Japanese adult male middle finger length is equal to the 58th percentile US adult male (Nippon Shuppan Service, 1996 & Pheasant, 1996). Other limitations of the study included the small study sample size (N=8), performance based on a single-word task, and the key top sizes differed between keyboards potentially confounding the results. A different study, carried out on numerical keypads, found greater input time and percent error when key spacing was 21 mm compared to 19 mm (Deiniger, 1960). Again, the key top sizes differed between conditions.

In 1972, a literature review on keyboard design and operation reported no industry or military standards for basic key characteristics, including spacing. Rather "it is due to design conventions rather than empirical data…that the typical spacing between key centers on these keyboards is 18.1 mm," (Alden et al., 1972). In 1987, Ilg examined 16 keyboard parameters including horizontal and vertical key spacings of 14.3, 16.6, 19.0, and 21.4 mm (Ilg et al., 1987). Thirty users typed on each keyboard while performance, percent error and user preference were recorded. An analysis using a variable that combined the 3 outcomes rated the 19.0 mm vertical and horizontal key spacing as preferable over the other key spacings. However, the study had some shortcomings such as, nonrandomized keyboard order, large difference in key spacing tested, and combining outcomes into a single metric. These studies did not evaluate the effects of key spacing on biomechanical or physiologic measures.

The purpose of this study was to determine whether reducing horizontal or vertical key spacing below the conventional 19 mm key spacing would modify typing speed, percent error, muscle activity, wrist posture and usability among computer users with large fingers. Based the Yoshitake study (1995), it is likely that computer users with small fingers would readily adapt to keyboards with smaller key spacing; therefore, this study focused on subjects with larger fingers – those most likely to be affected by smaller key spacings. The null hypothesis was that there is no difference in typing speed, percent error, muscle activity, wrist posture, preference, or fatigue for touch typists with large fingers when they type on keyboards with reduced key spacing in comparison to a keyboard with standard key spacing.

METHODS

In this laboratory study, 37 subjects performed touch-typing tasks in five different keyboard test conditions. The study was approved by the University Institutional Review Board and subjects signed a consent form.

Subjects. Eligibility criteria were male gender, age between 18 to 65 years, the ability to touch type at least 30 words per minute, and a middle finger length (from palmer proximal metacarpophalangeal crease to tip of finger) of 8.7 cm or proximal interphalangeal joint breadth (at proximal interphalangeal joint) of 2.3 cm or more. The finger length and breadth thresholds were the 75th percentile based on male hand anthropometry from the US military (Greiner, 1991). Subjects were excluded if they reported current upper extremity musculoskeletal disorders. A sample size of 30 was estimated using a two tailed alpha of 0.05, a beta of 0.80, and the mean and standard deviation of typing speed of large fingered typists from the Yoshitake study.

Keyboard Test Conditions. A customizable keyboard system (DX1; Ergodex, Mountain View, CA) was used to build five keyboards that differed only in horizontal and vertical key spacing. Four keyboards varied in horizontal key spacing 19.0, 18.0, 17.0, and 16.0 mm (all with 19.0 mm vertical key spacing) and one keyboard had a horizontal and vertical key spacing of 17.0 mm. Accuracy of key spacing was ±0.1 mm. All keyboards were the conventional QWERTY layout and did not include a backspace. The dimensions of the tops of all key caps were 14.7 mm horizontally and 13.7 mm vertically. Key activation force was between 63 and 77 gram-force for all keys.

Practice Session. On the day of the study, subjects first warmed up by touch-typing on the 19x16 mm keyboard for five ten-minute sessions with three-minute breaks between sessions. Before continuing with the experiment, subjects rested for 15 minutes.

A typing program (Typing Master Pro, Helsinki, Finland) presented text and highlighted and underlined the word to be typed, on the screen, which was typed by the subjects. Typing passages were from news articles and books with grammar at the 8th or 9th grade reading level (McLaughlin, 1969). All practice sessions contained the same five passages given in the same order. The program calculated gross typing speed and percent error.

Workstation Set-up. The subjects were provided a chair with an adjustable height seat pan (Aeron, Herman Miller, Zeeland, MI). The work surface was adjustable in height and the keyboards and a conventional 2-button mouse could be placed at any location on the work surface. Subjects were familiarized with the adjustments and during the practice session were instructed to adjust the workstation and keyboard to the most comfortable position. During the experiment subjects were not permitted to alter workstation or keyboard position.

Typing Tasks. A random number generator was used to assign test order of keyboards and typing passages. For each keyboard test condition, subjects typed three of fifteen possible passages in 5-minute blocks. All subjects typed all fifteen passages. Productivity measurements were calculated from the average of the three trials per keyboard condition. They were instructed to type as fast but as accurately as possible. They took a 1-minute break between blocks and a 5-minute break between keyboard test conditions.

Usability and Fatigue Ratings. After each keyboard was used, usability and fatigue were assessed with the ISO keyboard questionnaire (ISO9241-410; 2008). At the end of the study, the keyboards were rank ordered from least to most favorite.

Forearm Electromyography. Muscle activity of two muscles that move the wrist in ulnar deviation, extensor carpi ulnaris (ECU) and flexor carpi ulnaris (FCU), were recorded with surface electromyography (EMG) (TeleMyo 2400T, Noraxon USA Inc, Scottsdale, AZ). Self-adhesive silver-to-silver chloride snap electrodes (active diameter of 10 mm and a center-to-center distance of 20 mm) were placed on cleaned, shaved skin using anatomical landmarks (Perotto, 2005). EMG activity of both muscles was sampled from both the right and left arm at 1500 Hz. The data was normalized to the maximum voluntary electrical exertion obtained by having the subject perform three three-second maximum voluntary contractions (MVC) for each muscle (Shergill et al., 2009)

Wrist Posture Measurement. Wrist flexion/extension and ulnar/radial deviation were measured continuously for both wrists using two inline electrogoniometers (2D goniometer SG-65, Noraxon USA Inc, Scottsdale, AZ). The goniometers were secured to the dorsal surface of the hand and distal forearm and calibrated with the wrist in neutral (0 degrees of flexion, 0 degrees of ulnar deviation) and the forearm in pronation (Shergill et al., 2009). Goniometer output was recorded and converted to degrees deviated from neutral (MyoResearch XP Master Edition, Noraxon USA Inc, Scottsdale, AZ).

Statistical Analysis. Differences between keyboards were evaluated using repeated-measures analysis of variance (RMANOVA) with the Tukey follow-up test for mean typing speed, percent error, and 50% amplitude probability density functions (APDF50) of the EMG (SAS Institute, Cary, NC).

Trial order was also assessed with RMANOVA. Differences in usability scores, fatigue scores, and keyboard preference were analyzed using Friedman's matched group analysis of variance test with Nemenyi multiple comparison test.

RESULTS

The mean subject height and weight were 183.4 cm ± 8.4 cm and 88.1 kg ± 20.2 kg. The right middle finger length (from palmer proximal metacarpophalangeal crease to tip of finger) was 8.74 cm ± 0.30 cm (range 7.65 to 9.47 cm); the right hand length (palmer distal wrist crease to end of middle finger) was 11.5 cm ± 0.53 cm (range 10.6 to 12.7 cm); and the right middle finger width (at proximal interphalangeal joint) was 2.22 cm ± 0.15 cm (range 1.91 to 2.51 cm).

Gross typing speed was significantly slower and error rate was significantly higher for 19x16 compared to the other keyboards (Figure 2). There were no significant typing speed or error rate differences between the other keyboards. There was no significant effect of trial order on typing speed or error rate, indicating no learning effect.

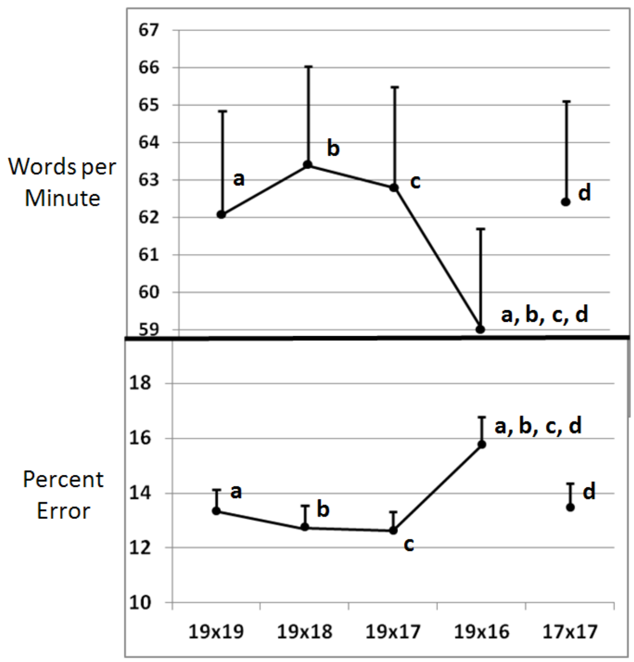

Figure 2. Mean words per minute and percent error by keyboard (key spacing: vertical x horizontal mm). Significant differences between keyboards are noted by a common superscript. Error bars are SEM. (N=37).

Median muscle activity (e.g., APDF50) and mean wrist posture by keyboard are summarized in Figure 3. Significant differences were observed between keyboards for APDF50 muscle activity for the left ECU ($p = 0.008$), right ECU ($p < 0.001$), and right FCU ($p < 0.001$). For the left ECU, muscle activity was significantly greater for the 19x19 keyboard compared to the 19x17 and 17x17 keyboards. For the right ECU, muscle activity was significantly greater for 19x19 than all other keyboards. For the right FCU, muscle activity was significantly greater for 19x19 than 19x17 and 17x17. In addition, right FCU muscle activity was greater for 19x18 compared to 17x17. There were no significant differences between keyboards for the left FCU ($p < 0.085$).

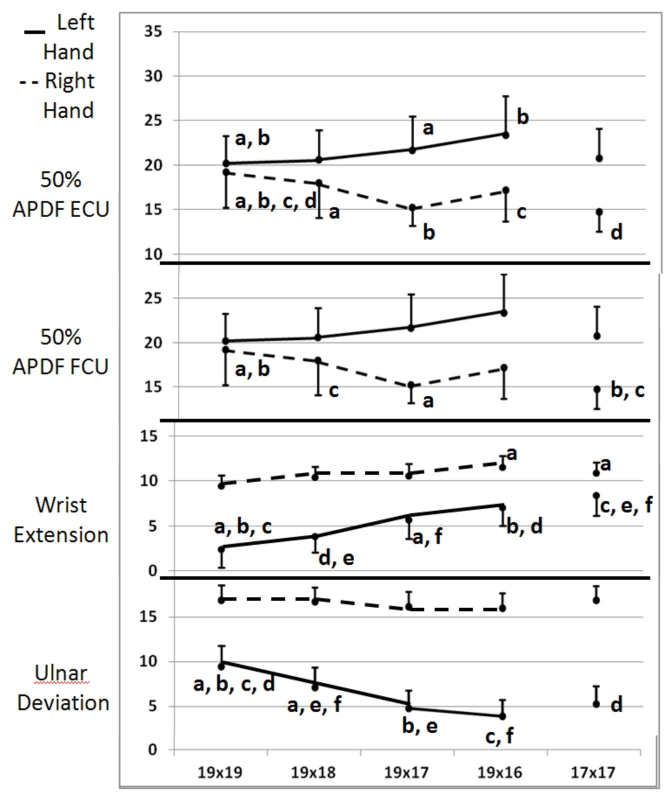

Figure 3. Muscle activity, wrist extension and ulnar deviation during typing by keyboard (key spacing: horizontal x vertical mm). Significant differences between keyboards are noted by a common superscript. Error bars are SEM. (N=35).

Left wrist extension was significantly greater for 17x17 compared to 19x19, 19x18, and 19x17 ($p < 0.001$). It was also significantly greater for 19x16 compared to 19x19 and 19x18 and it was significantly greater for 19x17 than 19x19. Right wrist extension was significantly greater for 19x16 than 17x17 ($p < 0.001$). Left wrist ulnar deviation was significantly greater for 19x19 when compared to all other keyboards ($p < 0.001$). It was also significantly greater for 19x18 compared to 19x17 and 19x16. For right ulnar deviation, no significant differences between keyboards were observed ($p = 0.14$). Average keyboard placement from the edge of the work surface was 6.5 (± 3.7) cm.

Subjective fatigue and usability ratings are summarized in Figure 4. Across all subjective ratings, 19x16 received the worst ratings compared to the other keyboards, while the differences between the other keyboards was not large. Specifically, for *force required to activate keys* and *keying rhythm*, 19x16 was rated significantly worse compared to all other keyboards ($p < 0.001$). For *fatigue in hands or wrists*, 19x16 was rated worse compared to 19x19 and 19x17 ($p = 0.001$). *Fatigue in arms* was significantly rated worse for keyboard 19x16 compared to 19x19 ($p = 0.005$). For *fatigue in* *shoulders*, 19x16 was rated significantly worse than keyboards 19x19, 19x18, and 17x17 ($p < 0.001$). *Posture required for keying* was rated significantly worse for 19x16 compared to 19x18 and 19x17 ($p < 0.001$). Overall, subjects least *preferred* 19x16 in comparison to the other keyboards ($p < 0.001$). There were no significant differences in preference between the other keyboards.

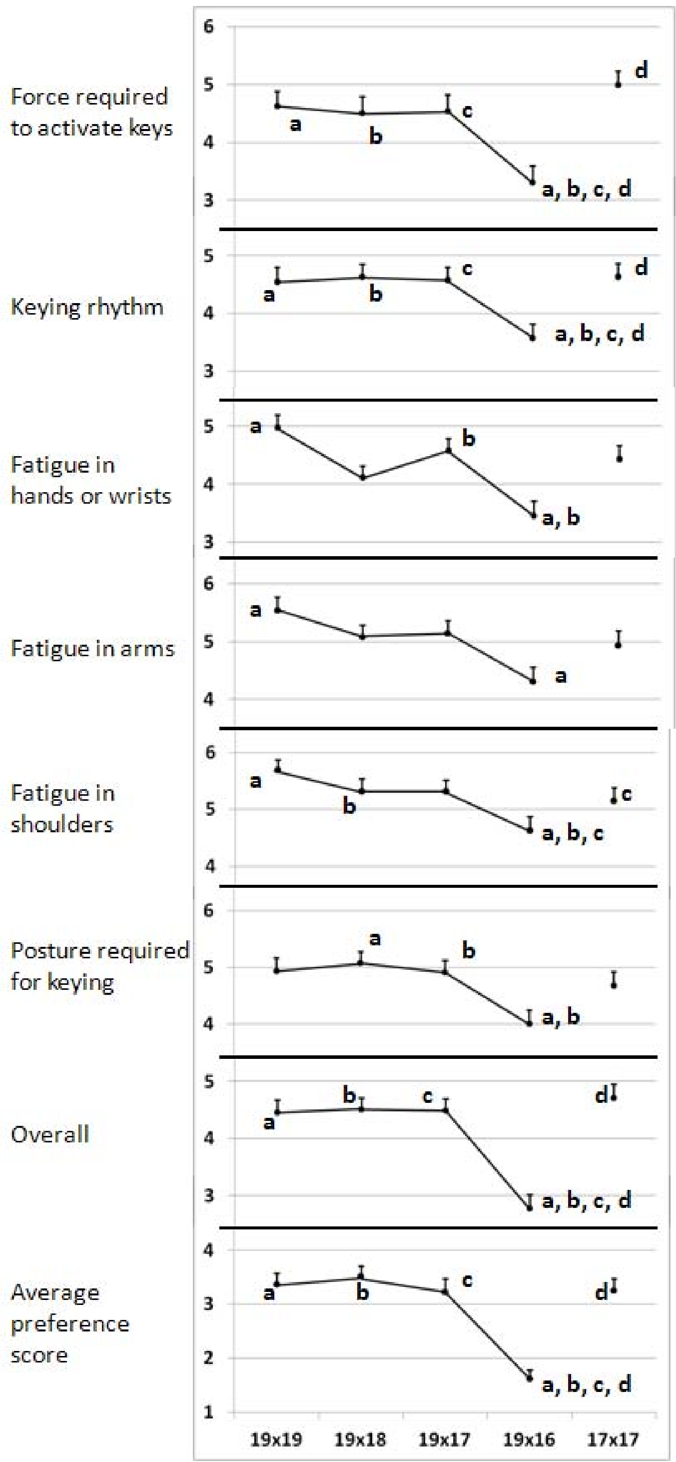

Figure 4. Subjective usability ratings of keyboards (1=poor characteristic and 7=good characteristic). Significant differences between keyboards are noted by a common superscript (Friedman's test and Nemenyi follow up). For preference, keyboards were rank ordered from 1-least favorite to 5-most favorite. Error bars are SEM. (N=37).

DISCUSSION

No significant differences in gross typing speed, percent error, and subjective usability ratings were measured between the keyboards with 17, 18 and 19 mm horizontal key spacing. However, typing speed, percent error, and usability ratings were significantly worse for the keyboard with horizontal key spacing of 16 mm compared to the other keyboards. For vertical key spacing (e.g., 17 and 19 mm) there was no significant difference in these outcome measures. These findings match those of Yoshitake (1995) who reported that subjects with large fingers had no difference in typing speed when the key spacing was 16.7 or 19.0 mm. However, the typing speed decreased when key spacing was 16.0 mm or lower. Although the Yoshitake study did not specifically report typing error rates for large fingered subjects, the combined data across all finger sizes showed a trend of increasing errors at 16mm.

Typically, during typing on a conventional keyboard, percent error decreases with decreasing typing speed. However, typing speed decreased and percent error increased at the 16 mm key spacing. This supports a finding that key spacing, not changes in typing speed, was the cause of increased error. In addition, one might expect that smaller key spacing would allow for faster typing speeds due to the shorter travel distance of the fingers. The decrease in typing speed implies that biomechanical factors, such as fingertip size, are interfering with productivity measurements.

Users reported an increase of key force to activate keys with 16 mm key spacing compared to all other spacings. Since the actual key activation forces were the same for all key spacings, this perception may have been due to fingers touching each other with the 16 mm key spacing. There was a non-significant increase in forearm muscle activity levels for the 16 mm spacing compared to the 17 mm spacing which could have been due to the interference of adjacent fingers with the narrower key spacing. For the 16 mm spaced keyboard, a post-hoc evaluation of the correlations between productivity and error and finger length and breadth, revealed a small correlation (r=0.33) between increasing finger width and increasing error and decreasing productivity and an opposite relationship with finger length (r=-0.40). These findings suggest that finger width, not finger length, may be the factor that limits key spacing.

Overall, however, the effects of key spacing on wrist posture and forearm muscle activity were minimal. There was a trend for muscle activity to increase in the left and decrease in the right forearm with decreasing horizontal key spacing, but the differences were low, only 2-5%. Similar, small differences were observed by Simoneau et al. (2003) when evaluating the effects of the slope of a conventional keyboard on forearm muscle activity. In a different study of auditory force feedback, Gerard et al. (2002) reported significant differences in forearm muscle activity of 1-2% between keyboard conditions. Ergonomic modifications for meat packing jobs have reported reductions of 2-5% in forearm muscle effort (Cook et al., 1999). Therefore, while the observed differences are small, these small differences may be important for tasks preformed for many hours a day.

In this study, as the key spacing decreased, left wrist ulnar deviation decreased and left wrist extension increased. A similar pattern occurred on the right side but the differences were not significant. We previously observed a similar relationship between extension and ulnar deviation when other keyboard design features were modified (e.g., split keyboard) (Rempel et al., 2007). Simoneau et al. (1999), reported greater left wrist extension than right wrist extension on conventional 19x19 keyboards; findings that matched our results.

A limitation of the study was the simple alpha typing task without numbers or punctuation. It is possible that increased numerical input or input using the punctuation keys could have altered the findings. Another potential limitation was the short duration of keyboard use. However, the finding that typists performed equally well on 17, 18, or 19 mm horizontal spacing, suggests that these result are likely to be stable over time. Similar findings have been observed in other studies (Gerard, et al., 1999 & Gerard et al., 2002). The lack of performance changes across the three test trials for the 16 mm spacing suggests that the measured differences were due to the smaller key spacing and not to a lack of familiarity with the small key spacing. Finally, the study population did not include typists with small fingers and did not include females. Subjects with smaller fingers may have demonstrated improved typing performance with the smaller key spacing. The results of Yoshitake (1995) suggest that typists with small fingers will do well with the smaller key separations, even down to 15 mm key spacing.

In conclusion, this study finds that there is little difference in typing speed, percent error and usability measures between keyboards with horizontal key spacing between 17 and 19 mm among typists with large fingers. However, a keyboard with key spacing of 16 mm was associated with a significant reduction in productivity measures and usability ratings. Differences in wrist posture and forearm muscle activity were small, on the order of 2-5%. The effect of key spacing on muscle activity was balanced between the right and left arms. An interesting effect of key spacing on posture was the increased left wrist extension with horizontal or vertical key spacing of 16 or 17 mm, respectively. This may be mitigated by the observed, simultaneous reduction in ulnar deviation. Based on these findings, keyboard designers are encouraged to consider designing keyboards with key spacing of 17 or 18 mm to gain the benefits of smaller keyboards (e.g., smaller and lighter laptops; reduced cost to manufacture; better usability for smaller users; and reduced reach to the computer mouse) while still accommodating the needs of typists with large fingers.

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