

## USER ASSESSMENT OF STANDARD AND REDUCED-SIZE NUMERIC KEYPADS

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As technology improves, portable computers become smaller and more compact. A clear design challenge is to provide a system that is as compact as possible without degrading system usability. The keyboard is still the primary input device for compact computers. Previous research has indicated that reduced key spacing adversely affects skilled typing. Therefore, a portable computer system should provide a keyboard with full-sized keys in the primary typing area. The purpose of this study was to determine if reducing key size and spacing adversely affects the usability of a numeric keypad. Skilled keypad operators compared a standard-size numeric keypad to two keypads that had reduced center-to-center key spacing. One of these keypads achieved its reduction primarily by reducing the key size and spacing. The other reduced both key size and spacing. (Note that the small changes in key size and spacing have little effect on the overall device dimensions of a numeric keypad.) Operators typed numbers faster with and preferred the standard keypad over the keypad with both reduced key size and key spacing. If a numeric keypad is offered as part of a portable computer, every effort should be made to provide full-sized keys. If reduced key spacing is unavoidable, wide keys are preferable to narrow keys.

### OBJECTIVE

The objective of this study was to determine if a numeric keypad could be reduced in size without degrading the performance of the keypad for skilled keypad operators. As technology improves, portable computers become smaller and more compact. A clear design challenge is to provide a system that is as compact as possible without degrading system usability. The keyboard is still the primary input device for compact computers. Previous research has indicated that reduced key spacing adversely affects skilled typing. Kennedy and Loricchio (1987) compared standard and reduced-size keyboards. The standard size keyboard had 19 mm spacing in both the horizontal and vertical dimensions. The reduced size keyboard had 19 mm horizontal spacing and 15 mm vertical spacing. The keyboards were identical except for the difference in vertical key spacing. Although there were no significant differences in typing speed or error rate, users significantly preferred the keyboard with 19 mm spacing over the keyboard with 15 mm spacing. They indicated that they believed that the full-size keyboard was easier to use and was the keyboard they would choose to purchase.

This research (Kennedy and Loricchio, 1987) indicated that a portable computer system should provide a keyboard with full-sized keys in the primary typing area. Based on this information, it is reasonable to hypothesize that reducing the size of the numeric keypad would show similar results. Because there are relatively few keys on a numeric keypad, small reductions in key size and spacing of a numeric keypad do not result in very large reductions in the overall dimensions of the device. However, if the reductions have no effect on user performance or preference, then the reduction in key spacing and size

would help the design goal of making the portable as compact as possible. The purpose of this study was to determine if reducing key size and spacing adversely affects the usability of a numeric keypad. To test this hypothesis, skilled keypad operators compared three commercially available numeric keypads.

### METHOD

#### Participants

Fifteen participants were recruited from a temporary-help employment agency. All but one participant had experience using spreadsheet applications on a computer. Experience with spreadsheets ranged from two months to more than four years. Six had more than four years of experience, five had from one to three years of experience, and three had less than one year of experience. Seven participants had college degrees, six had completed some college courses, and two had high school education. All participants said they could use a numeric keypad without looking at the keys.

#### Keypads

The layout of the numeric, add, and clear keys was the same on all three keypads. These were the only keys used by the participants. Table 1 shows the key size and spacing for these keypads. The keypads were categorized by two characteristics: center-to-center key spacing (18 mm or 16 mm); and width of the key cap (wide or narrow). The keypads are referred to as "18" (18 mm spacing), "16W" (16 mm

spacing, wide keys), and "16N" (16 mm spacing, narrow keys).

Table 1. Key Dimensions

Keypad	Key spacing		Key size	
	Horiz.	Vert.	Width	Height
18	18	15	14	10
16W	16	12	14	9
16N	16	15	10	10

**Procedure**

Pairs of Latin squares (Lewis, 1989) were used to counterbalance the order in which the participants used the keypads and stimulus sets. Participants received five minutes of practice on each keypad. Each participant used all three keypads to add a set of numbers. Each set consisted of 100 five-digit numbers. The numbers were arranged in 25 rows, with four numbers in each row. The participants' task was to add the four numbers in each row and to write the sum in the space beside each row. Participants' scores were the number of sums calculated during a seven-minute period. After completing the addition task with all three keypads, participants ranked the keypads in order of their preference.

**RESULTS AND DISCUSSION**

Tables 2, 3 and 4 show the results for the dependent variables of preference, input rate, and error rate. A Friedman test (Hollander and Wolfe, 1973) indicated a significant difference in preference among the keypads ( $X^2(2) = 8.93, p < .05$ ). Distribution-free multiple comparisons based on the rank sums (Hollander and Wolfe, 1973) showed that the 18 keypad was significantly preferred over the 16N keypad ( $p < .05$ ). Analyses of variance were used to analyze typing speed and errors. Keypad type had a significant effect on typing speed ( $F(2,14) = 3.02, p < 0.06$ ). Participants typed significantly faster with the 18 keypad than with the 16N keypad (Duncan range test,  $p < .05$ ). There were no significant differences in error rates ( $F(2,14) = 1.96, p = 0.16$ ).

Table 2. Mean Preference Ranks

18 keypad	Multiple Comparisons	
	16W keypad	16N keypad
1.40	2.13	2.47

Note: Means connected by a line are not significantly different at the .05 level.

Table 3. Mean Input Rate (keystrokes/minute)

18 keypad	Multiple Comparisons	
	16W keypad	16N keypad
79.75	76.18	73.29

Note: Means connected by a line are not significantly different at the .05 level.

Table 4. Mean Error Rate (incorrect calculations/minute)

16W keypad	Multiple Comparisons	
	18 keypad	16N keypad
0.33	0.29	0.15

Note: Means connected by a line are not significantly different at the .05 level.

**CONCLUSIONS**

Skilled keypad operators compared a standard-size numeric keypad to two keypads that had reduced center-to-center key spacing. One of these keypads achieved its reduction primarily by reducing the key spacing. The other reduced both key size and spacing. (Note that small changes in key size and spacing have little effect on the overall device dimensions of a numeric keypad.) Operators typed numbers faster with and preferred the standard keypad over the keypad with both reduced key size and key spacing. If a numeric keypad is offered as part of a portable computer, every effort should be made to provide full-sized keys. If reduced key spacing is unavoidable, wide keys are preferable to narrow keys.

**REFERENCES**

Kennedy, P.J., and Loricchio, D.F. (1987). Key space and user productivity. In *Abridged Proceedings of Poster Sessions of the Third International Conference on Human-Computer Interaction* (page 48). New York, N.Y.: Elsevier.

Hollander, M. and Wolfe, D. A. (1973). *Nonparametric statistical methods*. New York, NY: John Wiley.

Lewis, J.R. (1989). Pairs of Latin squares to counterbalance sequential effects and pairing of conditions and stimuli. In *Proceeding of the Human Factors Society 33rd Annual Meeting*, Santa Monica, CA: Human Factors Society.

## FINGERTIP FORCES WHILE USING THREE DIFFERENT KEYBOARDS

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The relationship of chronic musculoskeletal disorders, such as carpal tunnel syndrome and wrist tendinitis, to prolonged alphanumeric keyboard use is controversial. Known risk-factors for these disorders, such as repetition of task, forceful exertions, awkward joint postures, direct mechanical pressure, and prolonged constrained posture, may be applicable to keyboard use. In this study fingertip forces were measured for 10 typists using three alphanumeric keyboards that differed only in their key force and displacement characteristics. While subjects typed, peak fingertip force was collected for each keystroke using strain gauge load cells. The mean peak fingertip forces applied by all subjects for all keys for the three keyboards were 193 gm, 182 gm and 220 gm; significantly different means. The 18% reduction in fingertip force in the second keyboard compared with the third is attributed to a higher minimum force of activation and a higher force at total key travel in the third keyboard. This study indicates that keyboard key force-displacement characteristics can be altered to reduce the fingertip forces applied by typists and theoretically this may reduce the risk of developing chronic musculoskeletal disorders.

### Introduction

The relationship of chronic musculoskeletal disorders, such as carpal tunnel syndrome and wrist tendinitis, to prolonged alphanumeric keyboard use is controversial and the subject of OSHA citations and recent regulations. Several work-related risk factors for these disorders have been identified and may be applicable to keyboard use (Stock, 1991). These are: repetitiveness of a task, forceful exertions, awkward joint positions, direct mechanical pressure, and prolonged constrained posture. It is hypothesized that wordprocessors or data entry clerks apply varying fingertip forces to the keyboard when typing and may apply forces much higher than the minimum required for key contact closure. In this study, equipment and procedures were developed and tested to assess fingertip forces applied by wordprocessors using three different keyboards.

### Methods

Nine touch typists and one hunt-and-peck typist typed alphabetic sentences, containing all letters of the English alphabet, for approximately 10 minutes on each of three keyboards. The order of keyboard testing was random. The chair and keyboard height were adjusted for each subject so that thighs and forearms were approximately level. No support was provided for subjects' palms, wrists or forearms.

Vertical forces applied to a keyboard were recorded from a strain gauge load cell attached to each side of the keyboard. The load cell outputs were summed, amplified, converted to a digital signal and stored on a personal computer. Linearity of output was  $\pm 1\%$ , and was assessed by applying four known weights to the keyboard. The load cells are not sensitive to bending moments. Calibration of linearity of force measurement over the keyboard surface was  $\pm 4\%$  and was assessed by placing a fixed weight on each corner and center of the keyboard.

The three keyboards tested (Kb1, Zenith ZKB-2; Kb2, ICOM Wave; Kb3, IBM PC) were of standard alphanumeric Sholes brothers' layout (QWERTY) and differed only in their key force and displacement characteristics. Force-displacement characteristics of the five

keys most frequently and least frequently used (e, o, z, k, space bar) were determined for each keyboard (Mayzner and Tresselt, 1965). Key displacement was measured with a linear potentiometer advanced slowly with a rack and pinion drive while force values were collected simultaneously. Displacement accuracy was  $\pm 0.5\%$ . Key force-displacement curves can be characterized by three points: the peak tactile point (a), the inflection after peak tactile point (b), and total key travel point (c) (Figure 1).

Fingertip forces were recorded during the last four sentences of the typing task. Force values were collected every five milliseconds. Force values were stored for each keystroke, beginning 15 milliseconds before key contact and continuing for 50 milliseconds after contact, and the peak force for each key stroke was stored. For each subject and keyboard the average peak force applied for 270 keystrokes was calculated.

Statistical analysis was performed using SAS. A mixed effects ANOVA was used with the mean peak fingertip force as the dependent variable. The fixed effects were keyboard, row, and finger and typing rate was a covariate. The random effects were subject and the interaction between subject and each of the fixed effects.

### Results

Force-displacement characteristics of each keyboard differed markedly. Figure 1 shows the force-displacement characteristics of the "e" key for each keyboard. The mean peak tactile forces (and standard deviations) for selected keys for keyboards Kb1, Kb2 and Kb3 in grams were 57.1 (5.7), 53.8 (7.5), and 95.1 (24.1) respectively. The mean forces at total key travel were 64.0 (9.1), 55.4 (12.5), and 105.8 (24.0). The tactile feedback was calculated as the difference between the peak tactile force and the subsequent inflection after the peak tactile force. These values in grams were 4.7, 6.6, and 25.6, respectively. All key force-displacement characteristics fell within ANSI guidelines (ANSI, 1988).

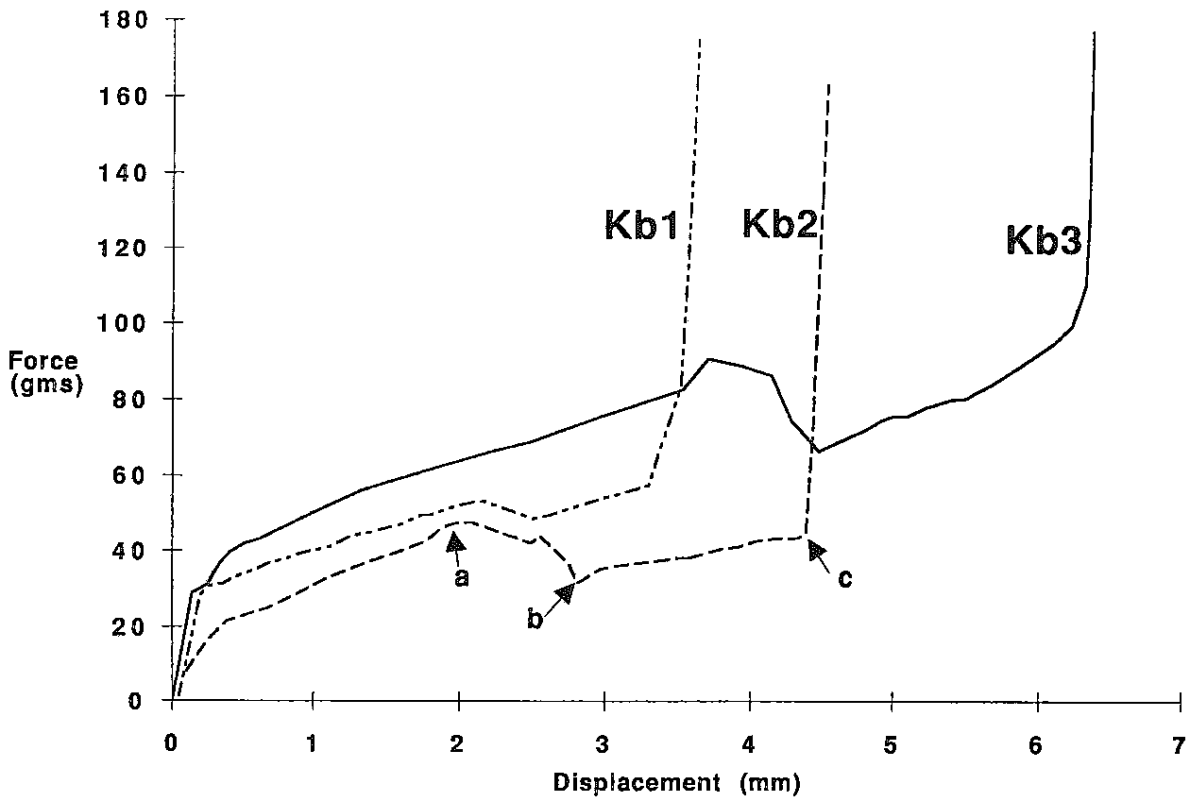


Figure 1. Mean force versus displacement for the "e" key on three keyboards. Peak tactile point (a), inflection after peak tactile point (b), and total key travel point (c) are indicated for keyboard 2.

The mean peak fingertip forces (standard deviation) applied by all subjects for all keys were 193 gm (62), 182 gm (55), and 220 gm (44), for each keyboard respectively. These values are significantly different using Scheffe's method for multiple comparison produced by SAS. The mean peak fingertip force applied to keyboard 2 was 18% less than the force applied to keyboard 3 and corresponded to the higher peak tactile force and force at total key travel of keyboard 3. The differences in fingertip forces were not related to tactile feedback force (a-b).

On average, the peak fingertip forces applied by subjects were 3.1 times greater than the force required for key activation. Subjects applied significantly different forces to the keyboards, with a range of 2.2 to 4.7 times the force required for key activation. Mean fingertip forces by finger are presented in Table 1 and grouped into significantly different force groupings using Scheffe's method for multiple comparison. The maximum differences between the mean finger forces (right middle finger and the right pinkie) is 14%. The Table also indicates the probability of using the finger when typing standard text (Mayzner, 1965).

Table 1. Mean force by finger grouped into significantly different grouping by Scheffe's method. Also, probability of use of the finger based on standard text (Mayzner, 1965).

Finger	Force (gm)	Probability of use
R middle	213.2	0.062
R index	211.0	0.215
L index	201.4	0.223
L middle	198.4	0.200
R ring	191.4	0.111
L pinkie	189.6	0.082
L ring	188.1	0.091
R pinkie	183.7	0.015

Table 2. ANOVA table with peak fingertip force as the dependent variable.

Variable	Mean Square	F Value	P Value
Keyboard	502403	315.42	0.001
Subject	765213	480.41	0.0001
Row	5680	3.57	0.435
Finger	73160	45.93	0.0002
Typing rate	8624	5.41	0.02
Kb * Subj	54523	34.23	0.0001
Subj * Row	6558	4.12	0.0001
Subj * Finger	15461	9.71	0.0001

Table 2 summarizes the results of the ANOVA. P values were generated by SAS using appropriate hypothesis tests. Consequently they do not correspond to the tabled F values. All effects were significant except the main effect for row. The main effects for subject and keyboard explained the most variation in each analysis.

### Discussion

Epidemiologic studies of assembly line workers have identified repetitive motions and forceful exertions as risk factors for chronic musculoskeletal disorders. Furthermore, when acting together, these two risk factors are multiplicative not additive (Silverstein et al, 1987). The implications of this for keyboard work are that for very repetitive key entry (keystroke rates can be as high as 50,000 to 200,000 keystrokes per day) high fingertip forces may contribute to the development of chronic musculoskeletal disorders. A relatively minor reduction in applied fingertip force will significantly reduce the daily cumulative force applied by the fingers.

Previous studies have reported that force-displacement characteristics of alphanumeric keyboards can affect typing performance (Kinkead and Gonzalez, 1969). This study indicates that force-displacement characteristics can also affect the fingertip forces applied during typing tasks. Specifically, reducing the key switch force of activation and the force for total key travel can reduce the peak fingertip force applied by as much as 18%. In order to prevent accidental key switching, however, there is a limit to how much the force of activation can be reduced.

Further studies are necessary to identify the factors that are associated with high fingertip forces while working with a keyboard. For example, what are the roles of (1) keyboard design, such as audio or tactile feedback and other force-displacement functions, (2) keyboard height, (3) support accessories, such as wrist, forearm or elbow rests, (4) work-rest cycle, (5) electronic monitoring and other sources of psychological stress, on modifying fingertip forces. Finally, the role of fingertip force as an independent risk factor for the development of chronic musculoskeletal disorders among wordprocessors needs further evaluation.

### References

- ANSI/HFS: American National Standard for Human Factors Engineering of Visual Display Terminals. Standard No. 100-1988, Human Factors Society, Santa Monica, 1988.
- Kinkead RD and Gonzalez BK: Human Factors Design Recommendations for Touch-Operated Keyboards - Final Report, Doc # 12091-FR. Honeywell, Inc. Minneapolis, 1969.
- Mayzner MS and Tresselt ME: Tables of single-letter and diagram frequency counts for various word-length and letter-position combinations. *Psychonomic Monograph Suppl* 1965; 1:13-32.
- Silverstein BA, Fine LJ, Armstrong TJ: Occupational factors and carpal tunnel syndrome, *Am J Ind Med* 1987; 11:343-358
- Stock SR: Workplace Ergonomic Factors and the Development of Musculoskeletal Disorders of the Neck and Upper Limbs: A Meta-Analysis. *Am J Ind Med* 1991; 19:87-107.