Relationship between Key Space and User Performance on Reduced Keyboards

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Abstract. Small computers are much in demand for mobile computing. However, keyboard size is an obstacle to further size reduction. Reducing the space occupied by keys would affect the usability of the keyboard. On the other hand, if the keys were closer together, the fingers would reach them faster. This could improve typing performance. An experiment was therefore conducted to investigate the relationship between users' performance and the center-to-center key space of reduced-size keyboards. Eighteen touch-typists were asked to do a word typing task on five different keyboards. A standard keyboard with a key space of 19.05 mm and smaller keyboards with key spaces of 16.7, 16.0, 15.6, and 15.0 mm were used in this study. No performance degradation was found on keyboards with a key space of 16.7 mm for faster typists (those capable of about 40 wpm), including those with large fingers (97.5 percentile of Japanese adult males). For faster typists with narrow fingers, there was no performance degradation on keyboards with a key space of 15.0 mm.

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Introduction

The market for notebook computers has increased as a result of the spread of mobile computing. The smaller the computer, the easier it is to carry. On the other hand, it is thought that reducing the size of either the display or the keyboard beyond a certain limit would degrade the usability of a computer. Users seem to prefer a large display when they want to read information from it, but they do not always require a larger keyboard. The center-to-center distance between two adjacent keys (henceforth termed the key space) of most currently used keyboards is about 19 mm. What constitutes an appropriate key space on keyboards for typewriters and computers does not seem to have been discussed adequately. According to a review by Alden et

al. (1972), there seems to be no scientific basis for the 19 mm size generally used as a standard. Some ergonomic standards, however, limit the size and spacing of keys. ANSI (1988) states that "center line distances between adjacent keys shall be between 18 and 19 mm horizontally and between 18 and 21 mm vertically." The ISO/DIS 9241-4 (1992) states that "the horizontal and vertical distances between two adjacent keys measured centre shall be $19 \text{ mm} \pm 1 \text{ mm}$ for the alphanumeric section." Defining a standard size for keyboards benefits both users and manufacturers. However, not all users may be satisfied with the standard size, because human hands vary in size and shape. Moreover, if the key spaces were smaller, the fingers would be able to reach the keys faster.

A large amount of research on ergonomic keyboard design has been reported (Alden et al., 1972; Norman and Fisher, 1982; Miller and Suther III, 1983; Paci and Gabbrielli, 1984; Weber et al., 1984; Cushman, 1984; Nakaseko et al., 1985; Irg, 1987; Drury and Hoffmann, 1992). Most of this research, however, has focused heavily on keyboard layout, profile, setting, and posture. Very little research has been reported on appropriate key spacing. With the recent strong demand for smaller computers, reducing key space has become one of the most important design issues. It is very important to find an appropriate and/or acceptable size for this space that does not reduce typing productivity. The purpose of the study described here was to investigate the relationship between the key space of reduced-size keyboards and the typing performance of typists with various finger sizes.

Method

Participants

Eighteen touch-typists participated in this study. Ten (5 females and 5 males) out of 18 subjects were residents in the U.S. and the rest (5 females and 3 males) were residents in Japan. Their ages ranged from 25 to 55. Subjects with various finger sizes were selected. Because of the need to find people with larger fingers,

some of the subjects were recruited by a local temporary employment agency.

Apparatus

Five different kinds of keyboard were compared in this study. Table 1 shows the profile of each. The keyboard of the IBM ThinkPad 700C, which has a center-to-center key space of 19.05 mm, was used as a standard, and the keyboard of the IBM ThinkPad 220, which has a key space of 15.0 mm, was also used. Three working prototypes of keyboards were manufactured for this study, with key spaces of 16.7, 16.0, and 15.6 mm. The same key switch was employed on the prototypes, and only the key spaces were different. A force displacement curve of the key switches on the prototype keyboards is shown in Fig. 1. These prototypes had some limitations. The tops of the keys were not marked, and some large keys such as "Shift" and "Return" were replaced by smaller keys. A word typing task was, therefore, developed to overcome these limitations.

Task

A program was developed for the word typing task used in this study. When a subject invoked the program and pressed the space bar, an English word of between two and fourteen characters appeared at the center of a CRT display. The subject was asked to type the word correctly and as quickly as possible. The characters typed were displayed below the corresponding initial characters. If the subject finished typing the word correctly, the next word to be typed automatically appeared at the same location on the display, without the

Table 1 Keyboard features used in this experiment

	Key pitch	Keyboard	Keytop width
A	19.05 mm	TP-700C	13.2 mm
B	16.7 mm	Prototype	10.4 mm
C	16.0 mm	Prototype	10.4 mm
D	15.6 mm	Prototype	10.4 mm
E	15.0 mm	TP-220	11.8 mm

Note) Keyboard slope: 7 degrees
Home-row height: 40 mm

"Return" key being pressed. If the subject typed a wrong character, a beep sounded and the program stopped until the correct character was typed. The program was run on the TP-700C, whose speaker volume was set at the maximum position. The words used in this experiment were randomly obtained from newspaper articles, and difficult words, such as proper nouns and words above the 10th-grade level, were omitted from the dictionary for this program. Words with capital letters were also removed from the dictionary. The number of words to be typed in a session was 129 and the number of characters that appeared in a session was 606. The task completion time was used as an index for evaluating user performance. The number of errors (typing mistakes) was also counted and analyzed as a reference data item, because the error factor was included in the task completion time. If the number of errors increased, the task completion time would generally be lengthened. One of the purposes in developing the word typing task was to incorporate an accuracy index into the typing speed. A monitor program that recorded and key-stamped key-strokes was also used. This program was always running in the background of the word typing task program.

Procedure

Before the test, some anthropometric data on hands

Fig. 2 Illustration of some measurements obtained in this experiment

Fig. 1 Force displacement curve of key switches on prototype keyboards

Fig. 3 Means and standard deviations of the task completion time for 18 subjects

Fig. 4 Means and standard deviations of the error times for 18 subjects

were obtained from all the subjects. Measured items were finger III length (D8), hand length (D4), maximum distance from finger I to finger V (D33), hand breadth at metacarpal (D13), maximum finger III breadth (D14), finger III breadth (D15), and finger tip breadth. The landmarks for the measurement were selected in accordance with the specifications given in an ergonomic encyclopedia (Inoue, 1983). Since the finger tip breadth was not defined in the encyclopedia, the maximum width of the part of the finger containing the finger nail was used as the finger tip breadth (width), as shown in Fig. 2. At the beginning of the test, each subject was asked to do some practice. This was divided into two sessions. One was for warming up in touch-typing. Each subject was asked to type a document in a typing-practice program at his/her own pace for about six minutes. The second practice session was to familiarize the subjects with the word typing task. All the subjects performed the task twice before beginning the test. An IBM 5576-003 keyboard of standard size was used in the practice session. After the practice, each subject was encouraged to adjust the chair height to a satisfactory level. The order in which the keyboards were tested was counterbalanced to minimize any first-order interference or task learning. Two sessions were carried out for each keyboard, and the faster trial on each keyboard was used as an evaluation index.

Experimental Condition

Lighting was provided by overhead fluorescent lamps. The level of ambient illumination was measured

and set to 250 lx (display surface). The table height was 700 mm. The keyboard slopes of the prototypes and the TP-220 were adjusted to that of the TP-700C, which was about 7 degrees. The height of the home row key on each keyboard was set at 40 mm. A CRT display (IBM 8512) was used for all conditions. The target word was displayed on the CRT display at about 1.1 meter from the floor.

Results

Fig. 3 shows the means and standard deviations of the task completion time on each keyboard for all subjects (N=18). As the key space became smaller, the task completion time tended to increase. However, one-way analysis of variance (ANOVA) showed that the key space had no significant effect on the task completion time. This seems to be due to the large variance in each task completion time. In other words, the typing skills of the subjects participating in this experiment

Table 2 Means and standard deviations of the task completion time for each group

Key board	Task completion time(sec)			
	Large-Fingered Group		Small-Fingered Group	
	Mean	S.D.	Mean	S.D.
A	169.23	10.59	188.97	22.45
B	169.03	12.96	197.00	24.20
C	173.01	10.81	195.93	27.05
D	176.87	12.46	194.79	23.08
E	193.85	23.77	208.74	30.22

Fig. 5 Means and standard deviations of the task completion time for each group

varied considerably, although all of them were touch typists. The mean and standard deviation of the number of errors on each keyboard, shown in Fig. 4, followed the same tendency as the task completion time.

In order to assess the effect of finger size, the subjects were divided into two groups according to the width of their finger tips. The means and standard deviations for each group are shown in Table 2. As a result of two-way ANOVA, significant differences were

found in two main factors (key space : $F(4,80) = 2.98$, $p < 0.05$, and finger size of group : $F(1,80) = 21.96$), $p < 0.01$, but no significant relation between the key space and the finger size of the group was found in the task completion time. Table 2 suggests that the difference in typing performance between the two groups was too large to allow the effects of finger size to be determined.

Some subjects showed constant typing performance, with narrow variances in the task completion time across keyboards. Since there were large variances in the time taken by slower typists, the faster typists were separated and their times were compared. The criterion for selecting the faster typists was a task completion time of less than 170 seconds in at least one trial in this experiment. In this experiment, 170 seconds approximately corresponded to a typing speed of 40 words/min (wpm). Eight subjects met the criterion, and were divided into two groups according to the width of their finger-tips. Table 3 shows anthropometric data on the eight subjects. As shown in Table 3, the finger tip breadths of the group with large fingers were significantly larger than those of the group with small fingers. Figure 5 shows the mean and standard deviation of the task completion time for each group. As a result of two-way ANOVA, significant differences were found in two main factors (key space: $F(4,30) = 5.78$, $p < 0.01$, and finger size of group : $F(1,30) = 21.13$, $p < 0.01$). There was also a significant relation between the key space and the finger size of the group ($F(4,30) = 3.21$, $p < 0.05$). This indicated that the effect of the key space on the typing performance was different for the groups with large and small fingers. In comparison with the results for standard key space of 19.05 mm, there was no performance

Table 3 Anthropometric data for 8 subjects (unit: mm)

Large-Fingered Group		L1	L2	L3	L4	Mean	S.D.
—	Finger tip breadth	20.0	19.2	20.5	19.0	19.7	0.70
D15	Finger III breadth	19.0	18.4	20.5	19.2	19.3	0.88
D14	Maximum finger III breadth	23.0	20.7	23.8	22.2	22.4	1.32
D13	Hand breadth at metacarpal	100.0	85.0	95.0	97.0	94.3	6.50
D33	Maximum distance finger I to V	230.0	206.0	230.0	250.0	229.0	18.00
D4	Hand length	195.0	185.0	202.0	203.0	196.3	8.30
D8	Finger III length	84.0	78.0	90.0	87.0	84.8	5.12
A1	Stature(height)	182.9	177.8	190.5	172.7	181.0	7.59

Small-Fingered Group		S1	S2	S3	S4	Mean	S.D.
—	Finger tip breadth	17.0	16.5	17.2	17.1	17.0	0.31
D15	Finger III breadth	17.0	17.0	17.4	15.8	16.8	0.69
D14	Maximum finger III breadth	17.5	19.0	20.0	19.6	19.0	1.10
D13	Hand breadth at metacarpal	80.0	84.0	92.0	85.0	85.3	4.99
D33	Maximum distance finger I to V	190.0	190.0	197.0	202.0	194.8	5.85
D4	Hand length	185.0	178.0	177.0	179.0	179.8	3.59
D8	Finger III length	80.0	78.0	76.0	80.0	78.5	1.91
A1	Stature(height)	170.2	167.6	170.0	173.0	170.2	2.21

degradation in either group for a key space of 16.7 mm. However, the performance of the group with large fingers started to decrease for a key space of 16.0 mm. The performance of the group with small fingers did not decrease even for a key space of 15.0 mm. No significant differences in the number of errors were found for the various key spaces and interactions, and only the effect of the finger size of the group was significant.

Discussion

A recent study (Irg, 1987) confirmed that a key space of about 19 mm was optimal both vertically and horizontally. In the results, however, the total rank numbers against the key spacing levels showed large variances. The relation between the key space and the finger size of the subjects was not discussed in the study. Another study (Drury and Hoffmann, 1992) systematically reported the relations between key space and the width of the finger pad on the movement time. However, that study was carried out on keyboards for single-finger operation, not on "QWERTY" keyboards for touch-typing. The present study concerns "QWERTY" keyboards, and how much their size can be reduced.

In this experiment, no performance degradation was found in the group with broad finger tips for a key space of 16.7 mm. This group included two subjects with larger fingers than the 97.5 percentile of Japanese adult males, which approximately corresponds to the 75 percentile of US adult males. The maximum finger III breadth was used to represent the percentiles, because reliable anthropometric data on finger-tip breadth and finger III breadth were not available. The anthropometric data were obtained from some references (Diffrient et al., 1974; Pheasant, 1986; Inoue et al., 1992). In the group with small fingers, there was no difference in the performance for any of the keyboards used in this experiment. If they became accustomed to a small keyboard, their performance might be better than for standard keyboards, as we hypothesized. Some people may still insist that the size of keyboard should be standardized to give touch-typists a consistent "feel". However, as some researchers have pointed out (Yamada, 1980, 1981; Sakamura, 1987), at least three sizes of keyboards (S, M, and L) are necessary from the anthropometric viewpoint. This claim seems to be supported by the results of the present study.

These results will be useful for designing usable small keyboards. Although user performance and productivity are among the most important measurable indexes in usability, comfort and absence of fatigue are also important. Reducing the size of the keyboard might cause a lateral deviation of the hands (ulnar deviation). Further research on these factors is needed.

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