Mind the Gap: The Effect of Keyboard Key Gap and Pitch on Typing Speed, Accuracy, and Usability, Part 3

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Objective: The aim of this study was to evaluate the effects of key gap (distance between edges of keys) on computer keyboards on typing speed, percentage error, preference, and usability.

Background: In Parts 1 and 2 of this series, a small key pitch (center-to-center distance between keys) was found to reduce productivity and usability, but the findings were confounded by gap. In this study, key gap was varied while holding key pitch constant.

Method: Participants (*N* = 25) typed on six keyboards, which differed in gap between keys (1, 3, or 5 mm) and pitch (16 or 17 mm; distance between centers of keys), while typing speed, accuracy, usability, and preference were measured.

Results: There was no statistical interaction between gap and pitch. Accuracy was better for keyboards with a gap of 5 mm compared to a 1-mm gap (p = .04). Net typing speed (p = .02), accuracy (p = .002), and most usability measures were better for keyboards with a pitch of 17 mm compared to a 16-mm pitch.

Conclusions: The study findings support keyboard designs with a gap between keys of 5 mm over 1 mm and a key pitch of 17 mm over 16 mm.

Applications: These findings may influence keyboard standards and design, especially the design of small keyboards used with portable devices, such as tablets and laptops.

Keywords: keyboard design, key cap, human–computer interaction, computer input devices

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INTRODUCTION

This is the third paper in a series of studies on the effects of keyboard key spacing on typing performance, preference, and usability. Smaller keyboards—both laptop and peripheral—are used increasingly as a result of the popularity of smaller laptop computers and tablets. Advantages of a smaller keyboard include a smaller, lighter computer with 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, 2008). Industrial designers can achieve smaller keyboard size in part by decreasing the distance between keys.

Key spacing is specified by horizontal and vertical key pitch, that is, the center-to-center distance between keys, and horizontal and vertical key gap, that is, the distance between adjacent key edges (Figure 1). Most national and international standards specify a key pitch of 19 mm but do not specify key gap (American National Standards Institute, 2007; International Organization for Standardization, 2008). Most laptop and desktop keyboards follow the key pitch specification of 19 mm. However, as discussed in the previous two papers in this series (Pereira et al., 2013; Pereira, Hsieh, Laroche, & Rempel, 2014), the recommended key pitch has been driven largely by design convention, not by empirical data on typing performance. The first two studies in our series showed that key pitch could be reduced to 17 mm without a reduction of typing speed, accuracy, or subjective usability.

There is a recent industrial design trend to smooth the keyboard into a uniform flat surface with key tops flat instead of concave and a small gap between the keys. Ilg (1987) investigated the effects of 16 keyboard design parameters on performance and preferences and found that participants preferred a concave key top to a flat

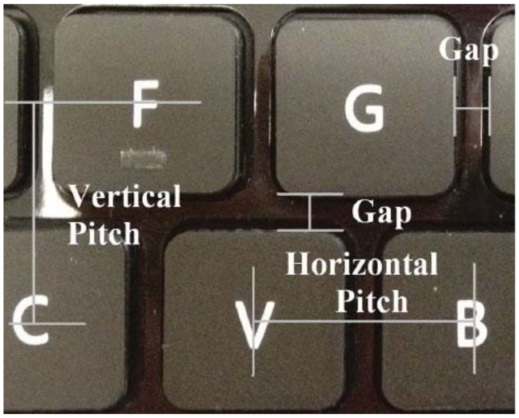

Figure 1. Schematic of key vertical pitch, horizontal pitch, and key gap.

one. However, the effect of a reduced gap between keys on typing performance or preference has not been studied. It is possible that a small key gap may reduce typing accuracy by increasing the probability of accidentally striking both the target key and an adjacent key. The problem may be compounded with the flat key top, where reduction of tactile feedback on key location impairs the typing activity of returning the fingertips to the center of the keys on the home row after a key strike.

In Parts 1 and 2 of this series, we primarily evaluated the effects of horizontal and vertical key pitch on keyboard performance and preference (Pereira et al., 2013, 2014). However, since the key top size was the same in the test conditions, gap varied with the pitch. For example, in Part 1 we compared keyboards with a horizontal pitch of 16.0, 17.0, 18.0, and 19.0 mm, all with a key top size of 14.7 mm; so the horizontal gap varied by 1.3, 2.3, 3.3, and 4.3 mm. In Part 2 we compared vertical pitch of 15.5, 16.0, 17.0, and 18.0 mm, all with a key top size of 13.7 mm; so the vertical gap varied by 1.8, 2.3, 3.3, and 4.3 mm. In those studies, the smallest pitch, and therefore the smallest gap, was associated with reduced performance and preference. Therefore, it was difficult to disentangle the effects of pitch and gap. For the present study, gap was varied (1.0, 3.0, and 5.0 mm) whereas pitch was held constant (either 16.0 or 17.0 mm). In the present study, key top size varied with gap to maintain key pitch constant. The null hypothesis is that there is no difference in typing speed, accuracy, preference, or usability for participants when typing on keyboards with the same key pitch but with a small key gap in comparison to a keyboard with a larger key gap.

METHOD

In this laboratory study, 25 participants typed text passages using six different keyboards. The two independent variables were keyboard key gap (1, 3, and 5 mm) and key pitch (17 and 16 mm). The dependent variables were gross and net typing speed, typing accuracy, and subjective ratings and rankings of keyboard usability and preference. The study was approved by the university institutional review board, and all participants signed consent forms.

Participants

Participants of different typing abilities were recruited from among participants in prior studies. They were excluded if they reported current upper-extremity musculoskeletal disorders.

The study population included 14 women and 11 men; the mean age was 36 years (Table 1). All participants were asked how often they looked at their hands while typing: never, always, or sometimes. The majority (72%) reported sometimes looking at their hands while typing. Right-hand finger width, hand length, and hand width were measured on each participant (Pereira et al., 2013). The mean middle-finger width (distal interphalangeal joint) was 1.6 cm (range 1.5 to 2.0 cm; 1st to 56th percentile); mean hand length (palmar distal wrist crease to end of middle finger), 18.1 cm (range 17.9 to 21.5 cm; 5th to 97th percentile); and mean palm width (radial edge to ulnar edge), 8.1 cm (range 8.1 to 9.6 cm; 1st to 57th percentile) for the male participants. For female participants, the mean middle-finger width was 1.5 cm (range 1.3 to 1.8 cm; 1st to 80th percentile); mean hand length, 17.1 cm (range 15.0 to 18.5 cm; 1st to 72nd percentile); and mean palm width, 7.7 cm (range 7.0 to 8.5 cm; 1st to 66th percentile). Percentiles are based on male and female hand anthropometry from the U.S. military (Greiner, 1991).

Keyboard Test Conditions

Six functional wireless keyboards were custom built for the study. The keyboards were

TABLE 1: Characteristics of Study Participants (*N* = 25)

Characteristic	Data
Demographic	
Mean age (years)	36.4 (15.5)
Sex	
Female	56%
Male	44%
Hand anthropometry	
Mean finger width (cm)	1.6 (0.2)
Mean hand length (cm)	18.1 (1.5)
Mean hand width (cm)	8.2 (0.6)
Typing ability	
Never looks at hands	12%
Sometimes looks at hands	72%
Always looks at hands	16%

Note. Standard deviations shown in parentheses.

identical except for differences in key gap and key pitch. Half the keyboards had a key pitch of 17 mm, and the other half had a pitch of 16 mm. Within pitch, the keyboards had a gap between the keys of 1, 3, or 5 mm. Therefore, the key top sizes for the 17-mm-pitch keyboards were 16, 14, and 12 mm (in both the horizontal and vertical direction) and for the 16-mm-pitch keyboards were 15, 13, and 11 mm. The tops of the keys for all keyboards were flat, and all keyboards had a similar make force (60 gm) and travel distance (1.5 mm). The keys were of a firm rubber-like material, and the radius of curvature of the corners was approximately 2 mm. All keyboards were of the conventional QWERTY layout.

Workstation Setup

The chair had an adjustable-height seat pan, adjustable back-support angle and tension, and five casters (Aeron, medium size; Herman Miller, Zeeland, MI). The work surface was 2 cm thick and adjustable in height. The keyboard and a tablet computer (Slate; Microsoft, Redmond, WA) were set on the work surface, and the keyboard was wirelessly linked to the tablet. Prior to the start of the experiment, chair height was adjusted so the participant's feet rested comfortably on the floor, work surface height was set to the participant's elbow height, and the participant was asked to place the keyboard at a comfortable location on the work surface. Participants were allowed to adjust the tablet's vertical tilt angle and distance. During the practice session, participants were encouraged to make adjustments to the chair, keyboard, and tablet location so that they were comfortable. During the experiment, the work surface height or the tablet or keyboard position were not changed. To achieve consistency of positioning across the different keyboards, the position of the bottom-row keys was marked on the work surface, and all keyboards for a participant were placed in the same location.

Typing Tasks

A typing program (Typing Master Pro, Helsinki, Finland) presented text on the screen, which was typed by the participants. Typing passages were excerpted from the young adult novel *Where the Red Fern Grows*; each passage contained a similar density of punctuation and capitalization. Participants were instructed to type as fast and accurately as possible while maintaining a sustainable pace and not to correct mistakes. The program calculated gross and net typing speed and percentage accuracy. Percentage accuracy was equal to correctly typed words multiplied by the average word length of five, divided by total keystrokes, and reported as a percentage. Gross typing speed was equal to total keystrokes divided by typing duration (e.g., keystrokes per minute [KPM]). KPM was divided by the standard word length of five keystrokes to calculate typing speed in words per minute (WPM). Net typing speed was equal to total keystrokes minus the number of mistyped words multiplied by 5 (the gross speed was reduced by five characters for each mistyped word) divided by typing duration and further divided by the standard word length of five keystrokes to calculate typing speed in WPM (Rempel, Barr, Brafman, & Young, 2007). Before beginning the experiment, participants performed a 2-min warm-up by typing on the keyboard with a pitch and gap of 16 mm and 1 mm, respectively.

A random number generator was used to assign test order of keyboards and typing passages. For each keyboard test condition, participants typed three of 18 possible passages in 2-min trial blocks. All participants typed all 18 passages. Productivity measurements were calculated from the average of the three trials per keyboard condition. Participants took a 1-min break between trials and a 5-min break between keyboard test conditions.

Usability and Preference Ratings

After each keyboard was used, usability was assessed with a questionnaire containing eight questions. Comfort, confidence in typing, ease of typing, typing without looking at the keyboard, ease of finding the home row keys, and accurate use of the space bar were rated on a 5-point scale (*strongly agree* = 1 and *strongly disagree* = 5). Users' experience compared to their usual keyboard was also rated on a 5-point scale (*much worse* = 1 and *much better* = 5). Overall keyboard rating used a 4-point scale (*very dissatisfied* = 1 and *very satisfied* = 4). At the end of the study, participants rank-ordered the six keyboards from least to most preferred (*best* = 1 and *worst* = 6).

Statistical Analysis

Differences between keyboards on gross typing speed, net typing speed, and accuracy were evaluated using a two-way (gap and pitch) repeated-measures analysis of variance (ANOVA) with Tukey follow-up test (SAS Institute, Cary, NC). If interaction between gap and pitch was not significant, then the effects of gap and pitch were evaluated separately. Differences in usability scores and keyboard preference were analyzed using Friedman's matched group ANOVA test with Nemenyi multiple comparison test.

RESULTS

Interaction between pitch and gap was not significant for the objective productivity measures of gross typing speed, net typing speed, or accuracy (p = .97, .88, and .93, respectively). Therefore, the effects of pitch and gap on these outcomes were analyzed separately. Both net typing speed and accuracy were significantly greater for the 17-mm-pitch keyboards as compared to the 16-mm-pitch keyboards (p = .02 and p = .002, repeated-measures ANOVA; Table 2). Accuracy was significantly greater for keyboards with a 5-mm gap than for those with a 1-mm gap (p = .04, Tukey follow-up). Test order was not significant.

Interaction between pitch and gap was also not significant for the subjective usability ratings, including preference. Across most usability and preference ratings, keyboards with a 17-mm pitch were rated significantly better than those with a 16-mm pitch. Significant differences on pitch were noted for comfort, confidence, ease to type on, looking at keyboard, finding the home row, comparison to usual keyboard, and preference.

Across all usability and preference ratings, the 1-mm-gap keyboard was rated worse than the 3- or 5-mm-gap keyboards; however, the differences were not statistically significant.

A post hoc analysis of the effect of hand width on gross and net speed and accuracy was also performed. For the participants with the smallest hands (n = 13), net typing speed and accuracy were significantly better on keyboards with 17-mm pitch compared to 16-mm pitch ($p < .02$ and $p < .04$). For the participants with the largest hands (n = 12), only accuracy was significantly better on the keyboards with 17-mm pitch compared to 16-mm pitch ($p < .02$). Gap was not significant in this post hoc analysis.

DISCUSSION

Across the range of key gaps studied on keyboards, accuracy was better (by 4%) for a 5-mm gap compared to a 1-mm gap. Typing speed, usability, or preference did not differ on gap. Typing speed, accuracy, and most usability measures were better on keyboards with a 17.0-mm pitch compared to 16.0-mm pitch.

Since key top size also varied by gap—that is, the larger the gap, the smaller the key top—one could argue that the effect on accuracy may be attributed to key top size and not gap. However, the expected direction of effect, based on Fitt's law, would be reduced accuracy with the smaller key top. Instead, the opposite was observed: The smaller key top with a larger gap was associated

TABLE 2: Summary of Productivity, Usability, and Preference by Keyboard Key Pitch and Key Gap (N = 25)

	16-mm Pitch						17-mm Pitch							
	1-mm Gap		3-mm Gap		5-mm Gap		1-mm Gap		3-mm Gap		5-mm Gap			
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	Pitch *p* Value[a]	Gap *p* Value[a]
Objective measures														
Gross speed (WPM)	44.9	15.5	45.8	15.8	44.9	15.9	48.7	17.3	49.7	16.9	50.1	15.8	.11	.95
Net speed (WPM)	37.0	13.7	38.9	14.6	38.4	14.4	42.0	16.3	44.2	15.9	45.6	14.8	.02	.67
Accuracy (%)	82.4[b]	11.6	84.5	9.2	85.5[b]	10.4	85.5	9.1	88.5	8.1	90.3	6.1	.002	.04
Subjective measures														
Typing on this keyboard is comfortable[c]	2.2	0.9	2.7	1.2	2.3	1.2	3.0	1.0	3.8	0.7	3.9	0.7	<.01	*ns*
I feel confident typing on this keyboard[c]	2.2	1.0	2.5	1.1	2.4	1.1	2.9	1.0	3.7	0.9	3.9	0.7	<.01	*ns*
This keyboard is easy to type on[c]	1.9	0.8	2.7	1.0	2.4	1.2	3.1	1.1	3.8	0.8	4.0	0.7	<.01	*ns*
I was able to type without looking at the keyboard[c]	2.2	1.0	2.6	1.1	2.3	1.3	2.9	1.1	3.4	1.2	3.4	1.1	<.01	*ns*
I could easily find the home row keys[c]	2.8	1.0	3.0	1.2	2.9	1.3	3.3	1.0	3.7	1.1	3.8	0.9	<.01	*ns*
I could accurately use the space bar[c]	3.6	1.1	3.9	0.9	3.5	1.4	3.9	1.0	4.2	0.9	4.3	0.7	*ns*	*ns*
Compared to the keyboard I usually type on, my typing speed on this keyboard is . . .[d]	1.6	0.6	1.8	0.7	1.7	0.9	2.3	0.8	2.8	0.8	2.6	0.6	<.01	*ns*
Overall, based on your own experience, how satisfied are you with this keyboard?[e]	1.6	0.7	2.2	0.8	1.8	0.9	2.3	0.8	3.0	0.7	3.0	0.6	<.01	*ns*
Preference ranking[f]	5.1	1.13	4.2	1.41	4.4	1.38	3.4	1.47	2.0	0.77	2.0	1.13	<.01	*ns*

Note. WPM = words per minute.
[a]Differences between objective measures tested with repeated-measures ANOVA and for subjective measures Friedman's ANOVA. Overall model p values are reported here.
[b]Differences between 1- and 5-mm gap are significantly different by Tukey follow-up test.
[c]*Strongly disagree* = 1; *strongly agree* = 5.
[d]*Much worse* = 1; *much better* = 5.
[e]*Very dissatisfied* = 1; *very satisfied* = 4.
[f]*Best* = 1; *worst* = 6.

with improved accuracy. Therefore, we attribute the effect on accuracy to be primarily due to gap. Unfortunately, it is impossible to design a study to completely disentangle the effects of pitch, gap, and key top size.

No prior studies have explicitly evaluated the effect of key gap on typing performance. Yoshitake (1995) investigated the effect of keyboards with different key pitch on typing performance, but there were also differences between the keyboards on gap. Key pitch varied from 15.0, 15.6, 16.0, 16.7 to 19.05 mm, and the corresponding gap varied from 3.2, 5.2, 5.6, 6.3 to 5.85 mm. For the four participants with larger fingers, performance decreased when the key pitch was 16.0 mm or less. The difference in gap between the keyboards with 16.0-mm versus 16.7-mm pitch (i.e., 5.6-mm vs. 6.3-mm gap) is unlikely to explain the observed difference in performance. The effect of pitch on performance in the Yoshitake study was noted only in subjects with large fingers. In our study, differences in hand size had little impact on the study conclusions.

The findings on key pitch are consistent with our first prior study (Pereira et al., 2013) where performance and usability were reduced for keyboards with a 16-mm horizontal pitch compared to a 17-mm pitch. However, there are notable methodological differences between the studies. The prior study included only male touch typists with large fingers, whereas the current study included participants of both genders with varying finger and hand sizes. The prior study involved the use of keys with concave-shaped key tops, whereas the current study involved keys with flat key tops.

There are at least two mechanisms that may explain the effect of gap on accuracy. A small gap may increase the probability that a finger will accidentally strike an adjacent key at the same time as the target key. Alternatively, through edge detection, a small gap may provide less tactile feedback on the location of the keys compared to a large gap, leading to more fingertip drift and reduced accuracy in key strikes. This effect may be especially true for keys with flat tops that provide no tactile feedback on the location of the key centers, which would reduce the probability that the fingertips return to the center of the home row keys after a key strike. If so, a concave key top that provides tactile feedback on key location may allow for smaller gaps without reduced accuracy.

A limitation of the study was its short duration—participants typed on each keyboard for three trials of only 2 min each. It is possible that given more time on the keyboards, participants would have noted stronger differences in usability and preference between keyboards.

KEY POINTS

- Typing accuracy was worse when the gap between keys on a keyboard was 1 mm compared to a gap of 5 mm.
- Keyboards should be designed with a key gap of 3 mm or larger; a gap of 1 mm between key tops should be avoided.
- Net typing speed, accuracy, usability, and preference were worse when the center-to-center key spacing on keyboards was 16 mm compared to a spacing of 17 mm.

REFERENCES

American National Standards Institute. (2007). *ANSI/HFES100-2007: Human factors engineering of computer workstations*. Santa Monica, CA: Human Factors and Ergonomics Society.

Greiner, T. (1991). *Hand anthropometry of U.S. army personnel*. Natick, MA: U.S. Army Natick Research, Development, and Engineering Center.

Ilg, R. (1987). Ergonomic keyboard design. *Behavior and Information Technology*, *6*, 303–309.

International Organization for Standardization. (2008). *Ergonomics of human–system interaction: Part 410. Design criteria for physical input devices* (Reference No. ISO9241-410:2008). Geneva, Switzerland: Author.

Pereira, A., Hsieh, C. M., Laroche, C., & Rempel, D. (2014). The effect of keyboard key spacing on typing speed, error, usability, and biomechanics, Part 2: Vertical spacing. *Human Factors*, *56*, 752–759.

Pereira, A., Lee, D. L., Sadeeshkumar, H., Laroche, C., Odell, D., & Rempel, D. (2013). The effect of keyboard key spacing on typing speed, error, usability, and biomechanics: Part 1. *Human Factors*, *55*, 557–566.

Rempel, D. (2008). The split keyboard: An ergonomics success story. *Human Factors*, *50*, 385–392.

Rempel, D., Barr, A., Brafman, D., & Young, E. (2007). The effect of six keyboard designs on wrist and forearm postures. *Applied Ergonomics*, *38*, 293–298.

Yoshitake, R. (1995). Relationship between key space and user performance on reduced keyboards. *Applied Human Science*, *14*, 287–292.

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