Effect of Button Size and Location When Pointing with Index Finger on Smartwatch

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Abstract. Users control smartwatches through touch screen interfaces such as smartphones. However, because smartwatches are very small and users' postures differ depending on the device, control using touch screens needs to be adapted for smartwatches. Users tap buttons on the touch screen to control the smartwatch, so speed and accuracy of button input are required. Users' button input speed and accuracy are affected by displayed button size and location. In this study, we investigated the effects of button size and location when pointing with the index finger on a smartwatch. The results suggest that the pointing error rate is significantly affected by button size and location. The error rates became lower as the buttons became larger and when the buttons were located near the center of the screen.

Keywords: Smartwatch · Touch input · Pointing performance

1 Introduction

Smartwatches provide users with access to various smartphone applications directly from their wrists without using their smartphones. While applications such as email and social networking clients display text and images on the watch, no text entry is supported, and text and image transmission functions are limited. To efficiently use smartwatches, text entry support on smartwatches is needed.

Users control smartwatches through touch screen interfaces like smartphones. However, because the smartwatch display is very small, it severely limits users' behaviors. Moreover, because users wear smartwatches on their wrists, their hand postures when controlling smartwatches are different from those when controlling smartphones. Text entry methods on touch screens need to be adapted for smartwatches.

Users tap buttons on the touch screen for text entry, so speed and accuracy of button input are important factors. Users' button input speed and accuracy are called pointing performance. Pointing performance on touch screens depends on displayed button size and location. There have been studies on pointing performance on many kinds of devices, but pointing performance on smartwatches has not been fully investigated. Therefore, we investigated the effects of button size and location when tapping with the index finger on a smartwatch. The results suggest that the pointing

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error rate was significantly affected by button size and location. We obtained basic data to optimize text-entry time.

2 Related Work

The size and location of buttons are known as important factors for pointing performance on touch screens. Pointing performance is measured using task completion time and error rate. Higher pointing performance is achieved when task completion time and error rate are lower. Text entry methods that utilize high pointing performance are easy to use because users can control the devices quickly without having to correct errors.

2.1 Effect of Button Size on Touch Screen

Colle and Hiszem [3] conducted research on pointing performance and preference for index finger input with different button size and space between buttons on a 12.1-inch touch screen. The results showed that button size had a significant effect on pointing performance. Task completion times and error rates were high for smaller keys. Similar results were shown in studies about pointing performance with one-handed thumb input on small devices like smartphones [10, 11]. Moreover, users' fingers occlude the buttons when they tap small buttons, and finger movement accuracy is limited, so users have difficulty in touching the buttons accurately (fat finger problem [7]).

Fitts' law model, which was originally published in 1954 [4], is used to estimate time to complete a targeting task. Fitts' law model has proven to be one of the most robust and successful models of human motor behavior and is defined by the following equation [8].

$$T = \mathrm{a} + \mathrm{b}ID \tag{1}$$

$$ID = \log_2\left(\frac{A}{W} + 1\right) \tag{2}$$

T is the average time taken to complete the movement, *ID* is the index of difficulty, *A* is the distance from the starting point to the center of the target, *W* is the width of the target, and *a* and *b* are constants reflecting the efficiency of the pointing system. Furthermore, FFitts' law model [2], which is applied to pointing to a small target by finger touch input, has been derived. FFitts' law model's index of difficulty validates the dual-distribution hypothesis, which provides a more logical and reasonable interpretation of the distribution of touch points than the target width interpretation. In accordance with Fitts' law model and FFitts' law model, the task completion time becomes low when the distance from the starting point to the center of the target is low or the width of the target is high.

In addition to the above research, there have been studies about relationships between pointing performance and button size on various devices. However, the effects of button sizes on smartwatches have not been fully investigated.

2.2 Effect of Button Location and Hand Posture on Touch Screen

Park and Han [10] investigated pointing performance of one-handed thumb input using only the right hand thumb on different button locations of a PDA. The results showed that task completion time was generally low in the left areas on the touch screen when the one-side length of a button was 4 mm while the task completion time was generally low in the center and right areas when the one-side length of a button was 7 mm and 10 mm. The error rates tend to be low in the left areas. Hwangbo et al. [6] studied the pointing performance of elderly smartphone users using their thumbs of right hands. The results showed that pointing performance was low when tapping on buttons in the four corners.

Moreover, it is known that the distribution of touch points depends on button location. Henze et al. [5] conducted research on pointing performance of one-handed thumb input when tapping on different button locations of smartphone. The results showed that touch points skewed towards the lower-right of the screen. The direction of the skew suggests that touches shift towards the base of his/her thumb when the phone is held in his/her right hand. In Azenkot and Zhai's study [1] about soft QWERTY keyboards on smartphones, hand postures (two thumbs, one thumb, and one index finger) affected the distribution of touch points.

Related work shows that pointing performance is affected by button location and hand postures. However, pointing performance has not been investigated in smartwatch control where button locations and hand postures are different from smartphone control. Therefore, pointing performance needs to be investigated.

3 Method

3.1 Participants

Fifteen university students (9 males and 6 females) participated in our experiment. The age of the participants ranged from 19 to 21 years old. There were 13 right-handed participants and 2 left-handed participants. No participants had used smartwatches, but 14 participants routinely used their smartphones, so they were used to controlling touch screen devices.

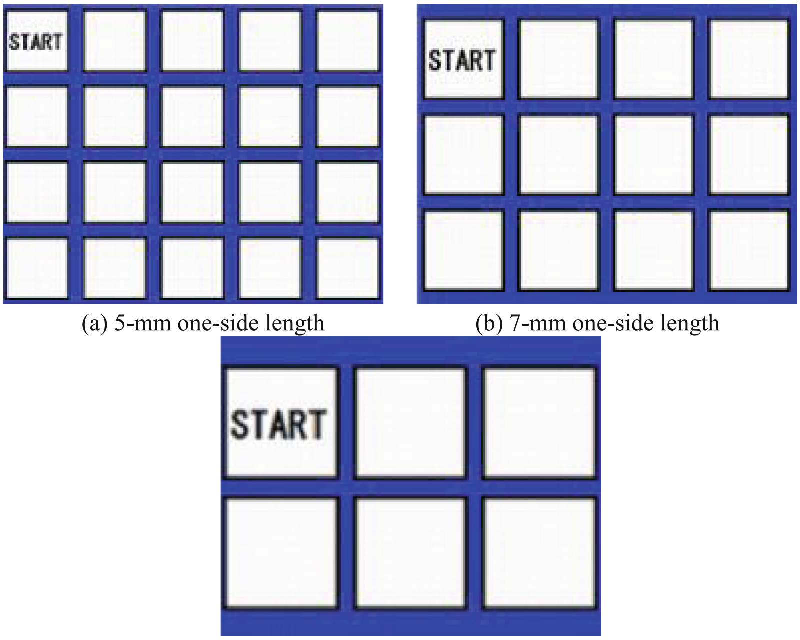
3.2 Apparatus

We used a SONY SmartWatch 2 SW2 for our experiment. The smartwatch has a display size of 32 × 26 mm and a resolution of 220 × 176 pixels.

We investigated the touch screen pointing performance of three square button sizes whose one-side lengths were 5, 7, and 10 mm (38, 49, 68 pixels) and spacing was 1 mm (7 pixels). The one-side length of buttons of a QWERTY keyboard on a smartphone is 5 mm; the recommended minimum and maximum sizes are 7 mm and 10 mm, respectively, for Android developers [9].

The number of buttons on a display depends on its size (Fig. 1). When the one-side length of buttons was 5, 7, and 10 mm, the display had 20, 12, and 6 buttons in 5 lines by 4 rows, 4 lines by 3 rows, and 3 lines by 2 rows, respectively. There were gaps between the buttons and the screen frame because the total size of the button arrays was smaller than the display size.

In this experiment, a participant was requested to tap designated buttons. When the participant touched on the smartwatch's screen, the time and touch points were recorded, and auditory feedback that differed depending on whether the tapping was on target or off target was sounded. The auditory feedback was played from an ASUS Nexus 7 connected to the smartwatch by Bluetooth. Moreover, to analyze participants' behaviors, videos of their upper bodies and hands were captured by a camera mounted on a control PC (NEC NS PC-LS700NS) and a web camera (Microsoft LifeCam HD-3000), respectively.



(a) 5-mm one-side length (b) 7-mm one-side length

(c) 10-mm one-side length

Fig. 1. Button layouts used in experiment

3.3 Experimental Procedure

The participant wore the smartwatch on his/her non-dominant wrist and used his/her dominant index finger for pointing while sitting on a chair. In one trial of button size, the participant tapped each button once. The buttons to be tapped were designated in a sequence. One set has a trial for each button size (three trials), and the participant repeated each set three times. Each participant was randomly assigned to an order of button sizes and buttons to be tapped.

The experiment and how the obtained data will be used were explained to all participants, and they gave their consent to participate in this study. The participants were requested to tap precisely without caring about tapping speed. The participant started a set by tapping the set start button. After that, the trial start button was displayed at the upper left corner. The participant started a trial by tapping the trial start button. The participant was requested to tap the button that was designated with a red circle. The next target button to be tapped was indicated with a blue ring. When the participant tapped on the display, the next target button was designated, that is, the blue ring changed to a red circle, the next blue ring was displayed on another button (Fig. 2), and sound feedback was played. After all buttons were designated, the trial finished, and the trial finish button was displayed at the upper left corner. After the trial finish button has been tapped, the participant proceeded to the next trial. After the set was complete, the set finish button was displayed. The pointing performance measurements were determined from the button tapping intervals (the time between tapping buttons) and error rates (rates of tapping outside the area of the designated button). After finishing all sets, participants answered a questionnaire to evaluate usability on a 5-point Likert scale.

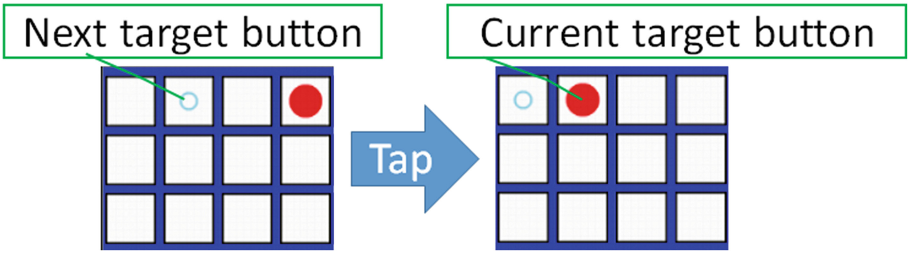


Fig. 2. Examples of displayed buttons in trial (Color figure online)

4 Results

Figure 3 shows the averages of button tapping intervals and error rates against button sizes. The averages of button tapping intervals are 0.91, 0.88, and 0.85 s for 5, 7, and 10 mm one-side length buttons, respectively. The averages of button tapping error rates were 25.22, 12.96, and 2.22 % for 5, 7, and 10 mm one-side length buttons, respectively. Performance was best (the shortest button tapping interval and lowest error rate) when the button size was a one-side length of 10 mm. Generally, participants performed better as the buttons became larger. Figure 4 shows the button tapping error rates on button locations. Figure 5 shows scatter plots of the tap positions. The circle, triangle, and broken line show the tap position, centroid of tap positions, and button frame, respectively. In Figs. 4 and 5, left-handed participants' data are flipped horizontally. For all button sizes, the error rates of tapping on buttons near the right side of the screen frame tend to be high, and for buttons near the center of the screen, the error rates tend to be low.

Figure 6 shows participants' answers to the question "operation was easy". The participants evaluated it using a 5-point Likert scale (5: strongly agree, 4: agree, 3: neutral, 2: disagree, 1: strongly disagree). The evaluation averages are 2.27, 3.87, and 4.73 for 5, 7, and 10 mm one-side length buttons, respectively.

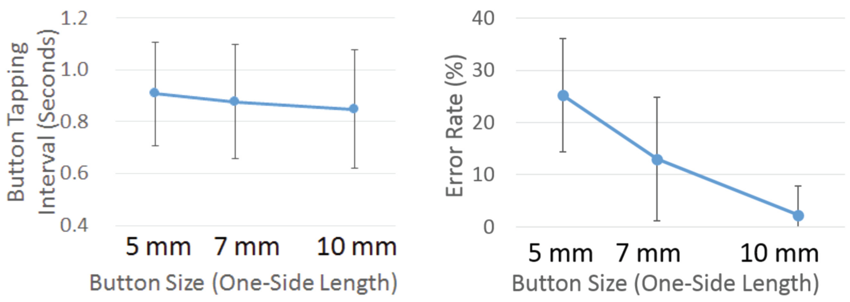


Fig. 3. Average of button tapping interval and error rate by button size (with standard deviation bars).

31.1	33.3	24.4	26.7	64.4
22.2	6.6	2.2	2.2	73.3
17.2	2.2	2.2	2.2	73.3
22.2	2.2	6.7	4.4	80.0

(a) 5-mm one-side length

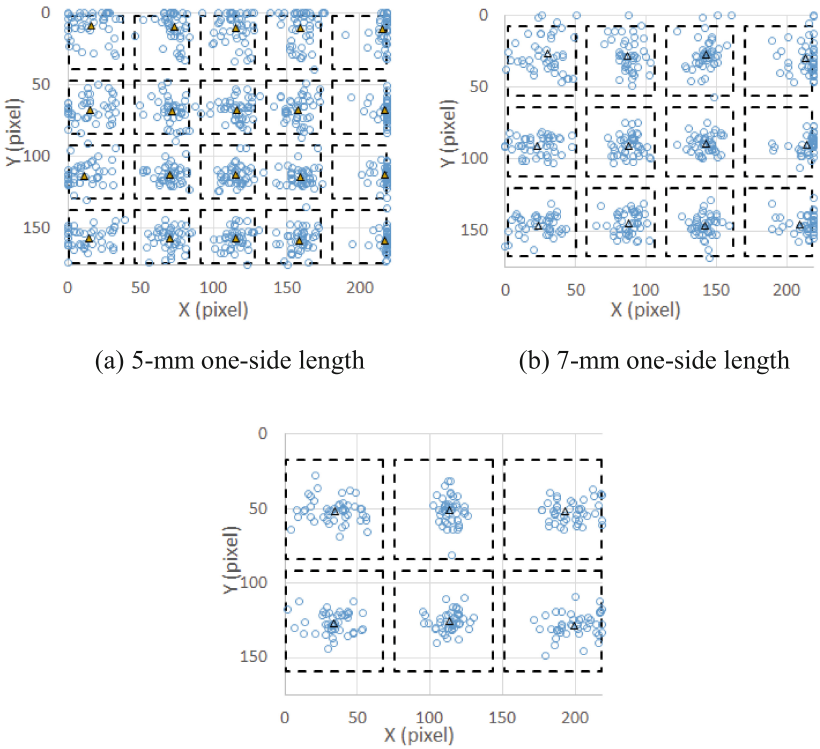
11.1	4.4	8.9	48.9
4.4	0.0	0.0	35.6
0.0	0.0	2.2	42.2

(b) 7-mm one-side length

0.0	0.0	6.7
2.2	0.0	4.4

(c) 10-mm one-side length

Fig. 4. Button tapping error rate by buttons (%)



(a) 5-mm one-side length

(b) 7-mm one-side length

(c) 10-mm one-side length

Fig. 5. Plot of tap position (circle: tap position, triangle: centroid of tap positions, broken line: button frame).

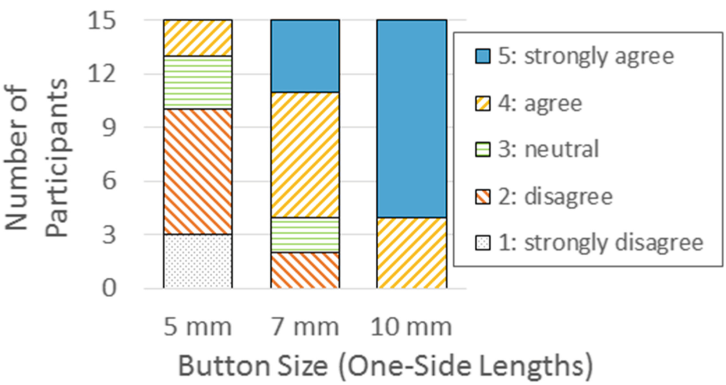


Fig. 6. Questionnaire results: operation was easy

5 Discussion

5.1 Effect of Button Size

The results show that the average of button tapping intervals did not vary largely with button size. The participants were able to comprehend the whole screen and find the designated button easily because the screen was small and was kept within their visual field.

However, the average of the error rates was significantly different. The error rate became lower as the buttons became larger. The analysis of variance showed that there were statistically significant differences between the error rates of the button sizes ($F(2, 132) = 59.97$, $p < .0001$), and the least significant difference multiple comparison test showed that there were statistically significant differences between each average of error rates of every combination of two button sizes (all $p < .0001$). We think that these results were affected by the fat finger problem in the same way as discussed in the related work.

We observed that the errors on small button sizes changed some subjects' hand postures. When he or she felt that the button size was small or he tapped wrong buttons frequently, he bents his dominant index finger so that it was nearly perpendicular to the screen to reduce errors by minimizing a contact area between his finger and the screen. The tendency is particularly strong among high error rate participants. We got the following comments for buttons of 5-mm one-side length.

- "I felt fatigue of my dominant index finger."
- "It was hard to tap buttons because my dominant index finger became perpendicular."

The hand posture that makes dominant index fingers perpendicular did not reduce the error rate, but it placed an extra load on the participants' hands.

5.2 Effect of Button Location

For all button sizes, tapping on buttons near the right side of the screen frame tended to be off to the right (left-handed participants tended to be off to the left when tapping on buttons near the left side), and the error rate was high. Moreover, when the button size was small (the one-side length of the button was 5 mm), tapping on buttons near the left and upper side of the screen frame tended to be off to the left and upper side, respectively (left-handed participants tended to be off to the right when tapping on buttons near the right side), and the error rate was high, too. Figure 7 shows a plot of tap positions on the 5-mm one-side length button at the bottom-right corner. The circle, X, triangle, and broken line show the correct tapping, errors, centroid of tap positions, and the button frame, respectively. Most of the errors occurred due to tapping on the gaps between the button and the screen frame. Errors when tapping on other buttons near the screen frame showed a similar tendency. Therefore, we think error rates can be reduced by having a button layout with no gaps between buttons and the screen frame. The error rates when tapping on buttons near the lower side of the screen are lower than those of buttons near the other sides of the screen. We think this result was caused by the button layout where functional keys, such as the Back key, Home key, and Action keys, are placed between displayed buttons and the lower screen frame. Participants tried to avoid tapping on the functional keys.

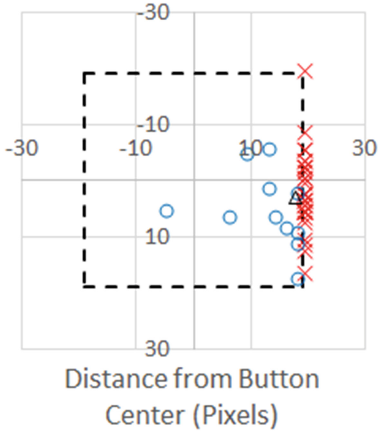


Fig. 7. Plot of tap positions on 5-mm one-side length button at bottom-right corner (circle: correct tapping, X: errors, triangle: centroid of tap positions, broken line: button frame).

6 Conclusion

Our study investigated the relationships between pointing performance and button layouts when tapping with the index finger on a smartwatch. The results show button sizes and button layouts have significant effects on pointing errors. Like pointing on larger devices, the error rates became lower as the buttons became larger. However, button tapping speed did not vary largely with button sizes. Regardless of button size, error rates when tapping on buttons near the right side of the screen frame tended to be high because the tap positions were off to the right (for left-handed participants, right and left are reversed), and on buttons near the center of the screen, the error rates tended to be low. For small buttons whose one-side length is 5 mm, tapping on buttons near the left and upper side of the screen frame tended to be off to the left and upper side, respectively, (for left-handed participants, the same as above), and the error rate was high.

We believe that these results contribute to determining appropriate button sizes for precise and efficient text entry for smartwatch applications.

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