An Analysis of Smartphone Size Regarding Operating Performance

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Abstract. An increasing number of electronic devices employ touchscreens as the operating method. Among these devices, smartphones have exhibited the most rapid development. To achieve more impressive visual effects, the size of smartphone displays has gradually increased. However, the resulting disadvantage is that these devices cannot be operated using one hand. In situations where users must operate the phone with one hand, some screen areas cannot be reached by their thumb. Thus, the demand for one-handed operation remains. This demand is related to operating convenience, which is obviously not provided by existing products. This study analyzes touchscreen cell phones with varying screen sizes, from 2.55 to 5.3 in, currently available on the market to examine the efficiency of one-handed operation by investigating four operating directions, that is, diagonal, horizontal, vertical, and center-cross. In addition, a customized application was developed to record the operating sequences, frequencies, numbers of errors, and positions of errors to understand the effect that display sizes have on one-handed operation. According to the analysis results, 4-in touchscreen cell phones generated the fewest operating errors, and 3-in touchscreen cell phones provided the shortest operating time. To obtain optimal visual effects, the implementation of 4-in screens for touchscreen cell phones may be the best option for one-handed operation.

Keywords: touchscreen, smartphone, interface design.

1 Foreword

Next-generation products such as smartphones and touchscreen tablets have continuously stimulated consumer demand (Len 2012). Users commonly play games, watch videos, and browse webpages using their smartphones, which also enhance users' interpersonal relationships and emotional communication (Lee and Lin 2006). Considering the number of sales, consumers desire smartphones with larger screens and a higher display quality (Lin 2012). Endeavoring to satisfy consumer desires, manufacturers have continued to create cell phones with larger displays and higher resolutions (Chang 2006), rapidly popularizing touchscreen smartphones. Consequently, larger and more detailed screens have become the primary developmental

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trend. Although large-size screens increase users' comfort when using the devices, if screens exceed a certain size, such as a 5.3-in screen, the ability to operate the device with one hand is sacrificed (David 2011). However, the one-handed operation of a large-screen cell phone poses a risk of users dropping the phone because of an insecure one-handed grip. Furthermore, as shown in Fig. 1, if users hold a large-screen cell phone with one hand, some screen areas cannot be reached easily with their thumb (Dustin 2011).

Fig. 1. Thumb-tapping range (Dustin 2011)

According to previous research (Chang 2006), the optimum strategy for improving cell phone operation is to design procedures that can be completed using only one hand. For convenience, most people operate devices such as remote controls, cell phones, and PDAs with one hand (Shih 2009). In addition, most users performing dialing and conversing operations using only one hand when moving around (Karlson et al. 2006). Surveys regarding the behavioral environments of cell phone operation have shown that cell phones are primarily used when users are moving and standing, when one-handed operation is more comfortable. Whereas when resting places are provided or when users are seated, the higher environmental comfort facilitates increased two-handed operation. However, in most situations, only one hand is used for operation (Karlson et al. 2006).

Existing studies regarding smartphone interfaces have focused on the button size and spacing (Chang 2011), the button shape (Chen 2002), touchable areas (Huang 2010), and how the button sizes and input methods are related to gestures (Lee and Kuo 2004). These studies analyzed the elements of user interfaces (UIs), but did not discuss issues related to various sizes. Therefore, this study investigates and conducts experiments regarding existing touch models, identifying the optimal display size for one-handed operation of smartphones of varying size. Furthermore, this study examines the influence of the directions of thumb movements by analyzing operating efficiency and error rates.

2 Literature

2.1 Touchscreen Interface

Although touchscreen technology emerged in the 1970s, it was not popularized and incorporated into people's lives until recently. The reasons for this recent popularization of touchscreens include the widespread use of flat-panel displays, the development of manufacturing technology, the decline in costs, the advancement of materials technology, and the emergence of UIs specifically designed for touchscreen operation. These factors have prompted manufacturers to choose touchscreen inter-faces as the major UI for their products. From a user perspective, touchscreen interfaces provide a useful design that is not restricted by technological attractiveness.

A marketing research survey conducted in the United States in 2009 indicated that more than 95% of adults under the age of 45 considered the touchscreen interface to be the most usable human-machine interface, and more than 80% of the interviewees believed that an operating method using a touchscreen provides a more intuitive and usable experience (Pen 2009). Therefore, we can infer that the touchscreen interface, because of its intuitive design and applications, will remain significant for product development and designs that emphasize user experience.

2.2 The Relationship between Cell Phone Operation and Palm Size

When designing handheld devices, to ensure that users can stably and comfortably grip the device, a standard palm size must be obtained before beginning the actual product design. Therefore, palm sizes have a significant influence on handheld devices (Huang 2010). Users with large palms experience greater difficulty operating small handheld devices, whereas users with small palms cannot easily operate large handheld devices. According to research regarding the operation of traditional cell phones, when operating or inputting text into a standard cell phone with physical buttons, changes in button position do not cause significant differences in operating speed or accuracy (Chang 2007). In addition, most relevant studies used a fixed cell phone size for experiments; even if size was among the concerns of a particular study, the experiments tended to focus on button sizes and the spacing between buttons (Huang 2011). Studies that concurrently discuss cell phone size and the directions of thumb movements are scarce.

3 Experimental Design

Using smartphones of various sizes, this study investigated touchscreen interfaces and conducted experiments using a customized application to examine the efficiency and accuracy of various smartphone sizes. Before the experiments begun, the participants' palm sizes were measured for subsequent analysis of the effect that palm size has on operating efficiency for smartphones.

Because Android is the operating system with the largest market share, various Android smartphone models of varying size were selected as the operating devices for the experiments. Furthermore, a customized application featuring an interface scaled to the smartphone size without altering the proportions was developed. Most of the study participants were users in Asia. When the participants were holding the cell phones, the operating errors that occurred were caused by their personal habits and the adaptability and responsiveness of the device. Therefore, future studies should record the experimental procedures to collect data to solve this problem.

3.1 Experimental Equipment

In this study, various sizes of smartphones were employed to analyze the effect that size has on operation. A total of 10 smartphones of differing size were obtained, and a customized application was designed for the Android operating system to provide a UI that conforms to the experimental settings. Fig. 2 shows the differing display sizes of the various models, facilitating a comparison of the frame and screen sizes of the 10 selected smartphones.

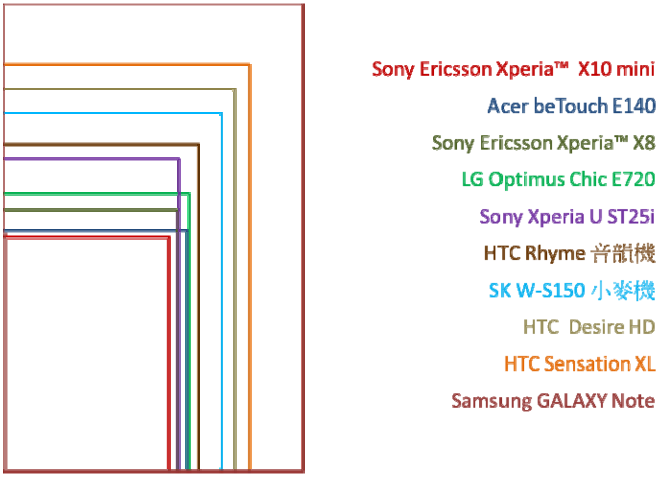
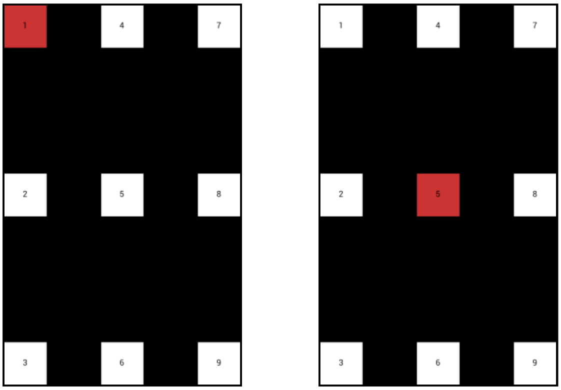


Fig. 2. Frame and screen comparison

3.2 UI Design

The operating area of the test application employed the entire screen. Fig. 3 shows the configuration of the application interface displayed throughout the experiment. Before the participants operated the devices, an operation sequence was hinted ran-domly. Considering the example shown in Fig. 3 (a), the participants were instructed to tap the position denoted by the red block, followed by the next location shown in Fig. 3 (b). The participants followed the hints until all the red blocks were tapped.

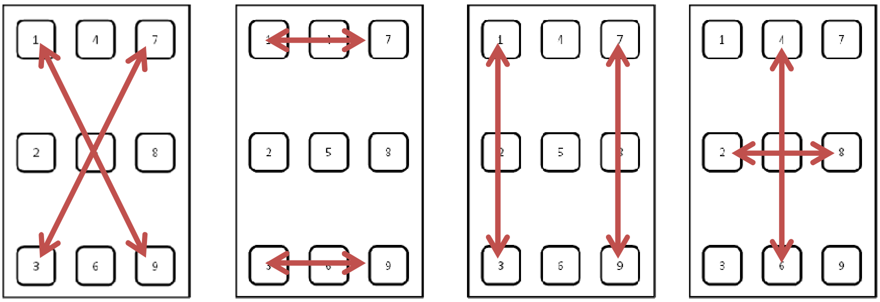


(a) Tapping 1 (b) Tapping 5

Fig. 3. Configuration of the application interface

3.3 Experimental Procedures and Setup

The participants' palm width and thumb lengths were measured before the experiment, during which the participants were tested in a randomized order using 10 smartphones. A questionnaire was issued to the participants after the test to collect their reflections, opinions, and comments regarding the possible causes of smartphone operation errors. The data obtained from the questionnaire were compared with the experimental results. A sequence of four operating steps was designed for the thumb-moving experiment; this comprised the (a) Diagonal direction, (b)Horizontal direction, (c) Vertical direction, and (d)Center-cross direction, as shown in Fig. 4. Using the diagonal direction (a) as an example of the experimental operation design, in each setting, two random figures were added before the to-and-fro actions, which were tapping to and fro from buttons 1 to 9 and buttons 3 to 7. This method was adopted to establish three sets of circular actions including buttons 1, 3, 7, and 9, and the operating sequence of each setting was randomized.



(a) Diagonal direction (b) Horizontal direction (c) Vertical direction (d) Center-cross direction

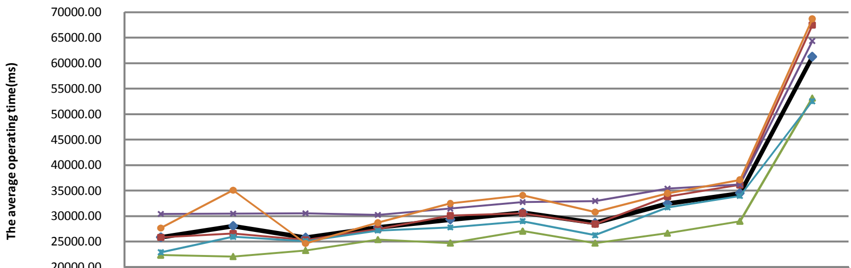
Fig. 4. Scheme of the operating sequence

4 Experimental Results

All the participants of the experiments were right-handed. Their average palm width ranged between 18 and 22.5 cm, and the average thumb lengths ranged between 5.5 and 6.6 cm. The experimental results can serve as a reference for users with a palm width and thumb lengths within these ranges.

4.1 Operating Time for Cell Phone of Differing Size

Fig. 5 shows the analysis results for the operating time of various cell phones. Larger cell phones required longer operating times. The operating time for a 5.3-in cell phone was significantly higher than that for the other cell phones.



	2.55"	2.8"	3"	3.2"	3.5"	3.7"	4"	4.3"	4.7"	5.3"
Average	25844.60	28048.95	25786.90	27802.65	29323.40	30700.75	28645.60	32427.50	34487.55	61241.90
Subjects1	25839.75	26601.75	25315.50	27484.50	30093.50	30573.75	28439.75	33862.00	36129.75	67474.75
Subjects2	22369.25	22105.75	23300.00	25413.75	24734.00	27084.75	24733.25	26665.00	29013.50	53166.50
Subjects3	30426.75	30494.75	30552.50	30240.00	31493.00	32766.75	32964.75	35404.50	36219.75	64352.50
Subjects4	22911.25	25949.00	25118.75	27164.00	27804.75	29001.75	26276.25	31722.00	33948.25	52536.25
Subjects5	27676.00	35093.50	24647.75	28711.00	32491.75	34076.75	30814.00	34484.00	37126.50	68679.50

Fig. 5. Operating time for cell phones of differing size

4.2 Analysis of the Number of Errors for Cell Phones of Different Size

After the participants had finished operating the smartphones according to the experimental procedures, the number of errors generated on each cell phone was compiled in statistical form and analyzed. The data showed that the cell phone size was not directly proportional to the error rates. The lowest error rate measured was for the 3.2-in cell phone, which had an average of 0.5 errors for each participant. This was followed by the 4-in cell phone with an average of 0.6 errors. The highest error rate measured was for the 5.3-in cell phone, which had an average of 1.55 errors for each participant.

In addition, the 10 smartphones were categorized into three size groups. Smartphones that were smaller than 3 in were categorized as small, those between 3.2 and 4 in were categorized as medium, and those larger than 4.3 in were categorized as large.

Table 1 shows the number of errors for each experiment; the results show that operations in the diagonal direction resulted in the highest number of errors. This suggests that diagonal operations were more difficult for the participants, especially with larger smartphones. The second highest number of errors was for operations in the center-cross direction; however, smaller rather than larger smartphones tended to generate center-cross operation errors.

Table 1. Number of errors

	3" and under	*3.2" to 4"*	*4.3" and above*	*Total*
Diagonal direction	11	18	52	81
Horizontal direction	23	18	18	59
Vertical direction	32	17	13	62
Center-cross direction	37	23	13	73
Total	103	76	96	275

4.3 The Error Distribution for the Interface

The areas where errors occurred were divided into locations based on the application interface. The screen interface configuration shown in Fig. 6 was used to compare the total errors in all locations for cell phones of various sizes, as shown in Table 2. The 10 smartphones were also categorized into three size groups for analysis, as explained in the previous section.

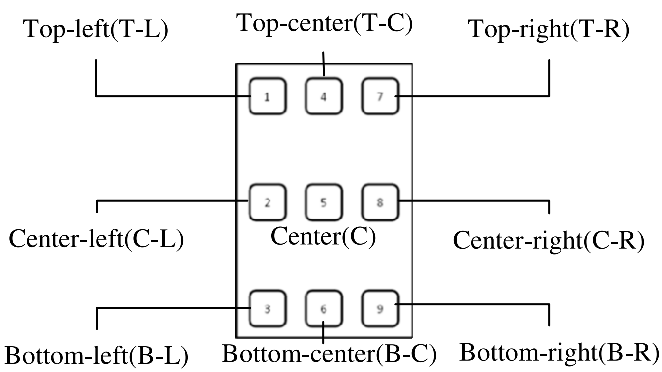


Fig. 6. Configuration of the screen interface locations

The findings listed in Table 2 are as follows: (a) For small cell phones, C errors were more likely to occur, and B-R errors were the least likely to occur; (b) for medium-sized cell phones, the number of C-R errors was the highest, and the number of B-R errors was the lowest; and (c) for large cell phones, the number of B-R errors was the highest, and that of T-C errors was the lowest.

Table 2. Sum of errors for all locations and sizes

Top-left 0.5	Top-center 0.75	Top-right 0.475
Center-left 0.75	center 1.125	Center-right 0.725
Bottom-left 0.25	Bottom-center 0.45	Bottom-right 0.125

(a) Small cell phones

Top-left 0.35	Top-center 0.575	Top-right 0.25
Center-left 0.575	center 0.7	Center-right 0.65
Bottom-left 0.25	Bottom-center 0.275	Bottom-right 0.175

(b) Medium-sized cell phones

Top-left 0.5	Top-center 0.15	Top-right 0.625
Center-left 0.675	center 0.6	Center-right 0.3
Bottom-left 1.25	Bottom-center 0.3	Bottom-right 0.4

(c) Large cell phones

4.4 Time Required for Movements in Various Directions

Fig. 7 shows the time required for movements in various directions; the results indicate that T-R>B-L operations required comparatively more time. This may be because of the longer moving distance, or because the right-handedness of the

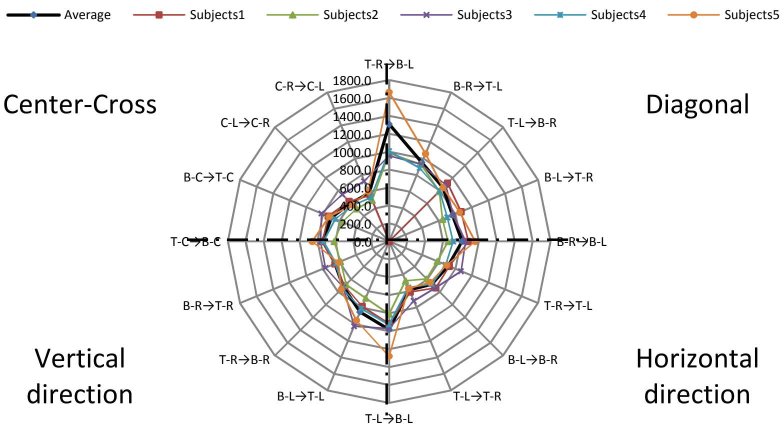


Fig. 7. Time required for movements in various directions

participants obstructed the movements. The directions that required more time included B-R>T-L, because of the longer distance and movement obstruction, and T-L>B-L, because these two locations could not be easily reached with the participants' right thumb; they had to adjust their hand position to complete the movement. The fastest movement in this figure was T-L>T-R and C-R>C-L, which are locations above the center of the screen, which is more reachable with the thumb when holding a cell phone.

5 Conclusions and Recommendations

The experiments were followed by a questionnaire survey regarding the participants' preferences. The participants all agreed that cell phones ranging between 3 and 4 in were more user-friendly. The 3.2-in cell phone was rated the optimum size. This may be related to the experimental results that showed superior operating speeds for the 3- and 4-in cell phones. Finally, the participants were instructed to select their favorite cell phones without considering the number of errors and operating speed. Their choices were not restricted by size because although small cell phones can be comfortably gripped, large cell phones provide superior visual effects. However, most of the participants considered large cell phones difficult to hold with one hand.

Smartphones measuring 3 to 4 in could be operated with greater efficiency and accuracy. The operating time increased for smartphones larger than 4.7 in. Regarding error rates, operating errors were the least likely to occur in the bottom-right of the interface for all sizes of smartphones. To respond to future trends for developing large cell phones, interface or exterior designers can reference the results of this study. The researchers will employ the same methods to conduct research with a greater number of participants, including left-handed people, and analyze the participants' palm width.

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