Optimization of GUI on Touchscreen Smartphones Based on Physiological Evaluation – Feasibility of Small Button Size and Spacing for Graphical Objects

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Abstract. Prompted by the increasing popularity of smartphones, we experimentally investigated how command button size and spacing influences users' operation and experience of the device. We measured user performance (input accuracy and operation time) and assessed physiological and psychological reactions. Tests were performed for a range of button sizes, spacing and handling modes. While large button size (9 mm) increased user comfort, a size of 7 mm aroused more user excitement, suggesting that user-interface design guidelines should be revised for uses such as games and amusement.

Keywords: GUI, touchscreen, smartphone, physiological evaluation, interest.

1 Introduction

In recent years, portable touchscreen terminals known as smartphones have experienced a global upsurge, which is expected to continue. Today, smartphones are used not merely as cellular phones but also in everyday online pursuits, such as SNS (Social Network Service) communication, browsing websites and gaming. In addition, a new role for smartphones is emerging for interface-control equipment in houses and home electronics.

Despite the diverse applicability of portable touchscreen terminals, structured GUI (Graphical User Interface) and corresponding design guidelines have yet to be established. In the UI guidelines of companies such as Microsoft and Apple, the recommended command button size is nearly 7 mm [1-3]. However, the optimal button size is expected to be purpose oriented; for example, controlling home electronics, creating a text message in SNS and repeatedly striking a game target should call for different button sizes.

Therefore, in this study, we experimentally investigated the effect of button size and spacing on both user performance (namely, input accuracy and operation time) and perception. The results will clarify whether user experience of smartphones could be enhanced by customizing button size to a particular task.

S. Yamamoto (Ed.): HIMI/HCII 2013, Part I, LNCS 8016, pp. 80–88, 2013.

2 Experimental Task

Prior to the experiment, participants rested with their eyes closed for two minutes. The assigned task involved repeated touching of command buttons on the touchscreen display of a smartphone (Android GALAXY S3, Samsung). The number of repeated touches was 20. The task was performed in the following sequence:

1. Participants were requested to press the central preparation button on the touch-screen display at arbitrary times.
2. At the time of touching the prepare button, a group of 9 (3*3) command buttons at random positions on the touchscreen display was shown. Among this group, participants were required to touch the centre button as quickly and precisely as possible. Touching point was determined as the first contact point of the fingers on the display. If the central button in the group was precisely touched, the detection was successful. If other points were touched, the detection was false.
3. Return to (1). A single task comprised 20 time repeats of sequences (1)–(3). Following a task, the participants evaluated performance usability on 100 levels and finally assessed the success rate of tasks.

The task was performed for different handgrips, button sizes and button spacings.

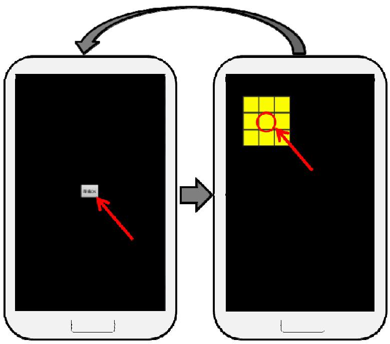

Fig. 1. Task sequence and display design used in the smartphone experiments

2.1 Experimental Conditions

Handgrips were dominant-handed dominant-thumb operation (Fig. 2), opposite-handed dominant-index-finger operation (Fig. 3) and ambidextrous thumb operation (Fig. 4). In the final case, participants also conducted thumb-free operations.

Four different button sizes were used: 3, 5, 7 and 9 mm. Button spacing was 0, 1 and 2 mm. Participants were given all 12 combined conditions in a perfect random order.

Fig. 2. Dominant-handed dominant-thumb operation

Fig. 3. Non-dominant handed dominant index finger operation

Fig. 4. Both-handed both-thumb operation

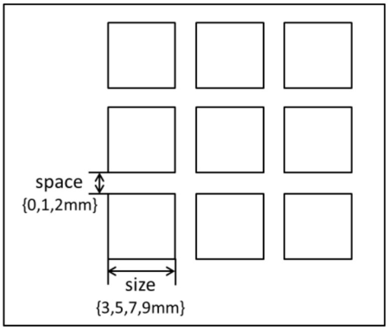

Fig. 5. Experimental conditions of button size and space

2.2 Measurements

The device was tested from performance, psychological and physiological viewpoints. Performance was assessed from input accuracy and operation time data. Input accuracy was defined as the probability of exactly touching the group central button in a single task; that is, the input accuracy measures the probability of successful touches per task. Operation time was the time difference between the fingers disconnecting from the prepare button and touching the next (arbitrary) position on the touchscreen display. As a measure of psychological impact, participants were asked the question "How easy was touching the command buttons in one task? Please valuate this task from 0 points (very easy) to 100 points (very difficult)" after task completion. Physiological measures were SCR (Skin Conductance Reflex) and re-rated human emotion; in particular, excitement and awareness. Measurement instruments were BIOPAC MP150 and GSR110C skin SCRamp (made by Monte System Corporation). Ag/AgCl electrode was placed on the index and middle fingers of the participant's non-dominant hand. Cutoff frequency was 0.05–1 Hz and sampling rate was 0.2 kHz.

2.3 Participants

10 male college male students (age 21–24) participated in the study. Participants had consumed no alcohol or caffeine since the previous day. All participants were right-handed. Eight of the participants used a smartphone in everyday use, while the remainder used a feature phone.

2.4 Ethics

We obtained informed consent from all individuals participating in this experiment.

3 Results

3.1 Task Performance

Accuracy as a function of size and spacing of command buttons was assessed using two-way analysis of variance (ANOVA). The results under dominant-handed dominant-thumb operations are shown in Fig.6. Size exerted a statistically significant effect on accuracy (Two-way ANOVA, $F(3,108) = 44.90$, $p < 0.01$), whereas spacing did not. Moreover, no interaction between size and space was observed. The above results were independent of handgrips.

Input accuracy decreased with button size. In particular, input accuracy declined from approximately 90% to 75% as the button size decreased from 7 mm to 5 mm, and reduced to below 50% when 3-mm buttons were used (Bonferroni multiple comparison). The accuracy achieved for a given button size was not affected by spacing between the buttons.

Next, operation time as a function of size and spacing of command buttons was analysed by two-way ANOVA. The results under dominant-handed dominant-thumb operation are shown in Fig. 7. Furthermore, button size exerted a significant effect (Two-Way ANOVA, $F(3,108) = 15.15$, $p < 0.01$) regardless of spacing, with no obvious interaction between size and spacing. These results were again independent of handgrips.

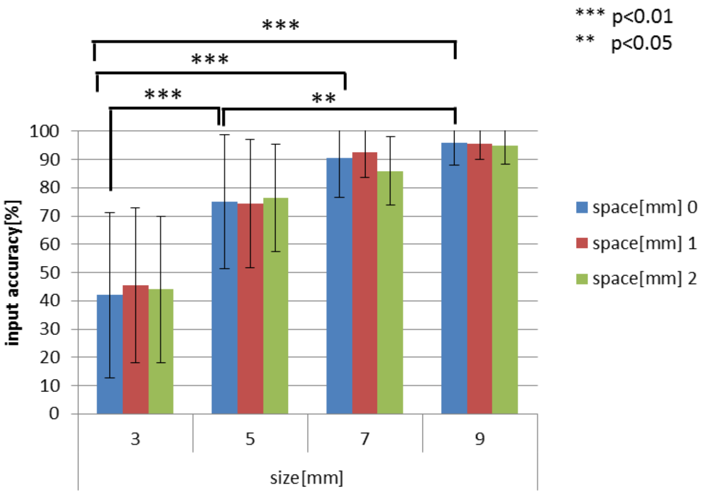

Fig. 6. Relationships between size, space and input accuracy under dominant-handed dominant-thumb operation

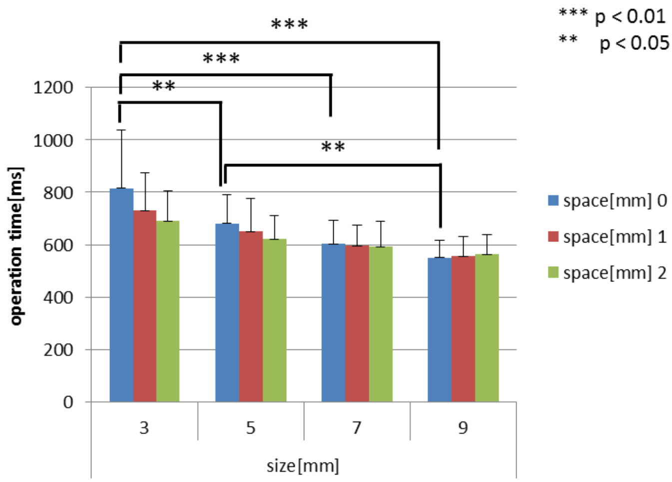

Fig. 7. Relationship between size, space and operation time under dominant-handed dominant-thumb operation

Operation time was inversely related to smaller button size. Operations performed on 9 mm buttons consumed less than 565 ms, whereas approximate operating times for 5 and 3 mm buttons were 651 and 746 ms, respectively (Bonferroni multiple comparison).

Meanwhile, spacing exerted no significant effect on input accuracy.

3.2 Subjective Evaluation

Two-way ANOVA was used to subjectively evaluate the ease of button touch for varying size and spacing of command buttons. Figure 8 summarizes the results under dominant-handed dominant-thumb operation. In this case, the effects of both size (Two-way ANOVA, $F(3,108) = 90.64$, $p < 0.01$) and spacing (Two-way ANOVA, $F(3,108) = 4.39$, $p < 0.05$) were statistically significant, but no interaction between size and spacing was detected. Similar results were obtained for other handgrips.

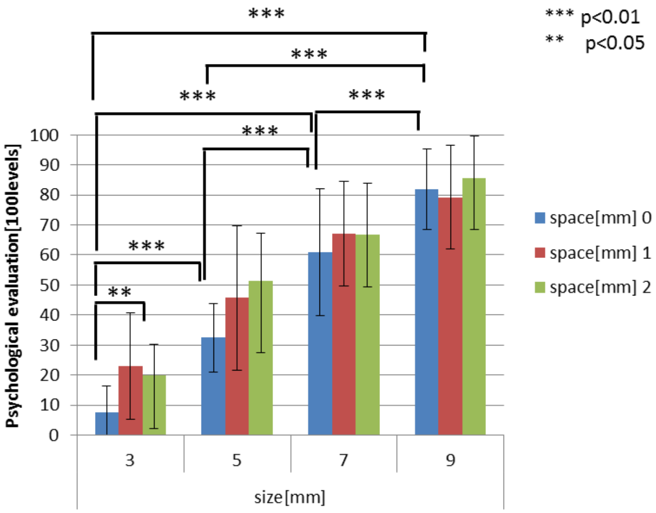

Fig. 8. Relationships between size, space and subjective evaluation points under dominant-handed dominant-thumb operation

Subjective evaluation points related to the ease of touch on command buttons increased with the button size (Bonferroni multiple comparison). Evaluation of the 3-mm buttons was especially low (around 20 points or less), with a significant increase as spacing was increased from 0 mm to 2 mm (Bonferroni multiple comparison).

3.3 Physiological Evaluation

It is known that physiological reactions markedly differ between individuals. Therefore, the SCR data were analysed as follows. The SCR of an individual was obtained as the average SCR during task performance minus the average resting SCR (measured prior to experiment). Also, the data measured from the same handgrip were standardized to satisfy average = 0 and variance = 1. In addition, because abnormal SCR measurements were obtained from three of the participants, the measured data are those from seven participants. SCR results, results under dominant-handed dominant-thumb operations, analysed by two-way ANOVA, are shown in Fig.8. Button size and spacing exerted no significant effects on physiological response, nor was any interaction between size and space detected.

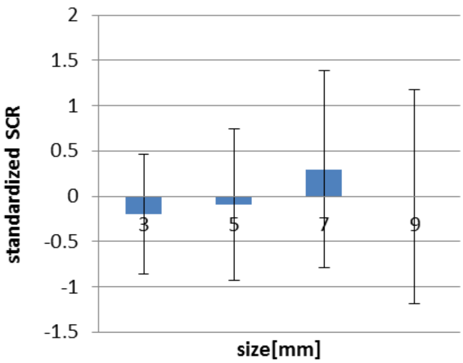

Fig. 9. Relationship between size and standardized SCR under dominant-handed dominant-thumb operation

Although no overall statistically significant differences were observed, on an average, 7-mm button size generated a higher physiological response than other button sizes. The relationship between standardized SCR and size showed an inverted U-shaped structure.

This physiological response curve was dependent on handgrip. Under the other two types of handgrip, SCR increased as button size decreased. An inverted U relationship did not emerge.

4 Discussion

The analysis of input accuracy and performance time revealed that users could operate exactly and quickly if command buttons were sufficiently large, consistent with a general hypothesis. Input accuracy was re-assessed for the eight participants in an ordinary manner using a smartphone (Fig.10).

In this sample, input accuracy was around 50% for the 3-mm buttons, but exceeded 80% and 90% for the 7-mm and 9-mm buttons, respectively. However, regardless of handgrip, the accuracy improvement as button size increased from 5 to 9 mm was not statistically significant. Therefore, we consider that most users can touch buttons over 7 mm 'exactly and quickly enough', whereas seasoned smartphone users can likely manipulate smaller buttons (5 mm) with an equally high accuracy.

However, we regard 9 mm as a suitable size for command buttons. With larger size buttons, the display has extra space and the 'ease of touch' judgment is maximized, as evidenced in the positive relationship between subjective evaluation points and increased size and spacing.

SCR analysis presents a different viewpoint. Ogawa et al. reported an inverted U relationship between 'interest' and information load (see Fig.11) [4].

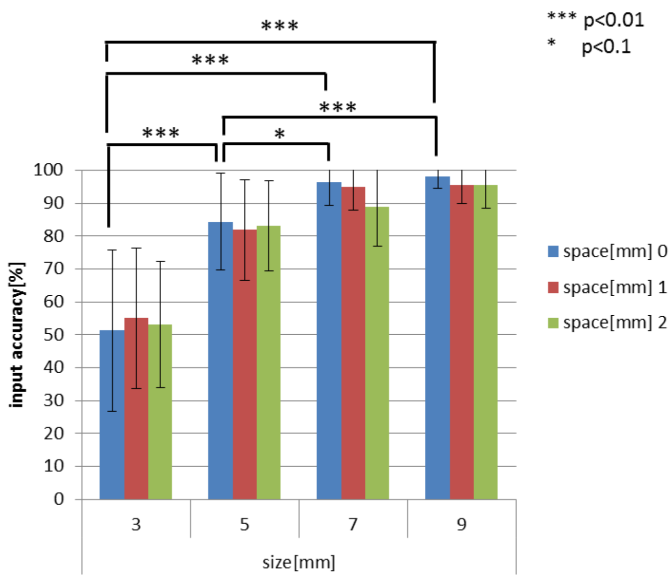

Fig. 10. Input accuracy as a function of size and space in smartphone users under dominant-handed dominant-thumb operation

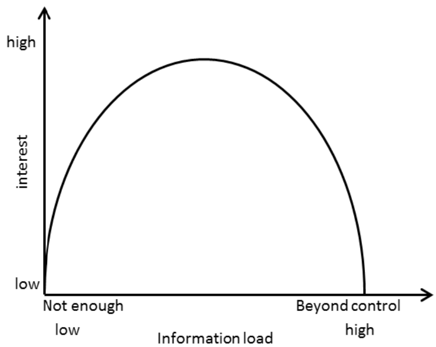

Fig. 11. Relation between 'interest' and information load (re-edited based on the chart presented by Ogawa, et. al. [4])

While the theory of Ogawa and colleagues is not entirely consistent with that of our study, it suggests that the inverted U-shaped relationship between load, which may be interpreted as 'difficulty to touch' and button size reflects a correspondence between the physiological response (SCR measurements) and psychological response, in particular, excitement and awareness. From the results of this experiment, the optimal size at which participants report exact and easy touching can be assumed as 7 mm. At this size, participants may conduct operations under the most active and excited psychological conditions. Therefore, a 7-mm command button, corresponding to the top of an inverted U curve, is ideal for applications intended to enhance the user's psychological state (such as gaming).

Comparing these findings with existing design guidelines, we note that the peripheral joint width of the index finger exceeds 14 mm in 95% of Japanese males (IOS9251-9(2000); [5]). Given that a 9-mm button size ensured sufficient performance in this experiment, we conclude that the existing guidelines are not suitable for modern interfaces. Also, in the latest UI guidelines released by companies, the minimum space allocated to button size plus spacing is approximately 9 mm, consistent with the results of our study in terms of task performance and subjective evaluation.

However, a 7-mm button size is sufficient to inspire smartphone users a sense of 'interest' and ensure high task performance. We suggest that UI design guidelines be reviewed for uses such as games and amusement.

5 Conclusion

In this study, we experimentally investigated how command button size affects the physical performance of users and the psychological perception of smartphone devices.

It was found that most users can easily and accurately touch command buttons exceeding 7 mm. Users who ordinarily use a smartphone can accurately manipulate buttons as small as 5 mm. However, the 'ease of touching' increases as button size increases. Thus, extra-space displays (9 mm command buttons) appear to offer the most user comfort. Meanwhile, the button size for which users reported 'not too difficult and not too easy' was 7 mm. At this size, button touching was accompanied with a rise in user excitement. Thus, applications such as gaming, in which users should feel excitement rather than relief, are well serviced by a 7-mm command button.

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