Touch Behavior Analysis for Large Screen Smartphones

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As phone touch screen becomes larger and larger, for single hand holding posture, the user interaction can be extremely hard if icon do not be placed into proper touch area. So it is necessary to know the specific suitable touch zone on large phone screen. In this paper we performed a target selection task on a large screen smartphone and analyzed the task performance under different variable conditions. Response time, hit rate and hit offset differences between gender and target location and the possible reasons for such difference are discussed. Design recommendation for button and icon location are also been discussed based on the experiment result.

INTRODUCTION

Nowadays, most mobile phones use a touch screen to display information and collect input from users. While users may choose to interact with their phone by using one or two hands based on their personal preference or the tasks they are performing (Trudeau, Young, Jindrich, Marcos, & Dennerlein, 2012b), the most commonly adopted posture is holding the phone with one hand and tapping on the screen with the thumb (Hoober, 2013). Compared with two-handed grip, single-handed grip is associated with more restricted thumb movement, larger phone movement, and poorer thumb motor performance (Trudeau, 2012b). Considering the popularity of single-handed grip among users, understanding how users interact with phones with one hand is important for the user interface design.

Single target selection task (Parhi, Karlson, & Bederson, 2006; Park & Han, 2010; Xiong & Muraki, 2014), serial target selection task (Parhi *et al*., 2006), and reciprocal tapping task (Karlson, Bederson, & Contreras-Vidal, 2006; Trudeau, Udtamadilok, Karlson, & Dennerlein, 2012a) are the three most commonly used tasks in the studies of one-handed interaction with mobile phones. Single target selection task emulates common actions like activating a button and selecting a checkbox on a mobile phone touch screen. For example, Park & Han (2010) employed a single target selection task, in which a participant was asked to press a target key that appeared a short time after he touched the screen anywhere. Serial target selection task and reciprocal tapping task, on the other hand, imitates activities that comprise a rapid sequence of selections, such as typing text and entering number. For example, Karlson et al. (2006) used a reciprocal tapping task, in which a participant tapped as quickly as possible between two targets in 5 seconds.

The location of targets, the size of targets, the size of the hand-held devices, and the direction of thumb movement were found to affect the performance and preference of target selection tasks. Targets located near the center of the screen were associated with shorter reaction time, better accuracy, and higher subjective comfortableness in single target selection tasks (Parhi et al., 2006; Park & Han, 2010), and they were also associated with higher movement speed and higher subjective satisfaction in reciprocal tapping tasks (Karlson et al., 2006).

Parhi et al. (2006) found that the speed of thumb movement generally increased as target size growing, but increasing the target size to over 9.2 mm for single target selection task would not further improve the speed, accuracy, or subjective ratings. Similarly, Park & Han (2010) found in a single target selection task that target size of 10 mm provided best results for time-related measures, accuracy-related measure, and subjective ratings, compared with 7-mm targets and 4-mm targets.

Tredeau et al. (2012) were the first to examine the effects of mobile phone size on the performance of target selection tasks. In their study, four hand-held devices were used to simulate mobile phones, whose dimensions varied from 90*54*23 mm to 114*71*13 mm. Generally speaking, performance of the reciprocal tapping task were significantly better for smaller devices. Although the smartphone screen size grows over time and the diagonal screen size of mainstream smartphones varies from 101.6 mm to 152.4 mm (Taylor, 2014), no studies have examine the one-handed interaction on mobile phones with which diagonal screen size is larger than 88.9 mm (Xiong, 2014).

There is also a dramatic hand holding pattern change with phone screen size increasing. For small-screen phone, users-supposing they use right hand-tend to hold the right bottom of phone (right bottom pattern), in contrast, they prefer to grip the center of phone (center pattern) with large-screen. These two different single hand-holding patterns will inevitably change users' preferred touch zone.

The present study was intended to fill this gap by conducting single target selection tasks on a large-screen mobile phone and to aid to give reasonable guideline in big screen interaction design. The single target selection task was preferred over serial target selection task, because it would better to help us understand how actions, such as activating a button, were carried out throughout the screen. Serial target selection task resembles activities like typing texts, in which both hands are likely to be involved and tapping mostly happen at the lower part of the screen. Also, the size of targets was set as 9.96 mm, because it was the target size that would not further improve performance on hand-held devices with smaller size (Parhi et al., 2006).

Besides target location and target selection task, human hand dimension can obviously have impact on the interaction zone, i.e. larger hand covers larger touch area. Hence hand dimension should be taken into consideration. However, hand dimension, which varies widely among individuals, is not realistic to be used as reference of interaction guideline. Instead, gender, owning natural hand dimension discrimination information, is a natural variables to influence touch area. As mentioned before, with phone screen size increasing, the single-hand right bottom holding pattern will change into center pattern, but for different genders, due to their different hand dimensions distribution, for the same specific phone size, maybe most male use right bottom pattern, meanwhile most female prefer center pattern. Under this condition, the difference of suitable touch area between male and female will consequently enlarge. Hence, gender need to be considered in touch zone evaluation for big screen.

METHOD

Participants

A total of 20 participants performed a target selection task. They had normal vision and no problem to freely move their thumbs. Half of the participants were male, one of which was left handed. Among the 10 female participants, 3 of which were left handed.

Apparatus

A large-screen mobile phone (Huawei Mate7) was used for the target selection task. The device had a size of 157*81*7.9 mm and weighted 185 g. The mobile phone had a touch screen (height of 132.8 mm and width of 74.7 mm) with the resolution of 1920*1080 pixels.

Stimuli

The screen was divided into 40 rectangular areas (fig. 1). The target appeared at the center of one of those areas, and it was 9.96mm in height and width. (Parhi et al., 2006; Park & Han, 2010). The central area (11 to 30) was shown in light yellow at the beginning of every trial.

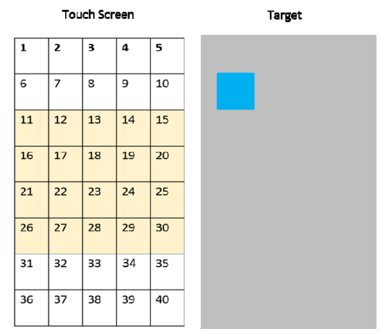

Figure 1. Target locations, their IDs, and an example of experimental target.

Experimental Design

A 40*2 mixed factorial design was used in the experiment, in which the target location (within-subject variable) and the gender (between-subject variable) were manipulated. The target location factor had 40 levels. In the experiment, the center point of a target was located at the center point of one of the 40 rectangular areas. For each target location, the target selection task was repeated 5 times. A total of 200 trials were performed by each participant. The target locations were randomized across all trials.

Target Selection Task

At the beginning of the experiment, each participant was asked to hold a mobile phone with his/her preferred hand and practice pressing targets with the thumb. All participants were asked to press the targets on the screen as fast and as accurately as possible. They were allowed to adjust his/her holding posture in order to hit the target, but they were not allowed to use the other hand either to support the mobile phone or to aid in conducting the tasks in any way.

At the beginning of each trial, the central area was shown in light yellow color. A participant can initiate a trial by pressing any location within the central area. In this case, the initial hand posture can be guaranteed to reflect the user's natural holdings. The central area turned grey (the same color as the background) immediately after a participant touched the central area. Then, 0.3 second after that, a blue target appeared at one of the 40 locations. When a participant hit the target within 1.5 seconds after the target onset, the target turned green immediately and remained for 1 second, indicating a correct response. When a participant missed the target or failed to response within 1.5 seconds, the target turned red, indicating an incorrect response.

Dependent Measures

The performance measures included one time-related measure (reaction time) and two accuracy measures (hit rate and hit offset magnitude).

The reaction time is defined as the time taken from the target onset to the first press whether or not it is hit the target. Reactions that longer than 1.5 seconds were excluded.

The hit rate for a target location is the percentage of trials in which the target is correctly pressed.

The hit offset magnitude is the 2-D distance from each target's center to the corresponding hit point. Both correct and incorrect responses were included in the calculation of average hit offset magnitude.

RESULTS

Reaction Time

Mean reaction time for all experimental conditions were shown in fig. 3.

1955.3	1218.5	911.6	913.2	962.9	2237.0	1502.9	993.3	1014.1	1118.5	1736.1	997.3	848.0	834.7	841.8
1274.2	883.1	781.8	735.2	755.9	1642.2	1018.4	875.1	779.3	822.3	988.0	777.9	709.2	701.0	704.3
947.3	758.1	675.1	623.5	718.3	1115.2	882.0	752.1	662.7	676.6	816.7	661.8	615.2	593.0	750.7
826.7	653.6	648.0	571.5	658.5	964.7	718.4	773.7	595.7	652.7	719.4	603.2	550.3	552.6	663.1
819.8	608.4	583.8	577.0	762.3	951.5	686.6	659.5	593.7	785.9	717.4	547.6	524.9	564.0	743.9
932.7	678.7	587.8	599.9	678.3	1210.7	784.2	604.7	622.1	712.6	716.4	596.7	574.5	582.7	651.6
1358.2	880.5	695.1	701.6	820.3	1698.1	1057.4	744.6	730.8	861.1	1093.9	742.9	656.7	678.9	788.6
2158.7	1367.4	1049.4	874.9	974.5	2774.2	1731.8	1269.5	919.2	983.0	1679.9	1084.0	878.3	840.5	967.9

Figure 3. Mean reaction times of all target locations for all participants (left), females (middle), and males (right). Red color represents poor performance, and green color represents good performance.

The repeated-measure two-way ANOVA were used to analyze the reaction time. The results showed that the target location ($F(39,546)=15.93$, $p<.01$), the gender ($F(1,14)= 5.41$, $p<.05$), and the interaction between them ($F(39,546)= 1.71$, $p<.01$) significantly influenced the reaction time.

Hit Rate

Mean hit rates for all experimental conditions were shown in fig. 3. The two-way ANOVA were used to analyze the reaction time. The results showed that the target location ($F(39,560)=7.03$, $p<.01$), the gender ($F(1,560)=34.76$, $p<.01$), and the interaction between them ($F(39,560)=1.68$, $p<.01$) significantly influenced the hit rate.

48%	80%	88%	96%	91%	40%	69%	80%	94%	89%	53%	89%	93%	98%	93%
69%	95%	91%	91%	94%	49%	89%	97%	91%	94%	84%	100%	87%	91%	93%
78%	96%	98%	93%	98%	69%	94%	97%	94%	94%	84%	98%	98%	91%	100%
89%	96%	100%	98%	96%	80%	91%	100%	100%	94%	96%	100%	100%	96%	98%
85%	95%	95%	89%	93%	74%	91%	94%	89%	89%	93%	98%	96%	89%	96%
84%	89%	100%	93%	98%	69%	89%	100%	94%	100%	96%	89%	100%	91%	96%
80%	81%	93%	98%	100%	66%	69%	91%	97%	100%	91%	91%	93%	98%	100%
53%	78%	83%	98%	96%	31%	57%	71%	94%	94%	69%	93%	91%	100%	98%

Figure 4. Mean hit rates of all target locations for all participants (left), females (middle), and males (right). Red color represents poor performance, and green color represents good performance.

Hit Offset Magnitude

Mean hit offset magnitude for all experimental conditions were shown in fig. 2. The repeated-measure two-way ANOVA were used to analyze the reaction time. The results showed that the target location ($F(39,546)=10.67$, $p<.01$) and the interaction between the two factors ($F(39,546)=2.30$, $p<.01$) significantly influenced the reaction time, but the effect of gender were not significant ($F(1,14)=4.37$, $p>.05$).

610.7	207.1	74.6	42.7	42.2	547.2	197.0	73.6	45.4	41.0	660.0	214.9	75.3	40.6	43.1
321.8	57.7	40.5	40.8	41.0	638.0	83.0	32.6	38.8	41.7	75.7	38.0	46.6	42.4	40.5
222.1	36.4	34.7	40.5	33.5	328.4	36.4	33.8	44.6	34.2	139.3	36.4	35.5	37.3	33.0
97.2	38.1	34.5	34.8	37.9	171.5	45.7	35.2	33.5	41.6	39.4	32.1	33.9	35.9	35.0
60.4	38.2	34.3	37.8	41.5	91.5	37.5	29.9	39.0	41.3	36.2	38.6	37.8	36.8	41.6
93.5	37.5	31.4	39.0	34.6	140.9	40.2	30.7	31.7	30.1	56.6	35.5	31.9	44.7	38.2
135.0	46.7	40.2	28.4	31.1	178.2	57.2	36.8	25.2	32.7	101.4	38.5	42.9	30.8	29.8
193.4	82.2	44.7	36.8	36.9	285.9	140.8	53.7	40.1	36.3	121.4	36.7	37.8	34.2	37.3

Figure 5. Mean hit offset magnitude of all target locations for all participants (left), females (middle), and males (right). Red color represents poor performance, and green color represents good performance.

Higher hit rate, shorter reaction time, and shorter distance stand for better performance. The three measurements demonstrate similar tendency across different target locations. That is, performance at areas adjacent to where the thumb naturally rests is generally better; performance at the two corners far from the thumb base is worse; performance at other areas is in between.

However, 40 locations-distribution is too specific to instruct interaction design in big screen. It is necessary to combine zones with similar performance together. Taking all three variables into consideration, three main zones can be divided, as shown in figure 6, zone 1 is the best touch zone, zone 3 is the zone that user feel difficult to touch, and zone 2 has the middle touchable level.

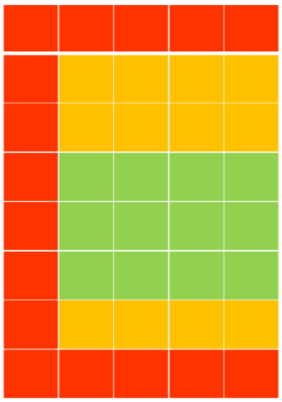

Figure 6, three combined zones, red, yellow and green represent low, middle and high performance level respectively.

DISCUSSION

Effects of Target Location

The results of the experiment showed that target location had a significant effect on the performance of target selection, when participants held a mobile phone in only one hand and tried to press an abruptly appearing target with thumb. Being located near the two corners far from the thumb base means longer reaction time and poorer accuracy, in terms of hit rate and target offset magnitude. As far as right-handed participants were concerned, performance for targets at the two left corners was the poorest, while performance for targets at the center was the best. In comparison with targets at the center, targets at the bottom right corner were associated with a slightly longer reaction time, but the hit rate and the hit offset magnitude for them were as good as those for targets at the center.

This finding is partly consistent with previous studies, in which the central area was also the best region for thumb motor performance. However, Park & Han (2010) and Trudeau et al. (2012) found that thumb motor performance for touch keys located in the bottom right corner, but not the two left corners, was the poorest for right-handed subjects. Park & Han (2010) found longer reaction time and greater number of errors for those keys. Trudeau et al. (2012) found smaller effective index of performance, smaller effective target width, and longer movement time for those keys. The difference in the poorest regions may be explained by the fact that both previous studies used smaller testing devices (114*70*13.4 mm, Park & Han, 2010; 115.2*58.6*9.3 mm, Trudeau et al., 2012) than did the present study (157*81*7.9 mm). A larger device meant that the two left corners were further away from where the tip of the thumb usually rested, so that participants had to assume a different grip and extend the thumb to tap on the two corners. Being further away also caused the surface area under the thumb to be greater, because the surface of the thumb was almost parallel to the screen. This is consistent with the observation of Trudeau et al. (2012) that shaper angle between the thumb and the screen was associated with larger effective target widths and poorer target selection accuracy.

Differences between Genders

The overall performance of male participants were better than the female. Considering all right-handed participants, male participants had a shorter reaction time for most target locations and a higher hit rate for targets on the left border than the female, although both genders had similar hit offset magnitudes. These gender differences may be explained by the different hand sizes of male and female participants. Scott & Conzola (1997) found that the index finger size affected keying speed and errors on numeric keypads of touch screens, and that gender differences in both measures were explained by finger size differences between males and females. The present study randomly selected participants with various hand and finger sizes. Although participants' hand and finger sizes were not measured in the present study, and thus their effects on the performance of the target selection task could not be examined, the findings from the previous study suggested that the gender differences were due to finger size differences.

Unlike the reaction time and the hit rate, no gender differences were found in the target offset magnitude. One possible explanation is that cases included in the analysis of the three measures were different. While the analysis of hit rate included all cases, the analysis of target offset and reaction time only included cases in which a response was made within 1.5 seconds after the target onset. Another possible explanation is that participants' palms sometimes touched the bottom right corner of the screen, which caused incorrect responses and extremely large target offset magnitude. This resulted in a large within-group variance and made the gender differences relatively small.

Design recommendation

According to the performance result above, it is obvious that important icons or buttons should be placed on Zone 1 since it has much more advantage in touch task performance such as hit rate, response time and offset distance.

However, since Zone 1 is also convenient to reach with the least effort, buttons that will lead to serious consequence should be considered to place somewhere outside Zone 1.

Zone 2 is an ideal area for buttons with average frequence of usage. And upper part of Zone 2 is slightly better than lower part of Zone 2 due to unblocked visual feedback.

Zone 3 is a highly risky area for miss-touch, buttons or icons should avoid this area. If inevitable, it is a wise compromise to provide alternative way to complete functions related to such buttons. For example, a back button in Zone 3 should also provide a shortcut gesture such as scroll left as an alternative gesture.

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