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Smartphone form factors: Effects of width and bottom bezel on touch performance, workload, and physical demand

Seul Chan Lee[a], Min Chul Cha[a], Hwan Hwangbo[a], Sookhee Mo[b,*], Yong Gu Ji[a]

[a] Department of Industrial Engineering, Yonsei University, Seoul, South Korea
[b] Graduate Program in Technology Policy, Yonsei University, Seoul, South Korea

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ABSTRACT

This study aimed at investigating the effect of two smartphone form factors (width and bottom bezel) on touch behaviors with one-handed interaction. User experiments on tapping tasks were conducted for four widths (67, 70, 72, and 74 mm) and five bottom bezel levels (2.5, 5, 7.5, 10, and 12.5 mm). Task performance, electromyography, and subjective workload data were collected to examine the touch behavior. The success rate and task completion time were collected as task performance measures. The NASA-TLX method was used to observe the subjective workload. The electromyogram signals of two thumb muscles, namely the first dorsal interosseous and abductor pollicis brevis, were observed. The task performances deteriorated with increasing width level. The subjective workload and electromyography data showed similar patterns with the task performances. The task performances of the bottom bezel devices were analyzed by using three different evaluation criteria. The results from these criteria indicated that tasks became increasingly difficult as the bottom bezel level decreased. The results of this study provide insights into the optimal range of smartphone form factors for one-handed interaction, which could contribute to the design of new smartphones.

1. Introduction

The data usage of smartphones has recently exceeded that of desktop computers as the number of smartphone users has increased. In other words, smartphones have become the primary device for information consumption and sharing. In addition, many people prefer to use smartphones for contents and activities such as games, media, blogging, or social networking services. Consequently, smartphone displays have increased in size because users prefer larger displays for consuming a variety of contents. In fact, the average screen size of a smartphone was 2.59 in. in 2007 and increased to 4.86 in. by 2014 (Victor, 2014).

Although a large display is convenient for accessing a variety of contents, from an ergonomic point of view, the increase in display size may cause users several difficulties in device utilization. Considering that a one-handed grip is widely used for smartphones (Steven, 2013), increasing the device size could negatively affect the grip comfort and increase the physical demand required in using a smartphone (Kietrys et al., 2015; Kwon et al., 2016; Pereira et al., 2013). Previous studies evaluated the physical demand considering one-handed interactions with a smartphone device. Kietrys et al. (2015) studied the effects of the input device type (physical keypad and touch screen), texting style, and screen size on muscle activities, confirming that there was an increase in muscle activities according to increasing screen size. Kwon et al. (2016) tested the effects of the curvature rate of a smartphone on hand comfort by assuming that the curvature rate will decrease hand fatigue when smartphone has a large-screen. When the curvature was moderate, less muscle activity was recorded compared with a flat device. Pereira et al. (2013) concluded that increasing the tablet size decreased usability and worsened biomechanics in terms of increased fatigue in the neck and shoulder regions.

Smartphone users have experienced inconveniences related to not only the physical aspects but also the usability of the device (Chiang et al., 2013; Oehl et al., 2007; Pereira et al., 2013; Xiong and Muraki, 2016). Chiang et al. (2013) conducted a touch pointing experiment with one-handed interaction by using 10 smartphone devices with size ranging from 2.5 to 5.3 in. Their results showed that the error rate and task completion time increased according to increasing screen size. Xiong and Muraki (2016) analyzed the thumb movement coverage on smartphone touch screens with a one-handed grip. They found that, although the thumb-coverage area has increased, the coverage area did not increase as much as the screen size has increased. Therefore, difficulty in tapping icons located on the edge of the screen can be expected.

* Corresponding author. Graduate Program in Technology Policy, Yonsei University, 262 Seongsanno, Seodaemun-gu, Seoul 120-749, South Korea.
E-mail address: soohmo6@gmail.com (S. Mo).

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In addition, many studies have demonstrated that Fitts' law applies to pointing interactions in mobile devices and touch screens (Lin et al., 2007; Oehl et al., 2007; Perry and Hourcade, 2008; Trudeau et al., 2016). According to Fitts' law, the task difficulty increases as the target distance increases. Therefore, large-sized screens include increased marginal areas for icons, resulting in increasing task difficulties.

Increasing display size will likely lead to the increase in device size, and it is unclear whether the negative impact on user performance is a result of the display size or the device size. However, previous studies focused on the effects of display size without considering device size variables (Kietrys et al., 2015; Xiong and Muraki, 2016). Therefore, the relationship between device size and user performance needs to be investigated.

Because the size of the display cannot be continuously increased, smartphone companies have tried to increase the screen-to-body size ratio in order to minimize the effects of increasing the screen size on increasing device size. Initial models of smartphones had about a 60% screen-to-body size ratio; however, most smartphones today exceed 70% (Petrovan, 2015). In particular, there is a new trend in designing displays that aim to increase the ratio, such as using edge displays or increasing the smartphone length. However, the physical bezel area decreases as the screen-to-body size ratio increases. Physical bezels play a role not only in protecting the screen area but also in improving usability. Users hold smartphones by the physical bezel. If the physical bezel area decreases, then interaction with the device becomes more difficult because the user's palm will touch the screen (Nick, 2012).

Whether these changes in smartphone form factors (FF)—increased display size and reduced physical bezel—would be ergonomically appropriate is unclear. However, there are few studies on the effects of these FF. Therefore, this study investigated the appropriateness of FF, and aimed to provide guidelines for mobile devices from an ergonomic perspective. Specifically, the width level was selected as a device size factor and the bottom bezel as a physical bezel factor. To achieve the study objective, an experiment based on touch tasks using one-handed interaction was designed. Data on the task performance, electromyogram (EMG) activity, and subjective workload were collected to analyze the touch behavior of the participants. On the basis of the results, this study provides insights useful for designing smartphone FF.

2. Research frameworks

2.1. Research hypothesis

This study tested the following hypotheses concerning the effects of smartphone FF on touch behaviors. The first hypothesis was that increasing the smartphone width level would have a negative effect on task performance (task success rate and task completion time), subjective workload, and EMG activity during one-handed interaction. The second hypothesis was that decreasing the smartphone bottom bezel would have a negative effect on task performance, subjective workload, and EMG activity during one-handed interaction. The width was defined as the length between the left and right side of a smartphone, and bottom bezel refers to the physical area existing between the bottom of the smartphone device and the bottom of the display.

In addition, these changes in the FF impose additional physical burden on the user's hand. However, in case of a subjective workload, it was expected that physical demand, performance, and effort measures were only significant according to changes in the FF because the dimensions of mental demand, temporal demand, and frustration were not highly related to smartphone touch tasks.

2.2. Pre-experiment: investigation of NTP for one-handed interaction

Before conducting the main experiment, a pre-experiment was conducted to investigate the users' NTP when interacting with a smartphone by using one hand. The NTP refers to the point of the thumb with a natural one-handed grip. The NTP was considered because the aim was to design an experimental task that would be similar to an actual task. Smartphone users usually use tapping interactions for many situations, such as running applications, selecting pictures, and navigating menus. In these situations, users move their thumb from the NTP of the one-handed grip. Therefore, we intended to find the basic thumb position and design tapping tasks were designed based on this position.

Table 1
Basic specifications of the experimental devices.

	Width device				Bezel device
	w67	w70	w72	w74	
Device size	145 × 67 × 8	142.4 × 69.6 × 7.9	146 × 72 × 8.1	149.4 × 73.9 × 7.3	145 × 67 × 8
Screen size	62.0 × 106.1	63.0 × 107.8	64.0 × 109.5	68.0 × 116.4	65.0 × 111.0
Weight	143 g	152 g	161 g	159 g	141 g

Note: Unit of size: mm.

Twenty-five participants (18 men, 7 women) were recruited for the pre-experiment. Their age was between 21 and 32 years (M = 26.8, SD = 3.72). The mean smartphone usage experience was 6.78 years (SD = 2.95). The participants were required to use smartphones for few a minutes using their hand posture in one hand. Then, they were required to run an experimental application and to tap their thumb on the screen three times. These data were used for setting the basic position of the tapping task in the main experiment session. The NTP was measured for each experimental device because the natural posture could be different depending on the device.

3. Methods

3.1. Experimental variables and tasks

In the main experiment session, a user experiment was designed with two independent variables: width and bottom bezel. The width of smartphones in the experiment ranged from 67 to 74 mm. Specifically, four smartphones with widths of 67, 70, 72, and 74 mm were used. The bottom bezel is defined as the physical bezel area below the smartphone screen. Five levels of the bottom bezel were used: 2.5, 5, 7.5, 10, and 12.5 mm. The range of variables was selected by considering the specifications of major premium smartphones.

Three different dependent variables were collected to investigate touch behaviors. First, data on effectiveness and efficiency were collected as task performance measures. Effectiveness was measured according to the success rate, defined as the percentage of success task in a single attempt. The task completion time was collected as an efficiency measure. Second, the EMG activity of thumb muscles was measured. The first dorsal interosseous (FDI) and abductor pollicis brevis (APB) muscles were selected because these two muscles were primarily used on smartphone touch behaviors in previous studies (Kwon et al., 2016; Xiong and Muraki, 2014). Third, the subjective workload level was collected based on NASA-TLX measures (Hart, 2006). The questionnaire consisted of 21 Likert-scale items.

3.2. Experimental tasks

To investigate one-handed interaction with smartphones, a tapping task that is widely used for smartphone interaction was selected. Participants were required to touch the circled target icon as quickly and as accurately as possible. After the participants tapped the target, the next target appeared immediately.

Grid-based task has been widely used to test one-handed tapping interactions in previous studies (Park and Han, 2010; Perry and