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Effects of age, thumb length and screen size on thumb movement coverage on smartphone touchscreens

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A B S T R A C T

This study investigated the relationship between the movement coverage on smartphone touchscreens and the factors (age, thumb length and screen size) affecting this. By referring to the thumb movement in the adduction-abduction orientation with a right-hand phone-holding posture, the thumb-coverage area that represents how far the thumb can reach and the centre of gravity in this coverage area were determined. The assessment focused on a comparison of these indices between ages, thumb lengths and screen sizes. The results showed that elderly users and those with longer thumbs are likely to leave more unreachable space at the right side and bottom of touchscreens. Moreover, the thumb-coverage area actually increased when the touchscreen size was increased; however, increasing the size of a smartphone touchscreen does not necessarily increase the thumb-coverage area at the same ratio as the touchscreen size increases.

1. Introduction

With the inclusion of touchscreen technology into mobile phone manufacturing, mobile phones may now be regarded as not only phones but also mobile computers, which facilitate work and help one to live in the Internet world (Bouwman et al., 2014; Choi and Lee, 2012; McCarthy et al., 2013; Othman et al., 2013). Moreover, in terms of mobility, touchscreen mobile phones (generally called smartphones) are supposed to be superior to actual mobile computers (laptops, tablets, etc.), since mobile phones are lighter and smaller, which makes them even more portable (Jewell, 2011; Nortcliffe and Middleton, 2013). In this era of mobile computers, it is believed that touchscreen smartphones will play an increasingly significant role in modern life, and efforts to develop better designs for these devices seem to be intensifying all over the world (Carayannis et al., 2013; Do and Gatica, 2013; Park and Han, 2013).

Apart from pursuing the development of hardware, the improvement of interface designs for touchscreen smartphones is also necessary (Tsai and Ho, 2013). For instance, the layout of PC keyboards is directly transplanted into smartphones, despite the reduced size, in order to fit into palm-size touchscreens. This could potentially cause uncomfortable interactions between the operating fingers and the touchscreen. For example, in order to cover the keys at the corners of the keyboard (single hand operation), the thumb needs to move dramatically across the screen from left to right. The rapid and repetitive movements may fatigue the thumb, which increases typing errors and unnecessary repetitive typing, thereby reducing the use performance.

Moreover, previous studies found that many factors could affect the use performance of small touchscreen devices. According to Xiong and Muraki (2014), the thumb tends to tap faster in an abduction-adduction than in a flexion-extension orientation movement when operating a smartphone touchscreen with a single hand posture. Trudeau et al. (2012) also pointed out that the use of distant keys (compared with the keys close to the lower right corner, right-hand phone-holding posture) on a mobile phone caused the participants to spend longer reaching for them; meanwhile, the precision of pushing those distant keys was also reduced. Besides, it has been found that aging has a degenerative effect on hand functions, especially in terms of precision grip, pinch force and maintaining a steady pinch posture (Carmeli et al., 2003; Ranganathan et al., 2001). In addition, a study found that a small touch button size, poor spacing among the touch buttons and inconvenient location of targets on touchscreen smartphones significantly reduced the finger pointing performance in elderly users (Hwangbo et al., 2013). Muraki et al. (2010) also revealed that

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the elderly tended to have more pushing errors than the young when operating small cell phones with the thumb. However, studies on thumb coverage on touchscreen smartphones specifically for elderly users have rarely been reported. Furthermore, screen size could also be another significant factor that limits the thumb from covering the screen surface; thus, a comparison of the thumb coverage among various screen sizes would be helpful for understanding more about the features of thumb movement on smartphone touchscreens.

This study examined the thumb movement coverage (thumb-coverage area and centre of gravity in the coverage area) by referring to the abduction-adduction orientation on smartphone touchscreens of two different sizes, as well as the relationship between the coverage and user age, thumb length and size of touchscreens. Since the centre of gravity (G) could represent the position of a given irregular rectangular within a defined coordinate system, G was referred to in the comparison of the thumb-coverage position in this study. In addition, this study focused on the keyboard area of the touchscreen, since the upper part of the touchscreen is not likely to be reached by the thumb, especially when the phone is being held with one hand. It is believed that the findings of this study can contribute to a better understanding of the features of thumb movement on smartphone touchscreens, and increase the knowledge base for better designs of user interfaces for not only touchscreen smartphones but also other handheld touchscreen devices with a similar form factor.

2. Methods

2.1. Participants

A total of 48 right-handed individuals who were identified by the Edinburgh Handedness Inventory (Oldfield, 1971) participated in this study and were divided into two groups according to age and thumb length. All participants were mentally and physically able to undertake the experimental tasks, and no visual or auditory problems were reported. None of the participants claimed to have any musculoskeletal disorders or pain, nor any motor symptoms or impaired tactile perception in their thumbs. This study was approved by the Ethics Review Board, Faculty of Design, Kyushu University, Japan, and informed consent was received from each participant.

2.1.1. Age groups

The participants were divided into two age groups, namely, a youth group (12 males and 12 females, mean age±standard deviation [SD] 23.6 ± 1.8 years) and an elderly group (12 males and 12 females, 67.5 ± 3.7 years). The participants in the elderly group claimed to have general knowledge of how to operate a touchscreen smartphone, and they had used tactile keypad mobiles on a daily basis; each young participant owned a touchscreen smartphone for daily use.

2.1.2. Thumb-length groups

The thumb length of the participants was measured and they were accordingly divided into two groups by its median value (97.9 mm), namely, a short-thumb group (4 males and 20 females, 12 young adults and 12 elderly, mean ± SD 93.9 ± 3.5 mm) and a long-thumb group (20 males and 4 females, 12 young adults and 12 elderly, 109.1 ± 5.2 mm).

In this study, the thumb length is defined as the distance between the top of the thumb tip and the apophysis at the proximal end of the metacarpal (Fig. 1). In order to measure the thumb length, the participants were asked to straighten their right forearms and place them comfortably on a desk with the palm facing downwards, with the thumb extended and remaining straight at 45° to the wrist interstate line, along with a comfortable posture and without generating extra muscle effort. The measuring tool used in the experiment was a 200-mm-long sliding caliper with a resolution of 0.1 mm. The age groups showed no significant difference in thumb length using paired T-test (youth group: mean ± SD 102.4 ± 10.2 mm, elderly group: 101.6 ± 8.7 mm). In addition, the longer-thumb group tended to have larger hands than the shorter-thumb group (Table 1).

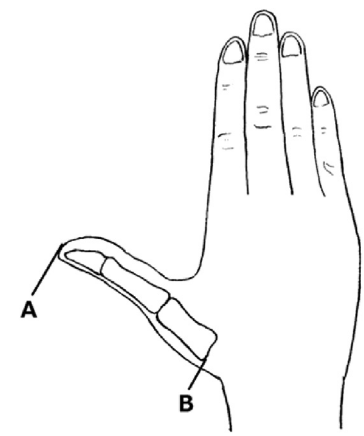

Fig. 1. Thumb length measurement. The distance between A and B represents the thumb length.

2.2. Experimental smartphones

The phones used in this experiment were an actual iPhone4 (phone A) and an actual Galaxy S4 (phone B), since they were considered to be the most popular touchscreen smartphones globally in recent years. The dimensions of phone A were 115.2 × 58.5 × 9.3 mm, with a weight of 140.0 g; and those of phone B were 136.6 × 69.8 × 7.9 mm, with a weight of 130.0 g.

2.3. Protocol

All participants sat comfortably in an armless chair (the height of which was adjustable to match various body heights) in front of a 70-cm-high desk. They placed the tested right arm on the desk in a posture and position that would provide them with acceptable comfort, so that their arms and wrists were fully supported in order to ensure that the participants could concentrate on the tasks during the experiment. The participants were asked to hold the smartphone in a posture matching that which they normally adopt on a daily basis. However, since the elderly participants may not have had sufficient experience using touchscreen smartphones, they were provided with about ten minutes to familiarise themselves with the experimental phones. Then, they decided on the holding posture that would enable them to hold the phones comfortably and steadily.

The experimental task is very simple to undertake since it

Table 1
Comparison of hand length and width between thumb length groups. Values indicate means ± SD (n = 48).

	Short thumb	Long thumb
Hand length (mm)	169.3 ± 9.7	191.6 ± 13.4**
Hand width (mm)	94.7 ± 5.3	108.1 ± 8.5**

T-test: *$p < 0.05$, **$p < 0.01$.