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## Abstract
**Purpose** – The purpose of this paper is to examine the effects of interaction techniques (e.g. swiping and tapping) and the range of thumb movement on interactivity, engagement, attitude, and behavioral intention in single-handed interaction with smartphones.
**Design/methodology/approach** – A 2 × 2 between-participant experiment (technological features: swiping and tapping × range of thumb movement: wide and narrow) was conducted to study the effects of interaction techniques and thumb movement ranges.
**Findings** – The results showed that the range of thumb movement had significant effects on perceived interactivity, engagement, attitude, and behavioral intention, whereas no effects were observed for interaction techniques. A narrow range of thumb movement had more influence on the interactivity outcomes in comparison to a wide range of thumb movement.
**Practical implications** – While the subject of actual and perceived interactivity has been discussed, the issue has not been applied to smartphone. Based on the research results, the mobile industry may come up with a design strategy that balances feature- and perception-based interactivity.
**Originality/value** – This study adopted the perspective of the hybrid definition of interactivity, which includes both actual and perceived interactivity. Interactivity effect outcomes mediated by perceived interactivity.

**Keywords** Behaviour, Cognitive mapping, Mobile communications, Human-computer interaction
**Paper type** Research paper

## 1. Introduction
Single-handed thumb interaction has widely been used for mobile devices with touch screens. This is because users generally prefer one- to two-handed interactions when operating mobile devices (Park and Han, 2010). Using smartphones in a mobile context imposes both physical and intellectual demands on users. Single-handed interaction can offer multiple benefits to the users by freeing one hand from such demands. Previous research (Karlson *et al.*, 2006) has consistently shown that single-handed interaction should be seriously considered when exploring the usability of mobile devices.

Smartphone users can tap and make gestures on the touch screen in order to control applications at the interface level. Gestures can also be useful for interacting with the interface and using the touch screen to overcome several limitations related to input capability (Boring *et al.*, 2012). Compared to the mouse-based control of desktop interactions, experiences of user actions with smartphones are quite different due to the limited screen space and the unique characteristic of mobility. Although several studies (Oh *et al.*, 2013; Xu and Sundar, 2014) have explored the effects of interface tools for interacting with interfaces or systems based on the psychology of interactivity, they simply specified the effects of the technological attributes of the web medium, particularly with regard to

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desktop environments. Considering the explosive increase in smartphone usage around the world, a variety of interactive actions on smartphones needs to be examined.

Other limitations of the current interactivity studies were caused by an inconsistency in the proposed conceptual definitions (Bucy and Tao, 2007). This resulted in conflicting and inconclusive findings on the effects of interactivity in various fields (Kiousis, 2002; Wu, 2005). Several scholars have suggested that the level of interactivity fluctuates within a medium when focussing on user perception (Bergstrom-Lehtovirta and Oulasvirta, 2014; Nicosia *et al.*, 2014), while others emphasized technological properties (Shin *et al.*, 2013). When it comes to the effect of interactivity on attitude, some researchers have indicated that it has a positive effect on attitude toward websites (Jee and Lee, 2002) and brands, while others reported no significant relationship between them (Coyle and Thorson, 2001). By examining the effects of gesture-based interaction in mobile-based interaction, Negulescu *et al.* (2012) found no significant differences in reaction time for motion gestures, taps, or surface gestures on smartphones. Furthermore, they showed that the use of motion gestures results in significantly less time looking at the smartphone while walking than the interaction of tapping on the screen, even with the optimization of the interactions for eye-free input. Wu (2005) argued that the inconsistent findings of several interactivity studies were due to a lack of integration of the types of research conducted, which can be clarified by regarding perceived interactivity and its role as a mediator between interaction techniques and interactivity effects, such as attitude. How interaction with mobile devices influences other factors is becoming increasingly important, as smartphones become more complex and support more diverse services and applications.

Given the ongoing discussion, it is important to clarify interactivity to improve the understanding of one-handed interaction with smart devices. In this light, the present study provides an explication of the effects of interactivity in single-handed interactions with smartphones, as mediated by perceived interactivity. With a focus on these effects, this study aimed to enhance the understanding of one-handed thumb interaction, which is widely used on mobile devices, especially smartphones. This study took a new approach in examining users' perceived interactivity with single-handed mobile interfaces instead of actual interactive performance. The study context of mobile devices is a much-needed area for scholarly investigation, and the findings make a valuable contribute to the investigation of interaction techniques in the smartphone context. The findings show that a narrow range of movement has positive effects on perceived interactivity. The range of thumb movement had significant effects on perceived interactivity, engagement, attitude, and behavioral intention, whereas no effects were observed for interaction techniques. From the findings, a key argument of this paper is that the interactivity effect outcomes mediated by perceived interactivity. Obviously, the actual interactive features may be fundamental; however, perceived interactivity plays a critical role in adoption and usage by mediating, enhancing, and facilitating user experience. While the subject of actual and perceived interactivity has been discussed so far, the issue has not yet been applied to smartphones. The results of this study provide heuristic implications, as little is known about the theoretical or practical effects of mobile interactive features. The results could assist the smartphone industry to develop a design strategy which balances feature- and perception-based interactivity.

The remainder of this study is organized as follows: Section 2 provides a literature review on interactivity and the related technology and the theories. Section 3 provides the research questions and the research hypotheses tested in this study in Section 4. Data collection and analysis methods are described in Section 5. Section 6 explains the findings and results; a discussion of the results and their implications are provided in Sections 7 and 8, respectively. Finally, it ends with the limitations and suggested topics for future studies.

## 2. Literature review

### *2.1 Interactivity as a technological feature*

Heeter (2000) defines interactivity as an episode or series of episodes of physical actions and reactions of an embodied human with the world, including the environment, objects, and humans; in addition is relates to the idea of designed experiences being a human attempt to structure an environment to create affordances for a human participant. Along with interactivity, affordance is considered one of the most important concepts signifying a relation between an object or an environment and an organism that affords the opportunity for that organism to perform an action.

With the widespread use of smart technologies, both affordances and interactivity have been understood in connection with technologies (e.g. Li and Li, 2014). This assumption, of course, would be established by limiting the definition to human-to-machine and machine-to-machine interactions, not human-to-human. Since interactivity places greater emphasis on media interaction by bringing out user interactions with the interface (Shin *et al.*, 2013; Sundar *et al.*, 2010), it should be distinguished from social interaction, person-to-person conversation, or face-to-face communication (Bucy and Tao, 2007). In addition, the most important notion of interactivity is that it changes the role of communication receivers from an audience to the user. While audiences are passive in receiving messages from the mass media, users become active gatekeepers, selectively choosing the information to view from the media by interacting with communication technologies. This has led media scholars to focus more on interactivity based on user perspectives when examining interactions with communication media.

Sundar *et al.* (2014) has defined interactivity as a set of system affordances that enable users to alter the source, medium, and message of their communications through a system based on the most central elements for the transmission of information in the traditional models of communication. Each of the three areas included in interactivity have different theoretical mechanisms and effects on user experiences. According to that definition, the technological features (e.g. tapping and swiping) are defined through modality interactivity. Interactivity is achieved by the presentation of information through different combinations of modalities, including visual, auditory, and other sensory modalities. While traditional media tend to employ only single modalities, such as text, audio, or images, the new digital media interfaces utilize various modalities by allowing users to interact with them. They also cover newer affordances, such as pointing, clicking, dragging, and so on. It is easy to notice that a combination of such modalities is represented in all forms of the present media. For example, news applications on a smartphone may offer a combination of texts, images, and videos, as well as the gestures required for their control.

Numerous scholars of computer-mediated communication have examined the social and psychological effects of different types of modality. Williams *et al.* (2007) found auditory modality to have a higher impact on the relationship and trust between voice-based communities, rather than text conditions. The results from the experiments of Sundar *et al.* (2014) show that the influences of a variety of interaction techniques (e.g. slide, click, mouse-over, and so on) differed during user experiences interacting with informational websites. For instance, while slide had a positive effect on user experience, drag had a negative effect with a different content domain. When it comes to flipping and clicking, Oh *et al.* (2013) showed that the flipping condition have more positive effects on the user evaluation of websites by causing greater perceived natural mapping and presence. Based on the differences regarding the impacts of various interactivity modalities on user experience suggested in the previous literature, the present study examined the different effects of interaction techniques during interaction with smartphones.

### *2.2 Technological features and perceived interactivity*

Thanks to the tremendous proliferation of smartphone technology, extensive studies have been conducted to define interactivity with application of various approaches. Shin *et al.* (2013) defined interactivity as an expression of the extent to which any third (or later) transmission (or message) in a given series of communication exchanges is related to the degree to which previous exchanges referred to even earlier transmissions. Li and Li (2014) defined interactivity as the extent to which users can participate in the real-time modification of the form and content of a mediated environment. While those studies defined interactivity in the context of technological features and communication, others took an approach that focussed more on perception.

To narrow the gaps among the multifaceted definitions of interactivity, Kiousis (2002) further defined interactivity as the degree to which communication technology can create a mediated environment in which participants can communicate (one-to-one, one-to-many, and many-to-many), both synchronously and asynchronously, and participate in reciprocal message exchange (third-order dependency). This idea of interactivity was suggested to include the users' ability to perceive the experience as a simulation of interpersonal communication and increase their awareness of telepresence. That said, three domains were emphasized in Kiousis' definition of interaction: communication context, technological features, and user perception. This perspective can also be found in the mediated moderation model of interactivity (Bucy and Tao, 2007). According to the unit of measure, the model incorporates interaction stimuli, user perception, and interaction effect.

The mediated moderation model of interactivity argues that the interaction effect of interaction stimuli is transmitted through user perception. Interaction stimuli may be understood by examining the technological features, interface affordances, and modes of information (Bucy and Tao, 2007). User perception considers situations in which users may perceive different degrees of interactivity when interacting with technological attributes. In itself, interactivity encompasses two different concepts: actual and perceived interactivity (Wu, 2005). Through evaluating the interactivity of three websites, Lee *et al.* (2004) found that interactivity differed according to user perception. Numerous studies have also proven the effects of technological features in association with perceived interactivity (Chung and Zhao, 2004).

### *2.3 Interaction with smartphones*

The surge of available interaction techniques, such as scroll-bars and the customization of Web portals, has led scholars to focus attention on the effects of such technologies. While a variety of studies have presented the different impacts of interactive tools (Oh *et al.*, 2013; Sundar *et al.*, 2014), the previous interactivity studies tended to document the interaction effects on web-based mass communication in desktop environments (Xu and Sundar, 2014). Although several studies have also attempted to examine the factors related to user experience for smartphone interactions (Kim *et al.*, 2012; Kim and Sundar, 2014), they did not consider the effects of interactivity afforded by the unique features of smartphones. Therefore, the types of features that affect interactivity during smartphone use need to be examined.

Users may have a tendency to use one hand when interacting with smartphones (Lai and Zhang, 2014). The capability for single-handed interaction allows users to make calls or access information when their other hand is not available. It also offers significant benefits to users by freeing the other hand, which requires physical and psychological attention when participating in mobile activities (Karlson *et al.*, 2006). Physical and attitudinal studies on mobile device users were first conducted on businessmen to provide design implications for the touch screen interface to allow one-handed interaction (Baudisch and Chu, 2009; Faizuddin *et al.*, 2014; Faizuddin and Noor, 2013; Ng *et al.*, 2014). However, since the generalization of these findings to normal users was limited, several approaches for single-handed mobile interaction have been proposed in the fields of computer engineering and ergonomics (Gustafsson *et al.*, 2010; Karlson *et al.*, 2005; Park and Han, 2010).

Karlson *et al.* (2006) conducted an experiment for understanding interactions with mobile devices in consideration of ergonomic factors. According to their results, since users generally interact with their mobile devices using one hand, the employment of large screens causes many areas to be unreachable through the one-handed thumb interaction, commonly used for controlling the devices. Trudeau *et al.* (2012) examined the effects of thumb orientation, thumb direction, and device size on thumb motor performance during one-handed device use. The results showed that adduction-abduction movement of the thumb allowed better performance with small screen size due to the effects of limited screen size for single-handed interaction. Odell and Chandrasekaran (2012) concentrated on thumb interactions also while using tablet computers, and suggested a methodology to measure the range of the thumb. Numerous studies on human-computer interaction (HCI) and ergonomics have emphasized the importance of thumb movement for enabling single-handed interaction with mobile devices. None of the studies, however, has closely examined its effects on the psychological factors of users. Given this gap in research, it is worthwhile to examine the effects of thumb movement on the cognitive, attitudinal, and behavioral factors of users while participating in single-handed interaction with smartphones.

### *2.4 Engagement, attitude, and behavioral intention*

The actual interactivity provided by technological features may affect the perceived interactivity of users and allow them to engage in the contents through specific interfaces (Sundar *et al.*, 2014). Bucy and Tao (2007) argued that interactivity increases the attractiveness of the interfaces themselves, going beyond the contents, by offering stickness to specific interfaces. Sundar *et al.* (2011) also pointed out that user engagement is affected by the different technological features of the websites being used. For instance, participants who interacted with websites through two different interaction techniques, such as mouse-over and cover-flow, were instructed to complete more actions than for the other interactive conditions (e.g. click, drag, slide, and zoom). Through this interaction, the influential users (the so-called power users, like power bloggers) were found to develop more positive attitudes toward the contents of the websites. Numerous studies have proven the relationship between interactivity and engagement (Xu and Sundar, 2014).

Lung and Feng (2014) showed that people remain in a stronger state of flow and process information more easily when using interactive websites. They also found that users tended to form more positive attitudes toward websites that allow for higher interaction. This finding was identical with the previous report that indicated that the interactivity of websites increases subsequent to evaluations (Jee and Lee, 2002). The effects of specific technological features on user attitudes might be explained by the heuristic and systematic model (Hsiao *et al.*, 2013). People use heuristic and systematic modes when making decisions that differ from their attitudes. While systematic processing involves analytics and comprehensive decisions, heuristic processing depends on heuristics cues, which rely on other knowledge structures rather than individual decisions. Heuristic processing causes judgments to be made based on other effects, such as distraction, time pressure, and communication modalities, without systematic processing (Skalski and Tamborini, 2007).

Based on the review of the previous literature, it can be said that interaction techniques trigger user interest and motivation, making their experiences with specific interfaces satisfying and delightful. Since digital platforms (e.g. smartphone applications with interactive features) represent the current reality, more trust may be elicited from individuals (e.g. Shin, 2013). Oh *et al.* (2013) explored the effects of interaction techniques, such as flipping and clicking on user experience when looking at online magazines in a desktop environment. Their findings showed flipping conditions to have more positive effects on the evaluation of websites from the perspective of user engagement and behavioral intention, which amounted to recommendations and revisiting the websites. According to the theory of planned behavior (Ajzen, 1991), the more positive the attitude, the more willing people will be to take additional action.

## 3. Research questions

With the aforementioned hypotheses in place, this study explores the mediatory effects on the interaction technique and behavioral variables. As single-handed thumb interaction is widely used, a number of researchers have wondered what triggers user motivation and how such behaviors are formed and enhanced. A group of researchers (e.g. Karlson *et al.*, 2006) argued that the usability of mobile devices is heavily dependent upon single-handed interaction. As mobile devices became smarter and more sophisticated, single-handed interaction and its effects have also become more complicated. Understanding the cognitive mechanisms of users in single-handed interaction requires further study – for example, a study encompassing the multiple mediation model. A mediation model explores the direct and indirect effects between an independent variable and a dependent variable with inclusion of mediators. Mediation analysis has recently been used to dissect the direct and indirect effects of interaction variables on the attitudes and behaviors toward new technologies (e.g. Shin, 2013). This method is particularly effective when seeking to identify and explicate the mechanisms or processes underlying an observed relationship between an independent and dependent variable via the inclusion of a mediating variable. The mediator serves to clarify the nature of the relationship between the independent and dependent variables. Understanding this relationship can provide insight into user experience in single-handed interaction. From there, better heuristics can be used for the design of user-centered mobile interactions in the future. In this light, three mediation models for engagement, attitude, and behavioral intention, according to the range of thumb movement, are proposed and tested herein. The following research questions guide this study:

*RQ1.* Is there an interaction effect between interaction technique and the influence of range of thumb movement on users' cognitive, attitudinal, and behavioral variables in single-handed interactions with smartphones?

*RQ2.* What role does engagement play in the relationships between interaction technique and range of thumb movement, perceived interactivity, attitude, and behavioral intention?

*RQ3*. Does attitude have any relation with interaction and behavior? If so, how does attitude mediate the relationships between interaction technique and range of thumb motion, perceived interactivity, engagement, and behavioral intention?

## 4. Research hypotheses

With the exception of a few studies, such as those by Ng *et al.* (2014) and Faizuddin *et al.* (2014), very few of the interaction studies have examined the interaction effects in a mobile context. Indeed, this lack of research is even more conspicuous in smartphones, where user interaction remains under-researched and thus unanswered. Furthermore, the single-handed studies carried out in computer sciences and ergonomics have not comprehensively examined the cognitive, attitudinal, and behavioral effects of mobile interactions. Lepicard and Vigouroux (2010) conducted experiments with a tabletop touch panel interface and found that the direct interaction metaphor was easy to understand, and had a pleasing effect that attracted and motivated the elderly participants in their study. Similarly, Blasko and Feiner (2004) examined the relation between single-handed interaction techniques and user acceptance. Despite the numerous empirical studies on interaction techniques (e.g. Blasko and Feiner, 2004; Caprani *et al.*, 2010), previous studies have not specifically addressed the comparison of swiping and tapping. Only few studies have compared swiping and tapping (e.g. Rantala *et al.*'s (2013) study which explored touch gesture vs finger touch). Thus, it is worthwhile to compare the effect of swiping and tapping on attitude. As implied in Rantala's (2013) study, it can be hypothesized as follow:

*H1*. Swiping conditions have more positive effects over tapping conditions on (a) perceived interactivity, (b) user engagement, (c) attitude, and (d) behavioral intention.

Shin *et al.* (2013) argued that interaction modality influences users' perceived factors. While numerous studies (Ng *et al.*, 2014) have examined the relationships between interaction conditions and user experience, they failed to study how interaction conditions specifically influence users' perceived dimensions. For example, existing studies have not been examined how the wide range of thumb movement affects user attitude in comparison to the narrow range of thumb movement. Although this may sound simple and obvious, the relationship should be tested and validated in order to develop further interaction techniques. That is, the relationship provide a basis for heuristic development. In this study, a wide range of thumb movement and a narrow range of thumb movement refer to the users' thumb reach in smartphones. In the case of wide range of thumb movement, logo contents are placed at the center of smartphone screen so that users use long thumb movement. In the case of narrow range of thumb movement, the contents are positioned at the bottom of the screen so that it can be reached within a short range of thumb movement by users:

*H2*. A wide range of thumb movement for controlling smartphones with one hand has a more negative effect than a narrow range on (a) perceived interactivity, (b) user engagement, (c) attitude, and (d) behavioral intentions.

There have been numerous studies on the role of perceived interactivity, particularly on its mediating role in the effect of actual interactivity on attitude (e.g. Wu, 2005). Such studies examined the mediating role of perceived interactivity on various user attitudes and behaviors toward interactive websites (Wu, 2005), smart TV (Shin *et al.*, 2013), and marketing (Song and Zinkhan, 2008). Actual interactivity and perceived interactivity have also been an interesting topic. How the perceived interactivity of users actually mediates between attitude and intention provides interesting and important implications. As it has never been tested in an interaction technique, it is worthwhile examining the mediating role of interactivity in smartphone interaction:

*H3*. Interaction technique and range of thumb movement have effects on (a) engagement, (b) attitude, and (c) behavioral intention in single-handed interactions with smartphones, which are mediated by perceived interactivity.

Conceptually, perceived interactivity is similar to engagement. In reality, it is common sense that users will perceive higher interactivity when they have a high level of engagement. The previous research showed overall improvement in the levels of engagement and perceived interactivity (e.g. Wang, 2011). Wu identified a positive relationship between perceived interactivity and the engagement of websites. Similarly, Jee and Lee (2002) found perceived engagement plays a mediating role in the effect of interactivity on attitude. In consideration of these points, it can be reasonably inferred that engagement plays a role between perceived interactivity and attitude:

*H4*. Engagement mediates the effect of perceived interactivity on attitude.

With these hypotheses in place, a theoretical model is proposed (Figure 1). The Korean context can best serve to test the model, as Koreans are generally known as technical-friendly and highly receptive to new technologies. In addition, Korean writing and reading habits with mobile devices tend to be swift, especially in the young generation (Shin, 2014). From examining Korean user behavior, it can be inferred that the thumb movement and touch-based interaction can be unique and heuristic. Furthermore, thanks to the particularly widespread use of smartphones in Korea, the habits of reading and writing via smartphones are drastically on the rise. Considering this aspect of unique Korean user behavior, it is worthwhile examining the interactivity effects on single-handed interaction in the Korean context. While it may be important to examine the influence of dexterity on interactive behaviors, this study excluded this influence mainly due to the inability to measure the levels of dexterity. Future studies may focus on the effects of dexterity on interaction.

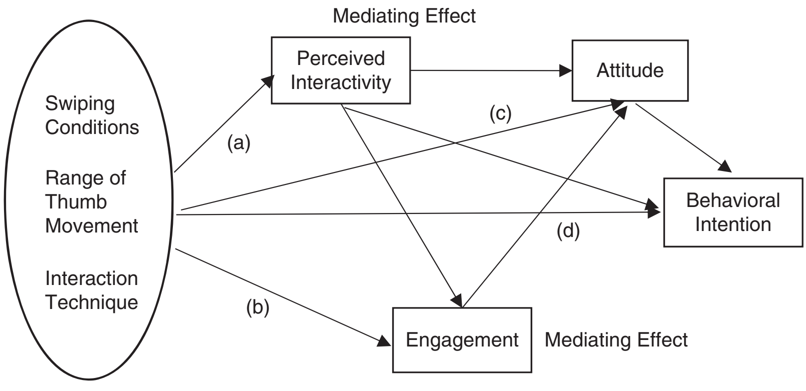



**Figure 1.**
A theoretical model

## 5. Method

A 2 (interaction techniques: swiping vs tapping) × 2 (range of thumb movement: wide vs narrow) between-subject experiment was conducted in order to explore how the touch-based interface on screens contributes to shaping the perceptions of smartphone users (e.g. perceived interactivity, engagement, attitude, and behavioral intention).

### *5.1 Participants*

A total of 129 participants were recruited for the experiment (Table I). To ensure the reliability and validity of the data, a specialized research company was hired to conduct the recruiting and overall methods. The sample participants were carefully recruited from January to June 2014 in consideration of the socio-demographics of the Korean smartphone user population. A pool of candidate participants was shortlisted by the professional survey firm employed, after which the final participants were selected by the research team to provide a representation of the socio-demographic proportions. Initial participants selected were then screened by the criteria of mobile experience and interaction skills. The participants were pre-screened to ensure they had certain experiences with mobile interaction. The pre-screening procedure involved two processes. First, the participants were asked about their current smartphone usage and interaction skills. The participants selected from the first screening then conducted a test of their single-handed interaction with smartphones. The participants were asked to demonstrate their interaction skills of swiping and tapping. Using these skills, the participants were to achieve certain tasks through the smartphones. This procedure was also used by previous studies (Lai and Zhang, 2014).

The final sample was provided with class credits and some monetary rewards. They were randomly assigned to one of four conditions: tapping × wide range of thumb movement, tapping × narrow range of thumb movement, swiping × wide range of thumb movement, and swiping × narrow range of thumb movement.

There might be a confounding effect of locations on interactivity. That is, the wide range condition required users to reach for the top and the bottom sections on the screen, which are more difficult to interact with than the section in the middle. In order to minimize this confounding effect, participants were noticed this aspect before experiments. Also, before the actual experiments, pre-test was conducted to see if the confounding effect was any significance. The result of the pre-test showed that

**Table I.** Characteristics of the respondents

| | Number | % |
|---|---|---|
| *Age* | | |
| Under 20 | 30 | 23.3 |
| 21-30 | 59 | 45.7 |
| 31-40 | 30 | 23.3 |
| Over 41 | 10 | 7.8 |
| *Smartphone experience* | | |
| Less than 1 year | 10 | 7.8 |
| 2-4 years | 40 | 31.0 |
| Over 5 years | 79 | 61.2 |
| *Gender* | | |
| Female | 60 | 46.5 |
| Male | 69 | 53.5 |

although participants felt the difference, it was found that the locations did not influence the interaction level. Any participants who showed the significant confounding effect level were dropped.

All participants signed an informed consent form before beginning the study. All procedures were monitored and overseen by a third party research team to ensure the reliability and validity of the results. Overall, the procedure was also proctored by a private research company.

### 5.2 Stimulus materials

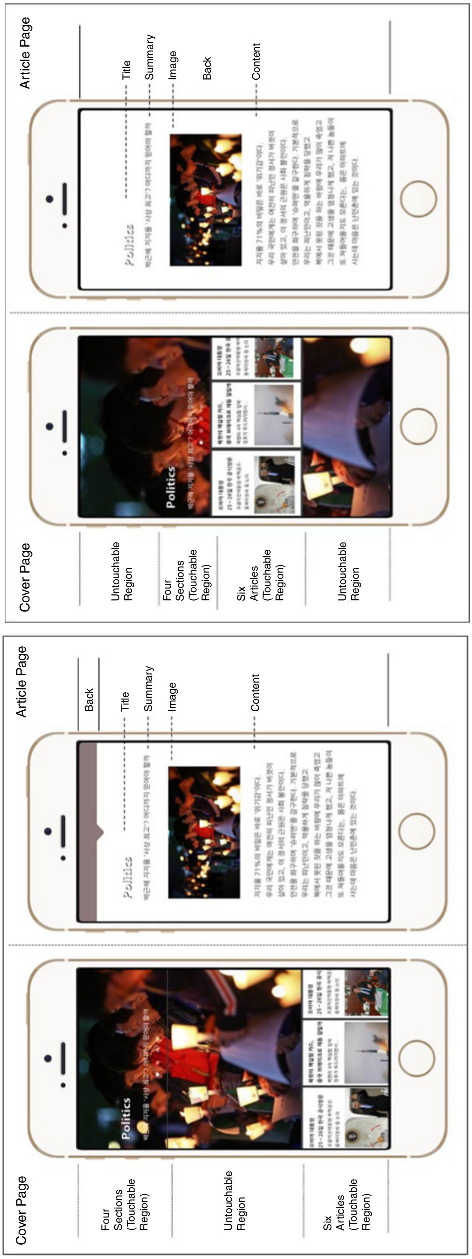
Four prototype news applications that resembled the famous news aggregator services Flipboard (https://flipboard.com) and Paper (https://facebook.com/paper) were created by the experimenter. The applications shared the same content and color, but applied different interaction techniques and layouts. Each application included a cover page and an article page. The cover page was made up of two parts: the top part, presenting four sections (policy, economy, life, and technology), and the bottom part, containing six articles related to each section. The article pages contained the title, summary, image, and content. Manipulation was carried out of the interaction techniques required for controlling the application and the layout distinguishing the reachable region of the thumb. The contents of the articles were identical across the four experimental conditions.

### 5.3 Experimental treatment conditions

The two interaction techniques (i.e. swiping and tapping) were employed by offering each of the applications with only one way in which to browse. For the condition of swiping, participants were only allowed to perform a surface swiping gesture in any direction (e.g. left, right, up, and down). The participants could hold and swipe with their thumbs to turn to another side for the top (choosing between four sections) and the bottom (choosing between six articles per section) parts. As the participants held and swiped one of the articles on the bottom of the layout upward, the article showed up (Figure 2). In contrast, the tapping condition only allowed clicking for navigation of the application. To turn to another section and to read an article in the tapping condition, participants used their thumbs to click on a specific section of the bar, and on one of the square boxes at the bottom of the screen (Figure 3).

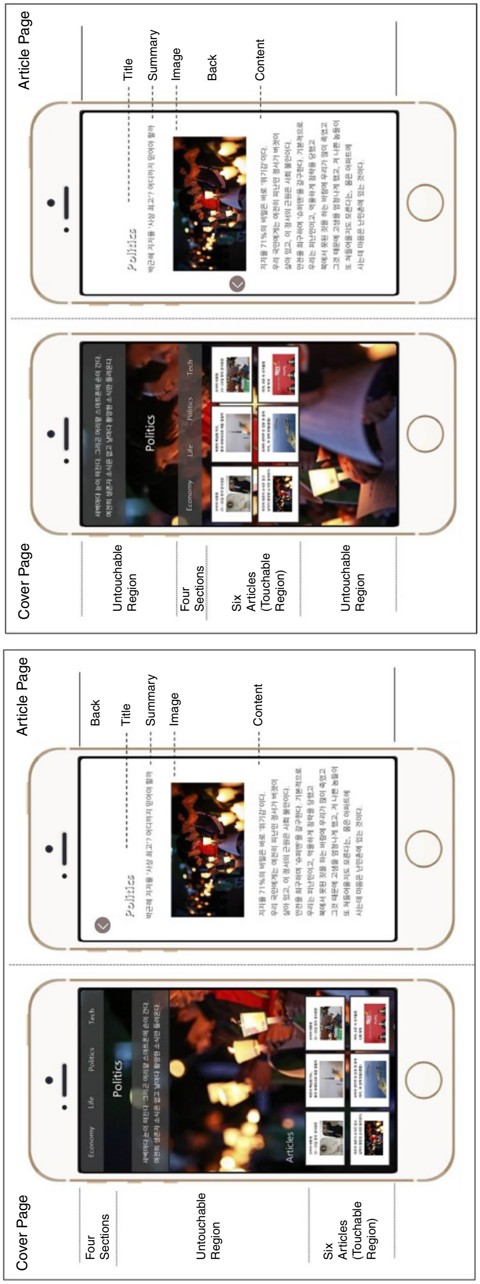
The regions for the range of thumb movement were divided by a test of selected respondents. A selection of 30 respondents tested the divided regions. The average size ratio was placed. In cases where the participants required adjustments, the regions were adjusted to the participants' hand sizes. The range of thumb movement (e.g. wide and narrow range) was also manipulated by changing the placement of the sections and articles in the layouts (changing the height of the touchable regions and the untouchable regions) in order to differentiate the range of interaction area with the thumb between wide and narrow conditions. Karlson (2008) found that users felt more comfortable when interactions were limited to a sub-region of the mobile device, and preferred to interact using the center of the device. Based on their findings, the overall interactions with the application were manipulated to occur specifically at the top or bottom of the screen, providing conditions requiring a wide range of thumb movement, or near the center of the interface in order to test the narrow range of thumb movement.

The four conditions provided in the applications also allowed participants to go back and browse the articles. As already mentioned above, the only differences among the four versions of the application were in the allowable interaction techniques or layout.




**Note:** The left side shows the conditions for a wide range of thumb movement, whereas the conditions for a narrow range of thumb movement are shown on the right

**Figure 2.**
Composition of the cover and article pages for the condition of swiping




**Note:** The left side shows the conditions for a wide range of thumb movement, whereas the conditions for a narrow range of thumb movement are shown on the right

**Figure 3.**
Composition of the cover and article pages for the condition of tapping

### *5.4 Procedure*

Participants were randomly assigned to one of the four conditions. They were then asked to hold an iPhone 5s (four inch) in one hand, placing their thumb on the center of the screen. The iPhone 5s has a new home button design with a laser-cut sapphire cover surrounded by a metallic ring, touch ID, and a fingerprint recognition system built directly into the home button. A pre-test was then conducted to ascertain how the users felt about the wide thumb movement conditions. In the pre-test, the thumb reach of each respondent was measured; subsequently, the manner in which respondents moved their thumbs around for both tap- and swipe-based interactions was observed. The thumb reaches of the participants were measured by having them draw an area on the screen using only the thumb until they felt uncomfortable. This method was also employed by Odell and Chandrasekaran (2012), who measured the thumb's reach on a tablet. They controlled one dimension of the grip in relation to the device: the position of the hand along the tablet's edge.

After being told how to navigate and operate the application, the participants were instructed to browse the application without turning on any of the other applications or settings, and to read several articles for ten minutes. After finishing the browsing session, participants filled out a questionnaire equipped within the application. As the sections and the articles were the same, it was possible that the participants may have become bored after reading the same content repeatedly. For this problem, the participants participated in the experiments with a two-week interval between the experiments. The order of the four experiment conditions was carefully balanced out. This procedure helped to minimize the boredom effect.

The respondents had the option to choose a paper- or web-based survey. While the survey application was available within the news application on the smartphones, a separate survey was used to avoid problems of data integration.

### *5.5 Measures*

*Perceived interactivity*. Based on the study by Shin *et al.* (2013), nine revised items were implemented to measure the perceived interactivity. The scale anchored seven points with "strongly disagree" and "strongly agree." Participant responses were quite reliable (Cronbach's $\alpha = 0.795$). This scale was previously used by several interactivity studies with acceptable internal reliability (e.g. Shin *et al.*, 2013, Cronbach's $\alpha = 0.93$; Liu and Shrum, 2009, Cronbach's $\alpha = 0.84$).

*Engagement*. Sundar *et al.*'s (2011) items were adopted to measure user engagement. The reliability of these items was moderately acceptable (Cronbach's $\alpha = 0.779$). The items included of the following statements: "Time appeared to go by very quickly when I was using the application"; "I felt in control when I was using the application"; "I spent more time on the application than I had intended"; "While using the application, I was able to block out most other distractions"; "While using the application, I was absorbed in what I was doing"; "While using the application, I was immersed in the task that I was performing"; "I had fun interacting with the application"; "Using the application provided me with a lot of enjoyment"; "Using the application bored me"; "I felt in control while I was using the application"; "I felt that I had no control over my interaction with the application"; "Using the application excited my curiosity"; "Using the application aroused my imagination"; and "Interacting with the application made me become interested in it."

*Attitude toward the application*. Attitude was measured with the items from Shin *et al.* (2013) on a seven-point Likert-type scale from "strongly disagree" to "strongly agree."

The items demonstrated a reliable index (Cronbach's $\alpha = 0.835$). Examples include "This application made it easy for me to build a relationship with this article"; "I would like to use the application again in the future"; "I am satisfied with the service provided by this application"; "I feel comfortable using this application"; "I think using this application is a good way to spend my time"; and "Compared to other news providers, I would rate this one as the best."

*Intentions to use the application*. The measure of behavioral intentions to use the application was adopted from Xu and Sundar's (2014) measurement of behavioral intentions toward website usage. These items were also found to be reliable (Cronbach's $\alpha = 0.863$). Some examples are "I would like to browse more articles on this application"; "I would discuss this application with my friends"; and "I would recommend this application to others."

### *5.6 Manipulation check*

The manipulation of the original interaction techniques and perceived difficulty of the range of thumb movement allowed was examined. First, participants were asked to indicate how the application was controlled by clicking answers on a seven-point Likert-type scale (1 = strongly disagree and 7 = strongly agree). Questions such as "I can use the application by swiping and tapping" and "I can freely swipe and tap the menu of the applications" were included. All questions were in Korean. Second, the participants were then asked whether the range of thumb movement by which they had just controlled the application using one hand was comfortable. The comfort of the range of thumb movement was measured on a seven-point Likert-type scale (1 = strong disagree and 7 = strongly agree) by the statement "I perceived the application to be highly comfortable."

## 6. Results

*RQ1* and the multiple mediating effects were measured with the PROCESS macro in SPSS. For testing of the main effects (*RQ2* and *RQ3*), the independent *t*-test and two-way ANOVA functions of SPSS were used. Where necessary, SAS was used for double-checking and additional data tests were used for reliability and validity.

### *6.1 Manipulation check*

*Interaction techniques*. The results of an independent *t*-test showed significant differences between the interaction techniques employed, $t(110) = -3.862$, $p < 0.001$. The tapping condition ($M = 6.09$, SE = 1.19) led to the highest level of perceived controllability with clicking, followed by the swiping condition ($M = 4.92$, SE = 1.90).

*Ranges of thumb movement*. An independent t-test showed that the perceived difficulty in controlling a smartphone with one hand varied significantly according to the range of thumb movement required for the manipulation, $t(110) = -7.416$, $p < 0.001$. The wide condition ($M = 6.09$, SE = 1.19) provided the highest level of perceived controllability with clicking, followed by swiping ($M = 4.92$, SE = 1.90).

### *6.2 Perceived interactivity*

The results of a two-way ANOVA, with interaction technique and range of thumb movement as the independent variables and perceived interactivity as the dependent variable, showed the main effect for range of thumb movement, $F(1, 108) = 17.310$, $p < 0.001$, $\eta_p^2 = 0.013$, indicating that the degree of perceived interactivity was significantly higher for the narrow range of thumb movement ($M = 5.57$, SE $= 0.78$) than for the wide range of thumb movement ($M = 4.92$, SE $= 0.85$). The significant main effect of the range of thumb movement on perceived interactivity indicates that *H2a* was supported. However, an analysis of the interaction between interaction technique and range of thumb movement showed no significant effect $F(1, 108) = 0.671$, $p = 0.32$, $\eta_p^2 = 0.009$.

### 6.3 Engagement

The same ANOVA as above was performed with engagement as the dependent variable, identifying a main effect for range of thumb movement, $F(1, 108) = 7.056$, $p < 0.01$, $\eta_p^2 = 0.06$. The degree of engagement in the condition allowing a narrow range of thumb movement ($M = 4.72$, SE $= 0.90$) was significantly higher than that requiring a wide range of thumb movement ($M = 4.84$, SE $= 0.73$). This supported *H2b*. No other main or interaction effects were significant.

### 6.4 Attitude

The two-way ANOVA conducted with attitude as the dependent variable identified a significant main effect of the range of thumb movement, $F(1, 108) = 9.711$, $p < 0.1$, $\eta_p^2 = 0.08$, with significantly higher attitude scores obtained for the narrow range of thumb movement ($M = 4.95$, SD $= 0.92$) than the wide range of thumb movement ($M = 4.42$, SD $= 0.89$). This finding supported *H2c*. No other statistically significant main or interaction effects were observed.

### 6.5 Behavioral intention

Another ANOVA performed with behavioral intention to use the applications as the dependent variable also showed a significant main effect for the range of thumb movement, $F(1, 108) = 4.768$, $p < 0.5$, $\eta_p^2 = 0.04$. Participants required to manipulate the applications with a narrow range of thumb movement had more behavioral intention ($M = 4.61$, SD $= 1.33$) than those using the wide range of thumb movement ($M = 4.07$, SD $= 1.28$). No other main or interaction effects were statistically significant.

### 6.6 The mediating effects

Given that significant main effects were only found for the range of thumb movement, it was worthwhile to test *H3*, regarding the mediating effects of perceived interactivity on engagement (*H3a*), attitude (*H3b*), and behavioral intention (*H3c*). To test the mediating effects, the following conditions must be met: the independent variable must significantly account for the variance in the mediator (e.g. perceived interactivity); the variance of the mediator must account for the variance in the dependent variables (e.g. engagement, attitude, or behavioral intention); and the relationship between the independent and dependent variable must not be significant when the variance of the mediator is accounted for in the dependent variables. To examine this possibility, the mediating effect of perceived interactivity was tested using the PROCESS macro for SPSS 19.0, developed by Hayes (2013). The PROCESS macro tests indirect effects using a bootstrap approach. This nonparametric approach can avoid the power problem introduced by non-normality, and is less restricted by sample size. Three mediation models for engagement, attitude, and behavioral intention according to the range of thumb movement were tested using PROCESS Model 4 with a 95 percent confidence level and 1,000 bootstrap samples.

As shown in Figure 4, Model 1 tested the mediating effect of engagement via perceived interactivity. The indirect effect of range of thumb movement via perceived interactivity was found to be significant ($B = 0.31$, $LLCI = 0.15$, $ULCI = 0.57$). However, once engagement was accounted for by perceived interactivity ($B = 0.47$, $p < 0.001$), the range of thumb movement and engagement were no longer significant ($B = 0.09$, $p = 0.50$). Model 2 tested the mediating effect of attitude via perceived interactivity. While the indirect effect of range of thumb movement was originally significant ($B = 0.41$, $LLCI = 0.21$, $ULCI = 0.65$), the significance disappeared ($B = 11$, $p = 0.43$) when perceived interactivity had a significant effect on attitude ($B = 0.64$, $p < 0.001$). Lastly, Model 3 tested the mediating effect of behavioral intention via perceived interactivity. The indirect effect of range of thumb movement via perceived interactivity was significant ($B = 0.46$, $LLCI = 0.25$, $ULCI = 0.78$). However, once behavioral intention was accounted for by perceived interactivity ($B = 71$, $p < 0.001$), the range of thumb movement also had no significant effect on perceived interactivity ($B = 0.08$, $p = 0.73$). These results therefore demonstrated that the range of thumb movement had significant effects on engagement, attitude, and behavioral intention, which were mediated by perceived interactivity. Hence, *H3* was partially supported.

To answer the second and third research questions, the multiple-step multiple mediator model proposed by Hayes (2013) was implemented. The multiple-step multiple mediator model (also called serial multiple mediation) defines those with more than a single proposed mediator variable. This model, used for the partitioning of total effects into direct and indirect components, is applied when the mediators are allowed to casually affect other mediators. This model is appropriate for use in the present study because thumb movement has both direct and indirect effects on attitude and intention, and because two or more mediators are present, with engagement being a cause of perceived interactivity. While previous research examined single mediators, this study analyzed multiple mediators separately or by using principal component analysis. The previous results

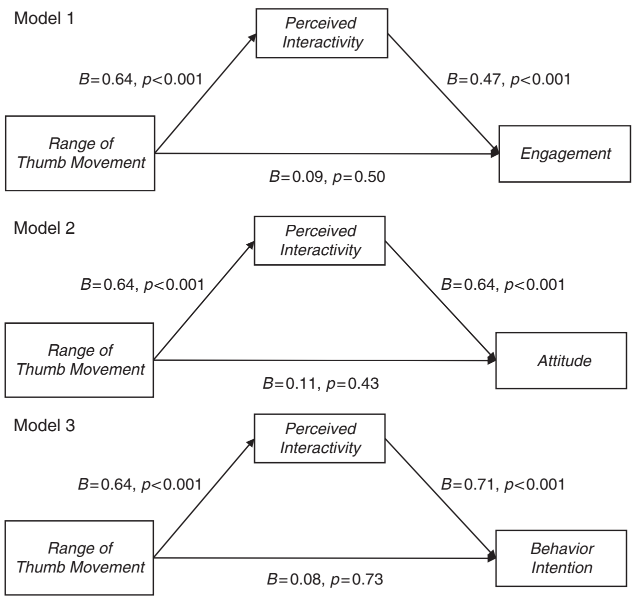


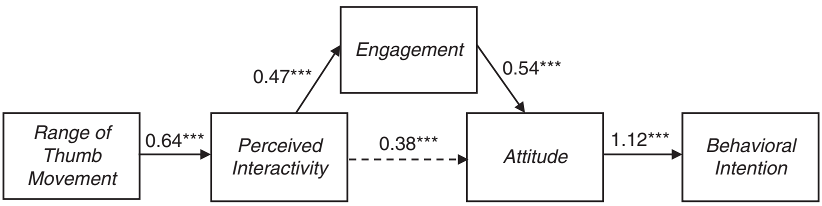

**Figure 4.**
Three models of the mediating effect of perceived interactivity on engagement, attitude, and behavioral intention

showed that interaction techniques have no significant effect on perceived interactivity, engagement, attitude, and behavioral intention. In this study, the multiple mediators' model was tested only using the range of thumb movement, as this study was focussed on thumb interaction. Since this model requires the independent variable to be coded as a continuous level or dummy code, the range of thumb movement was re-coded as 0 (wide range of thumb movement) or 1 (narrow range of thumb movement).

The results revealed that the range of thumb movement had significant effects on behavioral intention through perceived interactivity, followed by engagement and attitude ($B=0.19$, $LLCI=0.08$, $ULCI=0.38$, Figure 5). Range of thumb movement also affected behavioral intention by influencing the perceived interactivity and attitude without engagement ($B=0.27$, $LLCI=0.14$, $ULCI=0.49$, Figure 5). No other mediating effects were observed.

## 7. Discussion

In an exploratory manner, this study examined the effects of interaction techniques and the range of thumb movement on interactivity, engagement, attitude, and behavioral intention in single-handed interaction with smartphones. Despite the rising popularity of smartphones and the interactions involved, this topic has not yet been thoroughly researched. Thus, the goal of this study was to contribute knowledge in the form of empirically backed design guidelines and interaction techniques for improving the one-handed usability and operation of mobile devices, with particular emphasis on smartphones. With the exception of a few previous studies (Faizuddin *et al.*, 2014; Negulescu *et al.*, 2012), this study was one of the few attempts to test the effects of interactivity for identification of a useful predictor when interacting with smartphones. The findings showed that the range of thumb movement had a critical impact on the cognitive, attitudinal, and behavioral experiences of users during single-handed interactions, whereas the interaction techniques tested (e.g. tapping and swiping) did not have a significant impact. This implies that range of thumb movement becomes more important than interaction techniques. It can be seen that thumb movement can be a key factor as it increase the feeling of users' control. While the significant effect of thumb movement was expected, the insignificant results regarding tapping and swiping contradict the results of previous studies (e.g. Lai and Zhang, 2014). Though this is a rather unexpected result, it can be interpreted in a different way. The insignificant impact in itself has heuristic implications. With the development of numerous interaction techniques, such techniques themselves have become commoditized to the users. Regardless of the advancement and diversity of interaction techniques, users may have similar feelings and experience with different




**Notes:** ---, Line represents indirect effects through perceived interactivity and engagement when comparing conditions allowing wide and low range of thumb movement. ***$p<0.001$

**Figure 5.** Indirect effects through perceived interactivity, engagement, and attitude when comparing conditions allowing wide and low range of thumb movement

kinds of interaction modalities. In other words, interaction modalities, like tapping and swiping, are of little difference to users, and they might take such techniques for granted as part of embodied interaction. Therefore, it seems that interaction modalities, as features, make little difference to users. What is more important than tapping or swiping is the users' own activity and experiences that involve their actual behavior. This interpretation is in line with the significant relationship observed between thumb movement and engagement. Interactivity is greatly dependent upon users' perceived interactivity, which is highly related to engagement. Actual interactivity can only offer the potential to allow interaction; however, if users are not using or do not fully appreciate the interactive features, then perceived interactivity is low. This study showed that perceived interactivity can be enhanced by user-engaged interaction. This is an insightful heuristic implication for HCI in general. Although previous studies have researched the relationship between interactive features and perception of interactivity, the relationships so far identified have not been conclusive. With the changing nature of interactivity and the advancement of features, examination of smartphones suggests some possible relationships. Despite the belief that perceived interactivity lies at the heart of various interactions between users and technologies, users and people, this topic has been given little attention in the context of smartphones. The present research discussed the positive impact of the level of feature-based interactivity and actual user-engaged interaction on the perceived interactivity of smartphones. Feature-based interactivity, actual user-engaged interaction, and perceived interactivity are all related in a sequence with independent and multivariate random composition. Once this sequence of logic is empirically clarified, we will be able to really see the ensemble of actual and perceived interactivity. Academic researchers should further explore this relationship by potentially looking at other aspects of interaction techniques, while smartphone designers should focus on making smartphone interactivity a user-based interaction influenced by engagement. The relationship between actual and perceived interactivity in smartphones should be further pursued.

Too often, we make assumptions that the interactive features of smartphones automatically and proportionally increase their general interactivity, as well as user perception. HCI may pay more attention to user experience with technology wherein any modality or interaction mode should not override user activities. It can be said that the true meaning of interactivity lies in user perception, and the interactive interaction is processed by the cognitive perceptions of users. This reaffirms the importance of embodied interaction, and further implies user-centered modality for future interactions. Genuine HCI extends beyond the provision of a graphic user interface or simple interaction methods.

## 8. Implications

From the findings, implications can be drawn in terms of practice and theory. As to practical implication, users' actual experiences with smartphones of course are essential and, at the same time, users' perceptions are also critical as they form their attitude and intention. From this perceptual point of view, the mobile phone industry ought to focus on improving users' perception of smartphone interaction. Improved user perception on interaction itself increases behavioral intention. While users continue to use, users may become accustomed to interaction modality and features. This can be a virtuous cycle of perception and behavior. The smartphone industry ought to develop a new design practice to form this virtuous cycle that closely link user experience and cognitive perception.

Theoretically, this study contributed to interactivity research by exploring the interactivity effects in the mobile context, and by building empirical connections among range of thumb movement, perceived interactivity, cognitive, attitudinal, and behavioral outcomes of interactivity. This is consistent with the interactivity effects model (Shin *et al.*, 2013), which revealed positive effects of interactivity on engagement, attitude, and behavioral intention. It was also shown herein that perceived interactivity, determined by the range of thumb movement, affected behavioral intention through engagement and attitude, as well as through attitude itself, even without engagement. This finding can be a modest but significant heuristic contribution to the smartphone environment. While extensive research has been conducted on perceived interactivity, this topic has not yet been comprehensively applied to the smartphone. Furthermore, the question of how perceived interactivity of smartphones is related with other factors, behaviors, and interactions remains obscure. By clarifying the role and effect of perceived interactivity, the findings provide the industry with guidelines on how to design single-handed interaction, how to increase user perception of interactivity, and how to actually draw on user intention. The industry may realize that the perceived interactivity of users is equally important as the actual interactive features present in smart devices. Based on this point, future research may follow up on these findings. Based on the identified mediatory role of perceived interactivity, future research may continue to explore other effects, such as moderation and interaction effects. In addition, it is worthwhile to further examine how the identified role and effect of perceived interactivity of mobile devices would be applicable to other smart devices, such as wearable devices or machine-to-machine devices. Application of perceived interactivity to different devices would broaden the dimensions of interactivity, as well as provide insight for the development of new, truly interactive services that employ user-based interactivity.

In the smartphone environment, which is subject to a variety of distractions, the perceived ease of use, rather than the interaction techniques themselves, can provide users with better experiences when using smartphones. When users hold a smartphone in one hand, long distances and spaces between the functional buttons make it difficult for them to use the applications in any situation. This decreases user engagement or attitude, resulting in low intentions to use the application. The findings from this study provide insight into how interfaces should be configured and designed, especially for mobile devices with large screens.

Considering the aspect of the indirect effects of perceived interactivity, although interaction techniques were not found to have an effect, the range of thumb movement affected engagement, attitude, and behavioral intention, as mediated by perceived interactivity. Consistent with other research (Shin *et al.*, 2013; Wu, 2005), perceived interactivity was a driver for improving user experience when interacting with digital technologies, rather than the actual interactivity.

## 9. Limitations and future studies

Despite the meaningful findings of this study, it bears several weaknesses that should be addressed in future studies. First, there was a lack of explanation for the non-significant effect of interaction techniques in single-handed interactions with smartphones. Previous literature suggested that in evaluating usability, the relationships between the interface and the real world should be considered. This refers to natural mapping (Tamborini and Bowman, 2010) or intuitiveness (Turner, 2008). Future study should consider the effects of natural mapping with interaction techniques to explore the interaction effects of mobile devices.

A second limitation lies in the research methods. Only the iPhone was implemented as the experimental material. However, most users in Korea use Android smartphones with varying screen sizes. Since the screen size of a smartphone can affect the perceived ease of use and even the attitude toward the device, smartphones with different screen sizes may produce different effects of interactivity on user experience. While the current study offers useful insights for understanding the effects of interaction techniques and the range of thumb movement in single-handed interaction with smartphones, future studies may confirm and extend the findings from this study by investigating the interaction effects with inclusion of a variety of demographic groups and smartphones with different screen sizes.

Also, this study neglected to observe the effect of locations on screen, which might create distorted association between interaction and usage. Locations on the screen have impact on interaction difficulty. Those places on the top and near the bottom are much more difficult to reach than those around the center. In the tasks designed by the authors, for the wide range of thumb movement condition, the top and the bottom sections are touchable. The results could be because the top and the bottom sections are more difficult to interact with than the section in the middle. Given the confounding effect of locations on screen, future studies should focus more on this confounding effect.

Finally, the findings of this study suffer from the drawback that the control measures of participants' previous smartphone usage habits were excluded (e.g. familiarity with the swiping/tabbing interface, personal preference for swiping/tabbing, iPhone user vs Android user). For simplicity's sake, individual differences were excluded as factors for the analysis in this study. As previous studies have consistently shown that mobile acceptance is greatly dependent upon users' personal and contextual factors (e.g. demographics, user experience, and personal innovativeness), it may be wise to consider such individual variables in future studies, as the smartphone is becoming more and more individualized and user centered. A closer investigation of individual differences and their direct and indirect effects on mobile interaction would offer rich opportunities for future research. It is important to closely examine the personal traits when studying smartphone interaction, as user traits are eventually the source of user-centered interaction.

Taken together, these limitations may reduce the reliability of the findings reported herein. Furthermore, the validity of the conclusions can be challenged by questioning the correlations among variables. Possible interactions among the variables may attenuate the findings in this study, given the limited sample size, although the experiments, methods, and models used in this study can be implemented in future studies with some assurance. Testing them against other factors will also advance our understanding of user behavior in an interactive environment. Future studies should sample a larger population and obtain more generalizable results, while focussing not only on interactive smart features but also on different user groups to examine how perceived activity is affected by different demographic variables.

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