[UCI]I804:47020-200000371736

Doctoral Thesis

Development of an Ergonomic Design Framework for Determination of Smartphone Hard Key Locations

Younggeun Choi (최 영 근)

Department of Industrial and Management Engineering

(Human Factors and Ergonomics Program)

Pohang University of Science and Technology

2020

스마트폰 Hard Key 위치 결정을 위한 인간공학적 설계 방법 개발

Development of an Ergonomic Design Framework for Determination of Smartphone Hard Key Locations

Development of an Ergonomic Design Framework for Determination of Smartphone Hard Key Locations

by

Younggeun Choi
Department of Industrial and Management Engineering
(Human Factors and Ergonomics Program)
Pohang University of Science and Technology

A thesis submitted to the faculty of the Pohang University of Science and Technology in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Industrial and Management Engineering (Human Factors and Ergonomics Program)

Pohang, Korea

12. 4. 2020

Approved by

Dr. Heecheon You Heecheon You

Academic Advisor

Development of an Ergonomic Design Framework for Determination of Smartphone Hard Key Locations

Younggeun Choi

The undersigned have examined this dissertation and
hereby certify that it is worthy of acceptance for a
doctoral degree from POSTECH

12/4/2020

Committee Chair	Heecheon You	(Seal)
Member	Soo Young Chang	(Seal)
Member	Young Myoung Ko	(Seal)
Member	Seikwon Park	(Seal)
Member	Kihyo Jung	(Seal)

POHANG UNIVERSITY OF SCIENCE AND TECHNOLOGY
1986
포항공과대학교

DIME 20120791 최영근, Younggeun Choi, Development of an Ergonomic Design Framework for Determination of Smartphone Hard Key Locations, 스마트폰 Hard Key 위치 결정을 위한 인간공학적 설계 방법 개발, Department of Industrial and Management Engineering (Human Factors and Ergonomics Program), 2020, 104P, Advisor: Dr. Heecheon You, Text in English.

ABSTRACT

The location of smartphone hard key need to be ergonomically designed to improve grip stability and operational efficiency for better usability. Smartphone hard key includes power key to screen on/off for efficient energy management and volume key to volume up/down for intuitive volume control. Hard key could cause various usability problems such as grip loss, discomfort, and unintended operation if the location is improperly designed. In addition, the locations of commercial smartphones are different from manufacturer to manufacturer and from device to device even designed by the same manufacturer, which implies ergonomic design guide for hard key location is not available.

While many studies for ergonomic user interface design have been conducted on the graphical user interface (GUI) design on a touchscreen and design dimensions of a device, research on the ergonomic design location of the hard key is a few. Hard keys need to be carefully located as they are impossible to be relocated once manufactured unlike GUIs on a touchscreen, also, changing the location during design is difficult as well because the locations of the other parts are all

related to each other. Therefore, development of an ergonomic design method for determining the location of hard keys on smartphones with various sizes is necessary.

The objectives of the present study are (1) development of a design methodology for hard key location which determines recommended design location based on the analysis of preferred control range in preferred grip postures by users with various hand sizes, (2) application of the methodology on the design of hard key locations for various smartphone sizes, and (3) validation of the methodology by evaluation of operational satisfaction for the hard key locations.

The developed design methodology first analyzes the characteristics of target device, user, task, and use context, then preferred grip postures by users are analyzed. Next, preferred hard key control range in the preferred grip postures are investigated to derive preference distribution for control area. Finally recommended design location is determined by considering the size of hard key and preference for the control area.

Preferred grip postures of 45 participants were analyzed for operating power key and volume key on 9 smartphones with 3.0” to 7.0” screens. Out of 9 identified grip postures, 3 fingers at the left side-1 finger at the right side-1 finger at the back (L3-R1-K1), 4 fingers at the left side-1 finger at the right side (L4-R1), and 3 fingers at the left side-1 finger at the right side-1 finger at the top (L3-R1-T1) were the major grip postures with more than 95% of preference in total. Effect of device size on the preference for each preferred grip posture was significant that the preference of L3-R1-K1 increased from 32.2% to 84.4% when screen size increased from 3.0” to 7.0” ($p < 0.01$).

Recommended design locations for power key and volume key of 9 smartphones with 3.0” to 7.0” screens were investigated from preferred control ranges of 52 participants. The recommended design locations for power key and volume key were derived by accumulating the preference for each control location by participants with various hand sizes. The recommended hard key design locations moved from 69 mm to 116 mm above the bottom for power key and moved from 61 mm to 104 mm above the bottom for volume key.

Effectiveness of the design methodology of smartphone hard key location was validated by the evaluation of operational satisfactions from 70 participants for the three hard key locations (recommended location, 10 mm above/below) on 4 smartphones with 5.0” to 6.5” screens. Mean operational satisfactions for the recommended locations on the 4 smartphones were 1.2 point higher than the others with averages of 4.2 to 4.9 points ($p < 0.01$).

The developed design methodology for smartphone hard key location would be usefully applied to the design for user interface of various portable products in addition to smartphones.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 Introduction

1.1. Problem Statement

Graphical and physical user interfaces design affects the usability of a smartphone including operation efficiency, error preventability, grip stability, and aesthetics. User interface (UI) can be divided into graphical user interface (GUI) and physical user interface (PUI) of a product (Chung et al., 2007). GUIs stand for visual components to help users interact and exchange information with a computer (Preece et al., 2007). For example, users can interact with a computer by using GUIs on the screen such as menus, icons, cursors, scroll bars, etc. On the other hand, PUIs stand for physical components which is located on the product and tangible to be operated by users physically (Ham et al., 2006). For example, users can manipulate a device by using PUIs such as hard keys, knobs, dials, grips, etc. These UIs need to be carefully designed considering various usability components including operation efficiency, error preventability, grip stability, and aesthetics. First, UI needs to be designed in consideration of operation efficiency to help users quickly execute intended functions (Garrett, 2011). For efficient operation, UI needs to be (1) making users to understand the role of the UI and how to use it at a glance, (2) located where users can easily approach and try to operate it, and (3) designed to allow users to perform the operation in a convenient motion. Second, UI needs to be designed in consideration of error preventability to help users distinguish target interfaces so that unintended operations can be prevented (Garrett, 2011). Errors including operation of an untargeted interface and failure of operation due to lack of force delivery may occur when interfaces are too closed to each other or too small. Third, UI of a mobile device needs to be designed in consideration of grip stability to allow users to operate the device while holding it stably (Jin & Ji, 2010). A mobile device could slip out of the hand which may lead to eventual damage if the grip is unstable. Lastly, UI needs to be designed in consideration of aesthetics to have attractive appearance since a product is also used as a tool for showing users' identity these days. UI design is required to be well-matched with overall appearance of the product to avoid compromising the aesthetics since UI could be too large and bold when focused solely on operation efficiency.

The hard key of a smartphone is one of the effective PUI elements for intuitive manipulation, quick function execution. PUI has been used in various electronic devices for a long period of time since it is tangible to be manipulated intuitively (Jin & Ji, 2011) and remembering the shape and location of the PUI makes possible to accurately activate the intended functions without seeing it. The hard keys of smartphones are used to quickly execute frequently used functions as shown in Figure 1.1. Power keys are designed primarily for screen on/off and power on/off, and volume keys are designed for volume control and camera shutter. In addition, there are some hard keys provided in GUI-based soft keys depending on the manufacturer including back key to cancel the last operation or return to the previous screen, home key to move to the home screen, and multi-tasking key to move to another application which is running at the same time.

The location of the smartphone hard key can affect the grip posture for the smartphone, causing various usability problems, such as grip loss, discomfort and

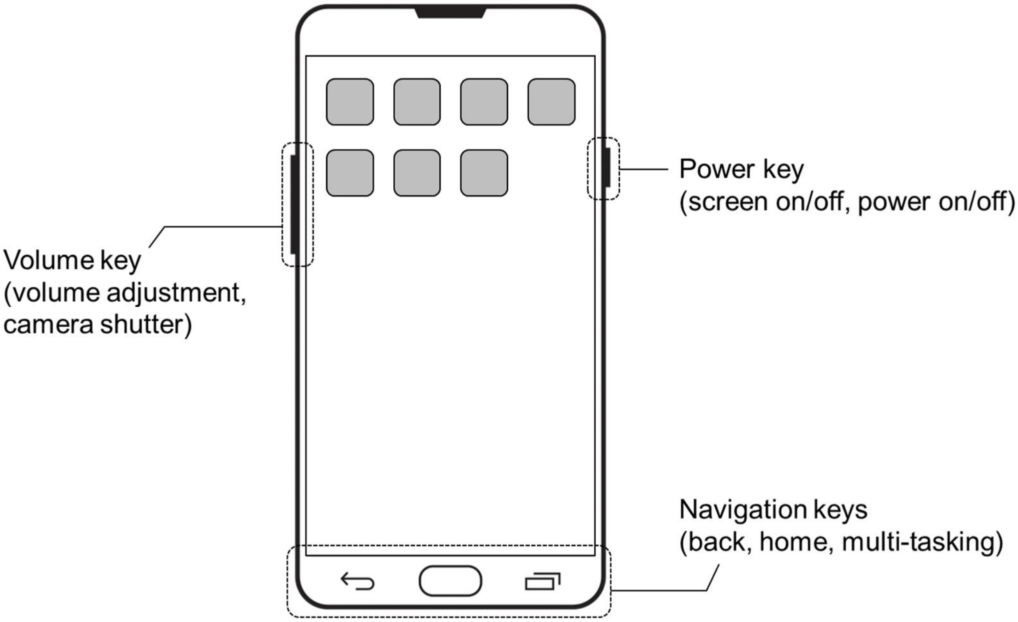
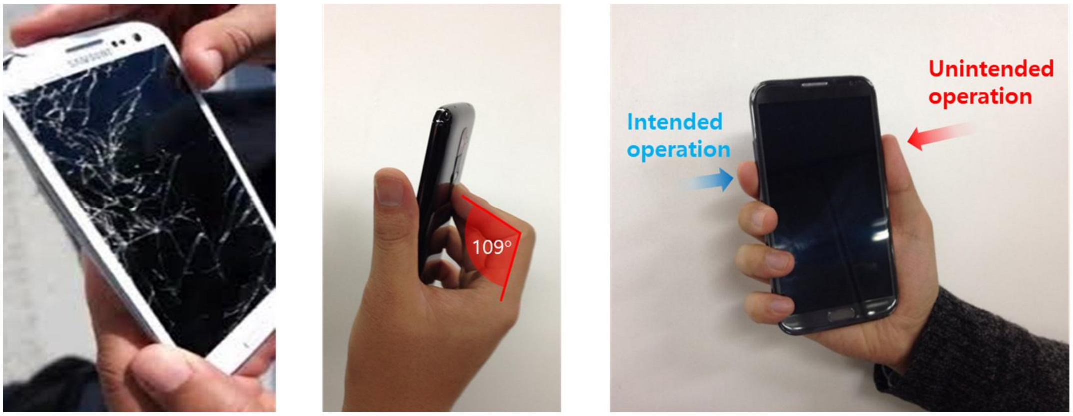


Figure 1.1. Smartphone physical user interfaces

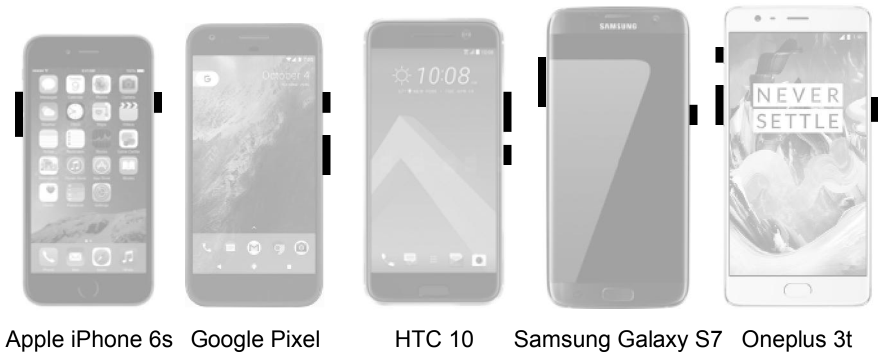
unintended operation, if improperly designed. If the smartphone hard key is designed in a location that is hard to operate, frequent change of grip postures may occur to operate the hard key, and that could cause damage by dropping the device (see Figure 1.2.a). On the other hand, as shown in Figure 1.2.b, operating the hard key without changing the grip posture can cause considerable discomfort to the fingers (Finnarian & O'Sullivan, 2013; Wobbrock et al., 2008), and as shown in Figure 1.2.c, the task performance can be decreased by unintended operation (e.g., intended operation: pressing volume key; unintended operation: tapping touch screen, pressing power key). As a practical evidence, some users raised issues about the discomfort due to the power key location change from the top side to the upper right side when Apple released iPhone 6 which was the first iPhone having power key on the upper right side (iMore, 2014).



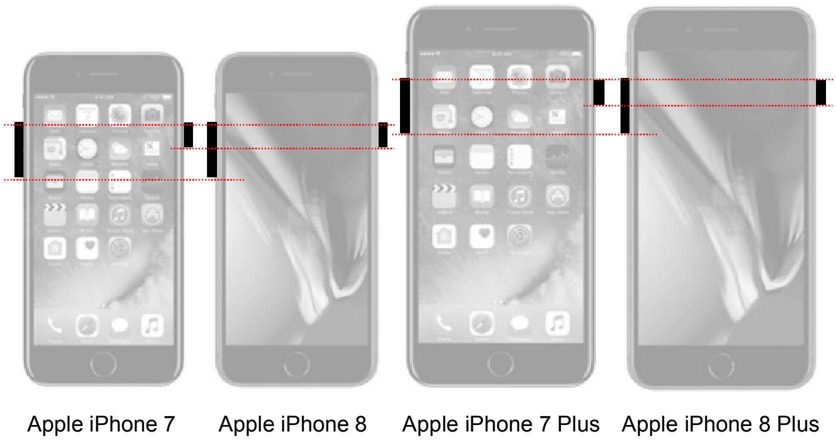
(a) Damage by grip loss (b) Uncomfortable posture (c) Unintended operations

Figure 1.2. Undesirable results of inappropriate hard key locations

While many studies for ergonomic user interface design have been conducted on the GUI design on a touchscreen and design dimensions of a device, research on the optimal design location of the hard key is still needed. With regard to the GUI design on a touch screen, Kim et al. (2014) identified preferable control zones for four different hand size groups by analyzing preferences of participants with various hand sizes for tapping the touchscreen areas segmented by 10 mm × 10 mm on 16 smartphone mock-ups with different sizes in combination of 4 different widths (40, 60, 80, 100 mm) and 4 different thicknesses (5, 15, 25, 35 mm). Im et al. (2010) constructed a discomfort map by evaluating the discomfort with 100-point scale (0: not felt discomfort at all; 100: felt discomfort very much) when operating 35 points (5 horizontal points with 10 mm gap, 7 vertical points with 15 mm gap, 10 mm margins for top/bottom/left/right) of a 60 mm × 110 mm touchscreen using the right hand, left hand, and both hands. Meanwhile, With regard to design dimensions of a device, Lee et al. (2018) identified relatively superior device width and bezel width by analyzing success rate, completion time, EMG, and subject workload for the tapping task that requires participants to tap a circular icon appears at random locations on the touchscreens of 4 smartphone mock-ups with different device width (67, 70, 72, and 74 mm) and 5 smartphone mock-ups with different bezel sizes (2.5, 5, 7,5, 10, and 12.5 mm). Kwon et al. (2016) compared the various curvatures and depths of smartphones for muscle activities by analyzing %MVC of four hand and forearm related muscles (abductor pollicis brevis, abductor pollicis longus, first dorsal interossei, and extensor digitorum communis) when conducting dragging, tapping, and texting tasks on smartphone mock-ups with 4 different curvatures (flat, 100, 200, 300 R) and 5 different depths (3, 5, 7, 9, 11 mm). However, research on the design location of a hard key, a user interface for physical manipulation of smartphones, is hardly available (Choi et al. 2016). In addition, the hard keys of similar-sized smartphones on the market are designed in various locations as shown in Figure 1.3.a, and smartphones in which the hard keys are located with design guide as shown in Figure 1.3.b are very limited even if they are developed by the same manufacturer. On the other hand, hard keys need to be carefully located as they are impossible to be relocated once manufactured unlike GUIs on a touchscreen, also, changing the location during design is difficult as well because the locations of the other parts are all related to each other. Therefore, development of an ergonomic design method for determining the location of hard keys on smartphones with various sizes is necessary.



(a) Various locations of hard keys on smartphones



(b) Guided locations of hard keys on smartphones

Figure 1.3. Smartphones with hard keys in different locations

1.2. Objectives of the Study

The present study is intended to suggest a method for determining hard key location and apply it to smartphones with various sizes to verify the applicability, in order to develop a design guide for hard key locations with desirable usability. To achieve this objective, first, a systematic methodology is developed to derive the optimal design locations of smartphone hard keys. A design methodology is developed considering the characteristics of device, user, task, and use context effectively which needs to be carefully addressed to UI design of a product. Second, types and preferences of preferred grip postures for smartphones with various sizes are identified. Types of user-preferred grip postures are investigated in detail for ergonomic user interface design. Also, preferences of the user-preferred grip postures are analyzed to find importance of each type of grip postures which will be applied to the optimal location design of smartphone hard keys. Third, optimal design locations of smartphone hard keys are identified by deriving the preferred control range of smartphone hard keys for users with various hand sizes. The optimal design locations of the smartphone hard keys are derived from the most frequently preferred location within control ranges when participants with various hand sizes hold the smartphones with the previously identified preferred grip postures. Finally, the appropriateness of the derived optimal hard key design locations was verified. This study derives the optimal hard key design locations through statistical analysis and applies it to the prototype to review the appropriateness of the methodology by ergonomic experiments. The verification ensures the usefulness of the analysis results by considering various hand sizes, handedness, tasks, and use contexts.

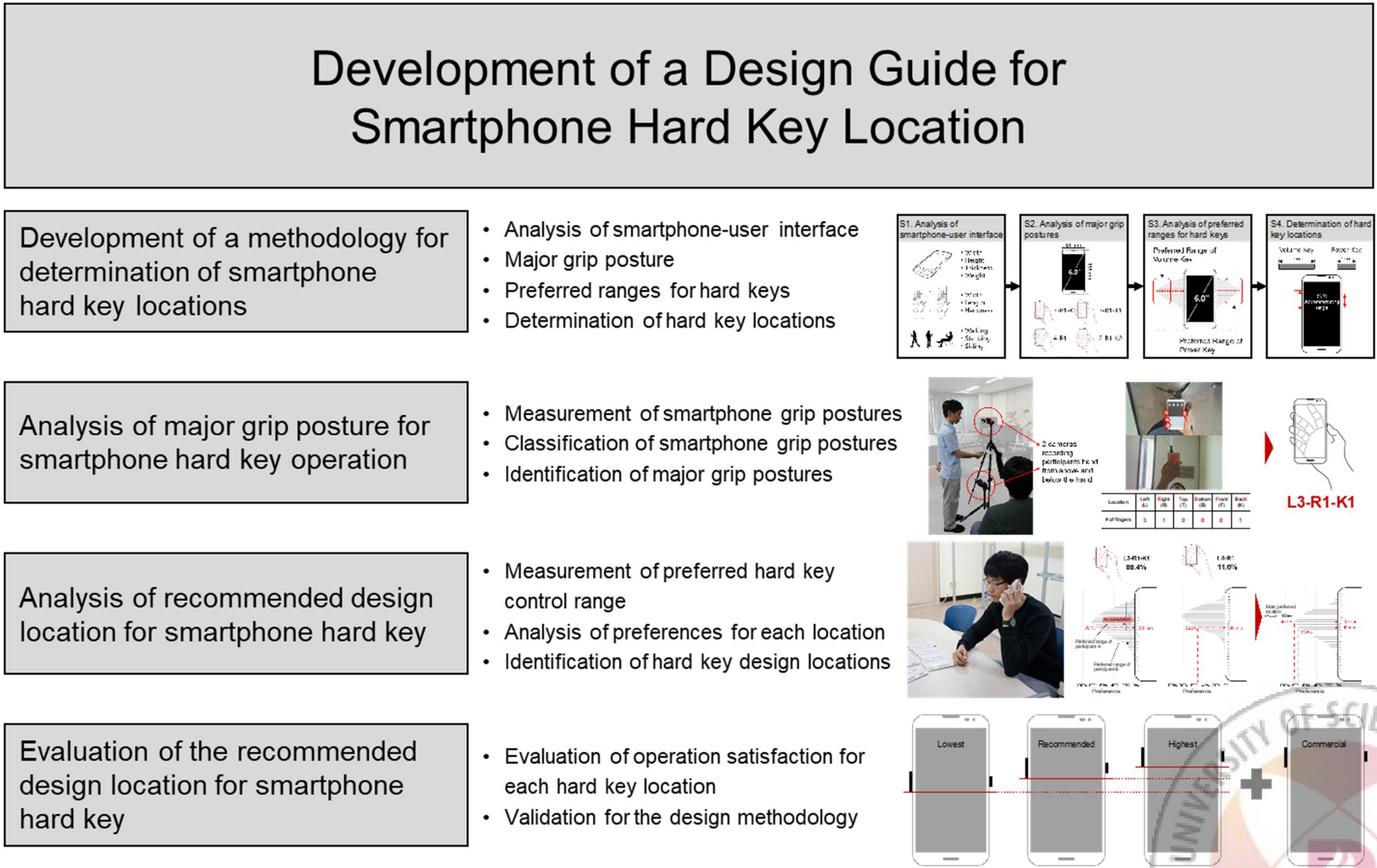


Figure 1.4. Research framework for hard key location design guide

1.3. Significance of the Study

The design methodology for optimal locations of smartphone hard keys developed in this study can be used effectively to systematically determine hard key locations for smartphones with various sizes. While various studies have been conducted for the design of user interfaces for mobile devices, sizes of the mobile devices were limited since development of a number of prototypes requires significant effort and the experiment needs to be conducted in an appropriate scale. In addition, while a number of studies developed methodologies for GUI design on a touchscreen, few studies about hard keys are available since hard keys are less frequently used than touchscreen although they are essential for efficient power management and intuitive operation of smartphones. This study presents a methodology for determination of hard key locations on smartphones in various sizes which systematically considers the characteristics of users, design characteristics of smartphones, and characteristics of major smartphone tasks, so that it can be used effectively in design of user interfaces with desirable usability.

The method of analyzing smartphone grip posture can be used effectively to quantify and categorize various grip postures. This study presents a method for measuring and objectively classifying the various user-preferred grip postures to design the optimal locations of the smartphone hard keys (see Figure 1.5). Existing studies that classify the grip posture of a smartphone or mobile device adopted the general categorization including one hand/two hands, left/right hand, and soft grip/firm grip to identify the overall behavior of users, but more subdivided classification of grip posture is needed for determination of

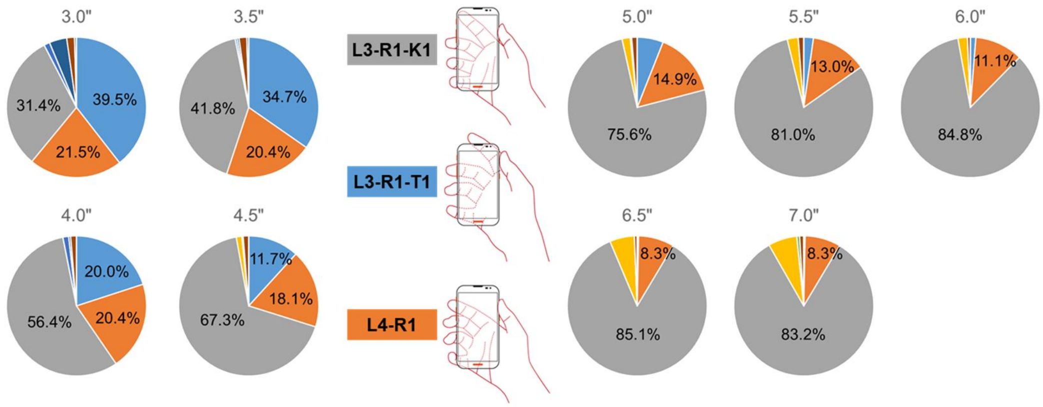


Figure 1.5. Quantitative analysis on smartphone grip postures

the hard key locations which may vary depending on the grip posture. The analysis method for smartphone grip posture presented in this study is expected to be effectively utilized to identify user-preferred grip postures that should be carefully considered to the smartphone design since it is designed to measure and classify user-preferred grip posture based on objective criteria when conducting various tasks with smartphones in various sizes.

Preference information for each smartphone hard key location identified in this study would be useful for determination of hard key locations on a target smartphone to be designed. PUIs including smartphone hard keys must be carefully designed because it requires serious effort and resources to change the design once manufactured. Therefore, the cost for design change can be reduced if the preference rate by users are estimated at the design stage. The optimal design locations of the smartphone hard keys proposed in this study is derived based on the preferences of users with various hand sizes, so it has the advantage of estimating users' preferences for each location for the smartphone hard keys.

1.4. Organization of the Dissertation

This dissertation consists of eight chapters. Chapter 1 introduces the general outline of this study including the background, objectives, and significance of the study. Chapter 2 reviews previous studies related to the present research including smartphone use behavior, grip posture, and preference / discomfort analysis for control range. Chapter 3 proposes the methodology for determination of optimal hard key locations on a smartphone systematically considering the characteristics of device, user, task, and use context. Chapter 4 describes the method of identifying user-preferred grip postures in conducting major tasks with smartphones in various sizes and the result of it. Chapter 5 illustrates the method of analyzing user-preferred hard key locations in major smartphone grip postures among various grip postures and the result of it. Chapter 6 depicts the method and result of verifying the optimal smartphone hard key locations through applying them to the smartphone prototypes with various sizes and analyzing the preference. Chapter 7 addresses a discussion regarding to the contributions, significance of the study, limitation, and further research issues. The last chapter concluded with contributions of the present study.

Chapter 2 Literature Review

This chapter describes studies of (1) design methods for user interface of mobile devices considering usability, (2) preferred grip posture analysis for mobile devices, and (3) preference analysis for control area.

2.1. User Interface Design for Mobile Devices

Mobile device is a handheld electronic device that can be portably used including mobile phone, PDA, tablet PC, e-book reader, digital camera, etc. Mobile devices refer to a variety of electronic devices of which the portability is maximized regardless of the functions available (Mobile Device, 2020). Some of the mobile devices are designed to be compact enough to be grasped and operated with one hand. For example, a smartphone is a type of mobile device that mobile phones were given the name 'smartphone' since their performance improved as good as a personal computer so that various functions can be conducted (Christensson, 2010). The world's first smartphone was a device called Simon released by IBM in 1994 (Andrew, 2018; see Figure 2.1), and besides, tablet PCs or digital cameras are also the types of mobile devices which can be operated with one hand and hold by the other hand unlike smartphones.

Studies were conducted to improve the usability of mobile devices by analyzing the usability and operational efficiency of user interfaces based on ergonomic experiments. Jin & Ji (2010) analyzed the usability of the keys, tasks, and grips for 133 types of mobile

Figure 2.1. World’s first smartphones: IBM Simon

phones. Factors affecting the usability of mobile phones were defined as keys, tasks, and grips, and evaluation criteria and weight of importance were determined for each item. Then, a total of 133 mobile phones (30 bar types, 48 folder types, 52 slider types, 3 swing types) were evaluated and the overall usability score was calculated. Finally, usability risk level for each device was defined quantitatively based on the evaluated usability score whether it could negatively affect users' satisfaction (see Figure 2.2).

Wobbrock et al. (2008) analyzed the effect of grip posture, location of the interface, and operating finger to the task completion time and error rate for PDA (see Table 2.1). Movement time and error rate were analyzed when participants conducted a task of moving a touch location shown on the touchscreen to a target area with their thumb or index finger while holding a PDA with two hands or one hand when the touchscreen faced up or down. As shown in Table 2.2, in terms of movement time, holding with two hands took less time than holding with one hand (two-handed: 1.4 sec; one-handed: 1.6 sec) and

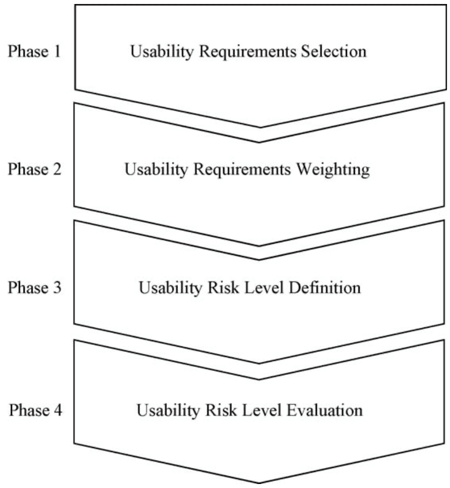


Figure 2.2. Procedure of usability risk level evaluation (Jin & Ji, 2010)

index finger operation took less time than thumb operation (index: 1.4 sec; thumb: 1.5 sec). On the other hand, the location of touchscreen did not make a significant difference (front: 1.4 sec; back: 1.5 sec). In terms of error rate, holding with two hands made less error rates than holding with one hand (two-handed: 4.6%; one-handed: 8.7%) and index finger

Table 2.1. Experimental conditions for PDA task performance (Wobbrock et al., 2008)

	Thumb-on-front	Thumb-on-back	Index-on-front	Index-on-back
Two-handed				
One-handed				

Table 2.2. PDA task performances in movement time and error rate (Wobbrock et al., 2008)

	# of hands		Operated finger		Touch screen location	
	Two	One	Index	Thumb	Front	Back
Movement time (sec.)	1.4	1.6	1.4	1.5	1.4	1.5
Error rate	4.6%	8.7%	5.3%	8.1%	6.0%	7.4%

operation made less error rates than thumb operation (index: 5.3%; thumb: 8.1%). Moreover, the operation when the touchscreen faced up showed less error rates than those when the touchscreen faced down (front: 6.0%; back: 7.4%).

2.2. Preferred Grip Posture

Although detailed understanding of the user's preferred grip posture for a target device is needed to design UI with desirable usability, previous studies analyzed grip postures for mobile devices are hard to be utilized in designing UI of mobile devices with various sizes since they analyzed a certain size of mobile device or classified grip postures comprehensively. For example, even though Pelosi et al. (2009) classified participant's preferred grip postures for mobile phones, they may differ for the larger devices such as smartphones these days. The participants used two experimental mobile phones (bar type: Nokia 1100, 106 × 46 × 20 mm; shell type: RAZR V3, 98 × 53 × 13.9 mm) and their own mobile phones to conduct tasks of calling and texting, and the tasks were recorded by using 21 webcams installed throughout the experimental space as shown in Figure 2.3.

Figure 2.3. Grip posture measurement for mobile phones (Pelosi et al., 2009)

As a result of grip posture analysis based on the captured images, the one-handed grip postures were classified into two types: soft grip and firm grip. Soft grip is defined as a type of grip posture that has a free space between the palm and the device by grasping a device only with the tip of fingers, while firm grip is defined as a type of grip posture that the middle of fingers supports the side of the device and the tip of fingers reaches the inside of the device. On the other hand, the two-handed grip postures were classified into two types: overlapped grip and interlaced grip. Overlapped grip is defined as a type of grip posture that holding the device with one hand and overlapping it with the other hand, and interlaced grip is defined as a type of grip posture that intersects fingers of both hands to hold the device. However, the two experimental mobile phones and participants' mobile phones used in Pelosi et al. (2009) were relatively smaller than smartphones with large screen these days, so the result of grip posture analysis is hard to be applied to smartphones directly. Because the firm grip gets harder to take as device size increases, and soft grip can be subdivided according to the position of the fingers.

Karlson et al. (2006) investigated mobile phone use contexts and natural grip postures, but the grip postures were too comprehensively classified to be used in UI design. The study observed the use contexts and grip postures of users who were using mobile phones at the main ticketing terminal in Baltimore Washington International Airport. Users were in a variety of use contexts such as walking, standing, and sitting, and they hold their mobile phones with either one hand or two hands (see Figure 2.4). The survey showed that 42% of the users were in walking situation which is the most dynamic, 36% of them were in standing situation, and the rest 22% of them were in sitting situation. In walking situation, most of them hold their mobile phones with one hand, and more than half of them hold with one hand in standing situation. On the other hand, more than half of them hold their mobile phones with two hands in sitting situation which is the most static. Karlson et al. (2006) investigated natural grip postures in various use contexts, but the grip postures are hard to be applied to UI designs that require the information of detailed

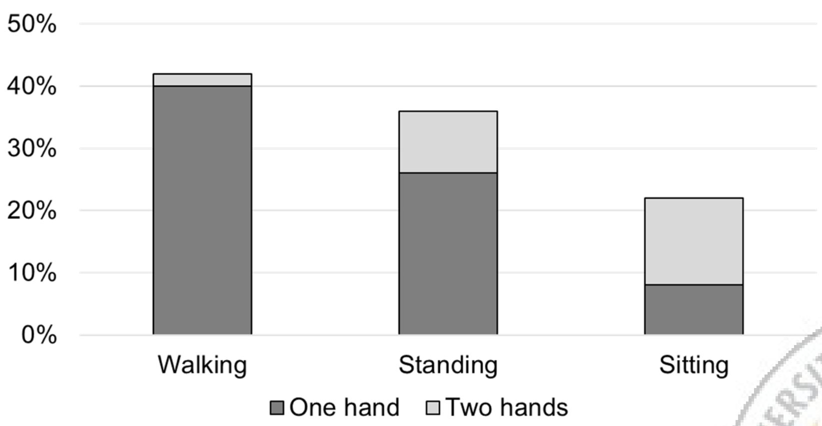
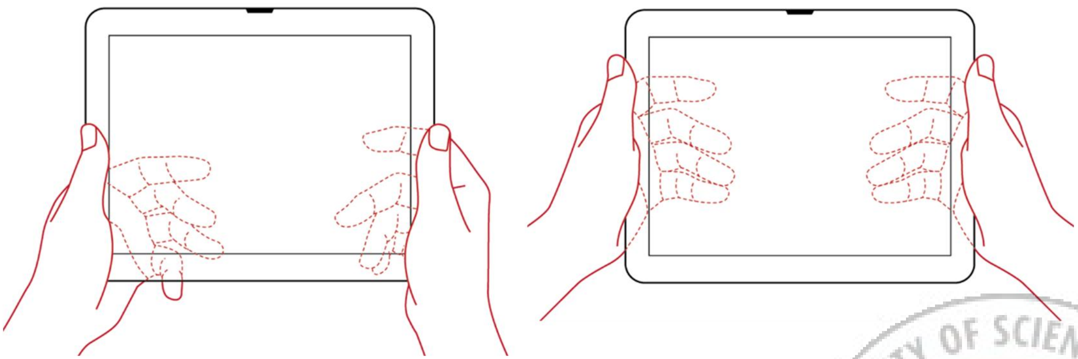


Figure 2.4. Grip posture by activity (Karlson et al., 2006)

location for fingers since the classification of the grip postures was comprehensively conducted as one hand and two hands. For example, when designing a hard key located on the right side of a mobile phone, it should be considered that various fingers including index finger, middle finger, and ring finger of left hand can participate in operation while only the thumb of the right hand can operate the hard key.

In addition, although Odell & Chandrasekarn (2012) investigated the preferred grip postures for tablet PCs when using virtual keyboard, grip postures in other tasks need to be also studied to design various UIs of tablet PCs. The grip postures were investigated when 12 tablet PC users with various lengths of thumb used a virtual keyboard on a tablet PC with both hands. The grip postures for tablet PCs using both hands were classified into two types: corner grip and side grip as shown in Figure 2.5. Corner grip is defined as a type of grip posture that the palm is located to the corner of a tablet PC, while side grip is defined as a type of grip posture that the palm is located to the side of a tablet PC. When taking a side grip, the thumbs of users were located at an average of 9 cm below the top of the



(a) Corner grip (b) Side grip

Figure 2.5. Grip posture for tablet PC (Odell & Chandrasekarn, 2012)

device. While Odell & Chandrasekarn (2012) identified the grip posture of tablet PCs for participants with various hand sizes, grip postures in various tasks need to be further studied since the task was limited to the texting with a virtual keyboard in both hands although grip postures can vary in various tasks. For example, in a simple handwriting note task, a grip posture that one hand supports the back of the tablet PC and the other hand writes on the front of the tablet PC can be used, and in a photo taking task, a grip posture that hold the center of the side rather than the corner to stably support the tablet PC considering the center of gravity.

Finally, Trudeau et al. (2012) analyzed the operating efficiency and grip stability of one-handed grip posture and two-handed grip posture when operating a touchscreen with thumb, and identified that two-handed grip posture is superior, but user's preferred grip posture was not considered. This study compared the operational efficiency (averages of movement time, distance, and finger joint angles) and stability (the change of slope angle and position of the device) when taping 12 touch points on a touchscreen with thumb in one-handed grip posture and two-handed grip posture. As shown in Figure 2.6, two-handed grip posture showed superior operational efficiency and stability than one-handed grip posture where the thumb motor performance (two-handed: 13.2 ± 3.1 bits/sec; one-handed: 12.0 ± 2.9 bits/sec) and movement variation of the device (two-handed: 4.3 ± 3.2 deg; one-handed: 8.7 ± 5.2 deg) in two-handed grip posture were greater than those in one-handed grip posture. Contrary, average finger joint angles did not show a significant difference for the two grip postures (two-handed: 38.3 ± 20.0 deg; one-handed: 36.5 ± 21.9 deg). However, the result of the study is hard to be generalized to devices with various sizes

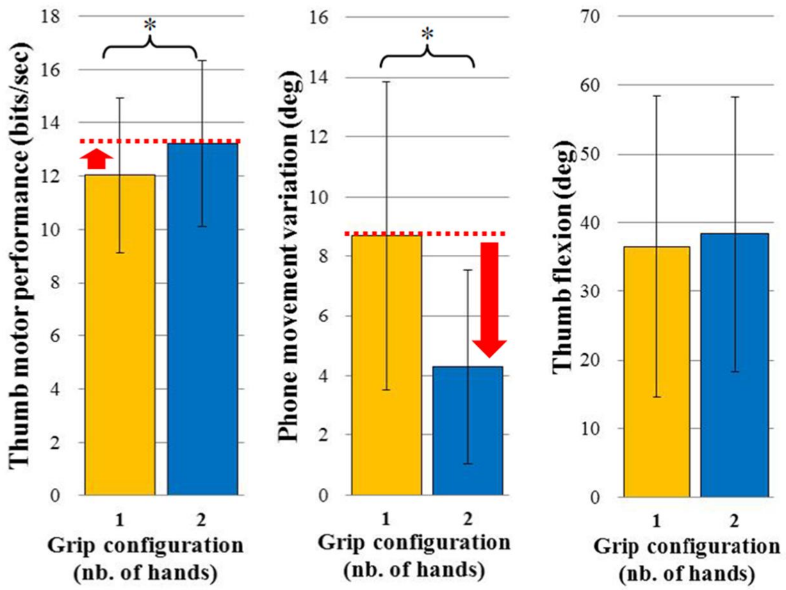
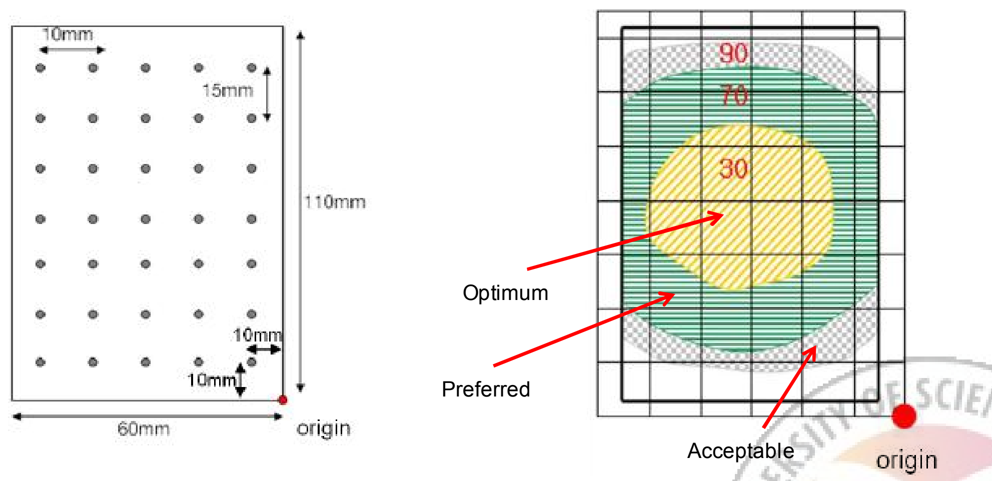


Figure 2.6. Comparison of one-handed grip and two-handed grip (Trudeau et al., 2012)

since Trudeau et al. (2012) evaluated only a certain size of device. For example, when the size of a mobile device is small, other types of one-handed grip posture (e.g., supporting the top of the device with index finger) can be utilized and that can be efficient and stable enough.

2.3. Preferred Control Area

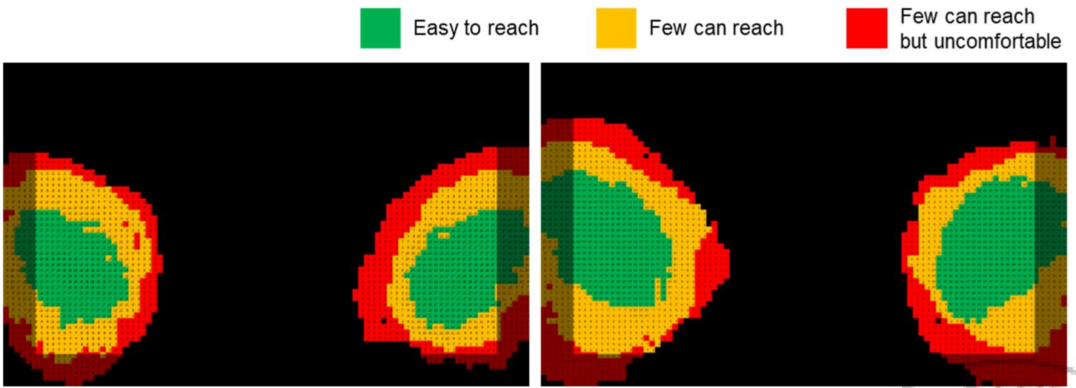
Studies that have developed the GUI design guide for desirable ergonomic user interfaces on a touchscreen based on the information of discomfort or preference distribution for operating area can be adopted to develop a PUI design guide. Im et al. (2010) developed a smartphone icon layout guide by analyzing the operational discomfort of 35 icon locations on a touchscreen. Discomfort scores for 35 touch points (5 horizontal points at 10 mm intervals and 7 vertical points at 15 mm intervals) on a 60 mm × 110 mm touchscreen were evaluated using a 100-point rating scale when operating with right hand, left hand, and both hands (see Figure 2.7.a). After the discomfort score for each touch point was assessed, the three-level (acceptable, preferred, optimum) icon layout guide by level of discomfort was estimated based on the discomfort scores as shown in Figure 2.7.b. This method for icon layout guide development can also be useful for designing smartphone hard key locations. For example, an approximate region (e.g., right side of the device) where the smartphone hard key will be located can be set first, then, the region is divided at certain intervals (e.g., 5 mm), and finally, hard key layout guide can be developed by analyzing the discomfort scores for the region when operating hard keys by participants.



(a) Touch points on a touch screen (b) icon layout guide based on discomfort level

Figure 2.7. Icon layout design guide (Im et al., 2010)

Odell & Chandrasekarn (2012) measured the range of thumb reach for each preferred tablet PC grip posture to design a virtual keyboard layout for a tablet PC. A piece of paper was attached on a tablet PC and participants identified two areas (movement is comfortable & movement is not comfortable but possible) with their painted thumb in different colors. After that, the results from participants were statistically analyzed, and the operating area was divided into three levels (easy to reach, few can reach, few can reach but uncomfortable) as shown in Figure 2.8. This keyboard layout guide can also be useful for designing smartphone hard key locations. For example, an approximate region (e.g., right side of the device) where the smartphone hard key will be located can be set first, then, the region is painted by several different colors (e.g., red for bad, yellow for neutral, green for good) by participants according to the operating satisfaction level, and finally, hard key layout guide can be developed by analyzing the satisfaction distribution for the region.



(a) corner grip (b) side grip

Figure 2.8. Reach heat map for corner and side grips (Odell & Chandrasekarn, 2012)

Chapter 3 Development of Design Framework for Determination of Hard Key Location

This study developed a method to determine the optimal locations of the smartphone hard keys by identifying the hard key control range that many users commonly prefer based on the preferred grip postures for smartphones with various sizes. The design methodology for optimal hard key locations on a smartphone consists of (1) analysis of smartphone-user interface, (2) analysis of major grip postures, (3) analysis of preferred control ranges for hard keys, and (4) determination of hard key locations, as shown in Figure 3.1.

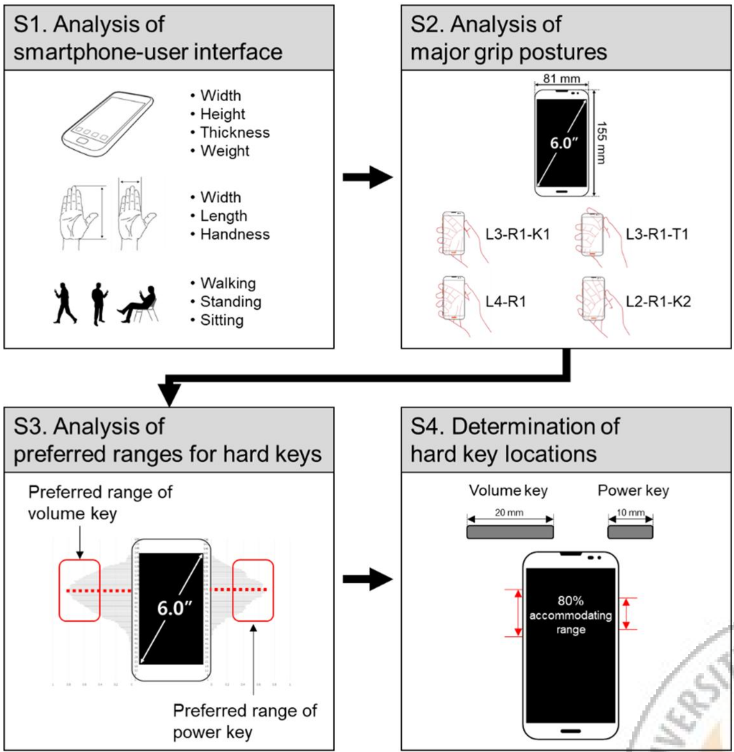


Figure 3.1. Design methodology for smartphone hard key locations

3.1. Analysis of Smartphone-User Interface Characteristics

In the analysis of smartphone-user interface phase, the characteristics of smartphone-user interface including smartphone design dimensions, user's anthropometric dimensions, major smartphone tasks, and use contexts are analyzed to design user interfaces in systematic consideration of the characteristics of product, user, task, and use context. To design a user interface with desirable usability, the characteristics of product design, the cognitive and physical aspects of users, the operation contexts of product, and tasks to be performed need to be systematically considered (Courage et al., 2009). First, in terms of product design, overall shape of the product (e.g., polyhedron, cylinder, and polypyramid) and detailed dimensions including width, height, thickness, weight, circumference, angle, etc. are analyzed. Second, in terms of the cognitive and physical aspects of users, the cognitive characteristics such as mental model and emotional satisfaction for the product and the physical characteristics such as the detailed dimensions of the body part directly utilized for manipulation and the mechanism of motion should be considered. Third, in terms of the operation contexts of product, the characteristics of various situations the product can be used such as 'sitting', 'walking', 'running', and 'lying down' are investigated. Finally, in terms of tasks to be performed, the types of tasks that can be performed using the product and the detailed operating procedures are identified.

In analysis of the design characteristics of a product, the specifications of design parameters such as width, height, thickness and weight of a smartphone are quantitatively analyzed. For example, the design parameters of smartphones can be width, height,

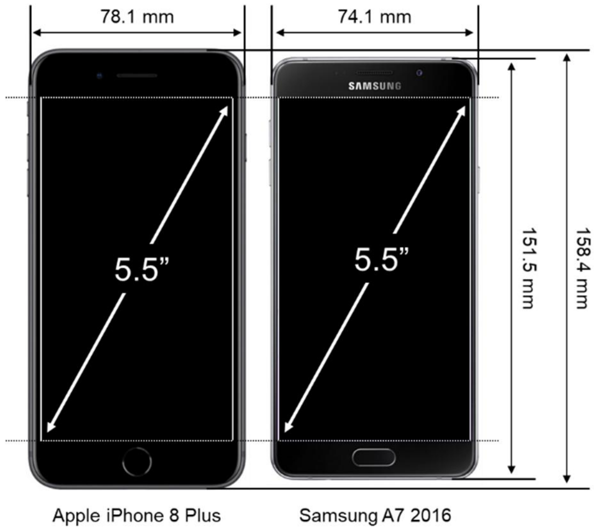


Figure 3.2. Smartphones with the same screen size in different device sizes

thickness, weight, screen size, etc. since smartphones are generally designed in hexahedron form. In analyzing dimensions by design parameter, design range can be set by market trends and development strategies, and various sizes of prototype can be defined. For example, according to the database from Gsmarena (2017), the screen size of smartphones manufactured by 2017 varies from 2.9 to 7.0 inches, and the target design specification can be determined within the distribution or an entirely new specification can also be determined. While smartphones are generally designed as vertically long and flat cubes, the overall device size varies depending on the manufacturer even though they have the same screen size as shown in Figure 3.2. The design range of smartphones is set in consideration of a variety of aspects, including the usability, aesthetics, and durability of the products, and there are recent design trends that extremely minimize non-screen space as shown in Figure 3.3 (Gsmarena, 2019).

Figure 3.3. Example of smartphones with narrow bezels (< 2 mm)

In analysis of user characteristics, major anthropometric variables that can affect the usability of a smartphone are selected and analyzed. The major anthropometric variables that may affect the usability of smartphones include gender, hand length, hand width, and handedness. In terms of gender, men generally have larger hand sizes than women (Size Korea 2010). In terms of hand length and hand width aspects, large-handed users may feel easier to manipulate the user interface located at the top of a smartphone compared to small-handed users. The distribution of hand length and hand widths in the Size Korea (2010) anthropometric data shows that Korean women (*n* = 2,025) have the hand length of 149 to 194 mm and the hand width of 63 to 87 mm, and Korean men (*n* = 2,471) have the hand length of 160 to 212 mm and the hand width of 72 to 97 mm (see Figure 3.4). In addition, in terms of handedness, there may be differences in usability for left-handed and

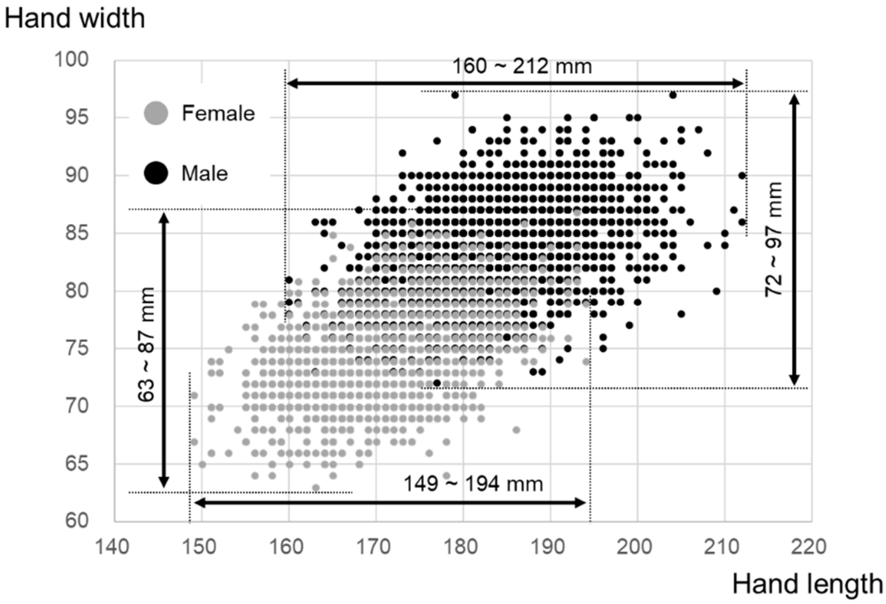


Figure 3.4. Hand size distribution of Korean 20s ~ 50s in Size Korea (2010)

right-handed users when operating the UI located on the right side of the smartphone, as left-handed smartphone users use their index finger or middle finger while right-handed smartphone users use their thumb. Meanwhile, it is reported that 8% to 12% of population in the world prefers to use their left hands over right hands (Hardyck & Petrinovich, 1977; Perelle & Ehrman, 1994; Reiss & Reiss, 1999).

In analysis of use context characteristics, various contexts using a smartphone are analyzed and the target use context is selected by considering design strategy. Smartphones have become essential electronic devices that are used regardless of time and place and can be used in various contexts (see Figure 3.5) that users experience in their daily lives. Static contexts with less movement include lying down context on a recliner, sofa, bed, etc., sitting context in a house, office, lab, etc., and standing context on a street, in a bus, on a

Figure 3.5. Types of smartphone use context

line to buy a ticket, etc. Meanwhile, dynamic contexts with a lot of movement include walking and running to other places. Some manufacturers (e.g., Samsung, LG) are developing smartphones that considers use contexts that a lot of violent movements are required, such as sports activities and underwater use contexts. Figure 3.6 is an example of smartphones that are durable for dynamic use contexts which passed MIL-STD-810G test (guarantees normal operation after dropped to a plywood, iron, and concrete with a

Figure 3.6. Smartphones for dynamic use contexts

thickness of 2 inches from 80 cm above ground level) and acquired the waterproof and dust-resistant rating IP68 (supports waterproof in 1.5 meters of freshwater for up to 30 minutes).

In analysis of task characteristics, the types of tasks (e.g., calling, listening to music, sending messages, web surfing, etc.) performed using a smartphone are identified and the major tasks are selected according to the design strategy. Smartphones have a variety of applications that can be installed, so there are many types of tasks that can be performed using the applications. Therefore, it is necessary to identify the types of tasks that are frequently used by many users through literature surveys, questionnaires, expert interviews, etc. and to select the major tasks to consider in the design. For example, Dunn et al. (2013) conducted a survey of 119 smartphone users to derive a list of tasks that should be considered important for evaluation of the usability for smartphones, and identified the major tasks such as check email, browse internet, answer a call, send text, take photo and get driving directions (see Figure 3.7). Meanwhile, this study needs to focus

Smartphone Task	*n*	Mean	SD	
Check Email	115	6.37	0.94	Email
Send Email	118	6.16	1.03	
Look Up Contact	117	5.86	1.12	Call
Answer Call	119	5.85	1.17	
Call a Contact	118	5.77	1.15	
Add a Contact	117	5.77	1.14	
Sent Text	118	5.73	1.58	Texting
Read Text	119	5.64	1.61	
Internet Search	118	5.86	1.2	Web browsing
Browse Internet	118	5.7	1.22	
Connect to Wireless	117	5.69	1.36	
Take Photo	119	5.69	1.3	Taking photo
Get Driving Directions	116	5.65	1.36	Get directions
Check Calendar	118	5.69	1.48	
Add an Appointment	118	5.51	1.45	
Read a Document	118	5.42	1.23	

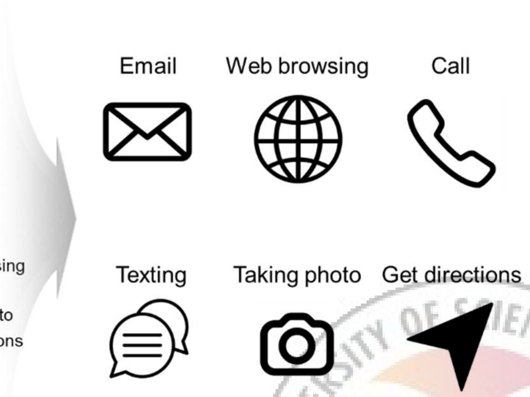


Figure 3.7. Major smartphone tasks (Dunn et al., 2013)

on the task performed using hard keys to design the optimal locations of the hard keys. It is necessary to select major tasks by segmenting what actions are made for each task and analyzing the timings and frequencies of the hard key operations.

3.2. Understanding of Dominant Grip Postures for Target Devices

In the major grip posture analysis phase, various types of grip postures that may vary depending on the device, user, task, and use context are quantitatively measured and categorized to identify the major grip postures to be considered in the smartphone hard key design. Smartphone grip posture can vary depending on the size of the user's hand or the hand they use. For instance, users with large hands can selectively take a grip posture among various grip postures because they can reach each part of the device relatively easily in many postures, but users with small hands may have limited options to select a grip posture for operating the device reliably. Moreover, when a button on the right side of the device is operated, the user operating with the left hand and the user operating with the right hand will take different grip postures using different fingers (e.g., left hand user: middle finger; right hand user: thumb). Next, smartphone grip posture may vary depending on the task and use context in which the product is used, so it is necessary to identify the user's preferred grip posture under various conditions and apply it to the hard key location design. For example, if a user uses a smartphone in a bed position, the user must bear the weight of the device to operate it, so a grip posture which guarantees more power for operation may be taken than those for sitting or standing contexts. Also, if a user uses a smartphone with both hands, they can hold the device with one hand and operate the user interface with the other, but when only one hand is used, a grip posture that allows to perform both holding and operation effectively at the same time is taken.

To identify smartphone major grip postures, preferred grip postures of users with various hand sizes when performing smartphone tasks are captured by video recording. First, participants with various hand sizes are recruited in terms of hand length and hand width considering the distribution of hand size for the target users. Next, major smartphone tasks and use contexts are defined, and the natural smartphone grip postures are recorded while participants are conducting the major tasks. A variety of methods such as motion capture system, 3D scanning, and depth camera tracking can be used for smartphone grip posture measurements, but a simple method such as 2D video recording can be used for efficiency of measurement and analysis. When capturing the grip posture by 2D video recording, participant's hand that holds a smartphone to operate can be recorded from multiple directions (e.g., top and bottom) for effective classification of grip postures as shown in Figure 3.8.

The types of grip postures are classified based on the number of fingers located on each side of the smartphone from the recorded grip posture images. The grip posture can be classified in a variety of ways, but overall grasping strategy and the approximate location of each finger contributing to the operation of the hard key are needed to be applied to the hard key design. This study used a grip posture classification method that analyzes the position of each finger at the moment of manipulating the hard key in the images recorded when conducting various tasks (e.g., texting and web browsing). The grip

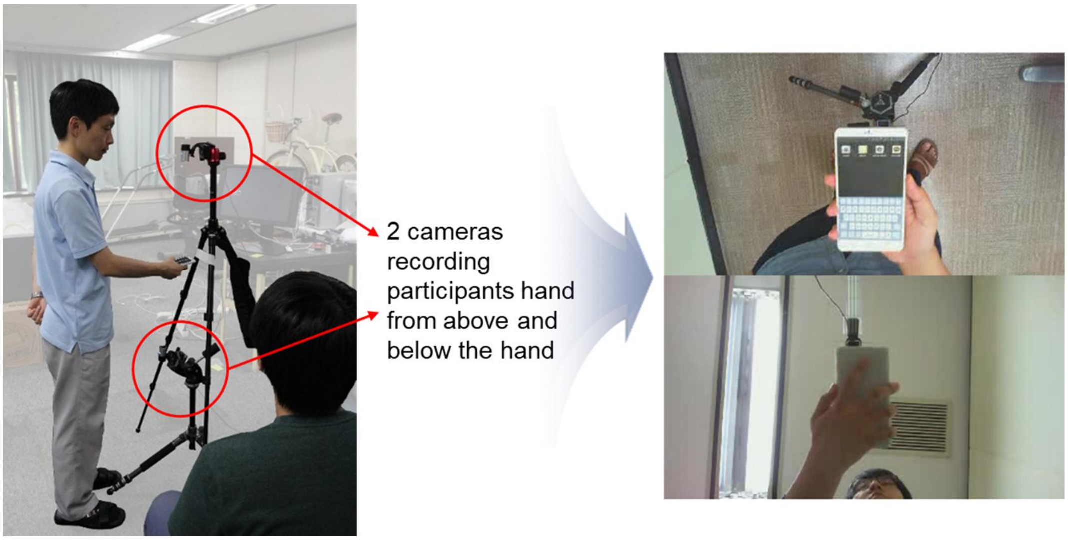
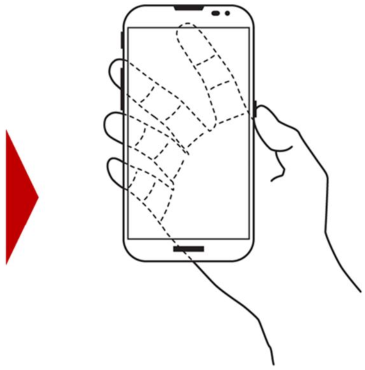


Figure 3.8. Video recording of smartphone grip postures

posture recorded for each sub action is coded by counting the number of fingers located on each side (left, L; right, R; top, T; bottom, B; front, F; back, K) of the device at each hard key operation. For example, when operating a power key to turn off the screen after sending a text as shown in Figure 3.9, the grip posture can be coded into L3-R1-K1 grip posture as the number of fingers located on each side of the device is three on the left, one on the right, and one on the back.

The major grip postures are identified by device size to considered important when designing a smartphone hard key through calculating the frequency of types of classified grip postures. After classified the types of grip postures for each hard key operation, the frequency of each grip posture relative to the total number of hard key operations is calculated to derive the preference rate for each type of grip posture. The preference rates for each type of grip posture can be used as the relative importance of that grip posture



Location	Left (L)	Right (R)	Top (T)	Bottom (B)	Front (F)	Rear (K)
# of fingers	3	1	0	0	0	1

Figure 3.9. An example of smartphone grip posture coding

when designing a smartphone hard key. In addition, the preference rates of the major grip postures can vary depending on device size and hand size, so further analysis can be carried out to find the effect of device size and hand size.

3.3. Analysis of Preferred Control Range for Smartphone Hard Keys

In the preferred hard key control range analysis phase, preferred control range by grip posture is analyzed to identify the common preferred control range for users with various hand sizes. The optimal hard key design locations are determined by identifying the preferred range for hard key operations in major grip postures by users with various hand sizes, because preferred hard key control range may also vary depending on the user's hand size and grip posture. A method is proposed in this study to measure preferred hard key control ranges by users with various hand sizes using a smartphone mock-up having location-adjustable hard keys and identify the range where many users prefer in common. The smartphone mock-up is developed in a structure that the locations of hard keys are adjustable to measure the preferred control range of the hard key (see Figure 3.10). The design specification of the mock-up is the same as the target smartphone, but hard keys are developed in sliding mechanism to enable continuous adjustment, and the grid is attached to record the locations of the hard keys quantitatively.

The preferred control range of hard keys are measured using smartphone mock-ups of which hard key location is adjustable while holding the mock-ups with the identified major grip postures from the previous phase. Participants need to practice the major smartphone grip postures first, then hold smartphone mock-ups to find their preferred control ranges for hard keys. After that, they find their lowest and highest locations of preferred hard key control ranges by adjusting up and down the location-adjustable hard

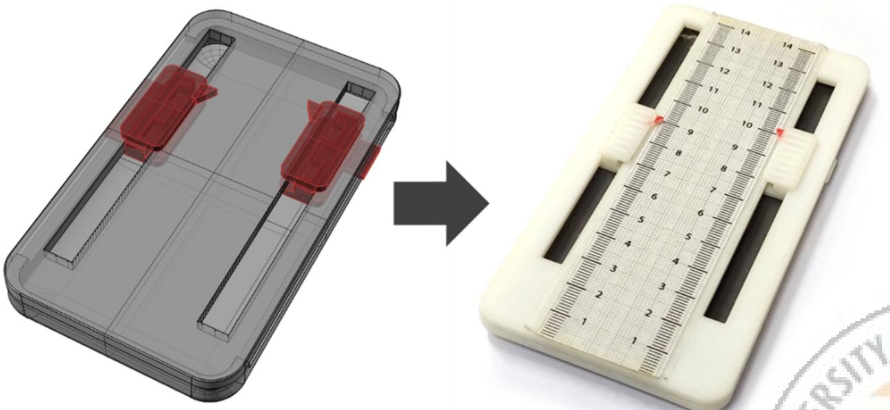
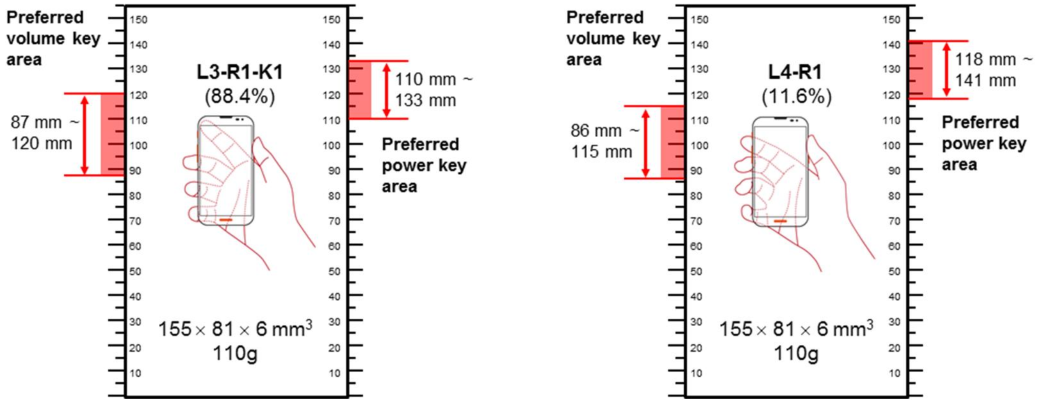


Figure 3.10. A smartphone mock-up having adjustable hard keys

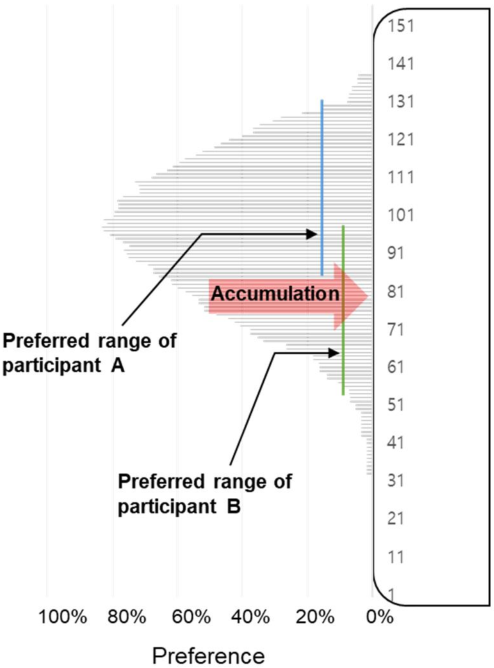


(a) Preferred area selected for L3-R1-K1 (b) Preferred area selected for L4-R1

Figure 3.11. An example of preferred control area measurement

keys on each side of the mock-ups (e.g., power key on the right and volume key on the left). Once the preferred hard key control ranges of the participants are identified, experimenter checks the grid and records the ranges. Figure 3.11 illustrates an example of the preferred hard key control ranges for L3-R1-K1 grip posture (a grip posture wrapping around the device while supporting the back, Figure 3.11-a) and L4-R1 grip posture (a grip posture grasping the device with all fingers, Figure 3.11-b) which are 110 to 133 mm area (L3-R1-K1) and 118 to 141 mm area (L4-R1).

Cumulative preference for each hard key location separated by a certain interval (e.g., 1 mm) is analyzed once the preferred hard key control ranges for individual participants are collected. For example, as shown in Figure 3.12, if participant A has selected the range of 84 to 133 mm from the bottom of the device and participant B has selected the range of 52 to 98 mm as the preferred control ranges, the preference frequency for the common range of 84 to 98 mm becomes 2 whereas those for the range of 52 to 84



	S1	S2	S3	S4	S5	S46	S47	S48	S49	S50	Total	Preference
140											0	0.0%
139	1										1	2.0%
138	1							1			2	4.0%
137	1							1			2	4.0%
136	1							1			2	4.0%
135	1	1						1			3	6.0%
134	1	1	1				1	1			5	10.0%
133	1	1	1				1	1			5	10.0%
132	1	1	1				1	1		1	6	12.0%
131	1	1	1				1	1	1	1	7	14.0%
130	1	1	1			1	1	1	1	1	8	16.0%
129	1	1	1		1	1	1	1	1	1	9	18.0%
128	1	1	1	1	1	1	1	1	1	1	10	20.0%
127	1	1	1	1	1	1	1	1	1	1	11	22.0%
126	1	1	1	1	1	1	1	1	1	1	12	24.0%
125	1	1	1	1	1	1	1	1	1	1	15	30.0%
124	1	1	1	1	1	1	1	1	1	1	18	36.0%
123	1	1	1	1	1	1	1	1	1	1	19	38.0%
122	1	1	1	1	1	1	1	1	1	1	19	38.0%
121	1	1	1	1	1	1	1	1	1	1	20	40.0%
120	1	1	1	1	1	1	1	1	1	1	21	42.0%
119	1	1	1	1	1	1	1	1	1	1	22	44.0%
118	1	1	1	1	1	1	1	1	1	1	22	44.0%
117	1	1	1	1	1	1	1	1	1	1	22	44.0%
116	1	1	1	1	1	1	1	1	1	1	22	44.0%
115	1	1	1	1	1	1	1	1		1	23	46.0%
114		1	1	1	1		1	1		1	23	46.0%
113		1	1	1	1		1	1		1	25	50.0%
112		1	1	1			1	1		1	28	56.0%
111		1	1	1			1	1		1	28	56.0%
110		1	1	1			1	1		1	30	60.0%
109		1	1	1			1	1		1	30	60.0%
108		1	1	1			1	1			31	62.0%
107			1	1			1	1			32	64.0%
106			1	1			1	1			32	64.0%
105			1	1			1	1			32	64.0%
104			1					1			32	64.0%
103			1					1			32	64.0%
102								1			32	64.0%
101								1			35	70.0%
100								1			35	70.0%

Figure 3.12. An example of analysis on the preference for each hard key control area

mm and 98 to 133 mm become 1, and the preference rate of each area becomes 100% and 50% respectively.

Next, the distribution of the preference rate for each hard key location is derived by applying the preference rate of each grip posture to the preference rate for each hard key locations in the grip postures using Equation 3.1. For example, if the preference rate for

$$CP_j = \sum_{i=1}^{N} P_i \times CP_j^i \qquad \text{Equation 3.1}$$

where CP_j = cumulated preference percentage of control location *j*, *j* = device height (mm), P_i = preference percentage of grip posture *i*, CP_j^i = cumulated preference of control location *j* in grip posture *i*.

grip posture L3-R1-K1 is 88.4% and those for L4-R1 is 11.6%, and the preference rates for the location 125 mm in the two grip posture are 93.9% and 44.0% respectively, the overall preference rate for the hard key location can be derived as 88.1% (= 88.4% × 93.9% + 11.6% × 44.0%).

L3-R1-K1
88.4%

L4-R1
11.6%

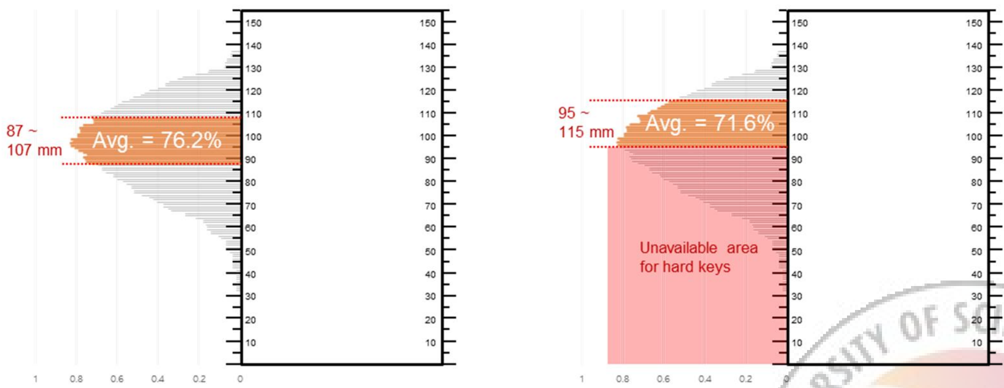
Combined

	L3-R1-K1 88.4%		L4-R1 11.6%		Combined
Location	Preference%	Preference% × GP%	Preference%	Preference% × GP%	Combined Preference%
130	84.8%	75.0%	38.9%	4.5%	79.5%
129	88.6%	78.3%	40.8%	4.7%	83.0%
128	90.1%	79.6%	42.5%	4.9%	84.5%
127	91.5%	80.9%	44.2%	5.1%	86.0%
126	92.6%	81.9%	44.2%	5.1%	87.0%
125	93.9%	83.1%	44.0%	5.1%	88.1%
124	95.3%	84.2%	44.2%	5.1%	89.3%
123	95.9%	84.8%	45.9%	5.3%	90.1%
122	97.4%	86.1%	45.4%	5.3%	91.4%
121	98.7%	87.2%	49.1%	5.7%	92.9%
120	98.7%	87.2%	55.9%	6.5%	93.7%
119	99.3%	87.8%	55.6%	6.5%	94.3%
118	99.3%	87.8%	60.7%	7.0%	94.9%
117	99.3%	87.8%	60.5%	7.0%	94.8%
116	99.3%	87.8%	63.5%	7.4%	95.2%
115	99.3%	87.8%	64.9%	7.5%	95.4%
114	100.0%	88.4%	65.4%	7.6%	96.0%
113	100.0%	88.4%	65.4%	7.6%	96.0%
112	100.0%	88.4%	64.7%	7.5%	95.9%
111	100.0%	88.4%	64.7%	7.5%	95.9%
110	100.0%	88.4%	64.3%	7.5%	95.9%
109	95.4%	84.4%	69.1%	8.0%	92.4%
108	93.3%	82.4%	70.6%	8.2%	90.6%
107	90.6%	80.1%	67.0%	7.8%	87.9%
106	83.5%	73.8%	68.3%	7.9%	81.7%
⋮		⋮		⋮	⋮

Figure 3.13. An example of analysis on the combined preference

3.4. Identification of Optimal Design Ranges for Smartphone Hard Keys

In the identification of optimal design range phase, optimal design ranges for smartphone hard keys are derived in consideration of the hard key design specifications of the target device and design constraints. Once the design specification of the target hard key is confirmed, the hard key location is determined to keep the highest preference rate in the hard key area by considering the preference distribution for each control location. For example, as shown in Figure 3.14-a, if the hard key is 20 mm long, the most preferred location for the entire 20 mm area is determined as the final design location (87 to 107 mm, average preference rate = 76.2%). On the other hand, if there is a design constraint for the location, the final design location can be determined within the allowed area but seeking the highest preference rates. For example, as shown in Figure 3.14-b, if a 20 mm hard key can be located only above 95 mm from the bottom of the device considering the design locations of other parts, 95 to 115 mm where the preference rates are highest within



(a) without design constraint (b) with design constraint

Figure 3.14. An example of determining optimal locations for smartphone hard keys

the range can be determined to be the final design location. In addition, if more than one hard key need to be designed on one side of the device as shown in Figure 3.15, considering importance of each hard key, the preference rate of a particular hard key could be higher than those of the other hard key, or all hard keys may be designed to have similar preference rates.

Figure 3.15. Smartphones with more than one hard key on a side

Chapter 4 Application of the Hard Key Location Design Framework: Preferred Grip Postures

Preferred grip postures for smartphone with various sizes are analyzed in this chapter to be applied to the determination of the preferred hard key locations based on the proposed methodology.

4.1. Analysis of Smartphone-User Interface Characteristics

The shape and specifications of smartphones, the size of user's hand, major tasks, and use contexts were analyzed to consider the characteristics of product, user, and use behavior systematically for design of smartphone user interface.

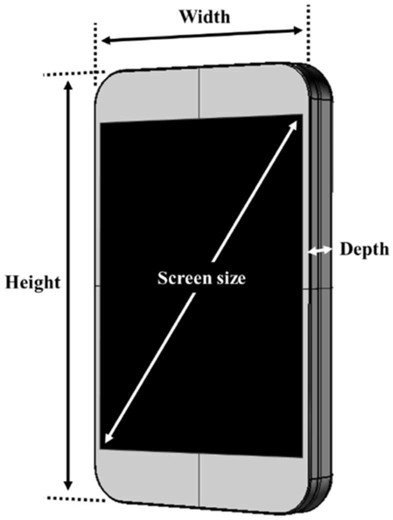
4.1.1. Analysis of Smartphone Characteristics

The design specifications of smartphones being sold in the market have been analyzed and defined the specifications of nine smartphones to apply the design methodology for optimal hard key locations on a smartphone to smartphones with various sizes and weights. According to the database in Phonearena (2019), smartphones in the market from 2010 to 2019 have been developed with a variety of screen sizes of 3.5" to 7.0" (see Table 4.1), and the size and weight of the device are also various along with the screen size. Some manufacturers, such as Apple and LG, have applied some curvature to their corners to prevent possible discomfort on the palm of user′s hand, but generally, smartphones are

Table 4.1. Smartphones in the market and their specifications

No.	Manufacturer	Model	Screen size (inch)	Height (mm)	Width (mm)	Thickness (mm)	Weight (g)
1	Apple	iPhone 4	3.5	115.2	58.6	9.3	137
2	Apple	iPhone 5	4.0	123.8	58.6	7.6	112
3	Apple	iPhone 6	4.7	138.1	67	6.9	129
4	LG	G3	5.5	146.3	74.6	8.9	149
5	LG	G pro2	5.9	157.9	81.9	8.3	172
6	Samsung	Galaxy S4	4.99	136.6	69.8	7.9	130
7	Samsung	Galaxy Note 3	5.5	151.2	79.2	8.3	168
8	Samsung	Galaxy W	7.0	191.8	99.6	8.8	245
9	Pantech	Vega No 6	5.9	158.6	83.2	9.9	209
10	Pantech	Vega Iron 2	5.3	144.2	73.5	7.9	153

designed in a rectangular shape to enhance the space-efficiency for the parts inside. As shown in Figure 4.1, 9 sizes of smartphone specifications were defined in this study, and mock-ups were developed to control the effect of brand image, color and shape between



No.	Code	Screen size (inch)	Height (mm)	Width (mm)	Depth (mm)	Weight (g)
1	S3.0	3.0	95	56	12	100
2	S3.5	3.5	105	57	12	110
3	S4.0	4.0	115	60	9.5	120
4	S4.5	4.5	125	67	9	130
5	S5.0	5.0	135	69	9	140
6	S5.5	5.5	145	75	8.5	160
7	S6.0	6.0	155	81	8	170
8	S6.5	6.5	165	87	8	180
9	S7.0	7.0	175	93	8	190

Figure 4.1. Diagram of a smartphone mockup and the specifications

products. The smartphone mock-ups were manufactured using a 3D printer (Dimension SST, Stratasys LtD., USA), and lead sheets were inserted in the mock-ups to implement the defined weights. Printed screens were attached to the front of the mock-ups.

4.1.2. Analysis of the User Characteristics

Participants were recruited under controls of gender, hand length, and hand width to consider users with various human factors. Participants in the experiment were recruited in nine groups (Small: < 33rd %ile, Medium: 33rd %ile ~ 66th %ile, Large: > 66th %ile) considering the distribution of Korean hand length and hand width of the Size Korea (2010) anthropometric data (hand length of Korean female: 33rd %ile = 166 mm, 66th %ile = 173 mm; hand width of Korean female: 33rd %ile = 74 mm, 66th %ile = 78 mm; hand length of Korean male: 33rd %ile = 181 mm, 66th %ile = 188 mm; hand width of Korean male: 33rd %ile = 83 mm, 66th %ile = 87 mm). A total of 45 participants (17 female, 28 male; age = 24.8 ± 4.7yr; hand length = 180.6 ± 10.7 mm; hand width = 80.8 ± 6.7 mm) were recruited (see Figure 4.2), and the hand size distribution of participants was not

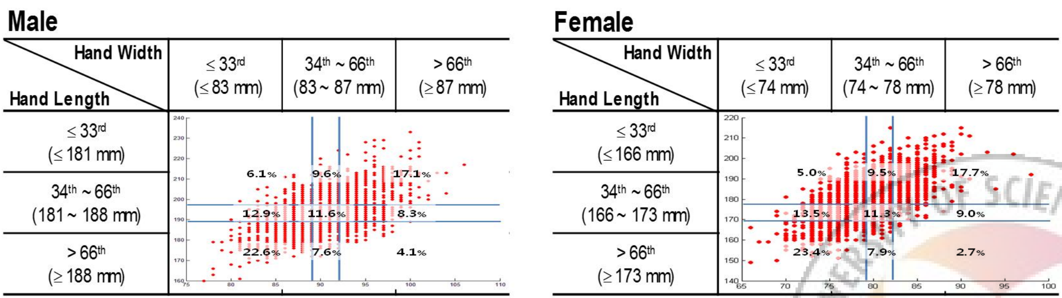


Figure 4.2. Hand size distribution of participants (28 males and 17 females) by gender

Table 4.2. Major tasks of smartphone (hard key operation in italic)

Tasks	Specific actions
Answering a call	1. Grasp the phone 2. Answer a call by flicking the screen 3. Turn volume up/down by *volume key*
Listening to music	1. Turn volume up/down by *volume key* 2. Scroll up/down 3. Show menus 4. Select a menu 5. Turn volume up/down by *volume key*
Texting	1. Turn screen on/off by *power key* 2. Navigate screens 3. Select a message app 4. Send a message 5. Return home
Browsing the web	1. Turn screen on/off by *power key* 2. Turn Wi-Fi on/off 3. Select a web browser app 4. Browse the internet 5. Turn screen on/off by *power key*

significantly different from the hand size distribution of Koreans in their 20s to 50s in terms of mean(t_{44} = 1.37, p = .09 for hand length; t_{44} = 1.41, p = .08 for hand width) and variance ($f_{44,\ 3920}$ = 1.03, p = .84 for hand length; $f_{44,\ 3920}$ = 1.23, p = .29 for hand width).

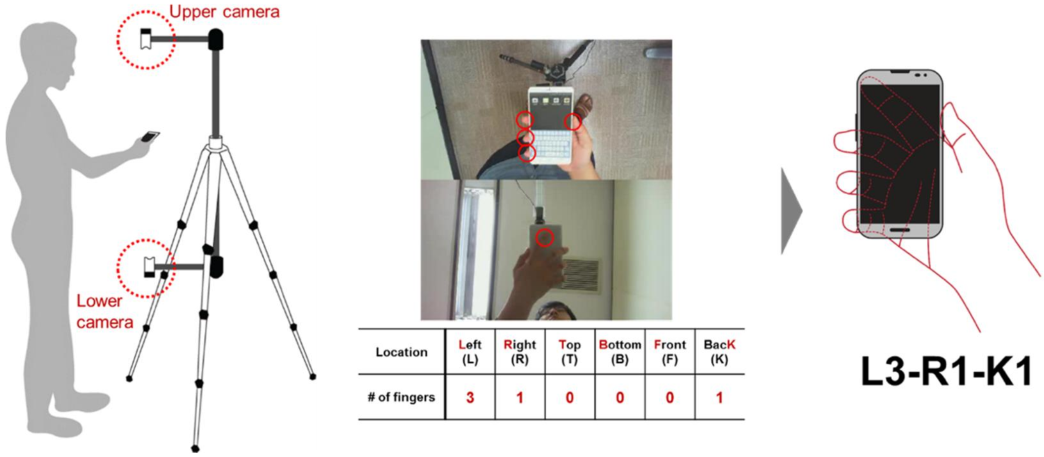
4.1.3. Analysis of the Major Smartphone Tasks

Major smartphone tasks related to hard key manipulation and the types of smartphone use contexts were identified to consider natural smartphone use behaviors. Major smartphone tasks were defined referring to existing studies (Kietrys et al., 2015; Dunn et al., 2013; Berolo et al., 2011; Levy et al., 2010; Suzuki et al., 2009) that analyzed user performance when conducting smartphone tasks, and the tasks were divided into sub actions as shown in Table 4.2. For example, texting task consists with (1) press the power key to turn on the screen, (2) navigate to the message app using the flick gesture, (3) enter the characters around the keypad (e.g., 'Question' for the Qwerty key pad), (4) press the back key to exit the app, and then (5) press the home key to return to the home screen. Also, it is reported that smartphones are mainly used in standing, seating, and walking contexts although they can be used in various situations.

4.2. Analysis of Preferred Grip Posture for Smartphone

Method

In the preferred smartphone grip posture measurement experiment, grip postures of 45 participants were videotaped when performing tasks of answering a call, listening to music, texting, and web browsing using smartphone mock-ups with nine different sizes. Each task was configured to operate the power key and volume key three times each, and the experiment order for the tasks were randomized by the Balanced Latin square method. Among static contexts, the standing context which is the most common use context and effective for the lab experiment was simulated for the grip posture measurement as Figure 4.3.a. Two video cameras (HDR-AS200, Sony Inc., Japan) installed at the top and bottom of a participant’s hand were used to capture the grip posture during natural task performance by the participant.



Location	Left (L)	Right (R)	Top (T)	Bottom (B)	Front (F)	BacK (K)
# of fingers	3	1	0	0	0	1

(a) Videotaping of grip posture

(b) Coding of grip posture

Figure 4.3. Measurement and encoding of smartphone grip posture (illustrated)

Smartphone grip postures were classified by counting the number of fingers located on each part of a device. The grip posture images captured for each sub action were coded by counting the number of fingers located on the device (left, L; right, R; top, T; bottom, B; front, F; back, K) for each moment of hard key operations. Figure 4.3.b is an example of L3-R1-K1 grip posture coding of which three fingers are on the left side of the device, one finger is on the right side of the device, and one finger is on the back of the device.

Results

A total of nine grip postures were found to be used when operating the power key and volume key of the smartphones with 3.0" to 7.0" screen size, and three of these grip postures (L3-R1-K1, L3-R1-T1, and L4-R1) were dominant with more than 95% of preference rate (see Figure 4.4). 70.0% of the total 2,430 hard key operations (= 45

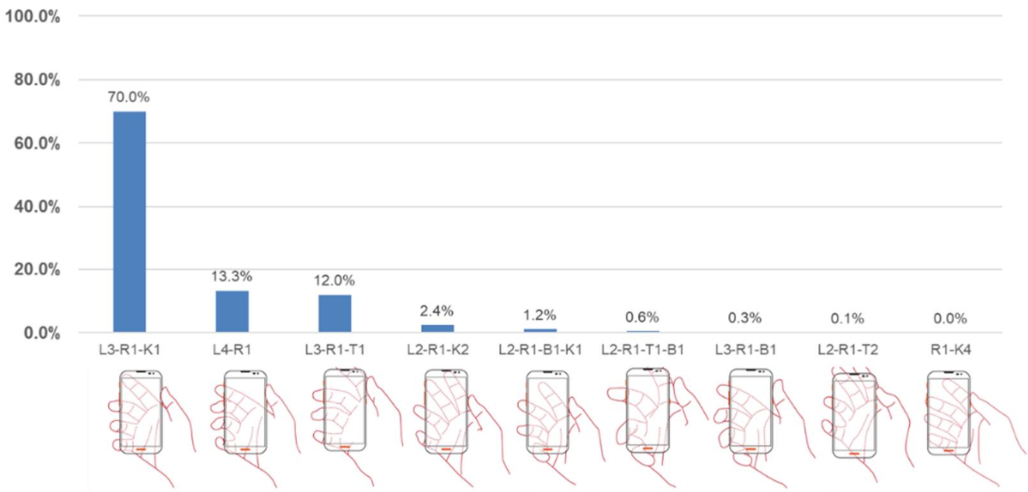


Figure 4.4. The use frequency distribution of grip posture for hard key operation

participants × 9 devices × 2 hard keys × 3 times) were conducted in L3-R1-K1 posture (a grip posture wrapping around the device while supporting the back) using smartphones with various sizes. In addition, 13.3% and 12.0% of the hard key operations were conducted in L4-R1 posture (a grip posture grasping the device with all fingers) and L3-R1-T1 posture (a grip posture wrapping around the device while supporting the top) respectively, and the remaining less than 3% of the hard key operations were conducted in 6 other grip postures (L2-R1-K2, L2-R1-B1-K1, L2-R1-T1-B1, L3-R1-B1, L2-R1-T2, and R1-K4) observed in the experiment.

4.3. Characteristics of Grip Posture for Smartphones

The frequency distribution of the major three grip postures varied significantly (L3-R1-K1: 32.2% ~ 87.0%; L3-R1-T1: 0% ~ 39.3%; L4-R1: 6.7% ~ 21.1%) by device size ($\chi^2(24) = 674.8$, $p < 0.01$) as shown in Figure 4.5. The frequency of L3-R1-K1 posture increased linearly from 32.2% to 87% as device size increased from 3.0 inch to 6.0 inch and became leveled off for 6.0 inch to 7.0 inch. On the other hand, the frequency of L3-R1-T1 posture decreased linearly from 39.3% to 2.2% as device size increased from 3.0 inch to 5.0 inch and became less than 1% from 5.5 inch to 7.0 inch, and those of L4-R1 also decreased gradually from 21.1% to 6.7%.

The frequency distribution of the major three grip postures varied significantly (L3-R1-K1: 64.3% ~ 77.4%; L3-R1-T1: 9.6% ~ 15.1%; L4-R1: 7.3% ~ 20.2%) by user's hand width ($\chi^2(6) = 75.3$, $p < 0.01$) as shown in Figure 4.6.a. The frequency of L3-R1-K1

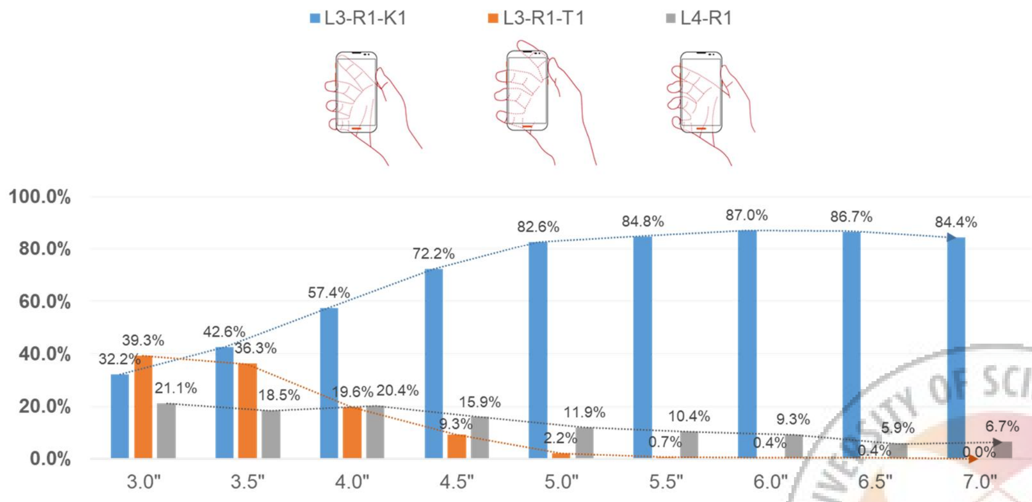
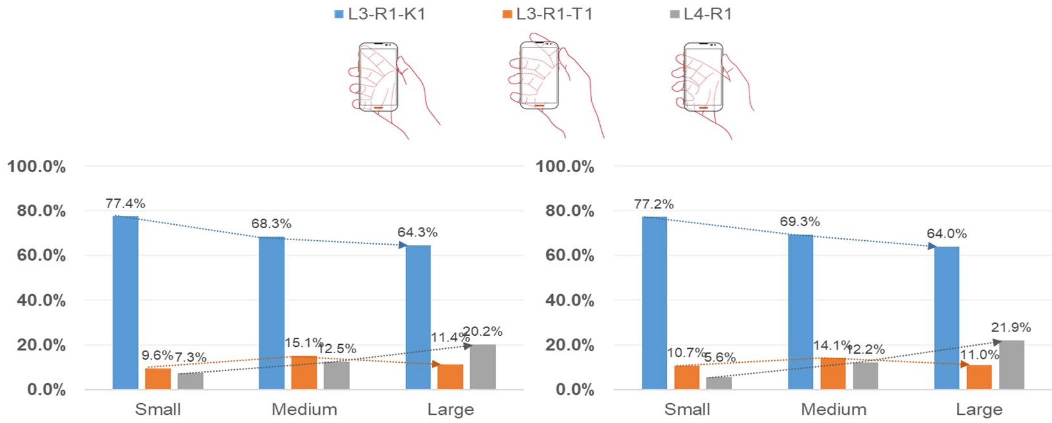


Figure 4.5. The use frequency distribution of grip posture by smartphone size



(a) use frequency distribution of grip posture by hand width

(b) use frequency distribution of grip posture by hand length

Figure 4.6. The use frequency distribution of grip posture by hand size

gradually decreased as hand width increased from small to large where 77.4% for small hand width group, 68.3% for middle hand width group, and 64.3% for large hand width group. On the other hand, the frequency of L4-R1 gradually increased from 7.3% to 20.2% as user's hand width increased from small to large, but L3-R1-T1 posture didn't show a specific trend.

The frequency distribution of the major three grip postures varied significantly (L3-R1-K1: 64.0% ~ 77.2%; L3-R1-T1: 10.7% ~ 14.1%; L4-R1: 5.6% ~ 21.9%) by user's hand length ($\chi^2(6) = 103.4$, $p < 0.01$) as shown in Figure 4.6.b. The frequency of L3-R1-K1 gradually decreased as hand length increased from small to large where 77.2% for small hand length group, 69.3% for middle hand length group, and 64.0% for large hand length group. On the other hand, the frequency of L4-R1 gradually increased from 5.6% to 21.9%

as user's hand length increased from small to large, but L3-R1-T1 posture didn't show a specific trend.

Chapter 5 Application of the Hard Key Location Design Framework: Preferred Hard Key Control Range

Preferred hard key control ranges in preferred grip postures were analyzed in this chapter to determine the hard key locations for smartphones with various sizes based on the proposed methodology.

5.1. Participants

A total of 52 participants with various hand sizes were recruited considering the distribution of Korean hand length and hand width to identify the preferred smartphone hard key control ranges. Participants in the experiment for preferred smartphone hard key control range were recruited in nine groups (Small: < 33^{rd} %ile, Medium: 33^{rd} %ile ~ 66^{th} %ile, Large: > 66^{th} %ile) considering the distribution of Korean hand length and hand width of the Size Korea (2010) anthropometric data (hand length of Korean female: 33^{rd} %ile = 166 mm, 66^{th} %ile = 173 mm; hand width of Korean female: 33^{rd} %ile = 74 mm, 66^{th} %ile = 78 mm; hand length of Korean male: 33^{rd} %ile = 181 mm, 66^{th} %ile = 188 mm; hand width of Korean male: 33^{rd} %ile = 83 mm, 66^{th} %ile = 87 mm), the same as the experiment for preferred smartphone grip posture. The participants were composed with 25 females and 27 males aged 25.8 ± 6.6 years on average, and their mean hand length was 178.7 ± 11.1 mm and mean hand width was 79.1 ± 6.2 mm. The hand size distribution of participants was not significantly different from the hand size distribution of Koreans in their 20s to 50s (see Figure 5.1) in terms of mean ($t_{51} = 0.22$, $p = .41$ for hand length; t_{51} =

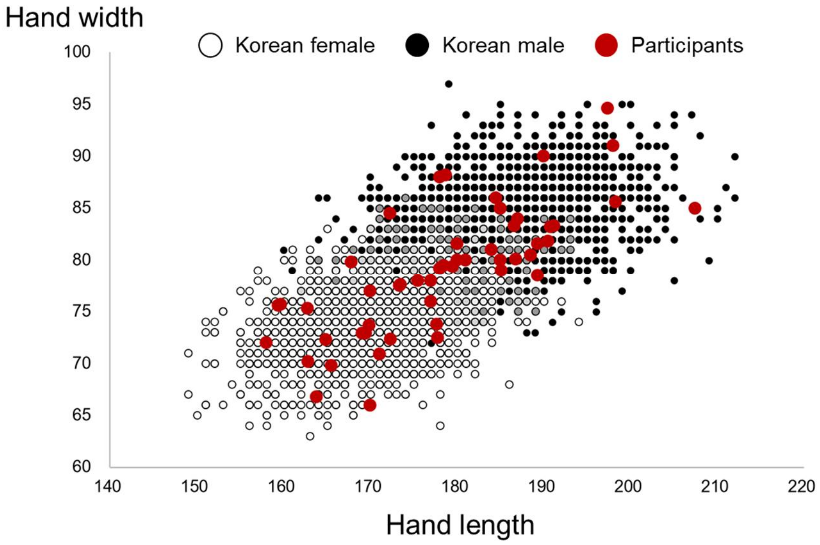


Figure 5.1. Hand size distribution of participants

0.24, p = .59 for hand width) and variance ($f_{51, 3920}$ = 1.11, p = .56 for hand length; $f_{51, 3920}$ = 1.05, p = .75 for hand width). The participants were instructed the experimental procedure and asked to sign the consent form before participated in the experiment.

5.2. Apparatus

Nine smartphone mock-ups have been developed of which the locations of the hard keys can be adjusted effectively to analyze the preferred control ranges of the smartphone hard keys. The nine smartphone mock-ups have the same design dimensions (screen size: 3.0 inch to 7.0 inch) with the mock-ups used in the experiment for preferred grip posture and the locations of the hard keys can be freely adjusted along the side of the smartphone to

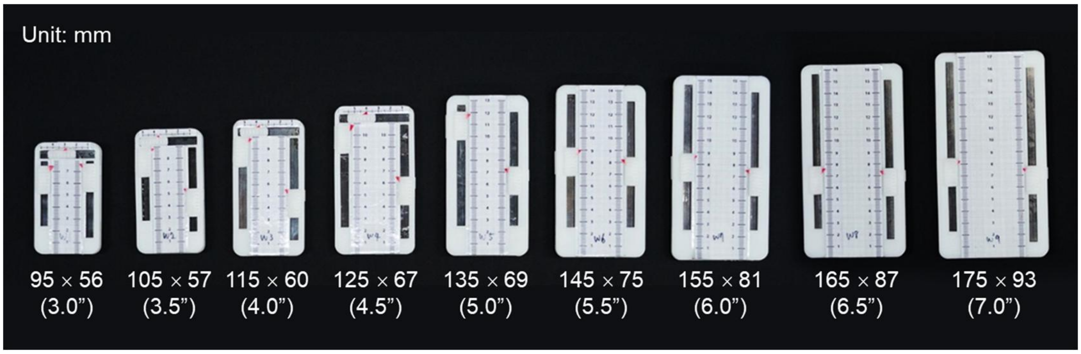


Figure 5.2. Smartphone mockups having adjustable hard keys

find participant’s preferred control ranges (see Figure 5.2). The hard key of the smartphone mock-up was developed to enable continuous location adjustment by sliding on the left and right sides of the mock-ups. Grids and numbers were attached on the face of the mock-up so that experimenter can easily identify and record the preferred control ranges found by participants.

5.3. Experimental Procedure

The preferred smartphone hard key control range measurement experiment in this study consisted of three steps: (1) introduction of experiment, (2) familiarization of experiment, and (3) identification of preferred hard key control range (see Figure 5.3). First, when participants arrived, the purpose and procedure of the experiment were introduced, and a consent form was signed to participate in the experiment. Second, the major grip postures, L3-R1-K1, L4-R1, and L3-R1-T1 identified in the preferred smartphone grip posture experiment were introduced to the participants and were familiarized by using smartphone

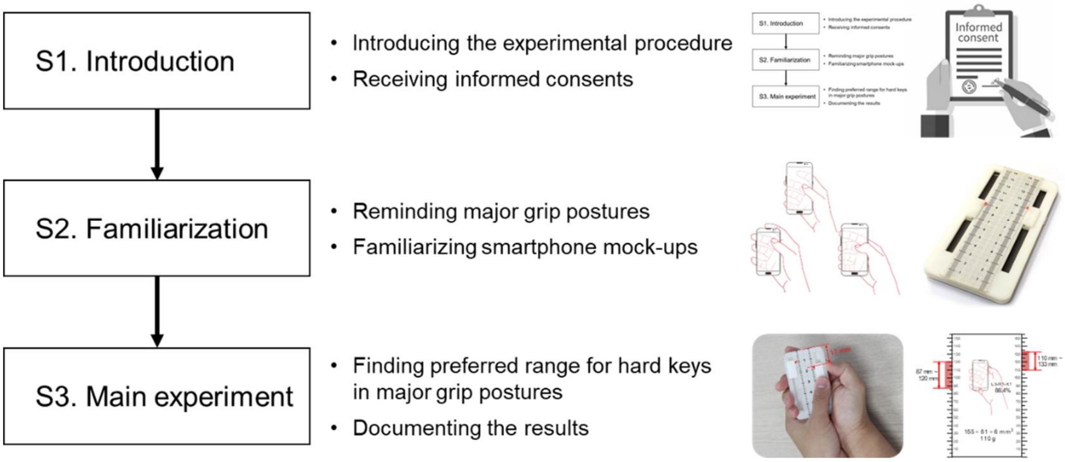


Figure 5.3. Experiment procedure

mock-ups with various sizes. Finally, while holding the smartphone mock-ups in the major grip postures, the lowest and highest locations of preferred hard key control ranges were identified by sliding up and down the power key and volume key and pressing them. Once the preferred control ranges for the power key and volume key are determined by participants, the experimenter recorded the location of the hard keys referring to the numbers in the grids on the front of the smartphone mock-up. The experiment took about 30 minutes per person.

5.4. Analysis of Preferred Hard Key Location

Method

The distribution of preference for hard key locations were calculated by the combination of preferences for hard key locations by grip posture and preference rates for grip postures.

First, the distribution of preferences for hard key locations by grip posture were derived by the ratio of the preference frequency for each left and right key location over the number of entire participants by dividing the hard key locations at intervals of 1 mm. Next, the distribution of preference for hard key locations were finally calculated by applying the preference rate of a grip posture to the distribution of preferences for hard key locations by grip posture.

Results

The most preferred hard key locations derived for 9 sizes of smartphones with screen size of 3.0 inch to 7.0 inch have the tendency to move slightly to the top of the device (left side: -1 ~ 13 mm; right side: 1 ~ 9 mm) as the device size increases (see Figure 5.4). The most preferred location of a hard key moved up as the size of the device increased. The most preferred location of the left hard key for the smartphone with 3.0 inch screen was 61 mm above from the bottom of the device and those for the smartphone with 7.0 inch screen was 104 mm above from the bottom of the device. Meanwhile, the most preferred locations for power keys on the right side of devices were 0 ~ 12 mm higher than the most preferred locations for volume keys on the left side of devices (see Table 5.1).

Regression equations which can be used for the new smartphone hard key location design were developed based on the information of the most preferred locations for hard keys identified from the experiment (see Equation 5.1, 5.2). The optimal hard key locations in this study were derived based on the preferred hard key control range information of participants with various hand sizes using smartphone mock-ups designed from 3.0 inch to

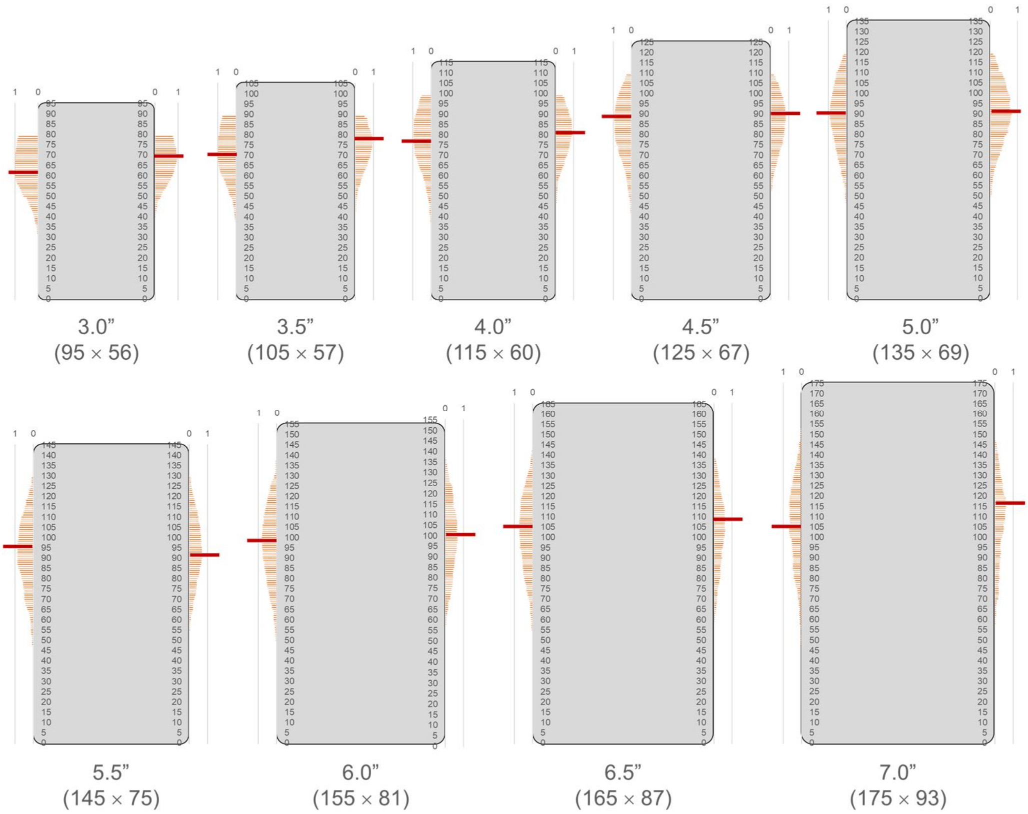


Figure 5.4. Distribution of preference for each hard key control area

7.0 inch at intervals of 0.5 inch. However, a design guide for hard key location is required to design a new smartphone since the new smartphone to be designed may differ in design specification from the mock-ups used in the experiment. Thus, two regression equations have been developed to statistically estimate the most preferred locations for the left and right hard keys of a smartphone with design specifications of 95 to 175 mm of device height and 56 to 93 mm of device width based on the information of the most preferred hard key locations derived from the experiment. The regression equations for the most

Table 5.1. Optimal hard key design ranges

		3.0”	3.5”	4.0”	4.5”	5.0”	5.5”	6.0”	6.5”	7.0”
Left Key	Recommended location	61	70	76	89	90	95	98	105	104
	> 60% preferred range	50 ~ 79 (29)	58 ~ 89 (31)	64 ~ 97 (33)	69 ~ 101 (32)	74 ~ 106 (32)	79 ~ 110 (31)	82 ~ 114 (32)	92 ~ 119 (27)	100 ~ 120 (20)
	> 70% preferred range	52 ~ 79 (27)	60 ~ 89 (29)	66 ~ 94 (28)	72 ~ 99 (27)	80 ~ 103 (23)	82 ~ 107 (25)	89 ~ 110 (21)	98 ~ 110 (12)	-
Right Key	Recommended location	69	78	80	89	90	91	100	108	116
	> 60% preferred range	57 ~ 79 (22)	64 ~ 88 (24)	70 ~ 94 (24)	75 ~ 99 (24)	81 ~ 102 (21)	86 ~ 105 (19)	92 ~ 110 (18)	103 ~ 112 (9)	114 ~ 119 (5)
	> 70% preferred range	59 ~ 79 (20)	67 ~ 85 (18)	72 ~ 92 (20)	79 ~ 96 (17)	85 ~ 99 (14)	90 ~ 95 (5)	100 (0)	-	-

preferred hard key locations were developed as linear equations with the variables of device height and device width.

Left key location (mm) = 1.06 × Height – 1.07 × Width + 21.4
(adj. R^2 = 0.947, RMSE = 3.55 mm) Equation 5.1

Right key location (mm) = 0.265 × Height + 0.559 × Width + 15.4
(adj. R^2 = 0.957, RMSE = 3.08 mm) Equation 5.2

Chapter 6 Evaluation of Hard Key Location Design for Smartphone

Hard keys were placed on smartphones of various sizes based on the derived recommended smartphone hard key design location information, and operational satisfaction for the hard keys was analyzed to validate the smartphone hard key location design methodology.

6.1. Participants

A total of 70 participants (35 males and 35 females) were recruited considering the distribution of Korean hand length and hand width to evaluate the operational satisfaction of users with various hand sizes for the recommended smartphone hard key design locations. Participants in the experiment for evaluation of recommended smartphone hard key locations were recruited in nine groups (Small: < 33^{rd} %ile, Medium: 33^{rd} %ile ~ 66^{th} %ile, Large: > 66^{th} %ile) considering the distribution of Korean hand length and hand width of the Size Korea (2010) anthropometric data (hand length of Korean female: 33^{rd} %ile = 166 mm, 66^{th} %ile = 173 mm; hand width of Korean female: 33^{rd} %ile = 74 mm, 66^{th} %ile = 78 mm; hand length of Korean male: 33^{rd} %ile = 181 mm, 66^{th} %ile = 188 mm; hand width of Korean male: 33^{rd} %ile = 83 mm, 66^{th} %ile = 87 mm). In addition, in consideration of the effect of hand dominance, Edinburgh handedness inventory as shown in Table 6.1 was conducted to recruit 20 left-handed and 50 right-handed users separately. The mean hand length and the mean hand width of the participants were 176.8 ± 11.1 mm and 78.3 ± 6.0 mm respectively, and the hand size distribution of participants was not

Table 6.1. Handedness evaluation by Edinburg handedness inventory (Oldfield, R. C., 1971)

		Left	Right
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking a match		
10	Opening a box		
	Total checks	LH=	RH=
		CT = LH + RH =	
		D = RH - LH	
		R = (D/CT) × 100 =	
	Interpretation (Left-handed: R < -40) (Ambidextrous: -40 ≤ R ≤ +40) (Right-handed: R > +40)		

significantly different from the hand size distribution of Koreans in their 20s to 50s (see Figure 6.1) in terms of mean (t_{69} = 1.18, p = .12 for hand length; t_{69} = 1.45, p = .08 for hand width) and variance ($f_{69,\ 3920}$ = 0.89, p = .46 for hand length; $f_{69,\ 3920}$ = 0.99, p = .91 for hand width).

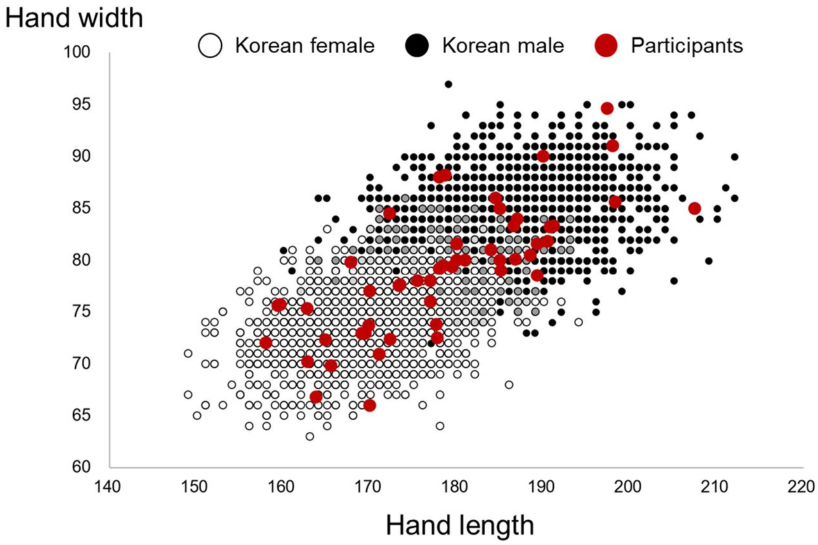


Figure 6.1. Hand size distribution of participants

6.2. Development of smartphone mock-ups

A total of 24 types (3 types of hard key location × 2 types of hard key × 4 types of screen size) of smartphone mock-ups were developed to ensure that the three locations of hard keys were placed on the left and right sides of each of the four sizes of devices. Four different-sized devices with 5.0”, 5.5”, 6.0” and 6.5” screens were selected for evaluation, which are included to the most frequently released size ranges in 2019 (Gsmarena., 2019). Three types of hard key location were applied to each size of the smartphone mock-ups to validate the relative superiority of the recommended smartphone hard key design location derived from prior experiments compare to the locations of 10 mm moved to the top and

Figure 6.2. Hard key locations of smartphone mock-ups

the bottom from the recommended location as shown in Figure 6.2. The hard keys of the smartphone mock-up were placed on only one side (left or right) of the mock-up, as shown in Figure 6.3.a, so that the opposite hard key does not affect the operational satisfaction of the hard key being evaluated.

Smartphone mock-ups with hard keys providing a similar operational feedback were developed to evaluate the appropriateness of the recommended smartphone hard key locations. The main body of smartphone mock-ups were made of PLA material using a 3D printer (Dimension SST, Stratasys LtD., USA) and has a lead sheet built to implement the defined weights in the design specifications. The hard keys of the smartphone mock-ups were developed to have a operation feedback similar to the commercial smartphone hard keys by embedding the components of a commercial smartphone (iPhone 7, Apple, USA) hard key. Hard key components consist of hard key parts which meet a user's finger directly and FPCB parts which produce resistance and elasticity when operated as shown in Figure 6.3.b.

(a) One-sided hard keys (b) Interior design of hard keys

Figure 6.3. Hard key design in smartphone mock-ups

6.3. Preparation of commercial smartphones

Commercial products having hard keys which designed to the locations matching one of the three hard key locations of the mock-ups and similar design specifications with the mock-ups were prepared to verify the applicability of the validation experiment. The design specifications of the mock-ups in the validation experiment were selected with the device height of 135 mm to 165 mm and the device width of 69 mm to 87 mm, and four commercial products (iPhone 8 & iPhone 8 plus from Apple, Galaxy S5 & Galaxy Mega 6.3 from Samsung) of similar size were found as shown in Figure 6.4. The locations of hard keys on commercial smartphones are similar with one of the three hard key locations

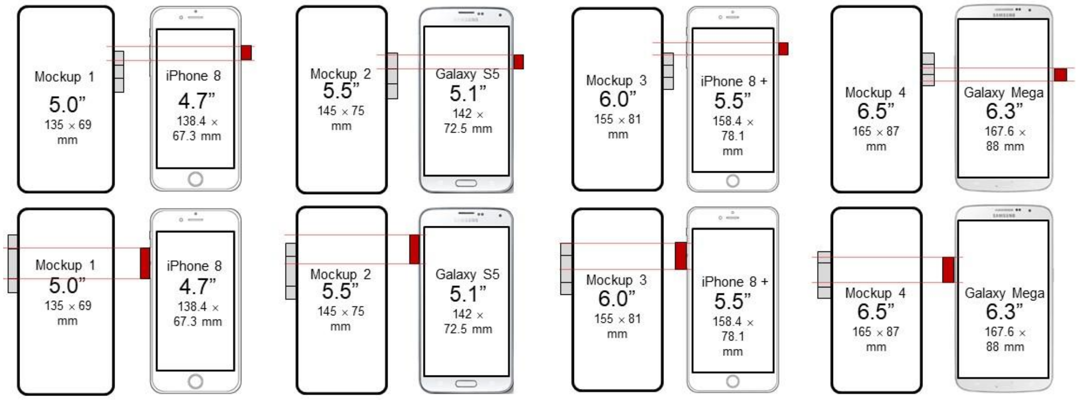


Figure 6.4. Comparison of mock-ups & commercial smartphone

of the mock-ups to verify the result of evaluation by comparing the operational satisfactions for the hard keys at similar locations on smartphones with similar sizes.

6.4. Experiment procedure

The experiment consisted of three stages: S1. Introduction, S2. Announcement and practice of major smartphone grip postures and tasks, and S3. Assessment of operational satisfaction for hard key. The purpose and procedure of the experiment were introduced when the participants arrived. Then, participants were informed about the two major preferred grip postures (L3-R1-K1, L4-R1, R3-L1-K1, and R4-L1) for smartphones and were asked to demonstrate them with the smartphone mock-ups. Once the participants had a sufficient understanding of each grip posture, the operational satisfactions of the hard keys were assessed.

The assessment of operational satisfaction for smartphone hard keys at different locations was conducted by finding the order of preference and rating the subjective satisfaction. The operational satisfactions of the three hard keys on the smartphone mock-ups were evaluated by a seven-point scale after manipulated by the participants grasping the mock-ups with the major grip postures. For example, the volume keys at three locations on a smartphone mock-up with 5.0” screen were evaluated while the mock-up was being grasped with L3-R1-K1 grip posture. The presentation order of the experimental condition including grip posture, device size, and hard key type was randomized by balanced Latin square method.

6.5. Results

A mixed design ANOVA with two within-subject factors (key location and grip posture) and three between-subject factors (hand length, hand width, and handedness) shows that key location and grip posture were significant on operational satisfaction while hand length, hand width, and handedness showed no significant effect as shown in Table 6.2.

Operational satisfactions of the recommended hard key design locations were found to be the highest with averages of 4.2 to 4.9 points among the three hard key locations of the smartphones with 5.0” to 6.5” screens (see Figure 6.5). For the power keys of the four smartphone mock-ups, operational satisfaction of the recommended hard key design location was found to be the highest with averages of 4.4 to 4.9 points, and those of the hard key locations of 10 mm above and below the recommended locations were found to

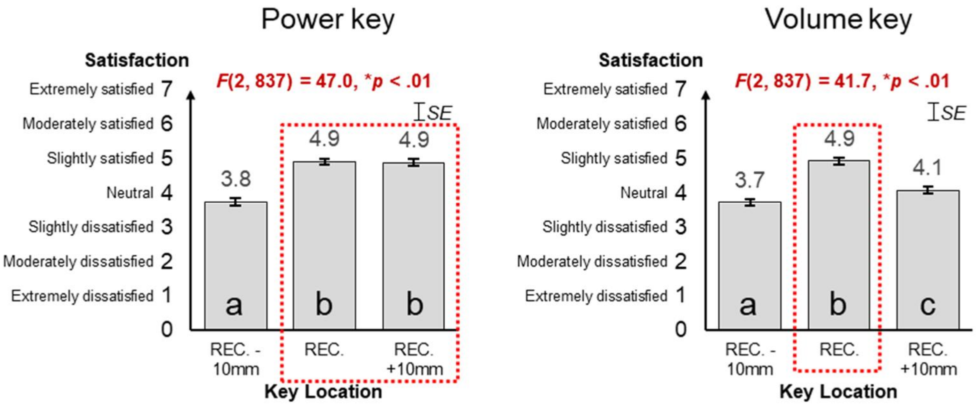
Table 6.2. ANOVA results of operation satisfaction for hard keys on smartphones

Screen size	Key type	Source	*df*	SS	MS	*F*	*p*
5.0”	Power key	Subject [S]	69	304.8	4.42	1.13	0.3
		Key location [KL]	2	249.3	124.66	37.02	*< 0.01
		Hand [H]	1	23.3	23.3	9.53	*< 0.01
		Grip posture (Hand) [GP(H)]	2	98.2	49.12	32.83	*< 0.01
		KL × H	2	288.6	144.3	75.4	*< 0.01
		KL × GP(H)	4	142.5	35.61	25.9	*< 0.01
		KL × S	138	464.7	3.37	1.76	*< 0.01
		H × S	69	169.0	2.45	1.2	0.21
		GP(H) × S	138	206.4	1.50	1.09	0.27
		KL × H × S	138	264.1	1.91	1.39	*<0.01
		KL × GP(H) × S	276	378.9	1.37		
		Hand length [HL]	2	16.8	8.41	2.73	0.07
		Hand width [HW]	2	8.8	4.41	1.43	0.24
		Hand dominance [HD]	1	4.0	3.98	1.29	0.26
	Volume key	Subject [S]	69	430.5	6.24	2.07	*< 0.01
		Key location [KL]	2	213.7	106.83	28.17	*< 0.01
		Hand [H]	1	19.5	19.5	17.1	*< 0.01
		Grip posture (Hand) [GP(H)]	2	60.9	30.4	20.41	*< 0.01
		KL × H	2	271.3	135.7	70.8	*< 0.01
		KL × GP(H)	4	133.8	33.5	22.55	*< 0.01
		KL × S	138	523.4	3.79	1.98	*< 0.01
		H × S	69	78.8	1.14	0.59	0.99
		GP(H) × S	138	205.8	1.49	1.01	0.48
		KL × H × S	138	264.4	1.92	1.29	*0.04
		KL × GP(H) × S	276	409.5	1.48		
		Hand length [HL]	2	6.3	3.17	1.02	0.36
		Hand width [HW]	2	29.1	14.53	4.70	*0.01
		Hand dominance [HD]	1	0.3	0.30	0.10	0.76
5.5”	Power key	Subject [S]	69	428.3	6.21	1.33	0.1
		Key location [KL]	2	141.9	70.93	16.31	*< 0.01
		Hand [H]	1	21.4	21.4	9.73	*< 0.01
		Grip posture (Hand) [GP(H)]	2	118.8	59.4	43.87	*< 0.01
		KL × H	2	276.9	138.5	73.74	*< 0.01
		KL × GP(H)	4	102.5	25.62	21.0	*< 0.01
		KL × S	138	600.1	4.35	2.32	*< 0.01
		H × S	69	151.6	2.2	1.09	0.34
		GP(H) × S	138	186.9	1.35	1.11	0.23
		KL × H × S	138	259.1	1.88	1.54	*< 0.01
		KL × GP(H) × S	276	336.8	1.22		
		Hand length [HL]	2	12.0	5.97	1.91	0.15

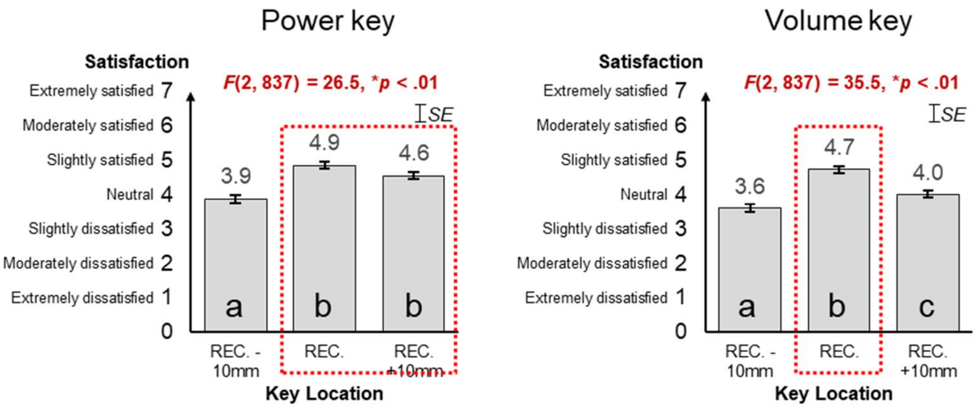
		Hand width [HW]	2	1.1	0.57	0.18	0.83
		Hand dominance [HD]	1	3.7	3.71	1.19	0.28
	Volume key	Subject [S]	69	404.0	5.86	1.76	*0.02
		Key location [KL]	2	182.3	91.16	25.38	*< 0.01
		Hand [H]	1	44.8	44.8	21.61	*< 0.01
		Grip posture (Hand) [GP(H)]	2	88.4	44.2	34.15	*< 0.01
		KL × H	2	243.19	121.59	52.03	*< 0.01
		KL × GP(H)	4	103.7	25.93	20.37	*< 0.01
		KL × S	138	495.7	3.59	1.54	*0.01
		H × S	69	143.03	2.07	0.88	0.713
		GP(H) × S	138	178.6	1.29	1.02	0.45
		KL × H × S	138	322.5	2.34	1.84	*< 0.01
		KL × GP(H) × S	276	351.3	1.27		
		Hand length [HL]	2	1.9	0.94	0.31	0.73
		Hand width [HW]	2	19.6	9.80	3.23	*0.04
		Hand dominance [HD]	1	5.9	5.91	1.95	0.16
6.0”	Power key	Subject [S]	69	437.7	6.34	1.43	0.06
		Key location [KL]	2	81.7	40.86	9.19	*< 0.01
		Hand [H]	1	7.2	7.2	3.28	0.08
		Grip posture (Hand) [GP(H)]	2	73.0	36.50	23.46	*< 0.01
		KL × H	2	158.7	79.33	35.54	*< 0.01
		KL × GP(H)	4	138.8	34.71	29.88	*< 0.01
		KL × S	138	613.6	4.45	1.99	*< 0.01
		H × S	69	152.6	2.21	0.84	0.78
		GP(H) × S	138	214.7	1.56	1.34	*0.02
		KL × H × S	138	308.0	2.23	1.92	*< 0.01
		KL × GP(H) × S	276	320.51	1.16		
		Hand length [HL]	2	3.6	1.79	0.60	0.55
		Hand width [HW]	2	3.6	1.81	0.60	0.55
		Hand dominance [HD]	1	2.6	2.61	0.87	0.35
	Volume key	Subject [S]	69	498.3	7.22	1.99	*< 0.01
		Key location [KL]	2	143.1	71.56	20.03	*< 0.01
		Hand [H]	1	63.0	62.98	31.98	*< 0.01
		Grip posture (Hand) [GP(H)]	2	136.1	68.0	55.92	*< 0.01
		KL × H	2	229.7	114.87	60.17	*< 0.01
		KL × GP(H)	4	53.3	13.31	9.86	*< 0.01
		KL × S	138	493.0	3.57	1.87	*< 0.01
		H × S	69	135.9	1.97	1.11	0.33
		GP(H) × S	138	167.9	1.22	0.9	0.75
		KL × H × S	138	263.4	1.91	1.41	*0.01
		KL × GP(H) × S	276	372.8	1.35		
		Hand length [HL]	2	0.8	0.38	0.13	0.88
		Hand width [HW]	2	11.0	5.49	1.81	0.17
		Hand dominance [HD]	1	2.0	2.04	0.67	0.41

6.5”	Power key	Subject [S]	69	586.9	8.51	2.35	*< 0.01
		Key location [KL]	2	112.6	56.29	17.04	*< 0.01
		Hand [H]	1	0.7	0.74	0.31	0.58
		Grip posture (Hand) [GP(H)]	2	86.1	43.05	27.08	*< 0.01
		KL × H	2	144.7	72.36	34.66	*< 0.01
		KL × GP(H)	4	181.8	45.44	29.29	*< 0.01
		KL × S	138	455.9	3.30	1.58	*< 0.01
		H × S	69	166.2	2.41	1.13	0.30
		GP(H) × S	138	219.4	1.59	1.02	0.43
		KL × H × S	138	288.1	2.09	1.35	*0.02
		KL × GP(H) × S	276	428.2	1.55		
		Hand length [HL]	2	14.0	6.99	2.21	0.11
		Hand width [HW]	2	9.2	4.59	1.45	0.24
		Hand dominance [HD]	1	0.8	0.84	0.26	0.61
	Volume key	Subject [S]	69	540.8	7.84	1.75	*0.01
		Key location [KL]	2	93.9	46.93	11.64	*< 0.01
		Hand [H]	1	40.3	40.31	15.25	*< 0.01
		Grip posture (Hand) [GP(H)]	2	152.1	76.06	41.67	*< 0.01
		KL × H	2	133.8	66.91	30.37	*< 0.01
		KL × GP(H)	4	46.0	11.50	11.17	*< 0.01
		KL × S	138	556.3	4.03	1.83	*< 0.01
		H × S	69	182.4	2.64	0.88	0.72
		GP(H) × S	138	251.9	1.83	1.77	*< 0.01
		KL × H × S	138	304.0	2.20	2.14	*< 0.01
		KL × GP(H) × S	276	284.0	1.03		
		Hand length [HL]	2	3.76	1.879	0.61	0.54
		Hand width [HW]	2	2.04	1.022	0.33	0.72
		Hand dominance [HD]	1	2.33	2.329	0.75	0.39

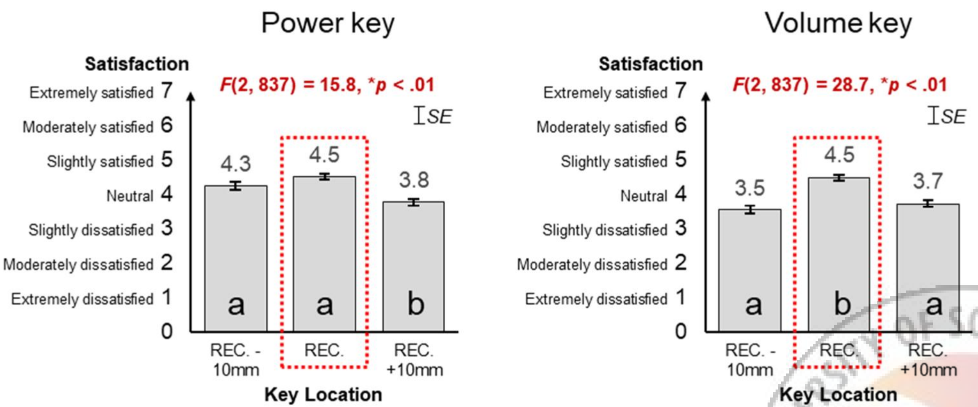
be averages of 3.5 to 4.9 points and 3.8 to 4.3 points respectively ($p < 0.01$). For the volume keys of the four smartphone mock-ups, operational satisfaction of the recommended hard key design location was found to be the highest with averages of 4.2 to 4.9 points, and those of the hard key locations of 10 mm above and below the recommended locations were found to be averages of 3.7 to 4.1 points and 3.4 to 3.7 points respectively ($p < 0.01$).


Power key
Satisfaction
F(2, 837) = 47.0, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly dissatisfied 3
Moderately dissatisfied 2
Extremely dissatisfied 1
0
SE
3.8
4.9
4.9
a
b
b
REC. -10mm
REC.
REC. +10mm
Key Location
Volume key
Satisfaction
F(2, 837) = 41.7, *p < .01
3.7
4.9
4.1
a
b
c
REC. -10mm
REC.
REC. +10mm
Key Location

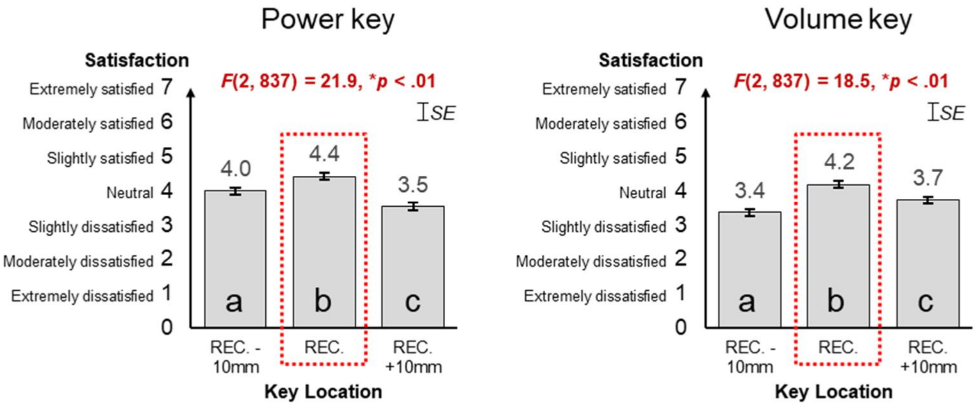
(a) 5.0”


Power key
Satisfaction
F(2, 837) = 26.5, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly dissatisfied 3
Moderately dissatisfied 2
Extremely dissatisfied 1
0
SE
3.9
4.9
4.6
a
b
b
REC. -10mm
REC.
REC. +10mm
Key Location
Volume key
Satisfaction
F(2, 837) = 35.5, *p < .01
3.6
4.7
4.0
a
b
c
REC. -10mm
REC.
REC. +10mm
Key Location

(b) 5.5”


Power key
Satisfaction
F(2, 837) = 15.8, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly dissatisfied 3
Moderately dissatisfied 2
Extremely dissatisfied 1
0
SE
4.3
4.5
3.8
a
a
b
REC. -10mm
REC.
REC. +10mm
Key Location
Volume key
Satisfaction
F(2, 837) = 28.7, *p < .01
3.5
4.5
3.7
a
b
a
REC. -10mm
REC.
REC. +10mm
Key Location

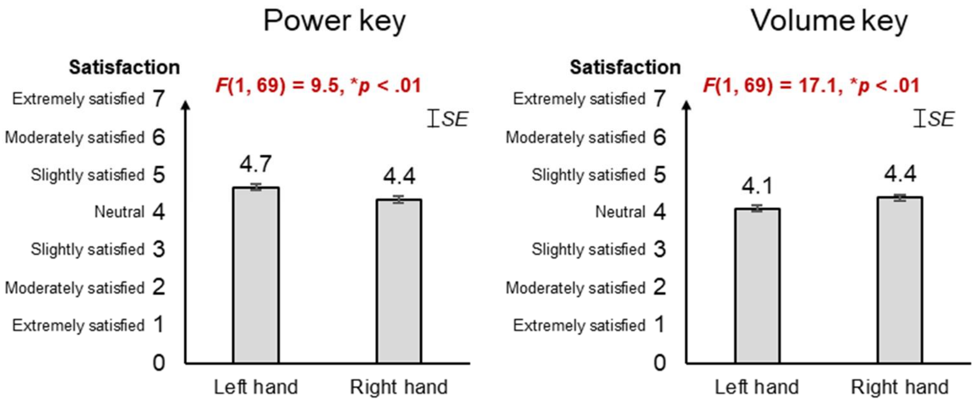
(c) 6.0”



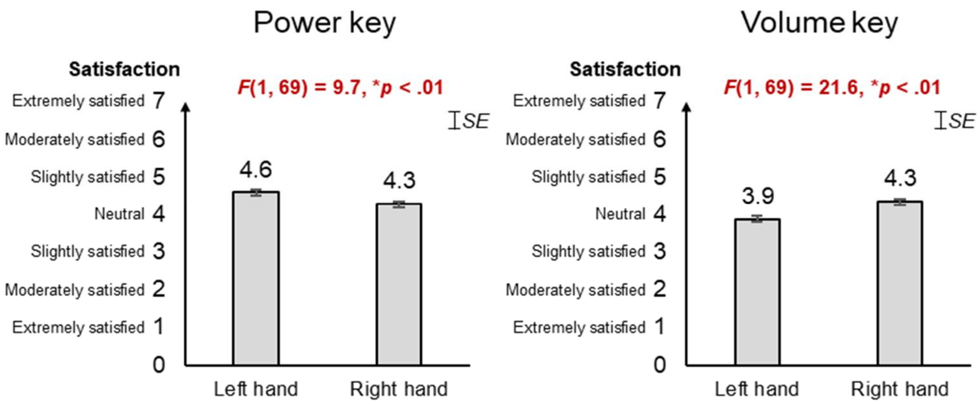
(d) 6.5”

Figure 6.5. Operation satisfactions for three hard key locations on smartphones

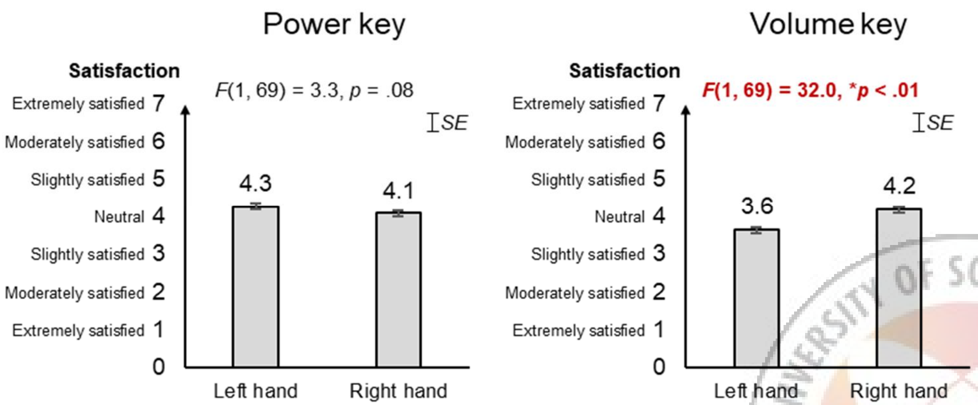
Operational satisfactions for power keys with left hand were found to be 0.1 to 0.3 points higher than with right hand and those for volume keys with left hand were found to be 0.3 to 0.5 points lower than with right hand for the smartphones with 5.0” to 6.5” screens (see Figure 6.6). For the power keys of the smartphone mock-ups with 5.0” and 5.5” screens, operational satisfactions in left hand were significantly higher with averages of 4.7 and 4.6 points than those in right hand with averages of 4.4 and 4.3 points ($p < 0.01$). Operational satisfactions for power keys of the smartphone mock-ups with 6.0” and 6.5” screens in left hand were also higher with averages of 4.3 and 4.0 points than those in right hand with averages of 4.1 and 4.0, but the differences were not significant ($p = 0.08$ for 6.0”; $p = 0.58$ for 6.5”). For the volume keys of the four smartphone mock-ups with 5.0” to 6.5” screens, operational satisfactions in left hand were significantly lower with averages of 3.5 to 4.1 points than those in right hand with averages of 4.0 to 4.4 points ($p < 0.01$).


Power key
Satisfaction
F(1, 69) = 9.5, *p < .01
SE
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
4.7
4.4
Left hand
Right hand
Volume key
Satisfaction
F(1, 69) = 17.1, *p < .01
SE
4.1
4.4
Left hand
Right hand

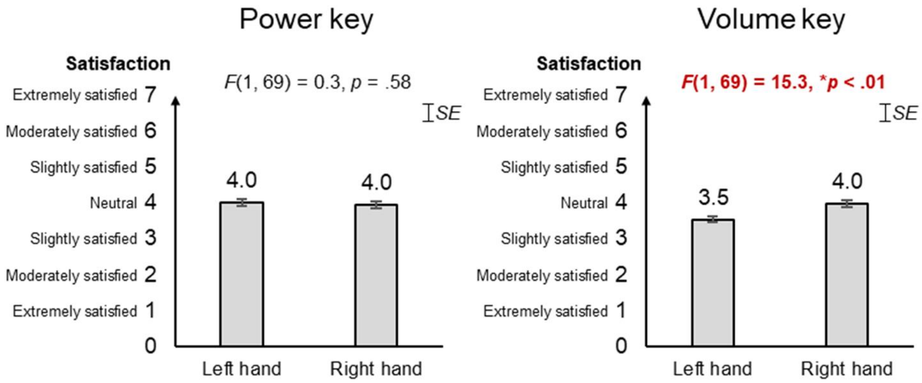
(a) 5.0”


Power key
Satisfaction
F(1, 69) = 9.7, *p < .01
SE
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
4.6
4.3
Left hand
Right hand
Volume key
Satisfaction
F(1, 69) = 21.6, *p < .01
SE
3.9
4.3
Left hand
Right hand

(b) 5.5”


Power key
Satisfaction
F(1, 69) = 3.3, p = .08
SE
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
4.3
4.1
Left hand
Right hand
Volume key
Satisfaction
F(1, 69) = 32.0, *p < .01
SE
3.6
4.2
Left hand
Right hand

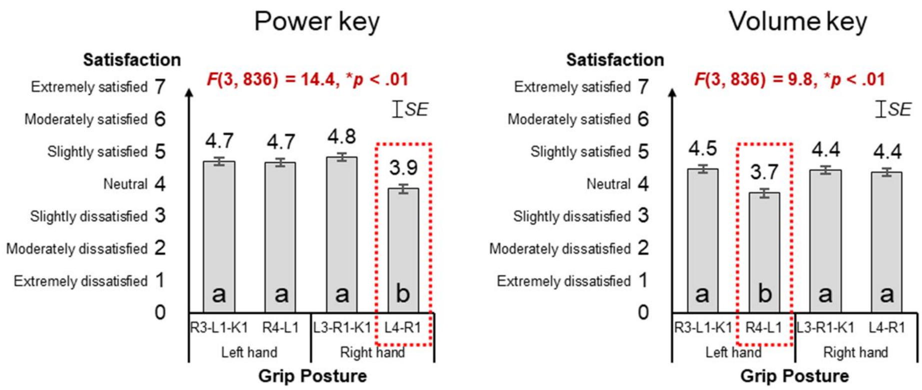
(c) 6.0”



(d) 6.5”

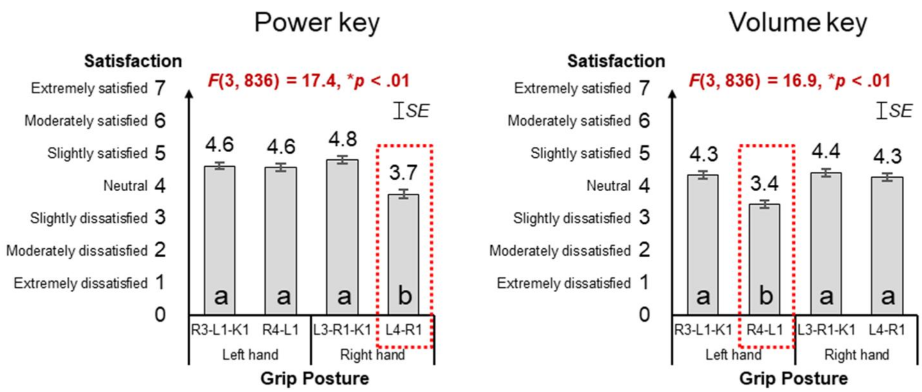
Figure 6.6. Operation satisfactions for hand to use

Operational satisfactions for power keys in L4-R1 grip posture and volume keys in R4-L1 grip posture were found to be the lowest with averages of 3.0 to 3.9 points for the smartphones with 5.0” to 6.5” screens (see Figure 6.7). For the power keys of the four smartphone mock-ups, operational satisfaction in L4-R1 grip posture was found to be the lowest with averages of 3.5 to 3.9 points, while those in the other grip postures were averages of 3.9 to 4.8 points ($p < 0.01$). For the volume keys of the four smartphone mock-ups, operational satisfaction in R4-L1 grip posture was found to be the lowest with averages of 3.0 to 3.7 points, while those in the other grip postures were averages of 3.7 to 4.5 points ($p < 0.01$).



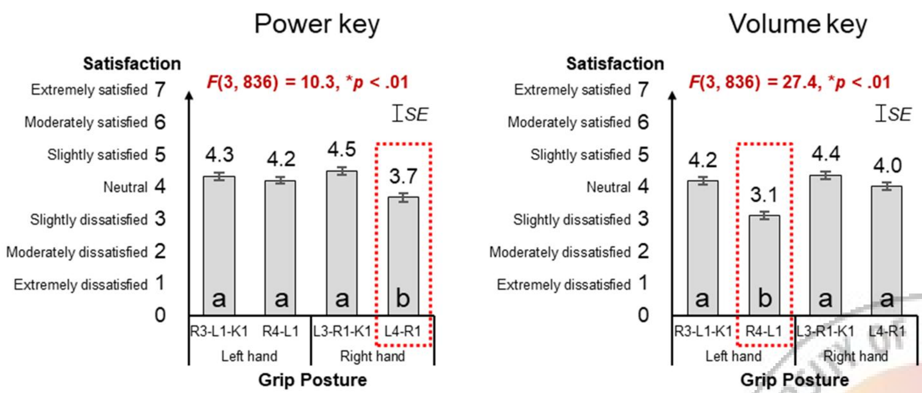
Power key
Satisfaction
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly dissatisfied 3
Moderately dissatisfied 2
Extremely dissatisfied 1
0
F(3, 836) = 14.4, *p < .01
SE
4.7 4.7 4.8 3.9
a a a b
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture
Volume key
Satisfaction
F(3, 836) = 9.8, *p < .01
SE
4.5 3.7 4.4 4.4
a b a a
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture

(a) 5.0”



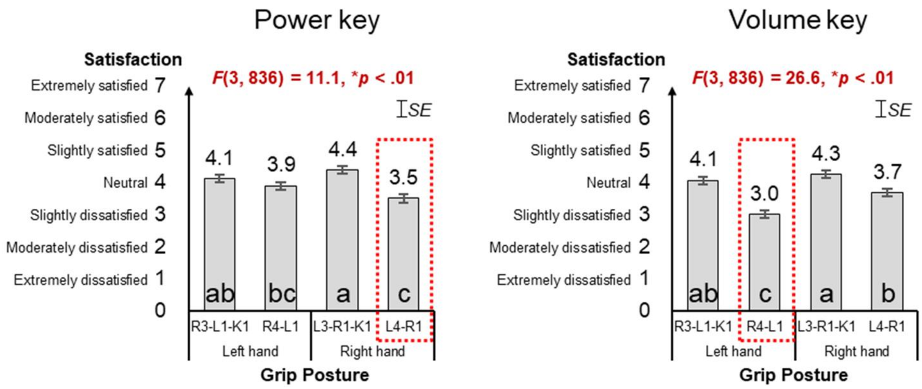
Power key
Satisfaction
F(3, 836) = 17.4, *p < .01
SE
4.6 4.6 4.8 3.7
a a a b
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture
Volume key
Satisfaction
F(3, 836) = 16.9, *p < .01
SE
4.3 3.4 4.4 4.3
a b a a
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture

(b) 5.5”



Power key
Satisfaction
F(3, 836) = 10.3, *p < .01
SE
4.3 4.2 4.5 3.7
a a a b
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture
Volume key
Satisfaction
F(3, 836) = 27.4, *p < .01
SE
4.2 3.1 4.4 4.0
a b a a
R3-L1-K1 R4-L1 L3-R1-K1 L4-R1
Left hand Right hand
Grip Posture

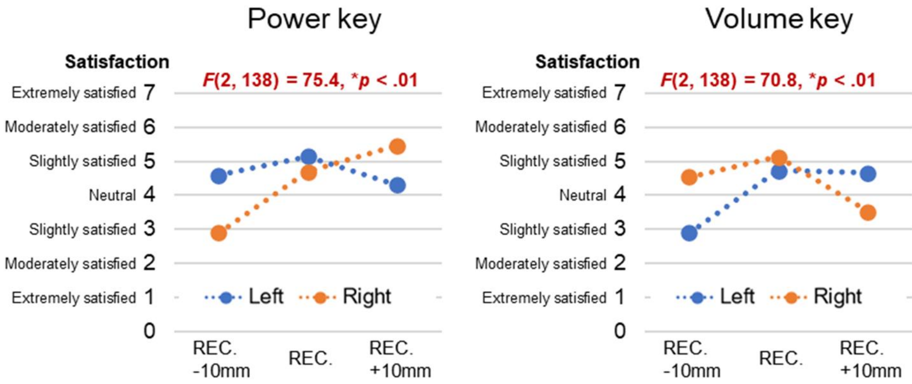
(c) 6.0”



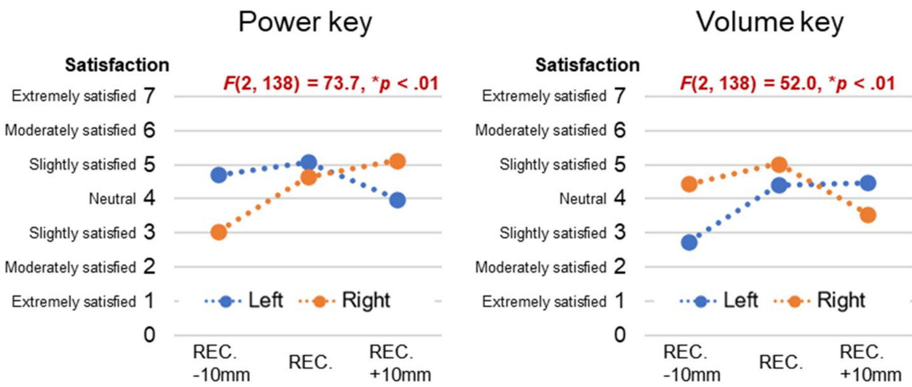
(d) 6.5”

Figure 6.7. Operation satisfactions for four grip postures of smartphones

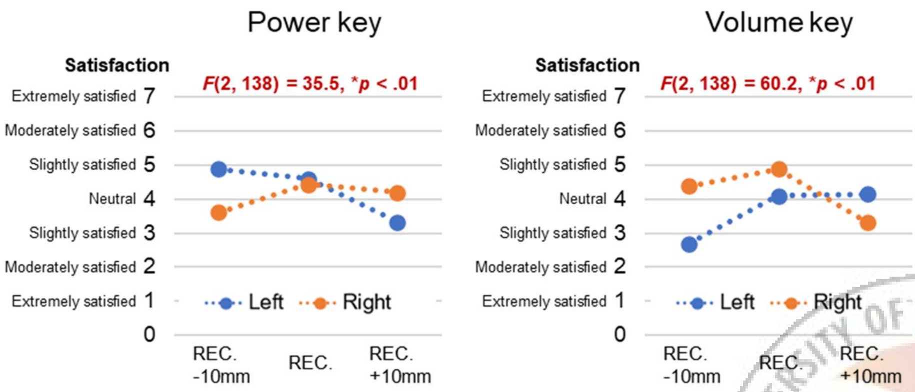
Significant interactions of key location and hand to use were observed for smartphones with 5.0” to 6.5” screens (see Figure 6.8). For the power keys of the smartphone mock-ups, operational satisfactions for right hand were lower than those for left hand at 10 mm below the recommended locations while operation satisfactions for right hand were higher than those for left hand at 10 mm above the recommended locations. In contrary, for the volume keys of the smartphone mock-ups, operational satisfactions for right hand were higher than those for left hand at 10 mm below the recommended locations while operation satisfactions for right hand were lower than those for left hand at 10 mm above the recommended locations.


Power key
Satisfaction
F(2, 138) = 75.4, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(2, 138) = 70.8, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm

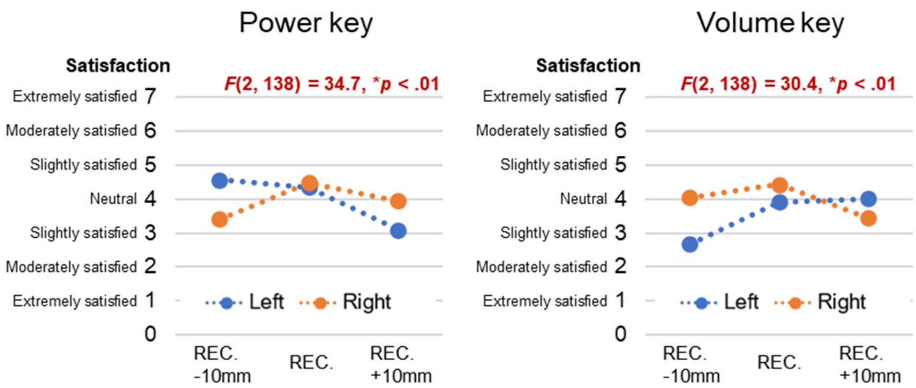
(a) 5.0”


Power key
Satisfaction
F(2, 138) = 73.7, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(2, 138) = 52.0, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm

(b) 5.5”


Power key
Satisfaction
F(2, 138) = 35.5, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(2, 138) = 60.2, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
Left
Right
REC. -10mm
REC.
REC. +10mm

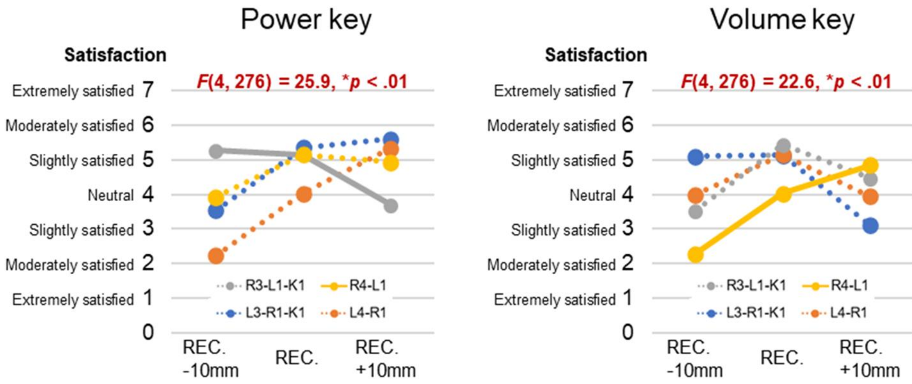
(c) 6.0”



(d) 6.5”

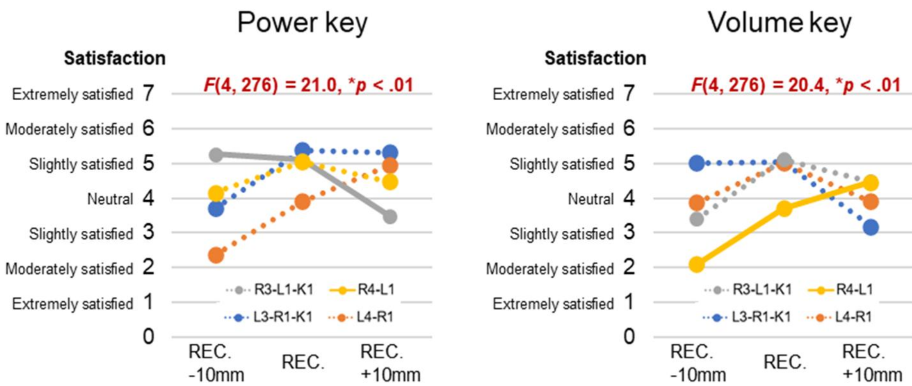
Figure 6.8. Interaction of key location and hand to use for operation satisfaction

Significant interactions of key location and grip posture were observed for smartphones with 5.0” to 6.5” screens (see Figure 6.9). For the power keys of the smartphone mock-ups, operational satisfactions for R3-L1-K1 were the highest at 10 mm below the recommended locations while operation satisfactions for the other grip postures were the highest at the recommended locations or 10 mm above those. In contrary, for the volume keys of the smartphone mock-ups, operational satisfactions for R4-L1 were the highest at 10 mm above the recommended locations while operation satisfactions for the other grip postures were the highest at the recommended locations.



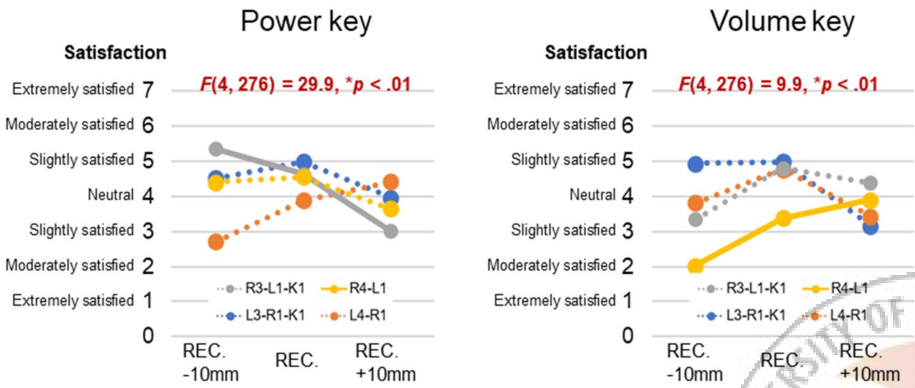
Power key
Satisfaction
F(4, 276) = 25.9, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
R3-L1-K1
R4-L1
L3-R1-K1
L4-R1
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(4, 276) = 22.6, *p < .01

(a) 5.0”



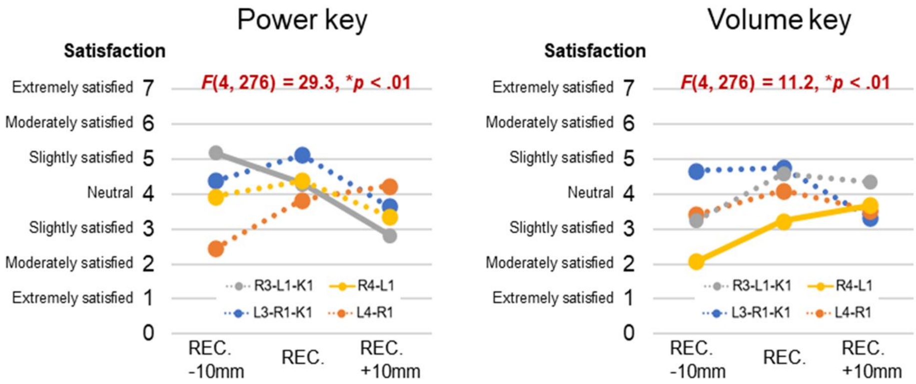
Power key
Satisfaction
F(4, 276) = 21.0, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
R3-L1-K1
R4-L1
L3-R1-K1
L4-R1
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(4, 276) = 20.4, *p < .01

(b) 5.5”



Power key
Satisfaction
F(4, 276) = 29.9, *p < .01
Extremely satisfied 7
Moderately satisfied 6
Slightly satisfied 5
Neutral 4
Slightly satisfied 3
Moderately satisfied 2
Extremely satisfied 1
0
R3-L1-K1
R4-L1
L3-R1-K1
L4-R1
REC. -10mm
REC.
REC. +10mm
Volume key
Satisfaction
F(4, 276) = 9.9, *p < .01

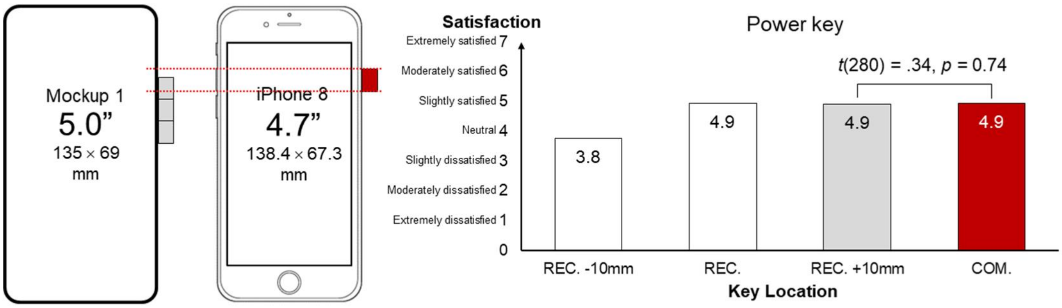
(c) 6.0”



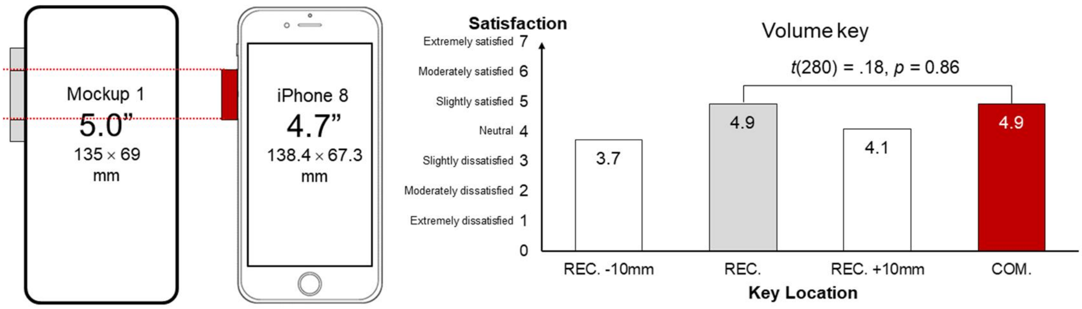
(d) 6.5”

Figure 6.9. Interaction of location and grip posture for operation satisfaction

Overall, operational satisfactions were not significantly different between hard keys on the smartphone mock-ups and commercial products designed at the similar locations to those of the mock-ups. Operational satisfaction for the power key on a commercial product ‘iPhone 8’ and the power key designed at 10 mm above the recommended location on a smartphone mock-up with 5.0” screen showed no significant difference with averages of 4.9 points for both (p = 0.74) as shown in Figure 6.10.a. Operational satisfaction for the volume key on a commercial product ‘iPhone 8’ and the volume key designed at the recommended location on a smartphone mock-up with 5.0” screen showed no significant difference with averages of 4.9 points for both (p = 0.86) as shown in Figure 6.10.b.



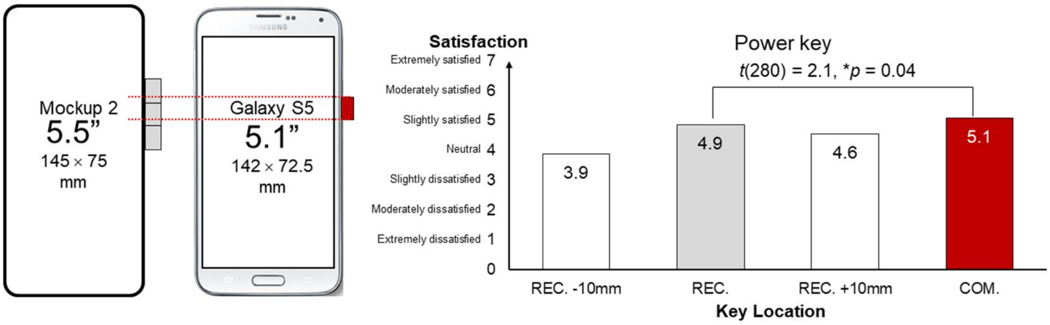
(a) Power key



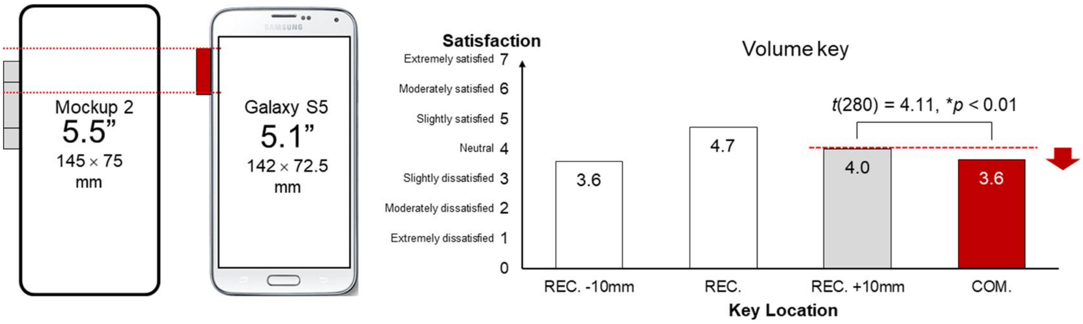
(b) Volume key

Figure 6.10. Comparison of operational satisfaction between mock-up with 5.0” screen & commercial Smartphone

Operational satisfaction for the power key on a commercial product ‘Galaxy S5’ and the power key designed at the recommended location on a smartphone mock-up with 5.5” screen showed significant difference with averages of 5.1 point and 4.9 point respectively ($p = 0.04$) as shown in Figure 6.11.a. Operational satisfaction for the volume key on a commercial product ‘Galaxy S5’ and the volume key designed at the recommended location on a smartphone mock-up with 5.5” screen showed significant difference with averages of 3.6 point and 4.0 point respectively ($p < 0.01$) as shown in Figure 6.11.b.



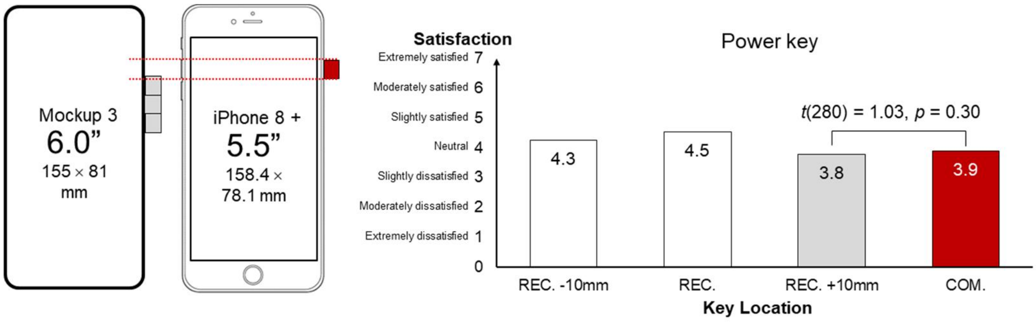
(a) Power key



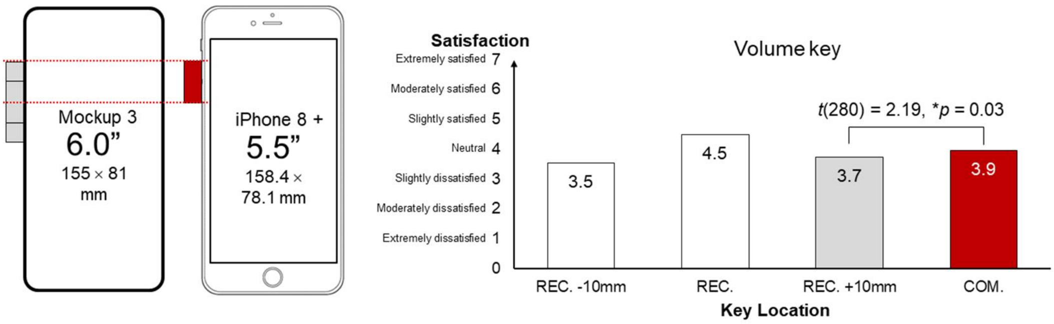
(b) Volume key

Figure 6.11. Comparison of operational satisfaction between mock-up with 5.5” screen & commercial Smartphone

Operational satisfaction for the power key on a commercial product ‘iPhone 8 Plus’ and the power key designed at 10 mm above the recommended location on a smartphone mock-up with 6.0” screen showed no significant difference with averages of 3.9 point and 3.8 point respectively (p = 0.30) as shown in Figure 6.12.a. Operational satisfaction for the volume key on a commercial product ‘iPhone 8 Plus’ and the volume key designed at 10 mm above the recommended location on a smartphone mock-up with 6.0” screen showed significant difference with averages of 3.9 point and 3.7 point respectively (p = 0.03) as shown in Figure 6.12.b.



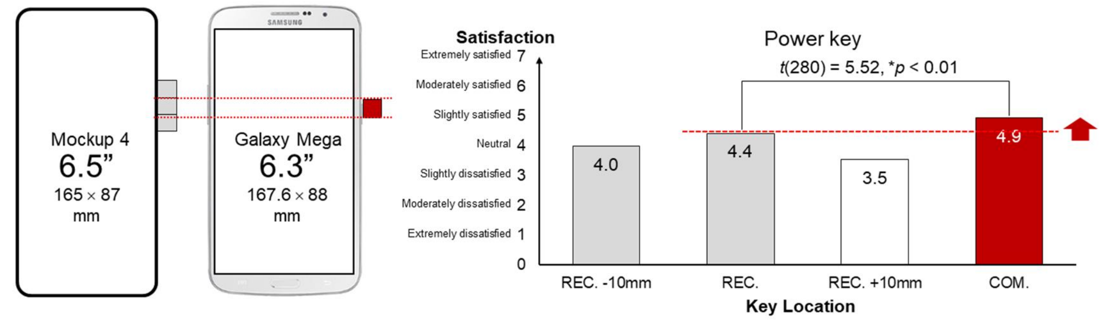
(a) Power key



(b) Volume key

Figure 6.12. Comparison of operational satisfaction between mock-up with 6.0” screen & commercial Smartphone

Operational satisfaction for the power key on a commercial product ‘Galaxy Mega 6.3’ and the power key designed at the recommended location on a smartphone mock-up with 6.5” screen showed significant difference with averages of 4.9 point and 4.4 point respectively ($p < 0.01$) as shown in Figure 6.13.a. Operational satisfaction for the volume key on a commercial product ‘Galaxy Mega 6.3’ and the volume key designed at 10 mm above the recommended location on a smartphone mock-up with 6.5” screen showed no significant difference with averages of 3.9 point and 3.7 point respectively ($p = 0.11$) as shown in Figure 6.13.b.



(a) Power key

(b) Volume key

Figure 6.13. Comparison of operational satisfaction between mock-up with 6.5” screen & commercial Smartphone

Chapter 7 Discussion

7.1. Design methodology for optimal hard key location

This study presented a design methodology for optimal hard key location of smartphone based on preference distribution for control locations by preferred grip posture, which systematically considers the characteristics of product, user, task, and use context. While previous studies (Im et al. 2010, Kim et al. 2014, and Odell and Chandrasekarn, 2012) were limited to particular device size, user, task, and use context, the design method in this study adopted various device sizes in terms of screen size from 3.0" to 7.0" by analyzing the major design specification of smartphone the target device and designed to recruit participants with three groups of hand width and three groups of hand length, respectively by analyzing the distribution of hand width and hand length of users. Also, the design method was proposed to develop a UI design guide which systematically analyzed the characteristics of smartphone-user interface by examining four types of major smartphone tasks and five types of smartphone use contexts. Since usability of UI can vary depending on grip posture (Im et al. 2010, Kim et al. 2014, & Wobbrock et al. 2008), a design methodology has been developed to identify the type of preferred grip posture when operating hard keys before investigating the preferred location of the hard keys. In addition, an effective design guide was proposed to determine the next best locations according to design constraints in addition to the optimal locations by deriving the cumulative preference distribution for control locations based on the preferred hard key control area information of participants. For example, if a hard key cannot be designed at the optimal location because of conflict with other parts, the next best location can be determined by checking the cumulative preference of the adjacent areas.

While previous studies which developed user interface design guide for smartphone were focused only on GUI design guide and considered general grip posture, this study improved the effectiveness of the design guide by analyzing the preferred smartphone grip posture in detail for the determination of hard key location on a smartphone. While existing studies (Im et al. 2010, Kim et al. 2014, Trudeau et al. 2012, Odell & Chandrasekarn, 2012) have focused on GUI designs because smartphones are primarily operated by using touchscreen, this study has developed design guides for hard keys that are essential for efficient power management and intuitive operation. Kim et al. (2014) and Im et al. (2010) developed the GUI design guide by analyzing the preferences for operating areas on a touchscreen when grasping the device by left hand and right hand. However, since usability of UI can vary depending on the position of fingers even for the same hand use (Wobbrock et al. 2008), this study proposed to specifically classify the grip posture according to the position of each finger for better effectiveness of the design guide. For example, L3-R1-K1 and L4-R1 grip posture were subclassified from the right hand grip posture by analyzing the number of fingers for each part of the device, and the preferred control areas were analyzed in the grip postures.

The developed design methodology for smartphone hard key location can be applied to the design for user interface of various mobile devices in addition to smartphones. User interface of mobile devices such as television remote controller, digital camera, and computer mouse which require similar way to operate as smartphone that grasping and operating are performed by one hand can be designed by using the design methodology in the present study. The design methodology can also be used when hard keys are replaced with other interfaces such as finger-print sensor and pressure sensor in the future as long as the grasping and operation are needed to be performed together. On the other hand, for mobile devices that are operated while both hands grasping or operated with one hand while the other hand grasping (e.g., tablet PCs, gaming controllers, and e-books), modified design methodologies can be used considering the characteristics of the product usage. For example, tablet PCs can be operated by one hand while grasped by the other hand, and various control locations (e.g., top, left, and right side of the device) can be preferred in one type of grip posture (e.g., grasping left bottom corner). Therefore, a procedure to determine approximate UI locations can be added to the design method ahead of finding the detailed control locations preferred by users.

The developed design methodology could be much useful when the locations of the interfaces can be customized. Users with special conditions on their hands because of congenital or acquired abnormalities can have different hand sizes and use different ways of grasping and operation. For example, fingers can be shorter than healthy people, some people might grasp the device with four fingers instead of five fingers, and hard key operation can also be performed by index finger and ring finger. Although the result of each procedure can vary depending on the condition of the users, the design methodology can still be applied. Therefore, the design methodology can be further useful if the customization for the location of interfaces is possible.

Since the developed design methodology for smartphone hard key location uses mock-up in a laboratory environment to derive design recommended locations, further field research is needed. The design methodology for smartphone hard key location measured the user's grip posture in natural smartphone manipulation in the laboratory environment, but the laboratory environment is limited to the quiet and psychologically stable context, so a dynamic context such as on the street where various external stimuli exist needs to be further considered. The preferred control area was also identified in the laboratory environment by adjusting the location of the hard key, so further field research is needed to see if there are any differences in the preferred control area in dynamic use context as grip posture measurement experiment.

7.2. Preferred grip postures

While previous studies generally classified the user's grip posture, the present study proposed a useful method for UI design which measures preferred grip postures in natural situations and classifies them in detail. Previous studies that considered grip posture for the UI design of mobile devices have classified grip postures into left hand grip / right hand grip or one hand grip / two hands grip, without considering detailed posture (Kim et al., 2014; Im et al., 2010), and Pelosi et al. (2009) classified the grip posture as soft / firm grips by observing the participants in various directions, but the positions of the fingers were not analyzed in detail. The video camera-based measurement method for grip posture in this study was referred from Pelosi et al. (2009), but the cameras were installed only at the top and the bottom of the device to capture the grip posture without disturbing users' natural behavior. In addition, Pelosi et al. (2009) classified soft & firm grips with a subjective method that visually determines whether the gap between the device and the hand is wide or narrow, while this study classified the type of grip posture by an objective method that counts the number of fingers at each side of smartphone.

The three major grip postures (L3-R1-K1, L4-R1, and L3-R1-T1) identified during hard key manipulation of the smartphones with 3.0" to 7.0" screen are intended to reliably wrap the device from side to side, and have similarities with those proposed in previous studies that classified the grip postures. The major grip postures (L3-R1-K1, L4-R1, and L3-R1-T1) have similarity of grasping the left and right sides of smartphone with thumb, middle finger, ring finger, and little finger and difference of the index finger location as on the back of the device (L3-R1-K1), on the left (L4-R1), or on the top (L3-R1-T1). These major grip postures have the advantage of being able to easily manipulate hard keys located on both sides with thumb, index finger, or middle finger while the device is securely grasped sticking to the palm. In particular, the L3-R1-K1 grip posture is the most dominant, accounting for 70% of the total, and can be quickly changed to L4-R1 (moving the index finger to the left side) or L3-R1-T1 (moving the index finger to the top) grip postures depending on the use situation. In addition, L3-R1-K1 grip posture can be interpreted similar to the soft grip in Pelosi et al. (2009) in terms of supporting the back of the device with the index finger, and the L4-R1 grip posture can be interpreted similar to the firm grip in terms of holding the device firmly on both sides.

As the size of the smartphone increased from 3.0" (32.2%) to 7.0" (84.4%), the preference for L3-R1-K1 grip posture increased by 53.2% because L3-R1-K1 grip posture was excellent in terms of grip stability and operational efficiency. While three grip postures were used evenly as 32.2% of L3-R1-K1, 39.3% of L3-R1-T1, and 21.1% of L4-R1 for the smallest device with a screen size of 3.0", L3-R1-K1 grip posture increased to 84.4% and the remaining two grip postures decreased to less than 10% for the largest device with a screen size of 7.0". This is because users who used to take L3-R1-T1 grip posture for grasping a short height (95 mm) device with 3.0" screen, changed their grip posture to L3-R1-K1 or L4-R1, which moved the index finger located at the top of the device to the back or left side of the device, considering the center of gravity of the device, when grasping a long height (175 mm) device with 7.0" screen. In addition, users who used to take L4-R1 grip posture for narrow width (56 mm) device with 3.0" screen have changed the grip posture to L3-R1-K1 by moving the index finger to the back of the device for stable grip when grasping wide width (93 mm) device with 7.0" screen.

As user's hand size increased, the preference for L3-R1-K1 grip posture tended to decrease by 13.1% to 13.2%, and the preference for L4-R1 grip posture tended to increase by 12.9% to 16.3%, which might be due to the greater hand sizes, the easier it is to grasp a smartphone from both sides. While the preferences for L3-R1-K1 and L4-R1 were 77.4% and 7.3% for participants with small hand width (<33^{rd}%ile, 77.4 mm), the preference for L3-R1-K1 decreased by 13.1% to 64.3% and those for L4-R1 increased by 12.9% to 20.2% for participants with large hand width (>66^{th}%ile, 84.0 mm). In addition, while the preferences for L3-R1-K1 and L4-R1 were 77.2% and 5.6% for participants with small hand length ($<33^{rd}$%ile, 177.0 mm), the preference for L3-R1-K1 decreased by 13.2% to 64.0% and those for L4-R1 increased by 16.3% to 21.9% for participants with large hand length ($>66^{th}$%ile, 184.7 mm). The reason for the decrease in L3-R1-K1 and increase in L4-R1 as hand width or hand length increases might because L4-R1 grip posture requires the index finger be moved to the left side of the device from the back, so users with longer hand width or hand length feel much easier than users with shorter hand width or hand length. Meanwhile, the ratios of decrease in L3-R1-K1 and increase in L4-R1 were similar as hand width and hand length increased, presumably due to the diagonal grasping direction of hand length and hand width while taking natural wrist posture and keeping the display vertical.

The method of measuring and analyzing grip posture in this study is expected to be useful in identifying the grip posture available for the design of user interface of various small home appliances. The grip posture measurement and analysis method has been developed for smartphones that grasping and operating are being conducted in hands, but it can be also useful for analyzing the grip posture and designing UI of various small home appliances. For example, when designing the position of buttons designed on the vacuum handle, different types of grip postures when users grasp the vacuum handle are identified, and the major grip postures that should be considered important in UI design can be investigated. Then, UI can be designed by identifying the areas where buttons can be operated in the major grip postures.

The standing situation was selected considering the efficient measurement of grip posture among situations in which smartphones are mainly used, but preferred grip posture needs to be studied in more various situations. Preferred grip posture can vary depending on use context such as sitting, lying down, and walking, so a verification in various situations is required. For example, in standing situation, L3-R1-K1 grip posture was preferred for grasping without much effort, but in walking situation, L4-R1 grip posture, which grasps left and right strongly to hold the device stably, might be preferred. Therefore, further study is needed for the type and preference of grip posture in various use contexts such as sitting, lying down, and walking by developing a novel way to measure grip posture in a natural manner. For example, in the case of walking situation, a treadmill can be adopted to the experimental setting, and cameras can be installed similar to the experiment in the standing situation, and in the case of a lying down situation, a camera can be installed above the bed and participant can wear a head mounted camera to identify grip posture.

Right-handed preferred grip posture was analyzed without considering the user's handedness in this study, so whether the left-handed grip posture has symmetry with the right-handed grip posture need to be examined. Grip posture analysis in this study identified the preferred grip posture when grasping a smartphone with the right hand without considering the handedness of the participants. On the other hand, according to the existing studies investigated handedness (Hardyck & Petrinovich, 1977; Perelle & Ehrman, 1994; Reiss & Reiss, 1999), 8% to 12% of people in the world are left-handed, and right-handed users may also use left hand to hold smartphones depending on the situation. Therefore, further study is needed to analyze the left-handed preferred grip posture and examine the difference or symmetry from the right-handed preferred grip posture.

7.3. Preferred hard key locations

The most preferred hard key location for smartphone derived from this study is expected to be effective in designing the hard key since it is based on the preference distribution by control location from users with different hand sizes for different sizes of smartphones with 3.0" to 7.0" screen sizes. Unlike Kim et al. (2014) and Im et al. (2010) did not recruit participants with various hand sizes when developing GUI design guide, this study analyzed preferences by hard key control location for the participants recruited based on the distribution of hand length and hand width of Koreans in their 20s and 50s. Also, the preference by hard key control location in this study is effective in designing new smartphones since it was analyzed for nine different sizes of smartphone mock-ups with screen size of 3.0" to 7.0" while some studies related to the UI design of smartphones (Im et al., 2010; Trudeau et al., 2012) conducted their experiment on a smartphone mock-up of one size (Im et al., 2010: 60 mm × 110 mm; Trudeau et al., 2012: 62.1 mm × 115.5 mm). The hard key design location in this study is determined based on the preference distribution by hard key location, so the next best locations can be determined flexibly even if design constraints occur during the design process.

The most preferred hard key locations for smartphone showed an average of 3.7 mm lower on the left side than on the right side, which might be due to the lower position of the finger manipulating the left hard key in the natural grip posture compared to the finger operating the right hard key. While the most preferred locations for left hard key of smartphones are located 61 to 105 mm from the bottom of the device, those for right hard key are located 69 to 116 mm from the bottom of the device, indicating that the lower location is preferred for left hard key compare to the right hard key. When a smartphone is hold with preferred grip posture L3-R1-K1, L4-R1, or L3-R1-T1, the index finger or middle finger will be placed on the left side and the thumb will be placed on the right side. At this time, the left hard key is considered to be preferred at the lower location than the right hard key as the index finger or middle finger on the left side is naturally placed lower than the thumb on the right side.

Although the tendency of control range preferred more than 60% become narrower as device size increases could imply less importance of recommended design locations, the information of recommended design location could still be utilized as a criterion of considering one-handed grip posture for a certain device. The control ranges preferred more than 60% for right hard keys on smartphone mockups with 6.5” and 7.0” screen were only 9 mm and 5 mm respectively and even the most preferred locations were preferred less than 70%. This could be interpreted that the recommended design location is not highly important for the usability of a device. However, the proposed methodology for hard key design location derives recommended locations by finding the most preferred location in one-handed grip posture for a reference information in developing a device. Therefore, the low preference of the recommended design location can be used as a reference information to consider two-handed grip posture prior to one-handed grip posture for a certain device.

The regression equations of optimal design locations for smartphone hard keys which are developed using the device width and device height as predictors, could be useful in estimating the hard key optimal design location for smartphones that have not been directly tested within the range of 3.0" to 7.0" screen size. The smartphone mock-up used in this study was designed at 0.5" intervals from 3.0" to 7.0" in terms of screen size. However, the design dimensions of the newly developed smartphone may differ somewhat from the mock-up used in the experiment. To compensate for this, regression equations were developed that could estimate the most preferred locations for hard keys of between-sized smartphones in the range of 95 to 175 mm of device height and 56 to 93 mm of device width that were not directly analyzed. The developed regression equations have device height and device width as predictors and were developed to estimate the most preferred locations of the left and right hard key respectively, and adj. R^2 of the regression equations were found to be high of 0.95 and 0.96.

The method for analysis of preference by control location utilized in this study can be used in the location design of various user interfaces. The preferred control range measurement and analysis method was developed for the design of smartphone hard key location, but it can be useful for analyzing preferred operating areas of various small appliances (e.g., television remote controller, mouse, gaming pad, digital camera) other than smartphones. For example, when designing the location for the shutter button of a digital camera, it can be designed in the most preferred location by measuring the preferred operating range with the digital camera hold in the preferred grip posture by users of various hand sizes.

In this study, preferred control ranges of participants were measured and analyzed, but further study is needed to analyze areas that users do not prefer, but controllable, considering the effectiveness of the design application. When determining the design location by considering the preference distribution of hard key, design priorities or design constraints between hard keys and other parts may become obstacles to design hard keys within a certain range of preferences. In the preferred control range measurement experiment, only comfortable reach envelop (CRE) was analyzed within user's reach envelope (RE), but analysis of the range that is not preferred but reachable can identify the limits that the user can manipulate, and that could overcome the obstacles by making the design range wider. Therefore, further analysis of uncomfortable RE can increase the applicability of the hard key location design methodology.

7.4. Evaluation of hard key locations for smartphone

The design methodology for optimal hard key location of smartphone proposed in this study was applied to different size smartphones with 5.0" to 6.5" of screen size and then operational satisfaction was evaluated and validated by users of different hand sizes. Recommended hard key design locations for smartphones with 5.0" to 6.5" of screen size were derived, and operational satisfaction for the locations and 10 mm above & below the recommended locations were also compared to review the relative superiority of the recommended design locations. In addition, operational satisfactions for hard keys of commercial smartphones with similar size to the smartphone mock-ups were compared to improve the generalizability of the experimental results. To determine the operational satisfaction of users of various hand sizes, participants were recruited considering hand size distribution of Koreans, and 20 left-handed and 50 right-handed people were involved in the experiment to consider handedness.

The operational satisfaction of recommended design locations derived from the design methodology averaged 0 to 0.8 points higher than the 10 mm above and below of them, thus the effectiveness of the design methodology is validated. Operational satisfactions for the recommended design locations of smartphone mock-ups with 5.0" to 6.5" of screen size were the highest among the three locations (10 mm above: 3.5 to 4.9 points; recommend location: 4.2 to 4.9; 10 mm below: 3.4 to 4.3 points) with significant differences ($p < 0.01$). Meanwhile, operational satisfaction for power keys at 10 mm above the recommended location of smartphone with 5.0" and 5.5" of screen size also showed excellent with average of 4.6 to 4.9 points. This seems to be because relatively small sized devices allow users move their fingers more easily even if there is a slight difference in the location of the hard key.

The operational satisfactions for smartphone hard keys were found to be 0.7 to 0.9 points lower on average when being manipulated with thumb in grip postures that grasp the both sides of the device than the other cases. The major grip postures for smartphones with 5.0" to 6.5" screen size are L3-R1-K1 & L4-R1 with right hand and L1-R3-K1 & L1-R4 with left hand, and they can be clustered into two types that one supporting the back side of a device with index finger while grasping both sides of the device with three fingers and thumb (L3-R1-K1-R1) and the other only grasp both sides of the device with four fingers and thumb (L4-R1 & L1-R4). Among them, operational satisfactions for the cases that hard keys are manipulated by thumb in two grip postures (L4-R1 & L1-R4) that grasp both sides of the device with four fingers and thumb averaged 3.0 to 3.9 points, which are 0.7 to 0.9 points lower than the others. This seems to be because the thumb motion in the grip posture that grasp both sides of the device with four fingers and thumb makes significant discomfort.

The results of mockup-based experiment in this study were found to be generalizable as it showed a similar tendency to average 0 to 0.5 points difference between the operational satisfactions for hard keys of the commercial smartphones and mockups. Operating satisfactions for the hard key of the smartphone mock-up with 5.0" screen size and those for both power key and volume key of Apple iPhone 8 were not significantly different. Operating satisfactions for the hard key of the smartphone mock-up with 5.5" screen size and those for the power key and volume key of Samsung Galaxy S5 showed significant differences of 0.2 and 0.4 points on average, respectively, but this follows the trend that the farther away from the recommended design location, the lower the operational satisfaction. Operating satisfactions for the hard key of the smartphone mock-up with 6.0" screen size and those for the power key of Apple iPhone 8 plus were not significantly different, but those for volume key showed significant differences of 0.2 points on average, but this follows the trend that the farther away from the recommended design location, the lower the operational satisfaction. Finally, operating satisfactions for the hard key of the smartphone mock-up with 6.5" screen size and those for the power key of Samsung Galaxy Mega 6.3 showed significant differences of 0.5 points on average, but this follows the trend that the more closed to the recommended design location, the higher the operational satisfaction. Also, operational satisfaction for volume key did not show significant difference with 0.2 point on average.

The validation method used in this study could be useful in evaluating various interface design locations other than the design methodology for optimal hard key location of smartphone. This study compared operational satisfaction of recommended design location and 10 mm above and below the location based on mockups to validate the adequacy of recommended hard key design location derived from the analysis of preference distribution by control location. This user-interface evaluation methods can be used to assess the adequacy of the design location of various user interfaces. For example, buttons on vacuum handles can be evaluated for the adequacy of the location. First, grip postures for vacuum handle by users of various hand sizes can be analyzed, then the operational satisfactions for buttons designed at different locations can be assessed at each grip posture.

Validation for users with smaller and larger hand than the participants in this study is needed to release the target device to the global market. The participants were recruited considering hand size distribution with hand length of 144.1 mm to 205.2 mm and hand width of 66.3 mm to 92.1 mm. Meanwhile, hand size of Korean people is larger than Vietnamese (Imrhan et al., 1993) and smaller than American (Garrett, 1971). Therefore, validation experiments for users with smaller and larger hand than the participants in this study is necessary to release a smartphone to the global market.

Further studies need to be conducted for the development of the prevention strategy for unintended operation which may occur while hard key operation in one-handed grip posture. This study intended to identify the preferred design locations for hard keys on both sides of the device. However, when hard keys are located on both sides of smartphone, unintended operation may occur for the hard key at the opposite side of the device while manipulating a hard key. Therefore, further research can be conducted to develop a design strategy that prevents unintended operation while maintaining an appropriate level of operational satisfaction when designing hard keys on both sides of the device.

Chapter 8 Conclusion

The aim of this study was to develop and validate methodology for designing optimal hard key locations of smartphone to satisfy users of various hand sizes. First, a framework was developed to systematically consider characteristics of product, user, task, and use context to determine the hard key design location of smartphone which provide high usability. The framework for optimal hard key design location was designed to first analyze the smartphone-user interface, such as device size, user's hand size, tasks, and use contexts, then plan experiments for measuring user's preferred grip posture and preferred control area. After that, user's preferred grip posture in natural smartphone use situation is analyzed, then preferred control range of each participant is investigated. Finally, recommended hard key design location is determined by finding the location where cumulative preference is the highest.

Second, L3-R1-K1, L4-R1, and L3-R1-T1 were identified as the major grip postures for hard key manipulation of smartphone mock-up with 3.0" to 7.0" screen size. Nine types of grip postures were identified for hard key manipulation by users with various hand sizes using the smartphone mock-ups with 3.0" to 7.0" screen size in a standing position by recording the grip posture when conducting answering a call, texting, music listening, and web browsing tasks. Grip postures were classified based on the number of fingers at each side of the device, of which L3-R1-K1 (70.0%), L4-R1 (13.3%) and L3-R1-T1 (12.0%) were identified as major grip postures used more than 10% in hard key operation.

Third, the recommended hard key design locations determined for the most preferred control locations on smartphones with 3.0" to 7.0" screen size were 61 mm to 105 mm from the bottom on the left side of the device and 69 mm to 116 mm from the bottom on the right side of the device. The recommended hard key design locations for smartphone was derived based on the cumulative preference distribution for each control location at 1 mm intervals after examining the preferred hard key control area in three major grip postures to consider various grip postures and user's preference distribution. The most preferred design locations for right key were found to be 3.7 mm higher than those for left key that 61 mm to 105 mm from the bottom on the left side and 69 mm to 116 mm from the bottom on the right side were the most preferred.

Finally, the proposed framework for smartphone hard key location design was validated by the result that the recommended design location was the most satisfied in the evaluation of operational satisfaction for three locations of the recommended design location and 10 mm above and below the locations. The derived recommended design location for smartphone hard key was applied to the smartphones with 5.0", 5.5", 6.0", and 6.5" screen size to evaluate the operational satisfaction. The operational satisfaction was evaluated on a 7-point scale for the three hard keys located at the recommended location and 10 mm above and below the location. The recommended design location was identified as the most preferred among three locations (10 mm below the recommended location: 3.4 to 4.3 points; recommended location: 4.2 to 4.9 points; 10 mm above the recommended location: 3.5 to 4.9 points), confirming the effectiveness of the proposed framework for smartphone hard key location design.

SUMMARY IN KOREAN

스마트폰 hard key 의 위치는 사용자들의 편의를 위해 파지 안정성, 조작 용이성이 높게 인간공학적으로 결정될 필요가 있다. 스마트폰의 hard key 에는 효율적인 전원 관리를 위해 screen on/off 를 수행하는 power key 와 직관적인 volume control 을 위한 volume key 등이 있다. 스마트폰 hard key 가 부적절한 위치에 설계되면 grip loss, discomfort, unintended operation 등 다양한 사용성 문제를 발생시킬 수 있다.
스마트폰 hard key 의 위치는 제조사별로 상이하며, 동일한 제조사에서 개발한 유사한 크기의 제품들도 서로 상이한 위치에 설계되고 있어 인간공학적 design guide 가 부재한 것으로 추측된다.

한 편, 인간공학적 사용자 인터페이스설계를 위해 touch screen 상의 GUI 와 기기 외형의 설계 치수에 대한 연구들은 많이 수행되고 있으나 hard key 의 최적 설계 위치에 대한 연구는 미미하여 심층적인 연구가 필요하다. hard key 는 touch screen 상의 GUI 와 달리 한 번 제조되면 위치를 변경할 수 없고, 제조 중에도 다른 부품들의 배치를 고려하여 위치를 변경하기 어려워 신중하게 위치가 결정될 필요가 있다. 따라서, 다양한 크기의 스마트폰 hard key 위치 결정을 위한 인간공학적 설계 방법의 개발이 필요하다.

본 연구는 사용자들의 선호 파지 자세 정보를 기반으로 다양한 손 크기를 가진 사용자들의 선호 hard key 조작 영역을 통계적으로 분석하여 스마트폰 hard key 의 위치를 결정하는 (1) 인간공학적 설계 방법을 개발하고 (2) 다양한 크기의 스마트폰 hard key 위치 도출에 적용한 후 (3) 조작 만족도 평가를 통해 방법론의 적절성을 검증하고자 하였다.

제안된 설계 방법은 먼저 제품의 설계 특성, 사용자 특성, task 특성, 그리고 사용 상황의 특성을 분석한 후, 사용자들의 선호 파지 자세 유형을 조사한다. 이 후 선호 파지 자세 유형별 사용자들이 선호하는 hard key 조작

영역을 분석하여 조작 영역의 선호도 분포를 도출하고 hard key 의 크기와 조작 영역별 선호도를 고려해서 권장 설계 범위를 도출하도록 고안되었다.

제안된 파지 자세 분석 방법을 활용하여 실험 참여자 45 명을 대상으로 화면 크기 3.0" ~ 7.0” 스마트폰 9 종의 power key 와 volume key 조작 시 선호 파지 자세 유형이 파악되었다. 총 9 가지 파지 자세 유형 중 L3-R1-K1, L4-R1, L3-R1-T1 이 전체의 95% 이상에게 선호되는 주요 파지 자세로 파악되었다. 선호 파지 자세의 선호 비율은 기기 크기의 영향이 유의하여 기기의 화면 크기가 3.0”에서 7.0”으로 증가할 때 L3-R1-K1 자세의 선호 비율이 32.2%에서 84.4%로 증가하였다($p < 0.01$).

다음으로 실험 참여자 52 명의 선호 파지 자세에서의 선호 조작 영역을 분석하여 화면 크기 3.0" ~ 7.0” 스마트폰 9 종의 power key 와 volume key 설계 추천 위치가 도출되었다. Power key 와 volume key 의 설계 추천 위치는 다양한 손 크기의 실험 참여자들의 조작 영역별 선호 여부를 누적하여 도출되었다. Hard key 설계 추천 위치는 기기의 화면 크기가 3.0”에서 7.0”으로 증가할 때 power key 는 하단으로부터 69 mm 에서 116 mm, volume key 는 하단으로부터 61 mm 에서 104 mm 로 증가하였다.

도출된 설계 추천 위치를 화면 크기 5.0” ~ 6.5” 기기에 적용하여 설계 추천 위치와 인접 위치(10 mm 상/하단)에 대한 실험 참여자 70 명의 조작 만족도를 비교 평가한 결과 모든 크기에서 설계 추천 위치가 가장 선호되는 것으로 파악되어 제안된 스마트폰 hard key 위치 설계 방법의 유효성이 검증되었다. 화면 크기 5.0” ~ 6.5” 스마트폰의 설계 추천 위치에 대한 조작 만족도는 평균 4.2 ~ 4.9 점으로 주변 위치들에 비해 최대 1.2 점 높았다($p < 0.01$).

본 연구에서 제안된 스마트폰 hard key 위치설계 절차는 스마트폰 외에도 다양한 portable 제품들의 인터페이스 위치 설계에 유용하게 활용될 수 있을 것으로 기대된다.

REFERENCES

Andrew, O. (2018). The history and evolution of the Smartphone: 1992-2018. Retrieved 2020, Feb 24, from http://www.textrequest.com/blog/history-evolution-smartphone/

Berolo, S., Wells, R. P., and Amick, B. C. III (2011). Musculoskeletal symptoms among mobile hand-held device users and their relationship to device use: A preliminary study in a Canadian university population, *Applied Ergonomics 42* (2011), pp. 371-378.

Christensson, P. (2010). Smartphone definition. Retrieved 2020, Feb 24, from http://techterms.com

Chung, S., Shim, J. H., and Kim, C. (2007). Display button: a marriage of GUI and PUI, *in: J. Jacko (Ed.), Human–Computer Interaction, Part II*, 2007, pp. 1086-1095.

Courage, C., Redish, J. G., Wixon, D. (2009). Task Analysis, in: Sears, A., Jacko, J.A. (Eds.), Human-Computer Interaction: Development Process. CRC Press, NW, pp. 33-53.

Dunn, B. K., Galletta, D. F., Hypolite, D., Puri, A., and Raghuwanshi, S. (2013). Development of Smart Phone Usability Benchmarking Tasks, *46th Hawaii International Conference on System Sciences.*

Finneran, A. and O'Sullivan, L. (2013). Effects of grip type and wrist posture on forearm EMG activity, endurance time and movement accuracy, *International Journal of Industrial Ergonomics 43*, pp. 91-99.

Garrett, J. W. (1971). The adult hand: some anthropometric and biomechanical considerations. *Human Factors 13*, pp. 117-131.

Garrett, J. J. (2011). The Elements of User Experience: User-Centered Design for the Web and Beyond (2nd Edition)

Gsmarena. (2017). Counterclockwise: monster-sized screens, the early days. Retrieved from http://www.gsmarena.com/counterclockwise_monstersized_screens_the_early_days-news-24881.php

Gsmarena. (2019). Opinion: bezel-less is not the way forward. Retrieved from http://www.gsmarena.com/no_bezelless_is_not_the_way_forward-news-35086.php

Ham, D. H., Heo, J. Y., Fossick, P., Wong, W., Park, S. H., Song, C. W., and Bradley, M. (2006). Conceptual framework and models for identifying and organizing usability impact factors of mobile phones, *in Proceedings of the 2006 Annual Conference of* *the Australian Computer–Human Interaction Special Interest Group (OZCHI 2006), Sydney, Australia*, 2006.

Hardyck, C., and Petrinovich, L. F. (1977). Left-handedness, *Psychological Bulletin 84*(3), pp. 385-399.

Hartmann, J., Sutcliffe, A., and De Angeli, A. (2008). Towards a theory of user judgment of aesthetics and user interface quality. *ACM Transactions on Computer-Human Interaction 15*(4), pp. 1-30.

Im, Y., Cho, S., Park, S., Jung, E., and Park, J. (2010). Controllability of Touch-screen Phones based on Various Grip Postures, *Proceedings of the International Multi Conference of Engineers and Computer Scientists 2010 Vol III*, Hong Kong.

iMore. (2014). Anyone else hate the location of the power buttons on the new iPhones? Retrieved from https://forums.imore.com/iphone-6-plus/302288

Imrhan, S. N., Nguyen, M., Nguyen, N. (1993). Hand anthropometry of Americans of Vietnamese origin. *International Journal of Industrial Ergonomics 12*, pp. 281-287.

Jin, B. and Ji, Y. (2010). Usability risk level evaluation for physical user interface of mobile phone, *Computers in Industry 61* (2010), pp. 350-363.

Karlson, A., Bederson, B., and Contreras-Vidal, J. (2006). Understanding one-handed use of mobile devices, *in Handbook of Research on User Interface Design and Evaluation for Mobile Technology*, pp. 86-101, IGI Global, 2007.

Kietrys, D. M., Gerg, M. J., Dropkin, J., and Gold, J. E. (2015). Mobile input device type, texting style and screen size influence upper extremity and trapezius muscle activity, and cervical posture while texting, *Applied Ergonomics 50* (2015), pp. 98-104.

Kim, T., Jung, E., and Im, Y. (2014). Optimal control location for the customer-oriented design of smart phones, *Information Sciences 257* (2014), pp. 264-275.

Korean Agency for Technology and Standards (KATS). (2010). *The Report on the 6th Size-Korea (Korean Body Measurement and Investigation)* Seoul, Korea: Size Korea, Ministry of Knowledge Economy.

Kwon, S., Bahn, S., Ahn, S. H., Lee, Y., and Yun, M. H. (2016). A study on the relationships among hand muscles and form factors of large-screen curved mobile devices, *International Journal of Industrial Ergonomics 56* (2016), pp. 17-24.

Levy, M., Shoval, P., Shapira, B., Dayan, A., and Tubi, M. (2010). Task Modeling Infrastructure for Analyzing Smart Phone Usage, *2010 Ninth International Conference on Mobile Business.*

Mobile device. (2020). In Wikipedia. Retrieved from http://en.wikipedia.org/wiki/Mobile_device

Odell, D. and Chandrasekarn, V. (2012). Enabling comfortable thumb interaction in tablet computers: a Windows 8 case study, *Proceedings of the Human Factors and Ergonomics Society 56th annual meeting.*

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory, *Neuropsychologia 9* (1), pp. 97-113.

Pelosi, M., Franek, O., Knudsen, M. B., Christensen, M., and Pedersen, G. (2009). A Grip Study for Talk and Data Modes in Mobile Phones, *IEEE Transactions on Antennas and Propagation 57* (4).

Perelle, I. B. and Ehrman, L. (1994). An international study of human handedness: The data, *Behavior Genetics 24* (3), pp. 217-227.

Phonearena. (2019). Phone specs comparison. Retrieved from http://www.phonearena.com/phones/compare

Preece, J., Rogers, Y., and Sharp, H. (2007). Interaction Design Beyond Human–Computer Interaction, *John wiley & sons*, 2007.

Reiss, M. and Reiss, G. (1999). Earedness and Handedness: Distribution in a German sample with some Family Data, *Cortex 35*, pp. 403-412.

Size Korea. (2019), Report on the Sixth Survey of Korean Anthropometry, Retrieved from http://sizekorea.kats.go.kr/.

Suzuki, S., Nakao, Y., Asahi, T., Bellotti, V., Yee, N., and Fukuzumi, S. (2009). Empirical Comparison of Task Completion Time between Mobile Phone Models with Matched Interaction Sequences, *Human-Computer Interaction, Part III*, pp. 114-122.

Trudeau, M. B., Udtamadilok, T., Karlson, A. K., and Dennerlein, J. T. (2012). Thumb Motor Performance Varies by Movement Orientation, Direction, and Device Size During Single-Handed Mobile Phone Use, *HUMAN FACTORS 54* (1), pp. 52-59.

Wobbrock, J. O., Myers, B. A., and Aung, H. H. (2008). The performance of hand postures in front- and back-of-device interaction for mobile computing, *International Journal of Human-Computer Studies 66*, pp. 857-875.

ACKNOWLEDGEMENTS

하나님의 인도하심으로 기나긴 학위과정의 결실을 맺게 되었음을 고백합니다. 저의 학위과정을 지원해주시고 응원해주신 분들께 감사의 인사를 전합니다.

CURRICULUM VITAE

Younggeun Choi, Ph.D. candidate
Department of Industrial and Management Engineering
Pohang University of Science and Technology (POSTECH)
Pohang, Gyungbuk, Korea, 37673

Research Interests

- User Needs Analysis
- User Experience Design
- Ergonomic Product Service System Design & Development
- Ergonomic Design Evaluation
- Human Performance & Workload Assessment

Education

Ph.D. (Mar. 2012 ~ Feb. 2021)

Major: Industrial Engineering

Pohang University of Science and Technology (POSTECH), Pohang, South Korea

Advisor: Dr. Heecheon You

M.S. (Mar. 2010 ~ Feb. 2012)

Major: Industrial Engineering

Pohang University of Science and Technology (POSTECH), Pohang, South Korea

Thesis: Sitting Strategy Analysis based on Driving Posture and Seating Pressure Distribution

Advisor: Dr. Heecheon You

B.S. (Mar. 2002 ~ Feb. 2010)

Major: Industrial and Media Design (UX design)

Handong Global University, Pohang, South Korea

Publications

International Journals

1. **Choi, Y.**, Yang, X., Park, J., Jung, H., Lee, W., and You, H. (under review). Development of an Ergonomic Design Process for Smartphone Hard Key Locations. *Applied Ergonomics*.
2. Yang, X., Pratama, G., **Choi, Y.**, You, H., Tam, M., Kim, G., Joe, Y., and Ko, M. Measurement of Nasalance Scores Without Touching the Philtrum for Better Comfort During Speech Assessment and Therapy: A Preliminary Study. *The Cleft Palate-Craniofacial Journal.* doi:10.1177/1055665620953340
3. **Choi, Y.**, Yang, X., Park, J., Lee, J., Lee, W., and You, H. (2020). Effects of Smartphone Size and Hand Size on Grip Posture in One-Handed Hard Key Operation. *Applied Sciences, 10,* 8374.
4. **Choi, Y.**, Kim, M., Lee, B., Yang, X., Kim, J., Kwon, D., Lee, S. E., Kim, H., Nam, S. I., Hong, S., Yang, G., Na, D. L., and You, H. (2020). Development of an Ultrasonic Doppler Sensor-Based Swallowing Monitoring and Assessment System. *Sensors, 20*(16), 4529.
5. Yang, X., Park, J., **Choi, Y.**, Lee, S., Lee, B., Jung, K, and You, H. (2019). Development of statistical geometric models for prediction of a driver’s hip and eye locations. *International Journal of Industrial Ergonomic, 72,* 320-329.
6. Yu, H., Yang, X., Yang, J., **Choi, Y.**, Hwang, H., Ahn, S., and You, H. (2018). Dr. Liver: A preoperative planning system of liver graft volumetry for living donor liver transplantation. *Computer Methods and Programs in Biomedicine, 158,* 11-19.
7. Kim, K., **Choi, Y.**, You, H., Na, D., Yoh, M., Park, J., Seo, J., Ko, M. (2015) Effects of a serious game training on cognitive functions in older adults. *Journal of the American Geriatrics Society, 63*(3), 603-605
8. Yang, X., Yu, H., **Choi, Y.**, Lee, W., Wang, B., Yang, J., Hwang, H., Kim, J., Song, J., Cho, B., You, H. (2014) A hybrid semi-automatic method for liver segmentation based on level-set methods using multiple seed points. *Computer Methods and Programs in Biomedicine, 113*(1), 69-79

Domestic Journals

1. Yang, X., Sadik, E., Pratama, G., **Choi, Y.**, Kim, Y., Lee, J., Jo, Y., Kim, G., Lee, J., Yu, M., Ko, M., and You, H. (2019). An analysis on serious games and stakeholders' needs for vocal training game development. *Communication Sciences & Disorders, 24*(3), 806-819.
2. Yang, X., Yu, H., **Choi, Y.**, Yang, J., Cho, B., You, H. (2017). Development and usability testing of a user-centered 3D virtual liver surgery planning system. *Journal of the Ergonomics Society of Korea, 36*(1), 37-52.
3. Lee, J., **Choi, Y.,** Yang, X., Lee, N., Oh, G., Kim, Y., Kang, J., You, H. (2016). The Effect of Gaze Fixation Induction Method on Visual Field Testing. *Journal of the Korean institute of Industrial Engineers, 42*(6), 412-420.
4. Kim, S., Lee, W., Lee, B., Lee, J., **Choi, Y.,** Jung, K., You, H. (2015). Learning from successes and failures of registration of patent applications based on physical ergonomics. *Journal of the Ergonomics Society of Korea, 34*(5), 455-467.
5. Park, J., Lee, H., **Choi, Y.,** Park, K., Kim, M., You, H. (2015). Development of an evaluation protocol for a bus seat. *Journal of the Korean institute of Industrial Engineers, 41*(1), 74-78.
6. Lee, W., Yang, X., Lee, S., **Choi, Y.,** Jung, H., Lee, H., You, H., Yu, M., Ko, M., Park, J. (2015). Development of a serious game for rehabilitation of articulation and fluency disorders. *Korean Society for Computer Game, 28*(2), 1-9.
7. Lee, S., **Choi, Y.,** Lee, W., Yu, M., Ko, M., Park, J., You, H. (2015). Development of a physical therapy system for enhancement of balance ability. *Korean Society for Computer Game, 28*(2), 205-214.
8. **Choi, Y.,** Jung, H., Lee, W., Yang, X., Lee, S., You, H., Yu, M., Ko, M., Park, J. (2015). Development of a serious game for active Kegel exercise. *Korean Society for Computer Game, 28*(2), 195-203.
9. **Choi, Y.,** Lee, B., You, H. (2014). A case study of eco-design for a bladelss fan by performance, usability, and life-cycle assessments. *Korean Journal of Life Cycle Assessment, 15*(1), 143-156.
10. Park, J., **Choi, Y.,** Lee, B., Jung, K., Sah, S., You, H. (2014). A classification of sitting strategies based on driving posture analysis. *Journal of the Ergonomics Society of Korea, 33*(2), 87-96.
11. **Choi, Y.,** Park, J., Lee, B., Jung, K., Sah, S., and You, H. (2013). A classification of sitting strategies based on seating pressure distribution. *Journal of the Korean Institute of Industrial Engineers, 39*(2), 105-108.

Intellectual Properties

International Patents

1. You, H., **Choi, Y.**, Kim, M., Kim, J., Kim, H., Lee, H., Nam, S., Lee, Y., Hong, S., Cheon, H., Yang, G., Na, D. Method, apparatus and system for monitoring eating. Application number: PCT/KR2020/008887, 2020. 7. 8
2. You, H., **Choi, Y.**, Lee, H., Pratama, G., Ko, M., Park, J., Kim, H., Yu, M. Smart nasometer. Application number: US15/686,207, 2017. 8. 25; registration number: US10,692,397, 2020. 6. 23

Korean Domestic Patents

1. You, H., **Choi, Y.**, Kim, M., Kim, J., Kim, H., Lee, H., Nam, S., Lee, Y., Hong, S., Cheon, H., Yang, G., Na, D. Method, apparatus and system for monitoring eating. Application number: 10-2019-0086606. 2019. 7. 17.
2. You, H., **Choi, Y.**, Lee, H., Pratama, G., Ko, M., Park, J., Kim, H., Yu, M. Smart nasometer. Application number: 10-2017-0107302. 2017. 8. 24.; registration number: 10-1979356, 2019. 5. 10.
3. Lee, J., **Choi, Y.**, Kang, J., You, H. Visual field tester. Application number: 30-2017-0027776, 2017. 6. 6; registration number: 30-0940832, 2018. 1. 15.
4. You, H., Park, B., **Choi, Y.**, Lee, N., Kim, S. Yellow dust mask. Application number: 10-2015-0083467, 2015. 6. 2; registration number: 10-1801828, 2017. 11. 21.
5. You, H., **Choi, Y.**, Park, J., Ko, M., Yu, M., Choung, W., Lee, E., Lee, S., Lee, C., Choe, J. Exercise apparatus for upper limb rehabilitation. Application number: 10-2015-0064723, 2015. 5. 8; registration number: 10-1708851, 2017. 2. 15.
6. You, H., **Choi, Y.**, Park, J., Ko, M., Yu, M., Choung, W., Lee, E., Lee, S., Lee, C., Choe, J. Medical functional game system for active Kegel exercise and abdominal breathing and driving method thereof. Application number: 10-2015-0031626, 2015. 3. 6; registration number: 10-1686983, 2016. 12. 9.
7. Kim, M., **Choi, Y.**, You, H. The arm rest of a seat. Application number: 10-2014-0152184, 2014. 11. 4; registration number: 10-1601525, 2016. 3. 2.
8. You, H., Lee, B., Park, J., **Choi, Y.**, Lee J., Sah, S. Seat motion system for eye location correction. Application number: 10-2013-0124903, 2013. 10. 18; registration number: 10-1520472, 2015. 5. 8.
9. You, H., Yang, X., **Choi, Y.**, Lee, W., Cho, B., Yu, H. 3-dimensional virtual liver surgery planning system. Application number: 10-2012-0021850, 2012. 3. 2; registration number: 10-1481796, 2015. 1. 6.

10. Kim, M., Lee, H., Gweon, O., Park, K., You, H., Jeong, Y., **Choi, Y.**, Park, J. Bus seat. Application number: 30-2014-0007912, 2014. 2. 17; registration number: 30-0774276, 2014. 12. 1.
11. You, H., Lee, B., Park, J., **Choi, Y.**, Lee J., You, T., Lee, H., Sah, S. Apparatus for reducing driver's fatigue. Application number: 10-2013-0109256, 2013. 9. 11; registration number: 10-1468116, 2014. 11. 26.
12. You, H., Park, J., Lee, B., **Choi, Y.**, Jung, K. Body pressure distribution analysis system and method thereof. Application number: 10-2012-0054438, 2012. 5. 22; registration number: 10-1351395, 2014. 1. 8.

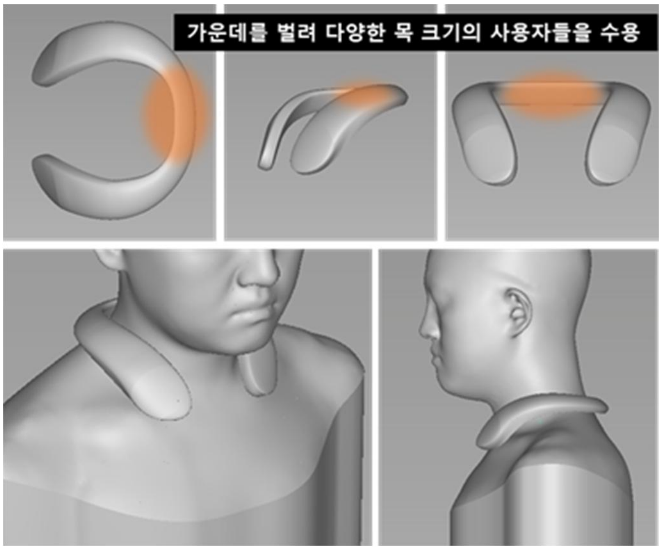
Awards

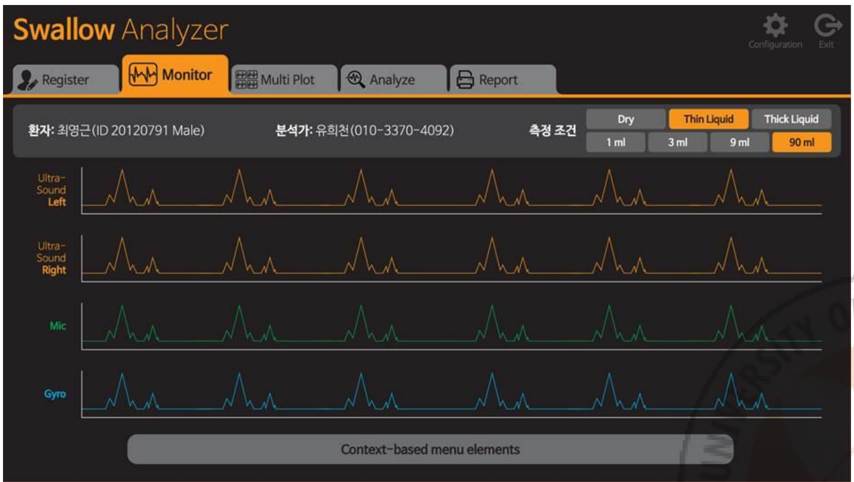
1. 2016 University Creative Invention Award, Excellence Award, Korea Invention Promotion Association (KIPA)
2. 2013 Industry-Academic Collaboration Project Award, Grand Prize, Korea Institute of Industrial Engineers (KIIE)
3. 2013 University Creative Invention Award, Excellence Award, Korea Invention Promotion Association (KIPA)
4. 2012 Seoul International Invention Fair, Silver Prize, Korea Invention Promotion Association (KIPA)
5. 2012 Best Student Paper Award, Korea Institute of Industrial Engineers (KIIE)
6. 2011 Seoul International Invention Fair, Gold Prize, Korea Invention Promotion Association (KIPA)

Projects

1. Enhancement of quality of life for the elderly by monitoring swallowing function

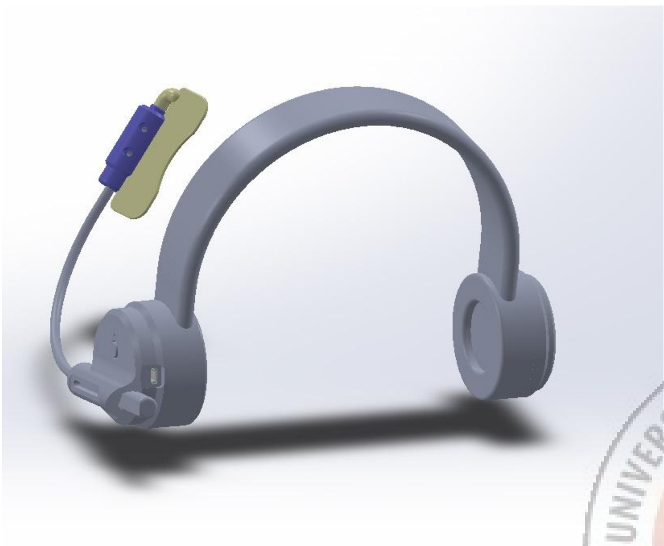
   - ✓ Research period: 2016. 10 ~ 2020. 7
   - ✓ Client: National Research Foundation of Korea (NRF)
   - ✓ Role: Project Management
   - ✓ Major achievements: Ergonomic design of a novel swallowing monitoring device and user interface





2. Development of serious games for healthcare

- ✓ Research period: 2012. 8 ~ 2020. 7
- ✓ Client: Chonbuk National University Hospital
- ✓ Role: Project Management
- ✓ Major achievements: Commercial level serious games for speech therapy and a novel vocal interface

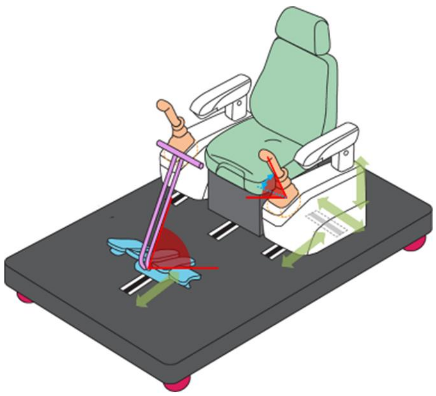


3. Analysis of passenger behavior patterns and development of improved designs for bus premium passenger seat system
   - ✓ Research period: 2017. 5 ~ 2018. 6
   - ✓ Client: NGV-Hyundai Kia Automotive Group
   - ✓ Role: Experiment design, idea development

4. Anthropometric analysis of the ear for earbud design
   - ✓ Research period: 2016. 6 ~ 2016. 8
   - ✓ Client: Logitech
   - ✓ Role: Project Planning

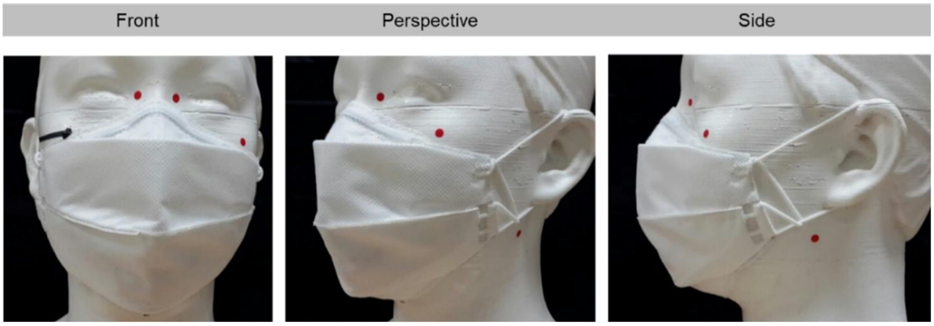
5. Anthropometric analysis of pilots and cockpit layout design for KF-X
   - ✓ Research period: 2016. 4 ~ 2018. 2
   - ✓ Client: Korea Aerospace Industries
   - ✓ Role: Project planning, experiment design, anthropometric measurement

6. Ergonomic evaluation of excavator designs
   - ✓ Research period: 2015. 12 ~ 2016. 5
   - ✓ Client: Hyundai Heavy Industries
   - ✓ Role: Project planning, experiment design, user behavior analysis
   - ✓ Major achievements: Suggestions for PUI designs of excavator



7. Development of an ergonomic dust mask design using 3D facial data

- ✓ Research period: 2015. 6 ~ 2015. 12
- ✓ Client: LG Household & Health Care
- ✓ Role: Project planning, experiment design, idea development
- ✓ Major achievements: Improved design for dust mask



8. Development of design strategies and ergonomic designs for earset using 3D ear scan data

- ✓ Research period: 2015. 5 ~ 2015. 8
- ✓ Client: LG Electronics
- ✓ Role: Project management
- ✓ Major achievements: Commercialized ear bud design for LG V20 smartphone

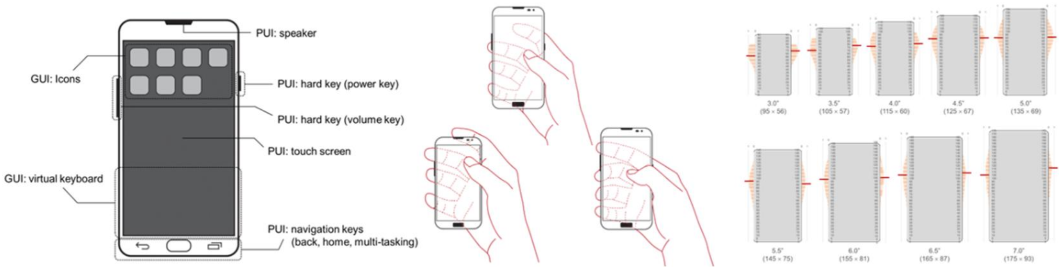
9. Development of ergonomic bus seat design using 3D sitting body shape data and cushion density preference
    - ✓ Research period: 2015. 4 ~ 2016. 3
    - ✓ Client: NGV-Hyundai Kia Automotive Group
    - ✓ Role: Project management

10. Evaluation of the clinical performance of a PC-based perimetry for glaucoma diagnosis
    - ✓ Research period: 2014. 6 ~ 2016. 4
    - ✓ Client: Ministry of Health & Welfare
    - ✓ Role: User interface design

11. Development of a seat design methodology based on the 3D profile analysis of sitting posture and an ergonomic armrest based on voices of customers
    - ✓ Research period: 2013. 9 ~ 2014. 8
    - ✓ Client: NGV-Hyundai Kia Automotive Group
    - ✓ Role: Project management
    - ✓ Major achievements: Commercialized seat design for Hyundai-Kia bus

12. Development of ergonomic design guidelines of button layout for smart phone

   ✓ Research period: 2013. 5 ~ 2013. 10
   ✓ Client: LG Electronics
   ✓ Role: Project management
   ✓ Major achievements: Design guidelines of button layout for LG smart phones



13. Evaluation of a ventilation structure at the midsole of shoe

   ✓ Research period: 2012. 12 ~ 2013. 8
   ✓ Client: Kyoungdo, Inc.
   ✓ Role: Experiment and statistical analysis support

14. Development of mass clothing custom design technology and system for living convenience of wheelchair users

   ✓ Research period: 2012. 9 ~ 2015. 8
   ✓ Client: National Research Foundation of Korea (NRF)
   ✓ Role: Experiment design, experiment support

15. Evaluation of ergonomic oxygen mask designs for Korean fighter pilots

- ✓ Research period: 2011. 11 ~ 2012. 10
- ✓ Client: ROK Air Force
- ✓ Role: Experiment support

16. An action plan for enhancement of POSCO design capabilities

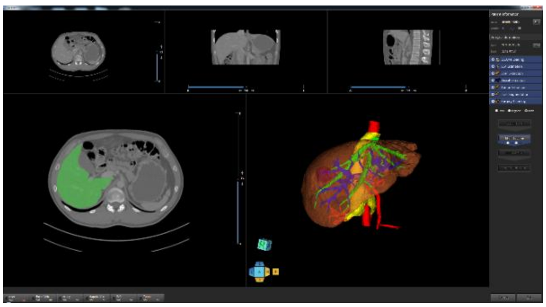
- ✓ Research period: 2011. 7 ~ 2011. 12
- ✓ Client: POSCO
- ✓ Role: Project planning

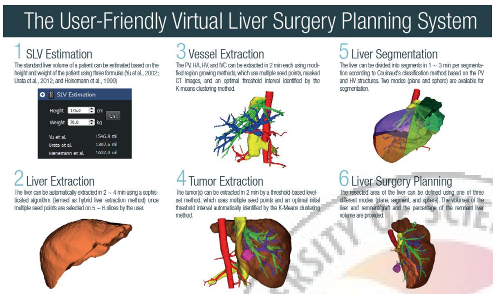
17. Seat comfort guide by ergonomic experimentation

- ✓ Research period: 2010. 4 ~ 2010. 10
- ✓ Client: NGV-Hyundai Kia Automotive Group
- ✓ Role: Experiment and analysis support

18. Exploration of new strategies for the diagnosis and treatment of hepatopancreaticobillary cancer

- ✓ Research period: 2008. 12 (2010 joined) ~ 2013. 3
- ✓ Client: Ministry of Health & Welfare
- ✓ Role: Use scenario development, user interface design
- ✓ Major achievements: User interface for 3D liver surgery planning system ‘Dr. Liver’

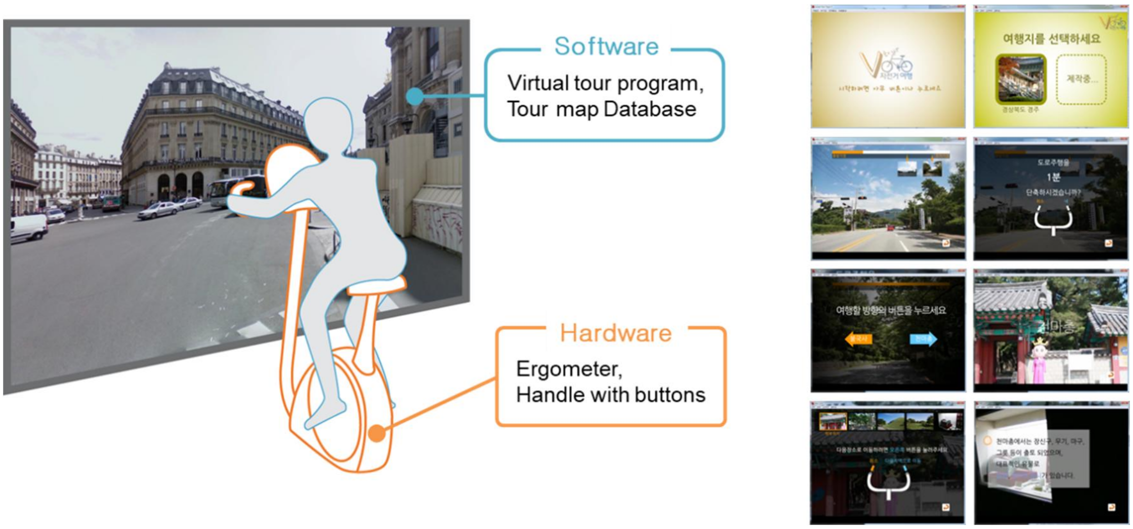




19. Development of brain fitness programs for social, physical, emotional, and cognitive capabilities of seniors

- ✓ Research period: 2010. 2 ~ 2013. 2
- ✓ Role: Project management
- ✓ Major achievements: A musical brain fitness program 'Smart Harmony' and a virtual tour program 'Brain Bike'


Smart Harmony



Brain Bike

Research Equipment Applied

1. Pressure mat: X3 PX100 48×48 (XSENSOR Co., Canada)

2. Electromyography: TELEMYO DTS Telemetry (Noraxon, Inc., USA)

3. Thermal infrared camera: FLIR T640 (FLIR Systems, Inc., USA)

4. Motion capture system: Hawk-I (Motion Analysis Co., USA)

5. 3D scanner: Artec 3D Eva (Artec Group, USA), Rexcan 560 (Solutionix Inc., Korea)

6. 3D printer: Dimension SST (Stratasys, Ltd., USA)

7. User observation system: Portable human behavior observation and analysis device (Noldus Information Technology, USA)