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Characterization of Korean Population Anthropometric Data Using Multivariate Statistics

다변량 통계를 활용한 한국인 인체측정 데이터 분석

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산업조선공학부 인간공학 전공

지수찬

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이 논문을 공학박사 학위논문으로 제출함
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Abstract

Characterization of Korean Population Anthropometric Data Using Multivariate Statistics

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Humans control the interface by using hands and feet. Thus, the men control the machines at their intent and use various tools. Therefore, to design an interface comfortable for men, designing products and systems based on the size information on hands and feet is important. Also, the hands and feet provides various size information as they are composed of numerous numbers of muscles, bones, and joints. Such information is used in various areas including interface design, forensics, and emergency medical science.

The purpose of this research is to identify physical properties of hands and feet of South Koreans, and the use the size information to develop a model estimating physical properties like gender, height, and weight. Also, the purpose of the research is to evaluate and estimate the degree of discomforts from using the product by applying the physical properties and measured values to frequently used interface (electronic products, and national defense weaponry system).

First, physical properties of hands and feet of South Koreans were understood at Phase I. From the hand size information of 321 adults provided from Size Korea, major factors determining the shape of South Koreans (Width of hand, length of palm, and length of fingers) were identified, and classified the shape into four sections. Compared to other ethnic groups, the research identified that the males and females of South Koreans have wider hand width than other ethnic groups. Moreover, representative hand manikin size accommodating 95% of South Koreans was deducted by using boundary condition method. In case of feet, major factors determining the shape of feet of Koreans were identified by analyzing feet size data of 461 people, and four clusters were identified by using cluster analysis. Also, feet manikin size representing the 95% of the feet size of Koreans was deducted.

Second, in phase II, the research has developed a statistical model estimating gender, height, and weight by using body measured value. The research separated males from females by using discriminant analysis on 29 measured variables in the hands. Highest level of accuracy was shown when using the maximum hand circumference, and variables related with width and circumference showed higher estimation accuracy than the length. Feet also estimated the gender by using the size information of 10 parts of feet and discriminant analysis, and navicular circumference showed the highest estimation accuracy (86.2%). When estimating height, height was estimated by using regression analysis using the parts with high relevance with heights among various parts of hand and feet. Both genders showed the highest level of accuracy when using hand length, and for the R^2 of the regression equation, males showed 0.678, and females showed 0.534. Among various parts of feet, feet length showed the highest level or accuracy, and for the R^2,males showed 0.567 and females showed 0.188 of accuracy. The weight estimation model has developed the model by using regression analysis

using the circumference length of 9 parts of the hands, feet and body. The level of accuracy was the highest when using the breast circumference (R^2=0.742).

Third, in phase III, ergonomic evaluation on the interface of smart phone, F-16 aircraft seat, and K-2 rifle was conducted by using the measured value of hands and feet. Mainly, the level of discomforts on 21 UI points frequently used on 4.3 inch android smartphone was evaluated, and the points capable of easy touching when considering body sizes were identified. For F-16 cockpit, the evaluation was conducted to find out whether the Korean pilots may use the cockpit without discomforts for 6 major piloting postures, and it was expected that the discomforts may arise as 11.6 % of the male pilots and 27.5% of the female pilots could not touch the brake with their feet or had to additionally change postures for their feet to touch the brake when using full brake. On the interface evaluation on the controlling part of the K-2 rifle, it was expected that 39.6% of the males would have collision of finger on the trigger guard when controlling the trigger as they have long finger. In case of 72.1% female soldiers, it was expected that they would feel discomforts as the index finger does not touch the switch on the controlling part of the rifle.

It is expected that the result of the current research would help the researchers and engineers when designing interface for South Koreans. The statistical methods and analysis tools may be utilized for evaluating and improving the interface of other products and systems beside smart phones, aircrafts, rifles and others that were evaluated in the current research.

Keywords : Hand Anthropometry, Anthropometric Design, User Interface, Forensic Anthropometry, Foot Anthropometry, Military Anthropometry

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Contents

List of Tables

List of Figures

Chapter Ⅰ

Introduction

1.1 Background and Problem Statement

Human may take various body motions using hands and feet, and conduct various activities through such motions. Among the body parts humans have, hand is the body part allowing most delicate movement, also allows various motions as hand is composed of a lot of muscles and joints, and takes different shapes for different person (Chaffin, Andersson, & Martin, 1999). Feet takes a lot of roles for moving and working, and takes different shapes for different person as feet are composed of numerous numbers of bones and muscles (Witana, Xiong, Zhao, & Goonetilleke, 2006).

Many researchers are researching for the production of hand tools convenient for users or designing of products related to the size design of gloves or hands through considering various postures and shapes of hands while understanding the properties of hands and feet (Meagher, 1987; Tichauer & Gage, 1977). The focus is on the development of shoes or pedals comfortably worn by users, and many researches are underway related to feet (Y.-C. Lee & Wang, 2014).

However, even with such efforts, hand tools frequently used in South Korea were used through the importation of tools reflecting the physical properties of Westerners, and even if the hand size of South Koreans are reflected, only the average length and the width of hands were considered (Kim & Kee, 2012). Thus, some users felt discomforts. For example, even if two people have identical length and width of hands, the discomfort from different shape of hands might differ from person to person. The cause of the problem comes from the leaving various hand shapes of South Koreans out of consideration at the production design process (Kee, 2011). For the development of hand tool-related products appropriate to South Koreans, understanding the properties on the various hand shapes of South Koreans are required.

Also, the size information of hands and feet are not only used in the development of related products and interface design, but also was used in confirming the identity of presumed personnel in the area of forensic and emergency medical science (Kanchan, Krishan, Shyamsundar, Aparna, & Jaiswal, 2012). For example, when conducting an analysis on the traces remaining on the scene of incident, handprints and the length of the footprints are used for the estimation of gender or height (Kanchan & Rastogi, 2009). Especially, in case of crime scene, there are many cases when the only clue for predicting the criminal is the handprints or footprints (Kanchan et al., 2012). So, Forensic anthropometry method using hand and foot size is a useful tool for confirming the identity on the presumed personnel. However, the hand and foot anthropometry research in South Korea is biased toward the development of interface related with production design, and the utilization on the forensic area is comparatively lower than other areas. Therefore, it is required to expand the area of hand and foot anthropometry research for the utilization in the forensic area. Measurement of hands and feet size of various South Koreans, and the development of estimation tool for confirmation of the identity of presumed personnel usable in the field of hands-on-area of forensics using reliable data are urgent for this.

Recently the attention on the wearable electronic devices used after attaching to various body parts for the measurement and management of health information of human body became big, and many products are under development (Mistry & Maes, 2009). These products are usually attached on the fingers, wrists, ankles, necks, and others. Especially, the devices are worn on the hands-related parts for convenient wearing and continuous acquisition of information. For wearable devices to provide better user experience, user’s context (Gender, physique, weight) should be considered for the provision of more accurate health information (Di Rienzo et al., 2005). However, the research on the relationships between various sizes of hands and feet of South Korean and the size of physical properties related with gender, weight, and height is lacking, and the limitation unable to provide enough guideline on related industry exists.

Lastly, the weapon system used in South Korean military are developed locally or imported from United States of America or Europe (Heo, 1999). In case of locally-developed weapon systems, the cases triggering discomfort of users sometimes occur from lack of consideration on the ergonomic elements in the design phase (Kim et al., 2001). Likewise, the weapon systems imported from foreign countries do not suit the physical size of the users in the South Korean military and arouse discomforts as the interfaces were designed targeting the physical sizes of Western users. For the prevention of discomforts by users and the safe operation of weapons system, the development of weapon system should be conducted for the usage by various users without discomforts through the evaluation of accommodation level of weapon system by the application of anthropometric design process on the national defense weapon system.

1.2 Research Objective

The purpose of the current research is to distinguish the properties of hands and feet of South Koreans through the analysis on the hands and feet size data, analyze relevance between the size per parts of hands and feet with gender, stature, and weight, and the suggest a guideline on the design of interface comfortable for the users through the utilization of hand and feet size of South Koreans. The specified objectives of this study are as follows.

First, the current research will distinguish the properties of hands and feet of South Koreans using statistical method. The existing researches usually suggested measured value of bodies, and the provision of information on various shapes of hands and feet lacked. The research shall distinguish the key factors determining the shape of hands and feet of South Koreans using the statistical method, and understand the properties of hands and feet of South Koreans after grouping the results to overcome the limitation. The properties of hands and feet of South Koreans shall be compared through the comparison of other ethnic groups of foreign countries with the understood shape information. Moreover, the research is trying to develop body manikins representing the hands and feet of South Koreans through the application of boundary condition method assuring 90% of accommodation level targeting South Koreans using few manikins representing the body type of target population.

Second, the research will suggest a model estimating gender, stature, and weight by using measured value of hands and feet of South Koreans. The existing researches estimated gender, length, or height by using the measured data of various parts of hands (length and width of hands, length of finger, length of palm) and parts of feet. The current research will estimate gender, stature, and weight and compare the accuracy of estimated model with existing research results by adding more specified parts of hands and feet beside the parts used in the existing researches.

Third, the current research tries to suggest a guideline for the interface design of smartphone, aircraft cockpit and K-2 rifle control unit which two of the weapon system frequently used by Korean military users by data measuring hands and feet of South Koreans.

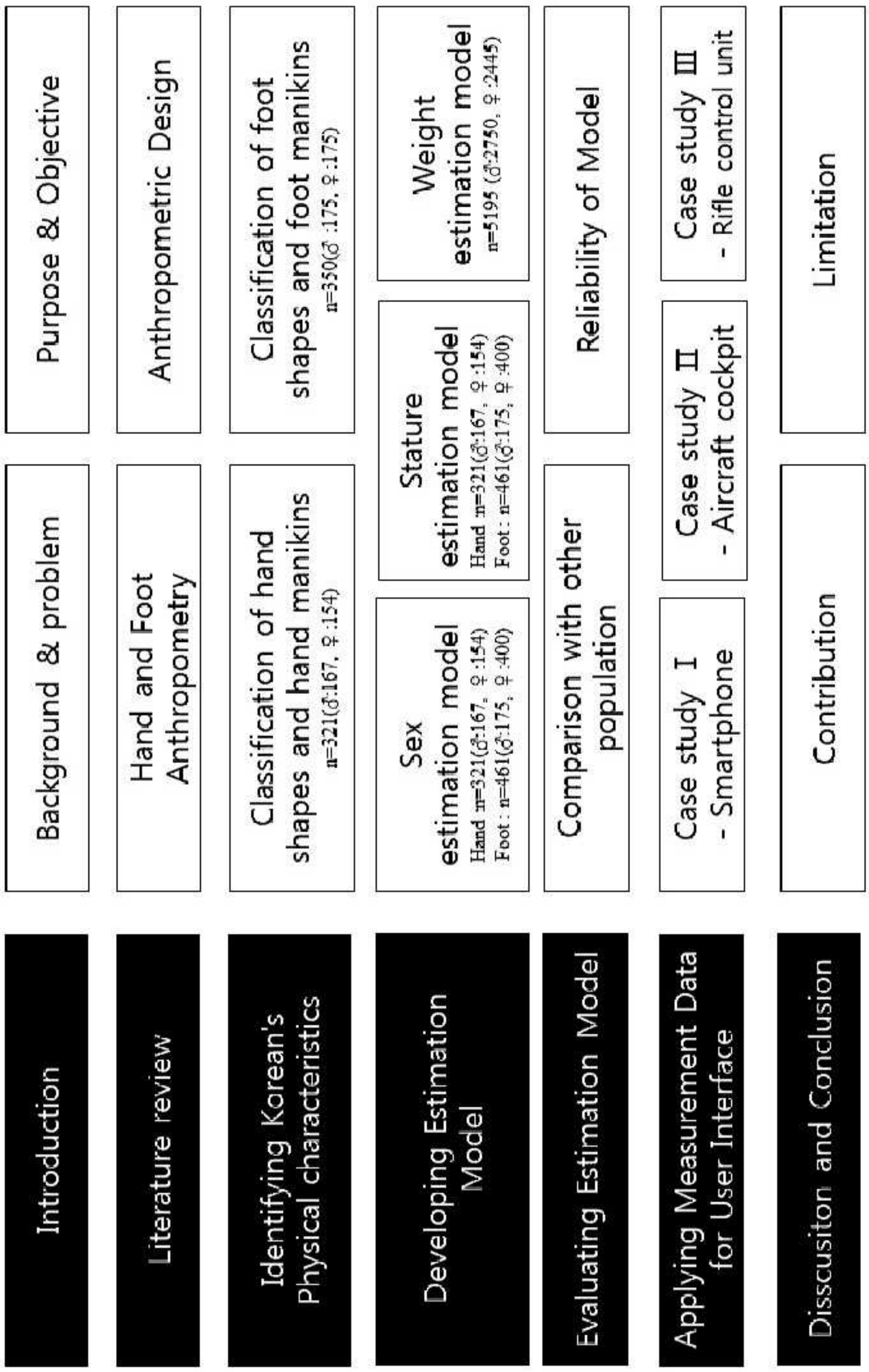
The existing researches had interests on smartphone UI design considering physical properties of users. However, a guideline on the design UI considering the size of hands of South Koreans lacked (Jee et al., 2014). Therefore, the current will identify point easy for touching by users based on the distribution of size of hands of South Koreans, and suggest a guideline for UI design for the enhancement of convenience of users based on the result of the test measuring the degree of discomforts of touching. Moreover, the research will evaluate the whether the users in South Korean military may use without difficulty or not when considering the physical properties of Koreans on the portion of national defense weapon system used in the South Korean military. The existing weapon system developed in South Korea are commonly developed without ergonomic consideration (Hancock & Hart, 2002), and the weapon systems introduced from foreign countries lacked sufficient verification on the physical size of local users as the systems were developed in accordance with the size of westerners. Therefore, the current research will evaluate the interface of the relevant weapon system in the view of anthropometric design after selecting K-2 rifle, and the cockpit of F-16 aircraft, and suggest a guideline for better interface.

1.3 Organization of Thesis

This thesis consists of 7 chapters and will cover the subjects shown in Figure 1.1.

Chapter 1 describes research problems and objective of this study. Chapter 2 reviews literature and introduces theories related to hand and foot anthropometry. Chapter 3 provides Korean's physical characteristics identified by analyzing hand and foot measurement data. Chapter 4 proposes sex, stature, and weight estimation model by using statistical method. Chapter 5 describes the evaluation result of estimation model developed in chapter 4 by comparing result with other nationalities. Chapter 6 describes application of hand and foot measurement data for evaluating user interface regarding ergonomic convenience. Chapter 7 discusses the summary of finding, contribution and limitation of this study

Figure 1.1. Overall procedure of this thesis



Chapter Ⅱ

Literature Review

2.1 Anthropometry

Anthropometry is a study for designing products and systems suiting the users through the measurement of various body parts and physical properties of users. (Wickens, Lee, Liu, & Gordon-Becker, 1998) Anthropometry may be divided into static dimension and dynamic dimension in accordance with the posture of measurement. (Sanders & McCormick, 1987) Static measurement is about measuring the sizes including the length, circumference, and width of fixed body while the subject maintains standard position. To get precise measurement results in the measurement of static sizes, the subject should maintain the measurement position in a correct manner, and the measurement process should be standardized through education or training on the measuring agent. Dynamic measurement is about measuring the range of body parts in accordance with the movements of upper and lower body parts of the subject, and measures sizes practical in the usage of real work or system. Static measurement is a measurement type reflecting the property which the body parts move in harmony (Sanders & McCormick, 1987).

Several errors exist when direct measuring by the measuring agent. First, there is the error of measurer. It is the error occurring when repeatedly measuring a single subject by a measurer. Next, it’s the error between the measurers. There are incident when the measured values are different between the measurers even the measurement is on the identical person. This may be occurred from the differences in the methods of measurement or the methods of viewing the gradations between the measurers. Next, there are the error occurring from the movement of the measurer’s posture during the measurement, and the measurement tool (Ulijaszek & Kerr, 1999).

In the past, direct measurement of various parts of the body by people were general, but the cases of measuring body parts using 3D scanner are increasing in number with the development of science and technology. Using the 3D scanner has the strength of reducing the time and the cost of measurement than manual measurement by the measurer. With such strengths, lots of countries including South Korea are using 3D scanner for body measurement, and the measured data are being used as a basic data for the designing of better products and systems (Krauss, Langbein, Horstmann, & Grau, 2011).

When using 3D scanner, markers are attached to the major parts of the body, and the attached markers are automatically identified and the three-dimensional coordinate value of body surface is acquired. Three-dimensional body shape image is created using the values, and the measurement value may be acquired through the designation of the value of specific part by using an analysis program.

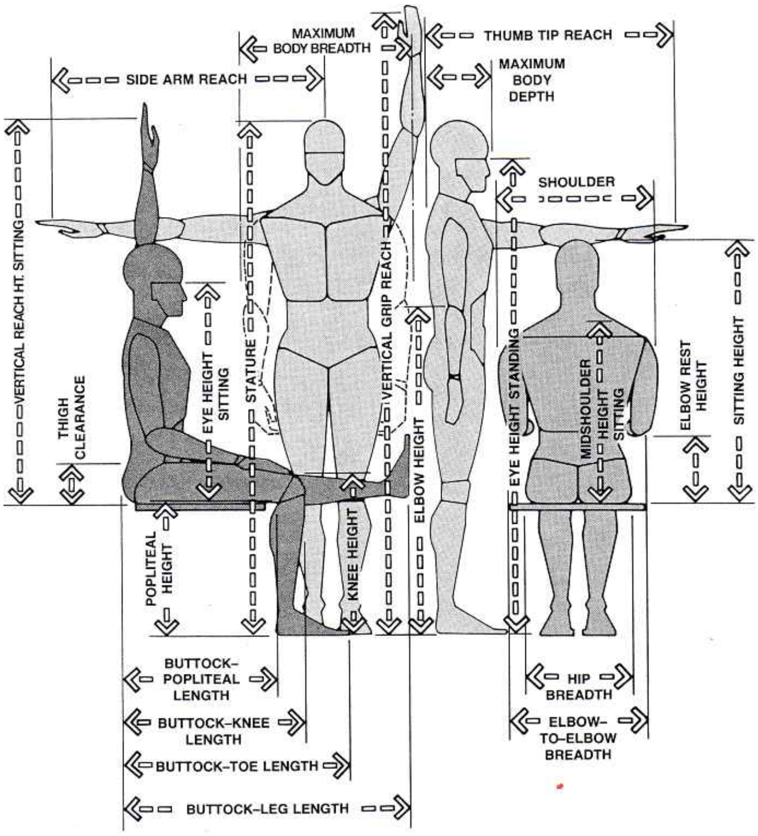


Figure 2.1. Anthropometric dimensions (Sanders & McCormick, 1987)

2.2 Hand Anthropometry

2.2.1 General hand anthropometry research

Hands are the most frequently used body part, and a single hand consists of 27 bones and 15 joints, allowing various postures, and also can provide various measured information (Figure 2.2).

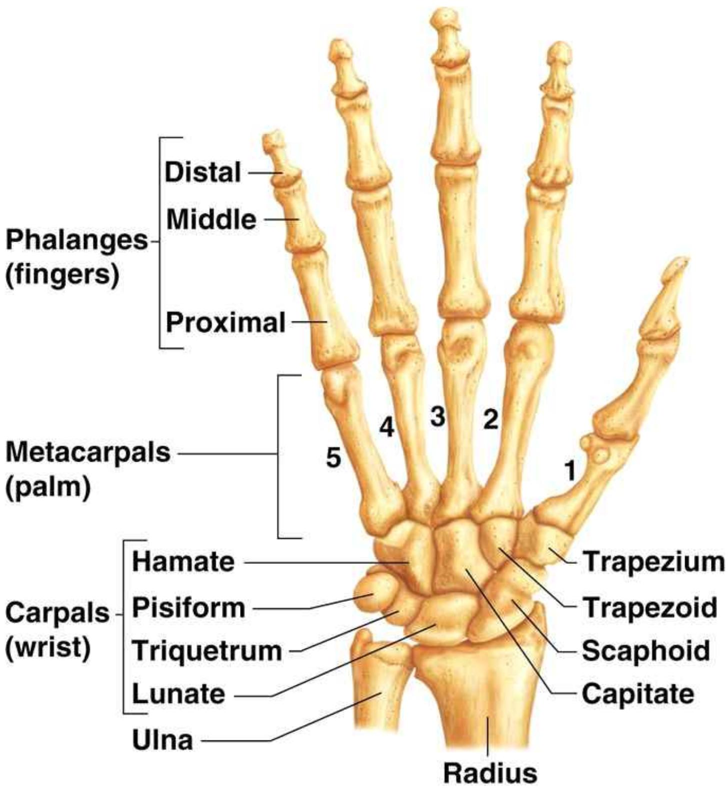


Figure 2.2. Structure of the hand (Ellison, 2002)

Anatomically, the bones of hand are composed of carpal bone, metacarpal bone, and phalanges like the picture. The carpal bone can be divided into proximal carpal row and distal carpal row. The metacarpal bone is a bone composing the palm, and is composed of 5 bones. For phalanges, the thumb case has 2 finger joints, and the other fingers are composed of 3 finger joints, and are composed of 14 different bones. Each finger is composed of four joints of carpal metacarpal (CMC), metacarpophalangeal

(MCP), Proximal interphalangeal (PIP), and distal interphalangeal (DIP).

There are 35 muscles on the hand moving hands and arms beside the bones and the joints. In accordance with the area of the muscle, the muscles can be divided into extrinsic muscle located in the forearm, and intrinsic muscle located within the hand (Kaplan, 1968).

Hand anthropometry measures various size information of hands, for example, the information on sizes and shapes, and uses the information on the product development and establishment of system through analysis. The existing researches recognize the importance of the information of hands, and various hand anthropometry researches were conducted (Hadler et al., 1978). The current research has investigated existing hand anthropometry research literatures. Foreign researches were collected using Google, Scopus, Springer link, and Science direct website, and the local researches were collected using search websites including RISS, DBpia, KERIS and others and the Seoul National University's library search portal. As a result of classifying existing researches related with hand anthropometry by subjects, the research could characterize the researches into two areas. First area was the researches measuring various parts of hands and confirming the distribution of sizes for the determination of hand tool or glove size appropriate for the users. The representative researches are as follows Table 2.1 and 2.2).

Table 2.1. Previous studies of Korean hand anthropometry

Authors	**Population**	**Measured dimension**
HS Jeong (2003)	Korean adult	Hand size (finger and palm)
EK Jeon (2004)	Korean girls	Hand size (finger, phalanges and palm)
DH Kee (2011)	Korean adult	Hand size (finger, phalanges and palm)

Table 2.2. Previous studies of hand general anthropometry

Authors (year)	**Population**	**Measured dimension**
Hertzberg (1950)	American pilot	Body and hand size
Courtney (1984)	Chinese female	Hand size (finger, phalanges and palm)
Wagner (1988)	German pianist	Hand size and range of finger movement
Gite (1989)	Indian farm workers	Body and hand size
Greiner (1991)	American soldiers	Hand size (finger, phalanges and palm)
OKunribido (2000)	Nigerian farm workers	Hand size (finger, phalanges and palm)
Kulakslz (2002)	Turkey university students	Hand size, hand length /body weight ratio
Kar (2003)	Indian farm workers	Hand size (finger, phalanges and palm)
Eksioglu (2004)	American	Thumb crotch span, grip force
Saengchaiya (2004)	Thai female workers	Hand size (finger, phalanges and palm)
Imrhan (2006)	Bangladesh male	Hand size (finger, phalanges and palm)
Motamedzade(2007)	Iranian	Hand size (finger, phalanges and palm)
Visnapuu (2007)	American young students	Hand size and hand grip strength
Mandahawi (2008)	Jordanian	Hand size (finger, phalanges and palm)
Hughes (2011)	American children	Hand length and width
Cáceres (2012)	Colombian farm workers	Hand size (finger, phalanges and palm)
Dianat (2015)	Iranian	Hand length, width, thickness, palm length

In the above mentioned researches, sizes on various parts of hands were reported based on the static or dynamic physical measurement, and there were researches for the suggestion of hand tool guideline or understanding of the properties of hands for the designing of products appropriate for the users. The existing local researches related with the physical properties of hands focused on the design of gloves, and hand limitation of focusing only on the reporting of size value on the measured items after selecting the measured items of hands, and on the analysis of basic statistics (Kim & Kee, 2012). The researches only limited the length, width and circumference of hands as central variables of designing of hands-related interface among various parts of hands, and mainly suggested designing of average value-centered interface.

2.2.2 Forensic Hand Anthropometry Research

As hands are most frequently used body part, traces related with the hands often remain at crime scenes, so hand anthropometry having purpose of confirming identity of a criminal by using hands-related measured information were conducted from the past (Aboul-Hagag, Mohamed, Hilal, & Mohamed, 2011). These researches classified the gender of an estimated person using the sizes of fingerprints, or predicted the length of a criminal by using various sizes of fingerprints (Table 2.3).

Table 2.3. Forensic hand anthropometry for ses estimation

Authors (year)	Population	Measured dimension for sex estimation
Manning (2004)	Chinese, Jamaican	2D, 4D length
Case (2007)	European	Phalange, metatarsal, metacarpal length
Kanchan (2009)	Indian	Hand length, hand breadth
Kanchan (2010)	Indian	2D, 4D length
Hagag (2011)	Egyptian	Hand length, breadth, 2D, 4D length
Krishan (2011)	Indian	Hand length, hand breadth
Jowaheer (2011)	Mauritian	Hand length, hand breadth
Ishak (2012)	West Australian	Hand length, palm length finger length
Mahak' (2013)	Thai	Proximal hand phalange length
El morsi (2013)	Egyptian	Phalange, metacarpal length
Krishan (2013)	Indian	2D, 4D length

Table 2.4. Forensic hand anthropometry for stature estimation

Authors (year)	Population	Measured dimension for stature estimation
Krishan (2007)	Indian	Hand length, hand breadth
Arun (2008)	Mauritius	Hand length, hand breadth
Agnihotri (2008)	Mauritius	hand lengths and hand breadths
Habib (2010)	Indian male	Phalanges
Ahemad (2011)	Indian male	Hand length, hand breadth, phalange
Nasir (2011)	Indian	Hand length, hand breadth
Ishak (2012)	West Australian	Hand length, hand breadth
Ozaslan (2012)	Turkish	Hand length, hand breadth
Altayeb (2013)	Sudan	Hand length, hand breadth
Petra (2014)	Slovak	Hand length, hand breadth

For the Indian population, many attempts have been made to estimate sex using hand dimensions (Krishan et al., 2011). Kanchan measured the hand length and palm length of 500 males and females (from 17 to 20 years old) in North and South India. He tried to identify the subject's sex using sectioning point analysis of hand and palm lengths (Kanchan & Rastogi, 2009). This study showed that the hand breadth, palm lengths, and hand lengths showed 87%, 85.7%, and 83% accuracies for males, and 91%, 89.6%, and 88.5% for females respectively. Ishak conducted a study to determine sex using the dimensions of various hand parts and hand prints collected from 200 Australian subjects (Ishak, Hemy, & Franklin, 2012). In the study, the hand breadth and length were reported to offer the highest identification accuracy. Jowaheer and Agnihotri measured the hand and foot lengths of 250 Mauritians (from 18 to 30 yrs old). They derived a logistic regression model for prediction, which showed 91.2% accuracy by using hand length and hand breadth; the model also yielded an R^2 value of 0.77 (Jowaheer & Agnihotri, 2011).

Previous studies using various hand parts have also been conducted (Table 2.4). Case and Ross predicted the sex of 259 individuals by using the length of the phalange, metatarsal, and metacarpal bones. In their research, the phalange length showed higher prediction accuracy than the length of the metatarsal or metacarpal (Case & Ross, 2007). Aboul-Hagag et al. attempted sex determination by using variables such as hand length, hand breadth, and index finger versus ring finger length ratio. In the study, the hand index (hand breadth/hand length) showed 80.0% of accuracy for males, and 78.0% for females (Aboul-Hagag et al., 2011). Manning et al. attempted to distinguish sex using the ratios of the length between the index (2D) and ring finger (4D). The study showed that there is a higher possibility of a greater 2D to 4D ratio for females than for males due to growth hormones (Manning et al., 2004; Trivers, Manning, & Jacobson, 2006). From an empirical study of Indian subjects, Kanchan, Kumar, and Menezes reported that 2D to 4D ratio can be used as a significant sex indicator (Krishan et al., 2013), but Voracek's study did not concur because the ratio varies considerably for different regions and nationalities (Voracek, 2009). Osteological and radiologic analysis of hand bones has been conducted. El Morsi and Howary used X-ray radiographs from 3800 Egyptian metacarpals and phalanges to derive a logistic regression model. In their research, the thumb proximal phalange length showed the highest accuracy value of 85% in prediction (El Morsi & Al Hawary, 2013). The model yielded 96.1% of accuracy by using diverse hand dimensions (Mahakkanukrauh et al., 2013). The previous studies discriminated the sex of subjects mainly based on the hand length and breadth. However, more diversified hand dimensions need to be investigated for sex estimation because hand prints or hand is often damaged (Kanchan & Krishan, 2011).

A number of previous studies used parts of the hand to estimate stature. Agnihotri used the hand lengths and breadths of 250 Mauritius students to predict their heights (Agnihotri et al., 2008). In the study, hand length was shown to be the most important predictor of stature, and the estimation accuracy was found to be higher in females (R^2=0.564) than in males (R^2=0.353). In the study by Habib on Egyptian subjects, the correlation between phalange lengths and stature was determined (Habib & Kamal, 2010). Ahemad, on the basis of the hand and phalange lengths of 503 Indian male subjects, showed that hand length is the most important predictor of stature (Ahmed, 2013). Akhlaghi derived a regression equation with high accuracy from the lengths of the upper limb and hand (Akhlaghi, Hajibeygi, Zamani, & Moradi, 2012). Krishan used various dimensions of the hands and feet of Indian subjects to estimate their stature (Krishan & Sharma, 2007). Altayeb Abdalla used various dimensions of body parts constituting the upper limb of Sudanese subjects and showed that hand length is more predictable than hand breadth (Ahmed, 2013). Uhrova used hands and foot lengths for stature estimation. In the study, no bilateral difference in the right and left hands was shown, and the estimation based on hand length was reported to be more accurate in males (R^2=0.40) than in females (R^2=0.34) (Uhrová et al., 2013).

Previous studies used hand lengths and breadths or hand and foot lengths as a variable for deriving a regression equation for stature estimation. However, in some forensic investigation, it is impossible to measure hand length or breadth owing to some loss of damage to fingers. In such cases, it is not possible to predict height by using hand length or breadth. However, if prediction regression equations are available for different hand parts in addition to hand length and hand breadth, it will be possible to increase the success rate of stature estimation by using other regression models for diverse hand parts .

2.3 Foot Anthropometry Research

2.3.1 General Foot Anthropometry Research

Humans uses feet to move, and hands are also one of the body parts frequently used by humans. The structure of feet not only affects the development of strength, but affects the motor ability (Cavanagh et al., 1997). Under anatomical analysis of feet, a foot consists of 26 bones, 19 muscles, and numerous numbers of tendons. When looking at the feet in a functional manner, a foot may be divided into forefoot which is toe part, mid foot which is the top of a foot, and rear foot which is the hell. A foot consists of 38 muscles, and 60 big and small joints (Kaufman, Brodine, Shaffer, Johnson, & Cullison, 1999).

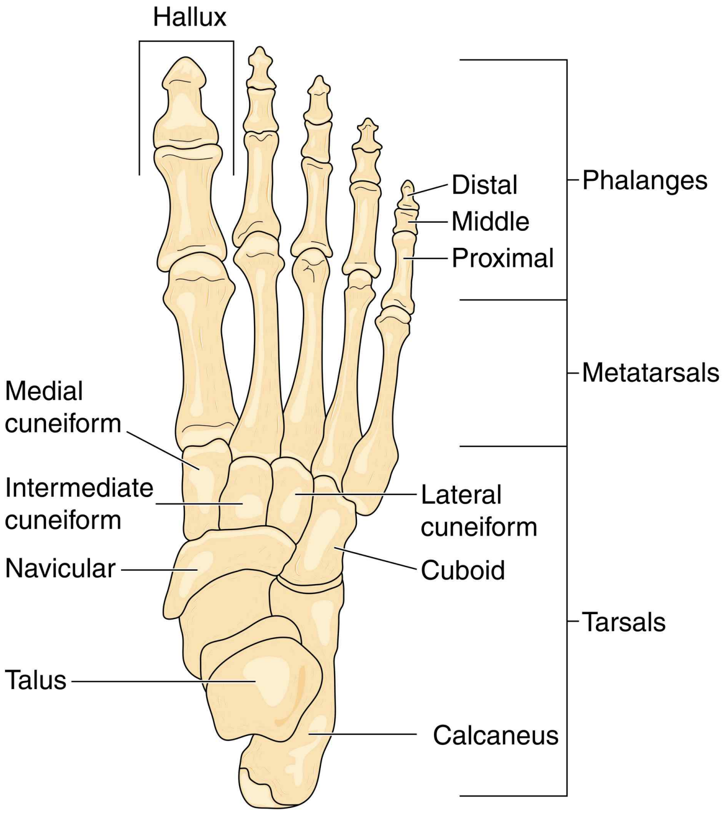


Figure 2.2. Structure of the foot (Williams, 2015)

A foot may be divided into 7 ankle bones composing an ankle, tarsals, metatarsal, and phalanges, ankle bones are composed of Talus, Calcaneus, Navicular, First cuneiform, Cuboid bone and others, and metatarsal is composed of 5 detailed metatarsal bones. A toe is composed of proximal phalanx, middle phalanx, and distal phalanx. Foot anthropometry research using the measured data of various parts of feet can be divided into two areas. The first area is the researches for the provision of shoes suitable for the users, and the development of appropriate sizing system through the study of various parts of feet (Table 2.5). As the shape of feet differ from person to person, researches classifying the shape of feet were conducted for systematic understanding of the shape.

Table 2.5. Previous studies for foot anthropometry

Authors (year)	**Population**	**Measured dimension**
Ferbabdez (1989)	Korean	Foot length and foot breadth
Parham (1992)	American	Foot length and breadth and toe size
Fernandez (1992)	Indian	Foot length and foot breadth
Huang (1994)	Taiwanese	Foot length and foot breadth
Goonetilleke(1997)	Chinese	Foot length and breadth and toe size
Mortazavi (2008)	Iranian	Foot length and breadth and toe size
Krauss (2008)	German	Foot length and foot breadth
Kanaani (2010)	Iranian	Foot length and breadth and toe size
Rawangwong(2011)	Thai	Foot length and breadth and toe size
Evans (2011)	Australian	Foot length and breadth and toe size
Hisham (2012)	Malaysian	Foot length and breadth and toe size
Rustagi (2013)	Indian	Foot length and breadth and toe size
Sarghie (2013)	Romanian	Foot length and breadth and toe size

Existing researches related with the shape of feet used the method of classifying properties through grouping the measure values on various parts of feet through statistical method focusing the production of footwear. Moreover, the researches on the shape of the elderly population were conducted with the increase of attention on elderly population from an aging of population.

Another area of research was the researches on the estimation of gender, heights and others of the estimated person using the traces of feet as the traces related with feet remained at the crime scene. Feet may provide information for understanding the identity of victims under huge disasters and accidents. These researches classify feet in accordance with the parts of feet, and analyze the connection between the size of the relevant part and the properties of a body with statistical method.

2.3.2 Forensic Foot Anthropometry Research

Table 2.6. Forensic foot anthropometry studies for sex estimation

Authors	Population	Measured parts for sex estimation
Ozden (2005)	Turkish	Foot length and foot breadth
Case (2007)	American	Phalanges
Sen (2011)	Indian	Foot length and foot breadth
Jowaheer (2011)	Indo-Mauritan	Foot length, foot breadth and foot index
Krishan (2007)	Indian	Foot length and foot breadth
Zeybek (2008)	Turkish	Foot length and foot breadth
Hemy (2013)	West Australian	Foot length and foot breadth
Ozaslan (2005)	Turkish	Foot length and foot breadth

Table 2.7. Forensic foot anthropometry studies for stature estimation

Authors	Population	Measured parts for stature estimation
Krishan (2007)	Indian male female	Foot length and foot breadth
Zeybek (2008)	Turkish	Foot length and foot breadth
Moorthy (2014)	Egyptian	Foot length and foot breadth
Hisham (2012)	Malaysian	Foot length and foot breadth
Hemy (2013)	West Australian	Foot length and foot breadth
Kanchan (2012)	Indian	Foot length and foot breadth
Pablo (2013)	Spain	Foot length and foot breadth
Ozaslan (2005)	Turkish	Foot length and foot breadth

There have been several attempts to utilize the different dimension data from foot traces in order to determine sex of the suspects (Table 2.6). Ozden measured feet dimension, shoe length and width of 569 people in Turkey and succeeded to predict their sex and height (Ozden, Balci, Demirüstü, Turgut, & Ertugrul, 2005). Case tried sex determination from hand and foot bone length. He collected skeletons from 342 individuals, and measured the length of the phalanges. He classified individual's sex by using discriminant function analysis. The functions from foot dimension showed over 80% of accuracy (Case & Ross, 2007). The Sen also analyzed foot length and breadth of 350 Indians to distinguish their sex using sectioning point analysis method. In this research, foot length was the most significant sex determinant while foot index, a ratio of foot breadth over length, was less critical (Sen, Kanchan, & Ghosh, 2011). Jowaheer investigated foot length, foot breadth and foot index of 250 Indo-Mauritan to produce a logistic regression model. Two variables in the study, foot length and breadth, showed 92% of significance in sex prediction (Jowaheer & Agnihotri, 2011). Krishan measured hand and foot dimension from 246 Indians, then, he classified sex using regression equations from measurements. In his study, foot breadth was the most accurate predictor (R^2=0.502) in foot dimensions (Krishan & Sharma, 2007). Pasuk examined 249 skeletons from Thai population, then he measured proximal hand phalanges and derived regression equations using measurements (Mahakkanukrauh et al., 2013). Using diversified hand dimension such as phalanges, the regression model yielded 96.1% of accuracy. Zeybek used various dimension of foot. He measured foot length, foot breadth, malleolus height and foot navicular height. Using this measurement, he created formulas for gender estimation (Zeybek, Ergur, & Demiroglu, 2008). The formulas of foot dimensions yielded 95.6% accuracy. Hemy studied foot breadth, foot heel breadth, foot length, and the distance from pternion to the tip of each toe of West Australians to predict their sex, among which foot heel breadth showed the highest significance in the prediction with 90.5% of precision level (Hemy, Flavel, Ishak, & Franklin, 2013). Ozaslan measured foot length, foot breadth and ankle breadth from 356 Turkish. In her research, foot length showed highest accuracy in sex determination (Ozaslan et al., 2012). Previous studies mostly focused on foot length and breadth for their sex prediction. However, foot can provide various numeric data for investigation, because foot has many bones, muscles, and joints.

There have been several studies for estimating stature by utilizing foot measurement data (Table 2.7). Krishan derived linear equations for estimating stature from foot measurements (Krishan & Sharma, 2007). He measured foot dimensions (foot length, foot breadth) of 246 Indians and reported the standard error of estimates (S.E.E). In his study, foot length is the predictor that shows the highest accuracy among the variables hand length, handbreadth, foot length, and foot breadth. Zeybek estimated 249 individuals' foot lengths, foot breadths, malleolus height, and navicular heights (Zeybek, Ergur, & Demiroglu, 2008). He estimated genders and heights by the use of each part of the foot data. In his research, the most valuable data to relate one's height was the length of foot, and the correlation coefficients were male 0.741, female, 0.678. Moorthy collected 1020 Egyptians' footprints, then created an estimation regression equation by measuring the lengths between the heel and each toe tip (Moorthy, Mostapa, Boominathan & Raman, 2014). Hisham measured the lengths and breadths of the feet of 213 Malaysians, and then created an estimation regression equation with the data (Hisham, Mamat, & Ibrahim, 2012). In her study, the regression equation involving the length of the foot provided the highest R^2—for females, the length of the foot provided an R^2 of 0.572. In other research conducted by Hemy, she reported a regression model using data on the feet of West Australians : foot length, foot breadth, and foot heel. In her research also showed that the length of foot played a key role in estimating heights (Hemy, Flavel, Ishak, & Franklin, 2013). However, due to the multi-racial representative population sample,

R^2 rates were less than for other similar research. Kanchan used various foot dimensions of Indians for deriving estimation regression models. He collected foot prints of 100 Indians, then defined foot land marks such as the length from the heel point to each toe tip (Kanchan et al., 2012). By using these lengths an R^2 of 0.637 was produced. In his research, the R^2 was higher in the male population than in the female population. Pablos used a robust regression method in order to estimate stature (Pablos et al., 2013). He analyzed 564 foot bones from 94 individuals. Using the length of the talus and metatarsal, his study yielded an R^2 of 0.952. However, the accuracy was quite different depending on ancestry. Ozaslan derived stature estimation regression models for 356 Turkish people. In her study, foot length showed the highest R^2 among the variables hand length, hand breadth, wrist breadth, foot length, foot breadth, and ankle breadth—and the lowest SEE. In this way, the previous studies showed that the regression equations that use foot length and breadth are reliable for estimating a suspect's stature (Ozaslan et al., 2012). However, if the foot or its footprints are damaged at the scene, there the circumstances may be that we are unable to estimate stature by using foot length and foot breadth. In this case, regression equations from various other dimensions of the foot can provide a solution because the foot consists of numerous bones and joints. Hence there is other useful information with which to estimate stature and body profile.

2.4 Anthropometric Method for Weight Estimation in Emergency Care

There were researches trying to predict the weight beside gender and height by using measurement information related with the size of hands and feet (Table 2.8). These researches were mainly used when predicting the weight of emergency patients without consciousness or pediatric patients those who cannot speak (Figure 2.4). According to past researches, the weight predicted based on the exterior of patients by surgeons included many errors (Lorenz et al., 2007). Thorough this, too low dosage of drugs not fitting the weight of the patient were inject and caused the delaying of treatment speed, and other times side effects were caused from injection of excessive amount of dosage of drugs (Lin, Yoshida, Quinn, & Strehlow, 2009). Therefore, anthropometric method may be effective in exactly knowing the weight of a patient under emergency treatment in emergency room or in emergency care out of doors.

Table 2.8. Previous anthropometry study for weight estimation

Authors (year)	Population	Measured dimension for weight estimation
Garland (1986)	American	Stature, age, and sex
Robbins (1986)	American	Foot length
Leary (2000)	English	Stature
Lorenz (2007)	American	Stature, waist and hip circumference
Krishan (2008)	Indian	Foot length and breadth
Lin (2009)	American	Arm circumference and knee height
Buckley (2010)	American	Abdominal and thigh circumference

Figure 2.4. Anthropometric method for weight estimation

According to previous studies on predicting weight based on a part of the body, Garland estimated weight by forming a multiple regression equation based on the patient’s height, sex and age (Garland, Kishaba, Nelson, Losek, & Sobocinski, 1986). Robbin suggested a weight estimation model that uses the length and breadth of feet of adult males and females (Robbins, 1986). Using foot prints of 50 Indian males, Krishan studied on the correlation between foot size and body weight, attempting to estimate body weights with various foot length and breadth values (Krishan, 2008). Another study attempted to predict body weight using arm measurements. Ja Atiea conducted a regression equation model for estimating body weights based on thickness of triceps, forearms and wrists, and circumference of forearms and calves (Atiea, Haboubi, Hudson, & Sastry, 1994). Lin measured middle arm circumferences and knee heights of 235 patients and built a regression model for predicting body weights. He compared the estimation error of this model and the error of estimating body weights based solely on visual information perceived by doctors (Lin, Yoshida, Quinn, & Strehlow, 2009).

However, existing studies mainly applied anthropometrics limited to abdomen, thighs areas of the body. In cases of patients who have lost parts of their bodies and patients with severe injuries on their abdomens or thighs at the site of an accident, it is common that measurements of such body parts are impossible. In these situations, measurements of various parts of patients’ upper or lower body, upper limb and feet could work as indexes for predicting patients’ body weights, or at least act as a supplement for other weight estimation models. In this regard, more body parts need to be investigated to derive regression model for estimating body weights of males and females..

2.5 Representative Manikin Model

For the realization of anthropometric design securing the convenience of the users, body model representing various sizes of body of the subject population is used. The usage of the model reduces time and efforts by utilizing small amount of representative models rather than applying all of vast measured data of body. Various representative body models were used for local and global automobile seat model, designing of workplace and others (Kim & Whang (1997), Bittner (2000), HFES 300 (2004))

Table 2.9. Previous studies for representative manikin

Authors (year)	**Population**	**Representative model**
Bittner (1987)	American	Manikins for work station design
Kim (1997)	Korean	Representative Korean manikins
Hsiao (2005)	American	Manikins for tractor cab
Kouchi (2005)	Japanese	Japanese representative hand model
Young (2008)	American	Manikins for spacesuit design
Jung (2009)	American	Manikins for work station design
Bertilsson (2012)	American	Manikins for work station design
Park (2014)	American	Manikins for obese passengers

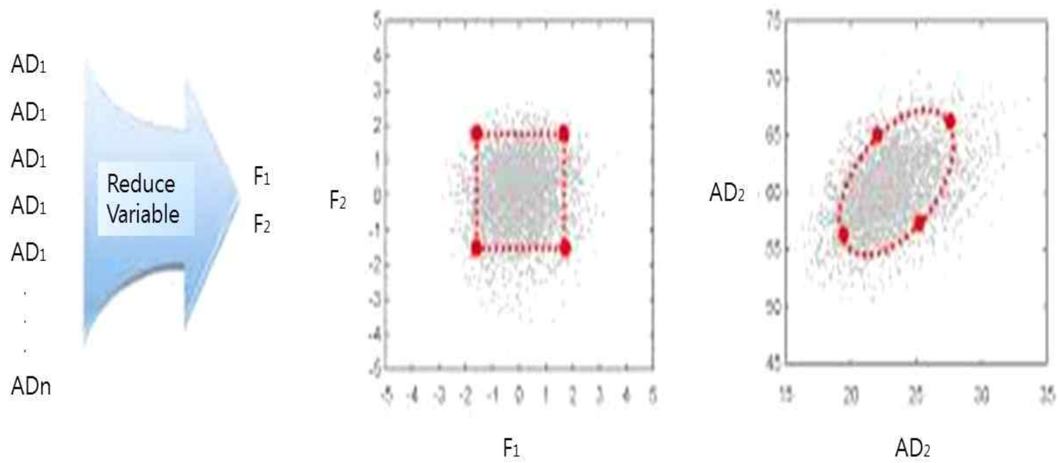


Figure 2.5. Boundary condition method for developing manikin (K. Jung, Kwon, & You, 2009)

However, using univariate anthropometry model through simple percentile method often may not represent the physical properties of target users. (HFES 300 (2004), Menunien, (1998)) For example, when determining a person with a height and shoulder width of 95 percentile, univariate accommodation percentage satisfies 95% of design accommodation level, but multivariate accommodation percentage was 91.8, lower than the goal of 95% (K. Jung, Kwon, & You, 2009).

To overcome the limits, Bittner and others have tried the method of finding the target boundary of the subject satisfying the capacity by using statistical methods (Figure 2.5) like data reduction (factor analysis, principal component analysis). As for such methods, there were square method (Bitner, 2000), rectangular method (Kim & Whang, 1997), circular method (Gregory F Zehner, Meindl, & Hudson, 1993) and others.

2.6 Anthropometry and Usability

When producing product and system used by human, consideration on the human should be prioritized. The user may feel safe and comfortable, and satisfactory user experience may be secured only through the consideration. On the interface part linking the product and the body o the user, one of the important procedures at user-centered design is to recognize detailed physical sizes of the users using interface and design by reflecting the sizes when designing a product (Jokela, Iivari, Matero, & Karukka, 2003).

However, there are cases causing inconvenience of the users as these basic principles are not followed. For example, if the chairs and desks used by students are not designed in a variable manner, students with long height or long leg may lack space for movement, or the desk may be too low for the students (Panagiotopoulou, Christoulas, Papanckolaou, & Mandroukas, 2004). Such problems may also occur at national defense system (Sekulova, Bures, Kurkin, & Simon, 2015). The case of the problem was from the importation of various local weaponries from foreign countries, lack of reflection of physical properties of South Koreans. Moreover, in case of local weaponry production companies, lack of reflection of physical properties of South Koreans are caused from the lack of understanding on the ergonomic at designing phase. These weaponries lacking consideration on the physical properties may cause inconvenience of users, and cause safety problems from malfunctioning or degradation. Therefore, product design applying anthropometry may be an important element in preventing inconvenience of users and safety problems. Thus, considerations on the correspondence of the size of products and composition of major interface elements with the physical properties of the users should be prioritized.

Chapter Ⅲ

Identifying Korean Physical Characteristics Based on Hand and Foot Measurement Data

3.1 Classification of Korean Hand Shapes and Development of Representative Hand Manikins

3.1.1. Overview

Previous studies on Korean hands tend to focus only on measuring the length and breadth of the hand, and the distribution of these measurements was then reported. Thus, most companies have selected only the hand length and breadth as relevant metrics to design gloves and user interfaces (Kim and Kee, 2012). Most of the time, companies design such products based on the average of these measurements and do not take into account for the distinct hand shapes within the Korean population because there are few studies providing such guidelines. In this study, the author includes various data on the hand dimensions of both Korean males and females, including variables related to the breadth and circumference of various hand parts. Statistical methods are then used to distinguish the major factors that determine the hand shapes, representative Korean hand manikins and to categorize the hand shapes that are found within the Korean population.

3.1.2 Method

3.1.2.1 Subjects

This study uses anthropometric data from the Korean Hand Measurement Project, led by the Korean Agency for Technology and Standards. 167 males and 154 females enrolled in this study of their own will, and a small stipend was provided to each participant as compensation for their involvement in this study. All 321 subjects had no history of hand or spine related disorders, were of the same race, born and raised in Korea, and were evenly distributed in terms of their occupation (office / manufacturing), and age. The demographics of the subjects are shown in Table 3.1.

Table 3.1. Subject characteristics

	Male			Female		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
Age (year)	42.5	13.2	20 – 70	46.5	16.4	20-83
Stature (cm)	169.5	6.3	153-188	155.5	7.4	137-174
Weight (kg)	70.6	10.4	45-101	55.4	8.5	40-90

Gender	**Age**					**Region**	
	20's	**30's**	**40's**	**50'**	**>60's**	**Urban**	**Rural**
Male	20.4%	20.4%	20.4%	19.2%	19.8%	69%	31%
Female	20.1%	20.1%	20.1%	19.6%	20.1%	58%	48%

3.1.2.2 Measurement

In this study, all 27 hand dimensions that were common among previous studies were measured, as defined in Figure 3.1 and Table 3.2 (García-Cáceres et al., 2012; J. G. Hall, Allanson, Gripp, & Slavotinek, 2007). Digital calipers were used to measure the length, breadth and thickness of the hands and fingers to an accuracy of 0.01 mm, and tape measures were used to measure the circumference of the hands and finger joints. Digital scales and a stadiometer were used to measure the body weight and stature. The individuals that were employed to conduct these measurements were provided with 18 hours of training in an anthropometric measurement

Table 3.2. Definition of hand dimensions

	Hand Dimensions	Definition
1	Fingertip to root digit 1	The distance from proximal flexion crease of the finger to the tip of the thumb
2	Fingertip to root digit 2	The distance from proximal flexion crease of the finger to the tip of the index finger
3	Fingertip to root digit 3 (3DL)	The distance from proximal flexion crease of the finger to the tip of the middle finger
4	Fingertip to root digit 4	The distance from proximal flexion crease of the finger to the tip of the ring finger
5	Fingertip to root digit 5	The distance from proximal flexion crease of the finger to the tip of the little finger
6	Center of wrist crease to root digit 1	The distance from center of wrist crease to the proximal flexion crease of the thumb
7	Center of wrist crease to root digit 2	The distance from center of wrist crease to the proximal flexion crease of the index finger
8	Center of wrist crease to root digit 3	The distance from center of wrist crease to the proximal flexion crease of the middle finger
9	Center of wrist crease to root digit 4	The distance from center of wrist crease to the proximal flexion crease of the ring finger
10	Center of wrist crease to root digit 5	The distance from center of wrist crease to the proximal flexion crease of the little finger
11	Hand length (HL)	The distance from the middle of inter stylion to the tip of middle finger
12	Palm length (PL)_	The distance from the middle of inter stylion to the proximal flexion crease of the middle finger
13	Breadth at PIP joint of digit 1	The distance from the most lateral point on thumb proximal joint to the most medial point
14	Breadth at PIP joint of digit 2	The distance from the most lateral point on index finger proximal joint to the most medial point
15	Breadth at PIP joint of digit 3	The distance from the most lateral point on middle finger proximal joint to the most medial point
16	Breadth at PIP joint of digit 4	The distance from the most lateral point on ring finger proximal joint to the most medial point
17	Breadth at PIP joint of digit 5	The distance from the most lateral point on little finger proximal joint to the most medial point
18	Hand breadth at metacarpals (HB)	The distance from the most lateral point on the index finger metacarpal to the most medial point on the little finger metacarpal
19	Wrist breadth	The distance from the most lateral point on the wrist to the most medial point of wrist
20	Circumference at PIP joint of digit 1	The superficial distance around the edge of proximal joint in thumb

Table 3.2. Definition of hand dimensions (continued)

	Hand Dimensions	Definition
21	Circumference at PIP joint of digit 2	The superficial distance around the edge of proximal joint in index finger
22	Circumference at PIP joint of digit 3	The superficial distance around the edge of proximal joint in middle finger
23	Circumference at PIP joint of digit 4	The superficial distance around the edge of proximal joint in ring finger
24	Circumference at PIP joint of digit 5	The superficial distance around the edge of proximal joint in little finger
25	Circumference at metacarpal	The superficial distance around the edge of metacarpal
26	Wrist circumference	The superficial distance around the edge of the wrist
27	Hand depth	The distance from the lowest part of the thumb interphalangeal joint to the upper most part of the back of hand

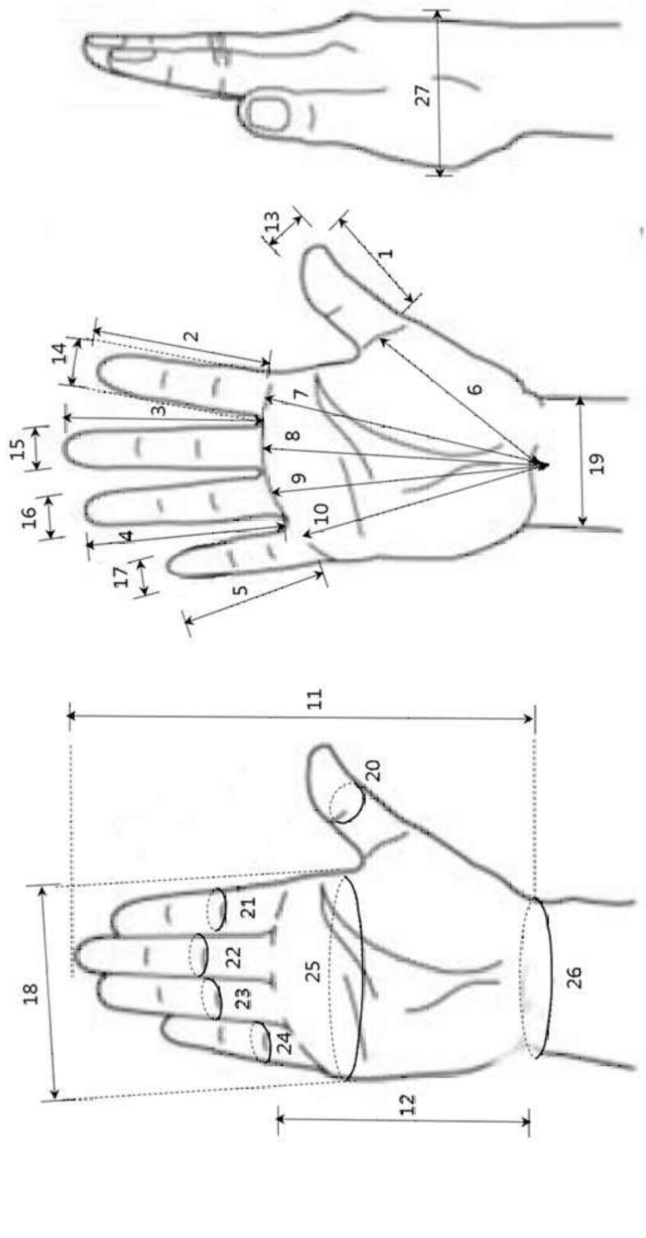


Figure 3.1 Hand dimensions for hand shapes classification

3.1.2.3 Data Analysis

All of the data were analyzed using MS EXCEL and SPSS 21. Descriptive statistics (including the mean, standard deviation and various percentiles) for the value of each hand dimension were calculated and are presented herein. A Kolmogorov-Smirnov test was conducted to test whether the data set of the measurements conformed to a normal distribution, and eight variables for males and two variables for females were found not to show normality. A T-test was used to compare the differences in the measurements for the males and females. The relationship between the hand measurement and the stature was identified by using Pearson correlation coefficients, and a factor analysis was carried out with 27 variables in order to determine a suitable set of factors to explain the variability in the hand shape (Varimax rotation). The change in the slope of the scree plot indicated that three factors were suitable to this end, and after the factor analysis, the Ward and Euclidian distance method was used to measure the distance between the groups, and a cluster analysis was performed for the factor score. We categorized the Korean hands into four groups, and a cluster analysis was carried out to distinguish the characteristics of each group so that groups with similar traits could be determined to belong to a single category.

In order to develop representative Korean hand manikins, boundary condition method was utilized (Bittner, 2000; Young, Margerum, Barr, Ferrer, & Rajulu, 2008). A factor analysis was conducted using the principal component method for hand measurement data. Three principal factors were extracted and they accounted for 43.0%, 22.8% and 19.3% of total variation. Factor loading was determined (Table 3.5). Standard normal scores (s: 25x1 vector) can be obtained by multiplying the lading matrix L* by any vector (v: 3x1), s = L* v (Bittner 1986). The proportions of unaccommodated people are then considered as follows

$$\Pr(F_i \in \chi_{vi} = (- \quad ,-v_i) \cup (v_i \ , \quad) \qquad (1)$$

The proportions of unaccommodated people due to each factor are then considered

$$Pr[F_1 \in \chi_{v1}] : Pr[F_2 \in \chi_{v2}] : Pr[F_i \in \chi_{v3}] = w_1 : w_2 : w_3 \quad (2)$$

As Kim and whang proposed (Kim & Whang, 1997), unaccommodated proportion (w_i) of the i-th factor as $w_i = / \lambda$ (i=1, 2, 3). Then, we obtain $w_1=1/ 0.430 \approx 1.52$, $w_2=2.09$ and $w_3=2.27$. Thus, we restate the equations

$$Pr[F_1 \in \chi_{v1}] = 1.52\alpha'$$

$$Pr[F_2 \in \chi_{v2}] = 2.09\alpha'$$

$$Pr[F_3 \in \chi_{v3}] = 2.27\alpha' \quad (3)$$

where α' is an unknown constant to be determined

The unaccommodated proportion can be expressed as follows:

$$Pr[F_1 \in \chi_{v1} \text{ or } F_2 \in \chi_{v2} \text{ or } F_3 \in \chi_{v3}] =$$

$$Pr[F_1 \in \chi_{v1}] + Pr[F_2 \in \chi_{v2}] + Pr[F_3 \in \chi_{v3}] - Pr[F_1 \in \chi_{v1}] * Pr[F_2 \in \chi_{v2}] - Pr[F_2 \in \chi_{v2}] * Pr[F_3 \in \chi_{v3}] - Pr[F_3 \in \chi_{v3}] * Pr[F_1 \in \chi_{v1}] + Pr[F_1 \in \chi_{v1}] * Pr[F_2 \in \chi_{v2}] * Pr[F_3 \in \chi_{v3}] = \alpha \quad (4)$$

Where α is the proportion of unaccommodated population. In this study, the author let α =0.05 in order to accommodate 95% of population.

$$7.269\alpha'^3 - 11.432\alpha'^2 + 5.895\alpha' - 0.05 \approx 0 \quad (5)$$

The solution of the equation (5) is $\alpha' \approx 0.0086$ Also, v_1, v_2, and v_3 can be computed as follows, where Φ is the cumulative normal distribution.

$$v_1 = \Phi^{-1}(1.524\alpha') \approx 2.222$$

$$v_2 = \Phi^{-1}(2.094\alpha') \approx 2.096$$

$$v_3 = \Phi^{-1}(2.276\alpha') \approx 2.062$$

In order to develop each manikin, the standard score vector(s) is calculated by multiplying the loading matrix L by each manikin's position in the factor space (s = L*v). The standard score vectors of the nine manikins are then converted into the equivalent vectors consisting of percentile values. The ninth manikin is developed by setting 50th percentile. Then, the percentile descriptions of each manikin can also be converted into the actual anthropometric dimension values.

3.1.3 Result of Hand Shapes Classification

3.1.3.1 Descriptive Statistics

The average and standard deviations of the hand measurements for Korean males and females are shown in Table 3.3. All measurements from the male portion of the sample group were significantly greater than those for the females ($p<0.001$). The hand length was the greatest value of the 27 dimensions that were measured, and the joint circumference of the little finger was the smallest. A T-test was used to compare the difference between the hand measurements in males and females, and the metacarpal circumference was found to have the greatest difference between the two genders. The breadth of the proximal interphalangeal joint of the ring finger and the wrist circumference also seemed to show significantly large differences between the males and females. To determine the influence that stature had in distinguishing the hand shapes of Koreans, we compared the correlation between the stature and the hand measurements in males and females.

In case of both males and females, length related measurements were positively correlated with stature, and all the coefficient of length related measurements were statistically significant ($p <0.01$). Highest coefficient was observed between the hand length and stature in both males ($r=0.628$) and females ($r=0.534$). All of the correlation factors between each hand part and stature were greater in males than were in females.

3.1.3.2 Factor and cluster analysis

A factor analysis was carried out for the 27 variables that were measured to distinguish the hand shapes of Koreans, and three factors were identified (Table 3.5). As suggested above, when the descriptive statistics and correlation factors are compared, all hand parts of the males and 11 hand parts of the females show a positive correlation with the stature. As a consequence, it is difficult to categorize the hand shapes of the subjects with a taller body height, since all hand measurements are probably greater in these subjects. Thus, we have used the measurements of each of the hand parts divided by the stature of the subject when conducting the factor analysis. This analysis can be used to compare the shape and characteristics of the hands of the subjects in a manner that is independent of their body heights (W. Park & Park, 2013). As shown in the Appendix, 78.3% of the variance in hand parts dimension variability (hand shape) was explained by the three major factors (factor 1: hand breadth, factor 2: palm length, factor 3: finger length).

Table 3.3. Descriptive Statistics of Korean Males and Females (in mm)

Hand Dimensions	Male		Female		Correlation		T-value
	Mean	SD	Mean	SD	Male	Female	
Fingertip to root digit 1	61.2	3.9	56.1	3.5	0.390**	0.375**	12.30
Fingertip to root digit 2	70.5	4.3	66.3	4.3	0.507**	0.424**	8.76
Fingertip to root digit 3	78.6	4.7	73.5	4.3	0.549**	0.436**	10.15
Fingertip to root digit 4	74.3†	4.7	69.2	4.3	0.487**	0.440**	10.03
Fingertip to root digit 5	59.0†	4.4	54.5	4.6	0.394**	0.407**	8.84
Center of wrist crease to root digit 1	79.6†	4.7	73.1	4.5	0.350**	0.314**	12.48
Center of wrist crease to root digit 2	113.1†	5.7	104.8	5.2	0.478**	0.430**	13.60
Center of wrist crease to root digit 3	112.6	5.9	104.7	5.2	0.488**	0.424**	12.71
Center of wrist crease to root digit 4	107.8	5.9	100.1	5.5	0.458**	0.394**	12.09
Center of wrist crease to root digit 5	99.4	5.9	91.9†	5.2	0.456**	0.371**	12.20
Hand length	183.3	9.0	170.7	7.7	0.628**	0.534**	13.35
Palm length	105.1	5.0	97.4	4.6	0.592**	0.505**	14.33
Breadth at PIP joint of digit 1	22.5	1.6	19.7	1.5	0.091	-0.168	15.81
Breadth at PIP joint of digit 2	20.6†	1.2	18.3†	1.2	0.222**	-0.104	16.91
Breadth at PIP joint of digit 3	20.8	1.2	18.5	1.2	0.167*	0.153	16.47
Breadth at PIP joint of digit 4	19.6	1.1	17.3	1.2	0.187*	-0.063	17.48
Breadth at PIP joint of digit 5	17.5	1.1	15.3	1.2	0.106	-0.080	16.54
Hand breadth at metacarpals	86.0	4.2	78.0	4.0	0.385**	0.099	17.34
Wrist breadth	61.4†	3.0	55.4	3.5	0.360**	0.090	16.43
Circumference at PIP joint of digit 1	68.6	4.3	61.0	4.6	0.071	-0.165*	15.32
Circumference at PIP joint of digit 2	64.9	3.7	58.2	4.0	0.191*	-0.060	15.26
Circumference at PIP joint of digit 3	66.4†	4.0	59.6	4.2	0.162*	-0.085	14.94
Circumference at PIP joint of digit 4	62.1†	3.9	55.6	4.0	0.095	-0.065	14.66
Circumference at PIP joint of digit 5	54.5	3.5	48.8	3.8	0.089	-0.026	14.19
Circumference at metacarpal	208.0	9.6	186.1	10.7	0.320**	0.096	19.34
Wrist circumference	175.8	10.9	156.2	8.9	0.213**	-0.037	17.47
Hand depth	49.1	4.0	42.2	3.7	0.161*	0.086	15.96

† Indicates hand dimension do not show normality, from the Kolmogorov-Smirnov t test (using α = 0.05 level of significance)
* Indicates statistically significant using α = 0.05 level of significance
** Indicates statistically significant using α = 0.01 level of significance
PIP : Proximal interphalangeal

Factor 1 (hand breadth) includes the PIP joint breadth, hand metacarpal breadth, hand metacarpal circumference, and wrist breadth and circumference. All of these characteristics are related to the horizontal length (breadth) of the hand shape. Factor 2 (palm length) includes the length between the center of the wrist and the root of each finger. The overall hand length is also included in this factor. Factor 3 (finger length) includes the length of the variables of each finger. The factor scores were derived using a factor analysis and were standardized to a normal distribution (with an average of 0 and a variance of 1), which makes it easier to interpret the hand shape, and these were then used to conduct a cluster analysis. For example, if the subject's factor 1 score is greater than the average of 0, the subject has greater size in hand breadth-related variables than the average. On the other hand, if the subject has negative score for factor 1, the subject has a smaller size in hand breadth-related variables than the average. These factor scores are thus used to group subjects with similar hand measurement together through the cluster analysis. The proper amount of groups is calculated by deriving a dendrogram and selecting four clusters by applying Ward's method of using the square euclidean distance (Table 3.4). The author verified that these four groups were significantly different from one another through the use of ANOVA (p value <0.05).

Table 3.4. Cluster Mean Factor Scores (Centroid Position) for Four Hand Types

Hand Types	**Cluster Mean Factor Scores**			**Proportion (%)**
	Factor 1 Hand breadth	**Factor 2 Palm length**	**Factor 3 Finger length**	**Pooled (male vs female)**
Type 1 : Spacious hand and short finger	0.879	0.180	-0.601	27.7 (38.9 vs 5.6)
Type 2 : Short palm but above average finger	0.121	-1.112	0.572	23.7 (26.9 vs 20.1)
Type 3 : Long palm and finger	-0.022	0.926	0.951	20.9 (15.6 vs 26.6)
Type 4 : Narrow hand and short finger	-0.967	0.073	-0.603	27.7 (18.6 vs 37.7)

Table 3.5. The factor analysis result for the hand dimensions

Hand dimension	Factor and factor loadings			Communality
	1	2	3	
Circumference at PIP joint of digit 3	0.897	0.239	0.148	0.884
Circumference at PIP joint of digit 1	0.894	0.207	0.110	0.855
Circumference at PIP joint of digit 2	0.894	0.196	0.171	0.867
Breadth at PIP joint of digit 4	0.884	0.162	0.165	0.835
Circumference at PIP joint of digit 4	0.879	0.193	0.183	0.844
Breadth at PIP joint of digit 2	0.878	0.218	0.135	0.837
Breadth at PIP joint of digit 3	0.876	0.205	0.152	0.833
Circumference at PIP joint of digit 5	0.874	0.130	0.158	0.806
Circumference at metacarpal	0.852	0.168	0.240	0.811
Breadth at PIP joint of digit 1	0.850	0.248	0.044	0.786
Breadth at PIP joint of digit 5	0.848	0.184	0.216	0.800
Wrist breadth	0.781	0.174	0.190	0.676
Wrist circumference	0.724	0.126	-0.015	0.540
Hand depth	0.715	-0.094	0.084	0.526
Hand breadth at metacarpals	0.712	0.318	0.260	0.676
Center of wrist crease to root digit 3	0.230	0.926	0.175	0.941
Center of wrist crease to root digit 4	0.156	0.922	0.196	0.913
Center of wrist crease to root digit 5	0.132	0.895	0.170	0.847
Center of wrist crease to root digit 2	0.267	0.869	0.212	0.872
Palm length	0.260	0.767	0.244	0.716
Center of wrist crease to root digit 1	0.238	0.760	0.094	0.643
Hand length	0.248	0.636	0.628	0.716
Fingertip to root digit 2	0.140	0.219	0.891	0.861
Fingertip to root digit 4	0.184	0.231	0.885	0.870
Fingertip to root digit 3	0.188	0.227	0.867	0.839
Fingertip to root digit 5	0.081	0.163	0.798	0.670
Fingertip to root digit 1	0.335	0.080	0.682	0.583
% Total variance explained (cumulative)	42.861	19.840	15.648	78.349

3.1.4 Result of Representative Hand Manikins

3.1.4.1 Manikin Description

The family of nine representative Korean hand manikin is characterized as follows. In case of manikin 1, manikin 1 reflects very large hand which have large breadth, palm length and finger length. Manikin 2 is the hand which has spacious hand breadth and long palm but relatively small finger length. Manikin 3 shows the hand which has large breadth and finger but relatively small palm length. Manikin 4 reflects the hand which has spacious hand breadth but small palm and fingers. Manikin 5 shows narrow hand which has relatively long palm and finger length. Manikin 6 reflects the narrow hand which has long palm length and small fingers. Manikin 7 shows the hand which has narrow hand breadth and small palm but has long fingers. Manikin 8 reflects the very small hand which has small hand breadth, palm and finger length. Manikin 9 shows the hand which has average of each hand dimension.

Figure 3.2. Size of each hand manikin (in mm)

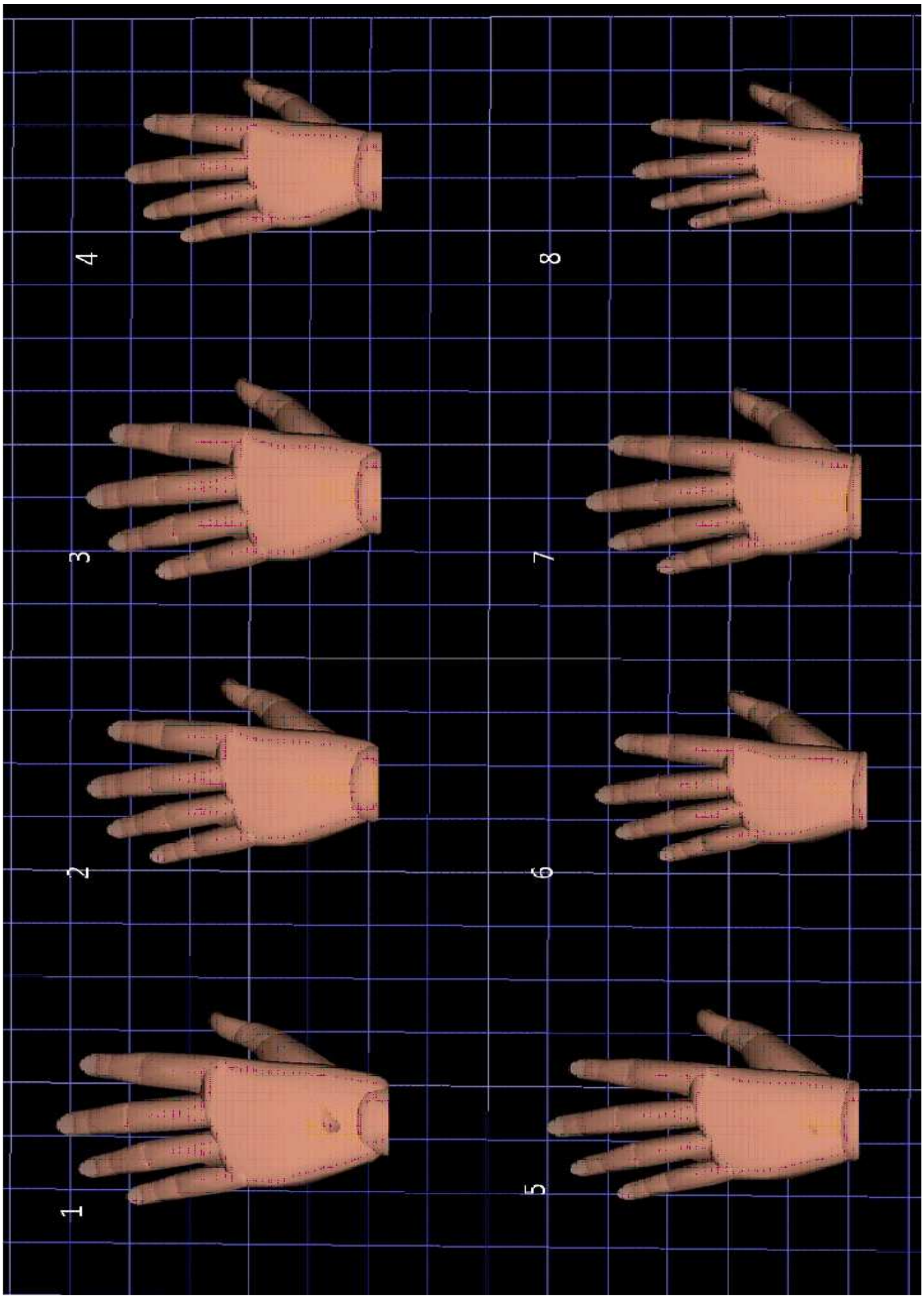


Figure 3.3. 95% accommodation hand manikin family

Table 3.6. The hypothetical hand manikins described in percentile format

Hand dimension	The hypothetical hands (%)								
	1	2	3	4	5	6	7	8	9
Breadth at PIP joint of digit 1	99.7	98.7	94.0	83.6	16.4	6.0	1.3	0.3	50
Breadth at PIP joint of digit 2	99.9	97.9	96.5	79.3	20.7	3.5	2.1	0.1	50
Breadth at PIP joint of digit 3	99.9	97.6	96.9	81.0	19.0	3.1	2.4	0.1	50
Breadth at PIP joint of digit 4	99.9	97.2	97.3	78.1	21.9	2.7	2.8	0.1	50
Breadth at PIP joint of digit 5	99.8	96.9	97.7	82.2	17.8	2.3	3.1	0.2	50
Hand breadth at metacarpals	99.9	94.5	92.9	44.1	55.9	7.1	5.5	0.1	50
Wrist breadth	99.9	94.5	96.5	65.3	34.7	3.5	5.5	0.1	50
Wrist circumference	99.6	96.6	92.3	72.6	27.4	7.7	3.4	0.4	50
Circumference at metacarpal	99.9	94.5	97.5	62.6	37.4	2.5	5.5	0.1	50
Circumference at PIP joint of digit 1	99.8	98.3	96.8	87.3	12.7	3.2	1.7	0.2	50
Circumference at PIP joint of digit 2	99.9	97.3	97.9	83.3	16.7	2.1	2.7	0.1	50
Circumference at PIP joint of digit 3	99.9	98.2	97.1	84.2	15.8	2.9	1.8	0.1	50
Circumference at PIP joint of digit 4	99.8	97.2	97.7	84.2	15.8	2.3	2.8	0.2	50
Circumference at PIP joint of digit 5	99.8	96.1	98.0	81.3	18.7	2.0	3.9	0.2	50
Hand depth	99.5	91.3	97.7	77.3	22.7	2.3	8.7	0.5	50
Hand length	99.9	75.2	80.3	2.3	97.7	19.7	24.8	0.0	50
Palm length	99.9	93.2	55.5	5.2	94.8	44.5	6.8	0.1	50
Center of wrist crease to root digit 1	99.8	97.0	32.3	7.8	92.2	67.7	3.0	0.2	50
Center of wrist crease to root digit 2	99.9	96.5	40.7	4.7	95.3	59.3	3.5	0.1	50
Center of wrist crease to root digit 3	99.9	97.2	31.7	3.8	96.2	68.3	2.8	0.1	50
Center of wrist crease to root digit 4	99.9	96.0	27.8	2.6	97.4	72.2	4.0	0.1	50
Center of wrist crease to root digit 5	99.9	95.7	27.2	2.7	97.3	72.8	4.3	0.1	50
Fingertip to root digit 1	99.9	43.8	97.9	12.3	87.7	2.1	56.2	0.1	50
Fingertip to root digit 2	99.9	21.8	97.0	2.1	97.9	3.0	78.2	0.1	50
Fingertip to root digit 3	99.9	28.5	96.5	2.3	97.7	3.5	71.5	0.1	50
Fingertip to root digit 4	99.9	28.4	96.9	2.5	97.5	3.1	71.6	0.1	50
Fingertip to root digit 5	99.8	22.7	95.5	2.5	97.5	4.5	77.3	0.2	50

Table 3.7. The 95% hand manikin actual measurement value (in mm)

Hand dimension	Manikins								
	1	2	3	4	5	6	7	8	9
Breadth at PIP joint of digit 1	26.9	25.8	24.4	23.2	19.1	17.9	16.5	15.4	21.1
Breadth at PIP joint of digit 2	24.4	22.8	22.5	20.8	18.2	16.5	16.2	14.6	19.5
Breadth at PIP joint of digit 3	24.6	23.0	22.8	21.1	18.2	16.6	16.4	14.7	19.7
Breadth at PIP joint of digit 4	23.5	21.6	21.7	19.8	17.2	15.3	15.3	13.4	18.5
Breadth at PIP joint of digit 5	21.1	19.4	19.6	17.9	15.0	13.3	13.5	11.8	16.4
Hand breadth at metacarpals	100.4	91.2	90.5	81.3	83.0	73.8	73.1	63.9	82.1
Wrist breadth	71.9	65.6	66.5	60.3	56.8	50.5	51.5	45.2	58.5
Wrist circumference	203.4	191.9	186.4	174.8	158.0	146.5	140.9	129.4	166.4
Circumference at metacarpal	245.8	221.4	226.7	202.3	192.7	168.3	173.6	149.2	197.5
Circumference at PIP joint of digit 1	81.4	77.3	75.8	71.6	58.3	54.2	52.6	48.5	65.0
Circumference at PIP joint of digit 2	76.9	71.5	72.0	66.6	56.8	51.4	51.8	46.4	61.7
Circumference at PIP joint of digit 3	79.0	74.3	73.2	68.5	57.8	53.0	52.0	47.2	63.1
Circumference at PIP joint of digit 4	73.8	68.7	69.2	64.1	53.9	48.8	49.3	44.2	59.0
Circumference at PIP joint of digit 5	65.2	59.9	61.2	55.9	47.6	42.3	43.6	38.3	51.8
Hand depth	59.3	52.9	56.2	49.7	41.9	35.4	38.7	32.2	45.8
Hand length	214.2	184.3	186.1	156.2	198.2	168.3	170.1	140.2	177.2
Palm length	121.4	110.5	102.2	91.4	111.4	100.5	92.2	81.4	101.4
Center of wrist crease to root digit 1	92.5	87.1	73.9	68.4	84.5	79.1	65.8	60.4	76.5
Center of wrist crease to root digit 2	131.5	121.6	107.5	97.6	120.7	110.8	96.7	86.8	109.2
Center of wrist crease to root digit 3	130.7	121.9	105.6	96.8	120.9	112.1	95.8	87.0	108.8
Center of wrist crease to root digit 4	125.5	116.2	100.1	90.8	117.5	108.2	92.0	82.7	104.1
Center of wrist crease to root digit 5	116.2	107.4	91.7	82.9	108.7	99.9	84.2	75.4	95.8
Fingertip to root digit 1	72.6	58.1	68.0	53.5	64.0	49.5	59.5	45.0	58.8
Fingertip to root digit 2	83.5	64.7	77.5	58.7	78.2	59.4	72.2	53.4	68.5
Fingertip to root digit 3	92.9	73.2	85.5	65.9	86.4	66.8	79.1	59.4	76.2
Fingertip to root digit 4	88.6	68.9	81.5	61.8	82.0	62.3	74.8	55.1	71.9
Fingertip to root digit 5	71.4	53.1	65.3	47.0	66.7	48.3	60.6	42.2	56.8

3.1.5 Discussion

The goal of this study is to measure and analyze the major hand measurements of Korean males and females to determine the particular traits of Korean hands in order to derive hand dimension values that can be used to design hand tools and interfaces. The measured hand size data for the Koreans subjects is compared to data from the previous studies to determine the characteristics that distinguish Korean hands from those of other nationalities. For example, Korean males have shorter finger and hand length but larger finger joints, metacarpal breadth and circumference than Turkish males. In males, there is little difference in the metacarpal breadth between Koreans, Jordanians, Mexicans and Americans, while Turkish males had smaller hand breadths (Cakit, Durgun, Cetik, & Yoldas, 2014 & Yoldas, 2014; Greiner, 1991; Nag, Nag, & Desai, 2003). Korean males tended to have thicker hands than Turkish, Jordanian and Mexican males (Table 3.8). Likewise, Korean females had shorter finger and hand lengths but greater wrist and metacarpal breadth and circumference than Turkish females (Table 3.9). Among Korean, Indian, Turkish and American females, Americans had the longest hand and finger length. This comparison with other nationalities indicates that the hands of Korean males and females can be characterized as having shorter but wider hands than Turkish, Indians and Mexicans.

According to the results of the T-test for the significance of the difference between Koreans and other populations (Table 3.10 and 3.11), there was a substantial difference in the thickness of the hands of Korean and Turkish males. The hands of Korean males were 5 mm thicker than those of their Turkish counterparts (Cakit et al., 2014). Therefore, when manufacturing gloves intended for Korean males, a clearance of approximately 5 mm should be provided in the back of the hand when compared to that necessary for the hands of Turkish men.

Table 3.8. Summary data of hand dimensions (Mean±SD) of Korean males and other populations (in mm)

Hand Dimension	Korean	Turkish	American	Jordanian	Mexican
Fingertip to root digit 1	61.2±3.9	65.6±4.5	69.7±4.8		
Fingertip to root digit 2	70.5±4.3	74.6±4.8	75.3±4.9		
Fingertip to root digit 3	78.6±4.7	81.8±5.1	83.8±5.4	81.2±7.1	78.5±4.4
Fingertip to root digit 4	74.3±4.7	75.5±5.2	79.2±5.2		
Fingertip to root digit 5	59.0±4.4	62.4±4.6	64.7±4.9	61.1±4.6	57.9±3.2
Breadth at PIP joint of digit 1	22.5±1.6	20.2±1.1			
Breadth at PIP joint of digit 2	20.6±1.2	19.0±0.9	23.0±1.6		
Breadth at PIP joint of digit 3	20.8±1.2	19.2±1.0	22.5±1.6	20.4±1.4	20±1.2
Breadth at PIP joint of digit 4	19.6±1.1	18.1±0.9	21.4±1.5		
Breadth at PIP joint of digit 5	17.5±1.1	16.1±0.8	19.2±1.3	17.4±1.3	17.3±1.2
Circumference at PIP joint of digit 1	68.6±4.3	66.0±4.4	72.3±2.9		
Circumference at PIP joint of digit 2	64.9±3.7	63.1±3.5			
Circumference at PIP joint of digit 3	66.4±4.0	64.0±3.3	69.6±2.0		
Circumference at PIP joint of digit 4	62.1±3.9	60.4±3.0	64.9±1.9		
Circumference at PIP joint of digit 5	54.5±3.5	53.9±3.2	57.8±1.8		
Hand length	183.3±9.0	190.4±9.6	194.1±9.9	191.2±10.2	185.5±7.1
Hand breadth at metacarpals	86.0±4.2	78.4±4.5	95.3±5.8	87.7±4.8	85.3±4.9
Hand depth	49.1±4.0	42.8±3.4		43.9±3.9	48.2±5.1
Wrist breadth	61.4±3.0	56.3±3.3	65.8±4.5		

Table 3.9. Summary data of hand dimensions (Mean±SD) of Korean females and other populations (in mm)

Hand Dimension	Korean	Turkish	American	European	Indian
Fingertip to root digit 1	56.1±3.5	59.4±3.7	63.5±4.8		64.1±6.3
Fingertip to root digit 2	66.3±4.3	68.3±3.4	69.6±4.6		69.2±5.5
Fingertip to root digit 3	73.5±4.3	74.4±3.9	77.2±5.1	77.0±4.7	76.0±5.7
Fingertip to root digit 4	69.2±4.3	68.3±3.4	72.2±5.0		70.2±5.4
Fingertip to root digit 5	54.5±4.6	55.6±3.2	58.3±4.6	56.7±4.5	56.3±5.4
Breadth at PIP joint of digit 1	19.7±1.5	17.6±0.9			
Breadth at PIP joint of digit 2	18.3±1.2	16.6±0.8	19.9±1.3		13.0±1.7
Breadth at PIP joint of digit 3	18.5±1.2	16.7±0.7	19.3±1.3	17.5±1.2	13.3±1.5
Breadth at PIP joint of digit 4	17.3±1.2	15.6±0.7	18.4±1.2		
Breadth at PIP joint of digit 5	15.3±1.2	13.7±0.7	16.5±1.1	14.0±1.1	
Circumference at PIP joint of digit 1	61.0±4.6	58.6±3.0	63.0±2.5		
Circumference at PIP joint of digit 2	58.2±4.0	56.4±2.6			57.0±3.1
Circumference at PIP joint of digit 3	59.6±4.2	56.3±2.3	61.3±1.9		59.2±3.6
Circumference at PIP joint of digit 4	55.6±4.0	53.0±2.9	57.4±1.9		
Circumference at PIP joint of digit 5	48.8±3.8	46.7±2.6	50.6±1.7		
Hand length	170.7±7.7	172.1±8.1	180.7±9.8	174.3±9.3	169.6±9.4
Hand breadth at metacarpals	78.0±4.0	69.9±3.2	83.1±4.4	77.2±4.7	68.0±5.1
Hand depth	42.2±3.7	37.3±3.4			34.2±5.2
Wrist breadth	55.4±3.5	49.8±2.8	57.0±3.4		46.1±4.8

Table 3.10. Comparison between Korean males and other nationalities

Hand dimensions	Korean vs Turkish		Korean vs American		Korean vs Jordanian	
	% Diff	t-value	% Diff	t-value	% Diff	t-value
Fingertip to root digit 1	-7.2	-7.88*	-13.9	-25.16*		
Fingertip to root digit 2	-5.8	-6.82*	-6.8	-13.08*		
Fingertip to root digit 3	-4.1	-4.96*	-6.6	-12.94*	-3.3	-3.44*
Fingertip to root digit 4	-1.6	-1.83	-6.6	-12.27*		
Fingertip to root digit 5	-5.8	-5.78*	-9.7	-15.24*	-3.6	-3.83*
Breadth at PIP joint of digit 1	10.2	13.62*				
Breadth at PIP joint of digit 2	7.8	12.12*	-11.7	-22.70*		
Breadth at PIP joint of digit 3	7.7	11.46*	-8.2	-16.08*	1.9	2.49*
Breadth at PIP joint of digit 4	7.7	11.84*	-9.2	-18.47*		
Breadth at PIP joint of digit 5	8.0	11.74*	-9.7	-17.98*	0.6	0.67
Circumference at PIP joint of digit 1	3.8	4.58*	-5.4	-10.72*		
Circumference at PIP joint of digit 2	2.8	3.88*				
Circumference at PIP joint of digit 3	3.6	5.18*	-4.8	-10.13*		
Circumference at PIP joint of digit 4	2.7	3.91*	-4.5	-9.10*		
Circumference at PIP joint of digit 5	1.1	1.39	-6.1	-11.92*		
Hand length	-3.9	-5.82*	-5.9	-14.14*	-4.3	-6.70*
Hand breadth at metacarpals	8.8	13.31*	-10.8	-24.92*	-2.0	-3.07*
Hand depth	12.8	13.38*			10.6	10.88*
Wrist breadth	8.3	12.28*	-7.2	-16.16*		

* Indicates statistically significant, using $\alpha = 0.05$ level of significance
% Difference = 100 *(mean of Korean – mean of other nationality)/mean of Korean

Table 3.11. Comparison between Korean females and other nationalities

Hand Dimensions	Korean vs Turkish		Korean vs American		Korean vs Indian	
	% Diff	t-value	% Diff	t-value	% Diff	t-value
Fingertip to root digit 1	-5.9	-6.38*	-13.2	-23.73*	-14.3	-11.34*
Fingertip to root digit 2	-3.0	-3.79*	-5.0	-8.93*	-4.4	-4.37*
Fingertip to root digit 3	-1.2	-1.57*	-5.0	-9.88*	-3.4	-3.67*
Fingertip to root digit 4	1.3	1.70	-4.3	-8.04*	-1.4	-1.53
Fingertip to root digit 5	-2.0	-2.08	-7.0	-9.69*	-3.3	-2.70*
Breadth at PIP joint of digit 1	10.7	13.09*				
Breadth at PIP joint of digit 2	9.3	12.63*	-8.7	-15.50*	29.0	26.57*
Breadth at PIP joint of digit 3	9.7	14.20*	-4.3	-7.75*	28.1	28.61*
Breadth at PIP joint of digit 4	9.8	13.41*	-6.4	-10.75*		
Breadth at PIP joint of digit 5	10.5	12.62*	-7.8	-11.83*		
Circumference at PIP joint of digit 1	3.9	4.70*	-3.3	-5.30*		
Circumference at PIP joint of digit 2	3.1	4.06*			2.1	2.65*
Circumference at PIP joint of digit 3	5.5	7.63*	-2.9	-4.96*	0.7	0.79
Circumference at PIP joint of digit 4	4.7	5.55*	-3.2	-5.51*		
Circumference at PIP joint of digit 5	4.3	4.86*	-3.7	-5.81*		
Hand length	-0.8	-1.23*	-5.9	-14.76*	0.6	0.95
Hand breadth at metacarpals	10.4	16.39*	-6.5	-14.80*	12.8	16.27*
Hand depth	11.6	9.85*			19.0	13.09*
Wrist breadth	10.1	12.95*	-2.9	-5.38*	16.8	16.38*

The comparison between Korean males and American males shows that the hands of the American male are significantly larger in size than those of the Korean male for all parts (Greiner, 1991). The most noticeable difference between the Korean male and the American male was the length of the thumb and the hand breadth. The thumbs of American males were 13.9% (8.5 mm) longer than those of Korean males, and they had a 9 mm (10.8%) greater hand breadth than the Korean male. Therefore, in order to produce the hand tools for Korean men, it may be appropriate to design them about 6-8% smaller than those designed to fit the hands of American males. In particular, the difference between the lengths of the Koreans male’s thumb and the Americans male’s thumb was of about 8.5 mm. This difference was relatively more substantialthan the other differences, and if gloves were produced based on the Korean male’s average thumb length (without any consideration to the difference in size), they would accommodate only 5% of American males, leading to discomfort for the wearer.

In terms of the hand width, there was a difference of about 9 mm, and thus, it would be convenient for American males to use hand tools that were a minimum of 9 mm longer in the handle than those created for Korean males. The size difference between Korean and Jordanian males was not so large (within 10%) (Mandahawi et al., 2008), and a difference of less than 10% in the population’s hands would not significantly cause an inconvenience for users, since hands have a greater range of motion than any other part of the body and other factors, such as grip type or work time, might have a greater effect on the user’s comfort (Berguer & Hreljac, 2004; Blackwell, 1999; Nag, 2003). Thus, Korean and Jordanian males’ hand tools can also be determined to result in no inconveniences if they share the same size. However, further case studies are needed to generalize the relationship between the hand size range and the user’s comfort level.

For Turkish females, the hand breadth was smaller than that of their

Korean counterparts by about 8 mm, so it is necessary to increase the handle length by 7 to 8 mm when producing hand tools for Korean females rather than for Turkish females. For Indian females, there is a greater difference in the proximal joint breadth of the index finger and the middle finger. When producing haircutting scissors, which require placing the index and middle fingers inside of the handle rings, the ring diameter needs to be 10 mm larger for Korean females than that for their Indian counterparts since Korean females have a wider proximal joint breadth of the index and middle fingers (Nag et al., 2003).

A comparison of the hand shape between Korean males and females shows that males had a more spacious hand (Type 1), while females had a more narrow hand (Type 4). Thus, it is necessary to further subdivide the design parameters related to the breadth (for male) and length (for female) when developing a sizing system for gloves, hand tools, and computer mice. In the case of power grip-type hand tool production for Korean users, if the handle length is designed to be larger than 92.3 mm (95th percentile value of the Korean male hand breadth), about 96% of Korean males and females would be able to use the tool without difficulties. When producing a wrist-wearable device for both males and females, if the strap has an adjustable wrist circumference that ranges from 143.7 mm (5th percentile value of Korean female wrist circumference) to 192.8 mm (95th percentile value of Korean male wrist circumference), then 95% of Korean males and females would be able to wear the device.

As mentioned above, the characteristics of the hand shapes for Korean males and females were identified by making a comparison with other nationalities. The author added the results for the 10 previous studies (from 11 nations) to the results of our study (Greiner, 1991; Imrhan et al., 2006; Ishak et al., 2012; Mandahawi et al., 2008; Nag et al., 2003; Okunribido, 2000). In case of European and Indian population, only female measurement data was reported and applied. Then, the author compared these results using the values of the hand breadth at the metacarpal level (HB) and the length of the finger (middle finger), which represent the horizontal length of the hand and the vertical length of finger, respectively, divided by the hand length. If a nationality is located on the left top of the plot, then this nationality has longer hands (short hand breadth and long fingers). On the other hand, if a nationality is positioned in the right bottom of the plot, then this nationality has wider hands (wide hand breadth and short fingers). When compared with other nationalities, Korean males and females had wider hands and shorter fingers than the individuals from the 8 other nations, putting them in the right bottom of the plot (Figure 3.4). Therefore, when manufacturing hand tools, hand-related products and interfaces for Koreans to use, products should be designed by considering the characteristics of Korean hands, which have a shorter finger length and a wider hand breadth.

As shown above, the author used three major factor scores to explain the hand shapes by applying a cluster analysis, and the author distinguished four hand shape types (Figure 3.5) based on the resulting dendrogram. Then, the author analyzed the proportion of each type among the subjects. In males, wide hands with short fingers (Type 1) were the most common, constituting 38.9% of all male subjects. Long palms with long fingers (Type 3) were the least common (15.6% of all male subjects). In contrast, narrow hands with short fingers (Type 4) was the most common for female subjects (30.9% of all females). Thus, even though they belong to the same race, Korean males and females had significantly different hand type distributions (p value<0.001). Previous studies have attributed this difference to biological and social differences (Bardin & Catterall, 1981).

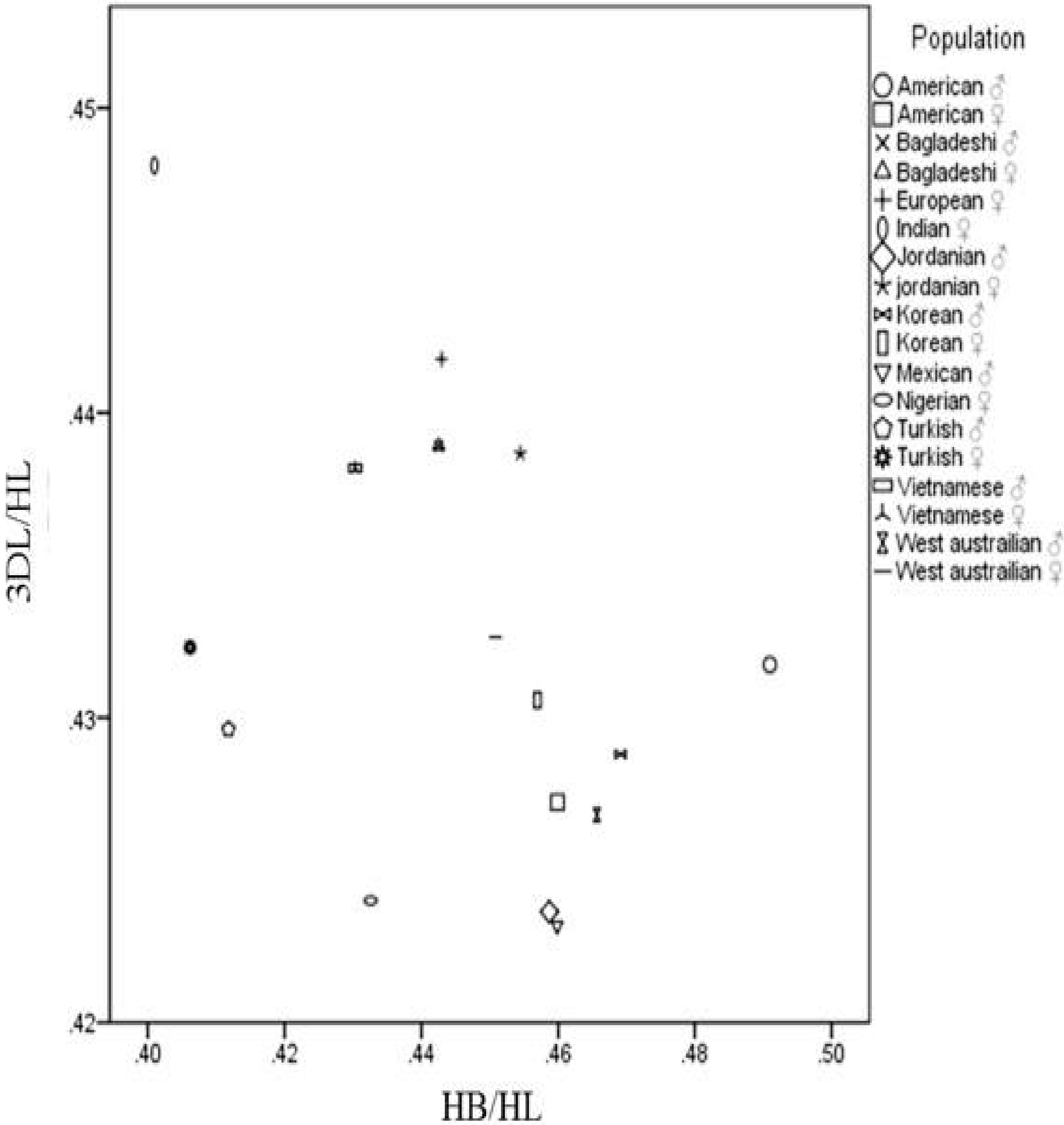


Figure 3.4. A comparison of the different hand shapes of various ethnicities

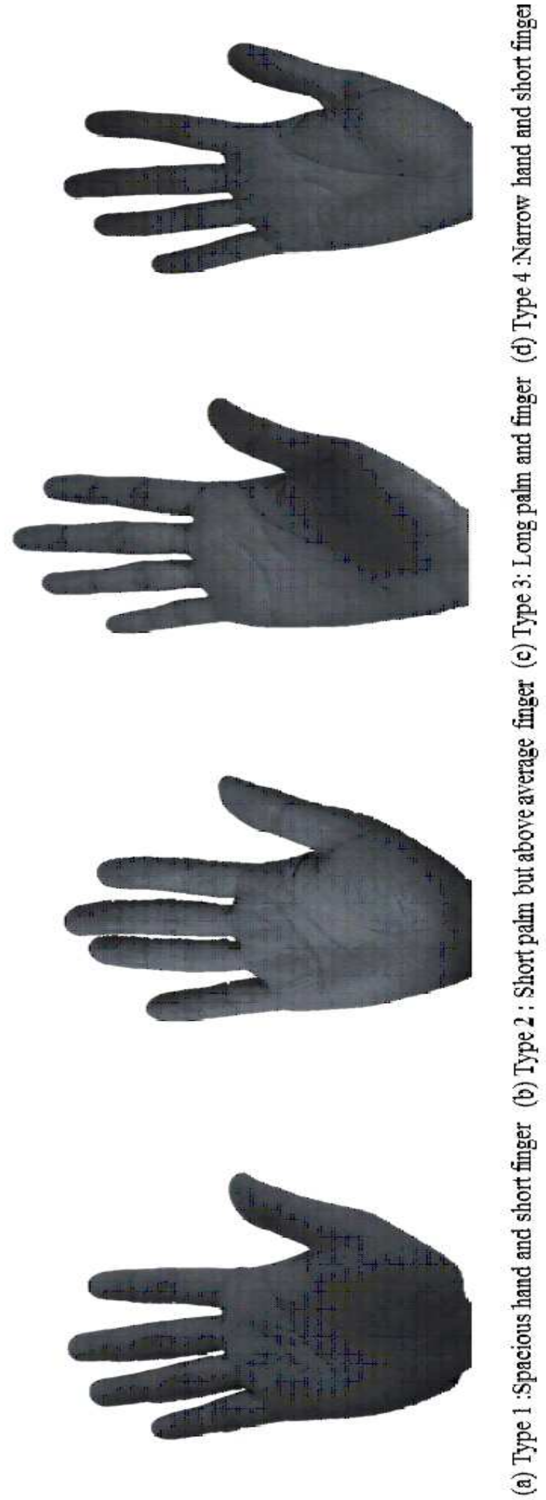


Figure 3.5. Images representing the four hand types

Hand representative model suggested in the current research has the limit on the comparison with other ethnic groups as there are no cases researching other ethnic groups or in other nations. Therefore, the current research's hand representative model was compared with the research result of the Kim & Whang which reported sizes of 9 mannequins using the body size of the whole body of South Koreans. The current research has identified 3 factors of hand width, length, and the length of fingers for the production of the representative model of hands of South Koreans. And Kim & Whang's research has produced a model by identifying the width of a torso, height, and sitting height as 3 major factors for determining the representative size model of South Koreans (Kim & Whang, 1997). Identification of 3 major factors in determining the representative body size was identical in two models. Park's thesis producing a model representing the body type of overweight passengers also suggested 9 representative models representing the body size of overweight U.S. citizens for the usage of the designing of aircraft seats (H. Park et al., 2014). The major factors included circumference, height, and sitting height.

In case of representative hand model deducted by using boundary method, it was analyzed that the model encompass 95.2% of the population of the design. The result showed to satisfy 95% of the target population capacity. Thus, designing the sizes of interface related with hands by using representative hand model suggested at the current research would enable making interface allowing usage without inconvenience from the majority(95%) of South Koreans.

3.2 Classification of foot shapes and representative manikins

3.2.1 Overview

Previous studies on Korean foot tend to focus only on reporting the length and breadth of the foot, and the distribution of these measurements. Thus, it is limited to fully understand characteristic of Korean’s various foot. More detailed research is in need in order to identifying characteristic of Korean’s foot. In this study, the author includes various data on the foot dimensions of both Korean males and females, including variables related to the breadth and circumference of various foot parts. Statistical methods are then used to distinguish the major factors that determine the foot shapes, representative Korean foot manikins and to categorize the foot shapes that are found within the Korean population.

3.2.2 Method

3.2.2.1 Subjects

In this research 350 numbers of participants who has no medical error of foots and backbone were participated in foot scanning (the numbers of male participants; 175 & Female; 175). Average age of male was 41.6 (minimum: 20, maximum: 69) and 38.4 for female (minimum: 20, maximum: 68). Identical rate of each age group were selected, and the maturity of participants' foot were examined that there were no more growth. All subjects were informed by written consent

3.2.2.2 Measurement

In the study, based on the prior research where foot dimension and ISO 7250's standard (Standard, 2003), 10 features of foot dimension where finally selected. (Table 3.12 and Figure 3.6). In addition, 3D scanner was used for faster and clear estimation.

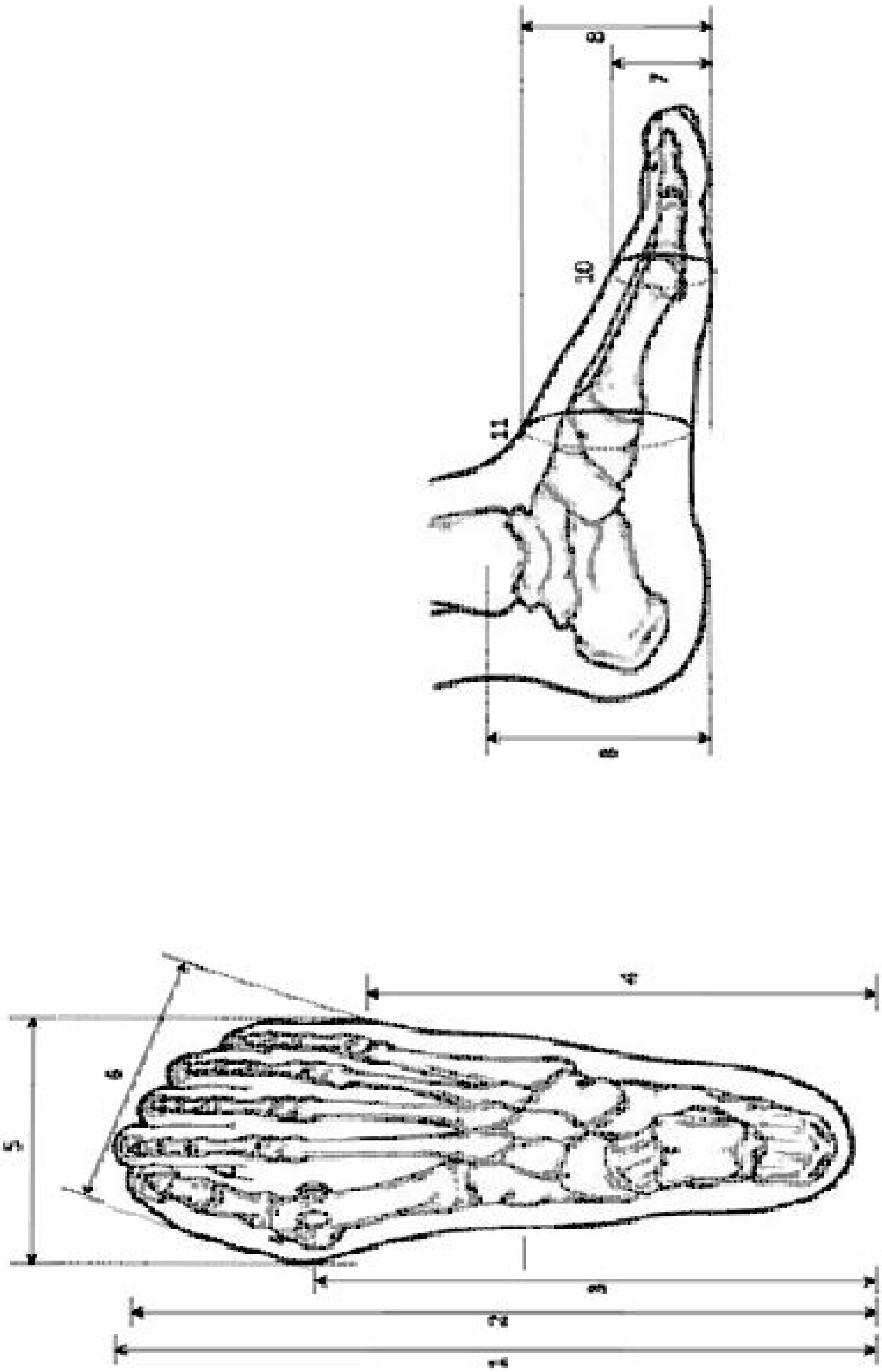


Figure 3.6. Various land marks in foot dimension

Table 3.12. Definition of foot measurement employed in this research with reference

No.	Foot dimensions	Abbreviation	Definition
1	Foot length	FL	The maximum distance from the pternion to the tip of longest toe
2	Pternion to great toe (length)	PGL	The distance from the pternion to the great toe
3	Pternion to first metatarsal tibiale (length)	PMTL	The distance from the pternion to the most medial point on the head of the first metatarsal(tibiale)
4	Pternion to fifth metatarsal fibulare (length)	PMFL	The distance from the pternion to the most lateral point on the head of fifth metatarsal(fibulare)
5	Breadth at the metatarsal	FB	The distance from the most medial point on the head of the first metatarsal to the most lateral point on th e head of fifth metatarsal
6	Diagonal breadth at the metatarsal	DFB	The distance from the most medial point on the head of the first metatarsal to the most lateral point on th e head of fifth metatarsal
7	Height at the ball(metatarsal)	BH	The distance from the floor to the most prominent point on the head of the first metatarsal
8	Height at the instep(navicular)	IH	The distance from the floor to the most prominent point on the navicular bone
9	Height at the lateral malleolus	MAH	The distance from the floor to the most prominent point on the later malleolus bone
10	Circumference at ball(metatarsal)	BC	The superficial distance around the edge of the metatarsal
11	Circumference at instep(navicular)	IC	The superficial distance around the edge of the prominent point of navicular and the sole in the vertical direction

This scanner extracts automatically the feature’s information due to CCD camera and laser. The accuracy of this scanner was 1mm, and test subject group attached marker at 1st, 5th metatarsal head, navicular height, and prominent point in malleolus. Participants then were asked to step up the scanner in which their right foot on the outside of scanner and left one on inside were located as possible as parallel. They were also asked to stand up parallel and the toes should direct forward with naturally opening their toes. For heights, participants were asked to attach heels together, to open their foot's angle almost 30 degree and to maintain their standing with Frankfurt plane.

3.2.2.3 Data analysis

All of the data were analyzed using MS EXCEL and SPSS 21. Descriptive statistics (including the mean, standard deviation and various percentiles) for the value of each foot dimension were calculated and are presented herein. A Kolmogorov-Smirnov test was conducted to test whether the data set of the measurements conformed to a normal distribution. A T-test was used to compare the differences in the measurements for the males and females. The relationship between the foot measurement and the stature was identified by using Pearson correlation coefficients, and a factor analysis was carried out with 11 variables in order to determine a suitable set of factors to explain the variability in the foot shape (Varimax rotation). The change in the slope of the scree plot indicated that two factors were suitable. The Ward and Euclidian distance method was used to measure the distance between the groups, and a cluster analysis was performed for the factor score. We categorized the Korean foot into four groups, and a cluster analysis was carried out to distinguish the characteristics of each group so that groups with similar traits could be determined to belong to a single category.

In order to develop Korean representative foot manikins which accommodate various Koreans' foot size variation, boundary condition method was utilized same as establishing hand representative manikins (Bittner, 1987; Young, 2004 ; HFES 300, 2004). A factor analysis was conducted using the principal component method for hand measurement data. Three principal factors were extracted and they accounted for 30.37%, 30.11% and 21.15% of total variation. The statistical procedures for represent model is same to that of hand representative model.

3.2.3 Result of Foot Shapes Classification

3.2.3.1 Descriptive Statistics

The average and standard deviations of the hand measurements for Korean males and females are shown in Table 3. All measurements from the male portion of the sample group were significantly greater than those for the females (p value<0.001). The foot length was the greatest value of the 11 dimensions that were measured, and the height at the ball(metatarsal) was the smallest. A T-test was used to compare the difference between the hand measurements in males and females, and the circumference at instep(navicular) was found to have the greatest difference between the two genders. To determine the influence that stature had in distinguishing the foot shapes of Koreans, we compared the correlation between the stature and the hand measurements in males and females.

In case of both males and females, length and circumference related measurements were positively correlated with stature, and all the coefficient of length and circumference related measurements were statistically significant (p value<0.01). Highest coefficient was observed between the foot length and stature in both males (r=0.753) and females (r=0.433). All of the correlation factors between each foot part and stature were greater in males than were in females.

Table 3.13. Descriptive statistics for foot measurement (cm) in Korean male and female

	Variable	Male (n=175)		Female(n=175)		T-test	
		Mean	SD	Mean	SD	T	*P* value
	Stature	169.7	6.6	159.7	5.3	17.0	***
1	FL	25.2	1.2	23.1	1.0	17.0	***
2	PGL	25.1	1.2	23.1	1.0	18.0	***
3	PMTL	18.4	0.9	17.0	0.8	16.6	***
4	PMFL	15.9	0.9	14.8	0.8	14.2	***
5	FB	9.9	0.5	9.2	0.5	15.3	***
6	DFB	10.2	0.5	9.5	0.5	15.1	***
7	BH	3.7	0.3	3.3	0.3	11.9	***
8	IH	6.1	0.5	5.2	0.6	17.3	***
9	MAH	7.2	0.5	6.7	0.6	10.1	***
10	BC	25.4	1.2	23.3	1.0	20.3	***
11	IC	25.5	1.2	22.9	1.1	23.5	***

*** $P<0.001$ is significant

Table 3.14. Correlation coefficient between foot dimension and stature

No.	Variable	Male	Female
1	FL	0.753**	0.433**
2	PGL	0.742**	0.433
3	PMTL	0.675**	0.393**
4	PMFL	0.666**	0.334**
5	FB	0.544**	0.224**
6	DFB	0.503**	0.224**
7	BH	0.140	0.016
8	IH	0.051	-0.006
9	MAH	0.494**	0.069
10	BC	0.331**	0.212**
11	IC	0.328**	0.222**

** Significant at 0.01 level (two tailed).
* Significant at 0.05 level (two tailed).

3.2.3.2 Factor and cluster analysis

A factor analysis was carried out for the 11 variables that were measured to distinguish the foot shapes of Koreans, and three factors were identified. As suggested above, when the descriptive statistics and correlation factors are compared, all foot parts of the males and 10 hand parts of the females show a positive correlation with the stature. As a consequence, the author have used the measurements of each of the foot parts divided by the stature of the subject when conducting the factor analysis. As shown in the table , 81.6% of the variance in foot parts dimension variability (foot shape) was explained by the three major factors (factor 1: foot length, factor 2: foot breadth, factor 3: foot height).

Factor 1 (foot length) includes the foot length, PGL, PMFL and PMTL. This factor shows the characteristics related to the longitudinal length of the foot shape. Factor 2 (foot breadth) includes the horizontal length of the foot shape, and this factor includes DFB, FB, BC and IC. Factor 3 (foot height) includes the variables related to vertical height of the foot such as IH, BH, and MAH. The factor scores were derived using a factor analysis and were standardized to a normal distribution (with an average of 0 and a variance of 1), which makes it easier to interpret the foot shape, and these factor scores were then used to conduct a cluster analysis. The proper amount of groups is calculated by deriving a dendrogram and selecting four clusters by applying Ward's method of using the square Euclidean distance (Table 3.16). We verified that these four groups were significantly different from one another through the use of ANOVA (p value<0.05).

Table 3.15. The factor analysis result for the foot dimensions

Hand dimension	Factors and factor loadings			Communality
	1	2	3	
FL	0.905	0.320	0.101	0.932
PGL	0.904	0.321	0.095	0.930
PMFL	0.865	-0.021	0.029	0.749
PMTL _	0.846	0.296	0.013	0.804
DFB	0.227	0.947	0.107	0.961
FB	0.251	0.910	0.138	0.911
BC	0.210	0.862	0.372	0.925
IC	0.263	0.690	0.555	0.854
IH	0.077	0.074	0.896	0.814
BH	0.075	0.210	0.840	0.755
MAH	-0.023	0.155	0.568	0.347
% Total variance explained (cumulative)	30.37%	30.11%	21.15%	81.64%

Table 3.16. The cluster analysis result for the foot dimensions

Foot Types	Cluster Mean Factor Scores			Relative Frequencies(%)
	Factor 1 : Foot length	Factor 2 : Foot breadth	Factor 3 : Foot height	Pooled (male vs female)
Type 1 : Long foot	1.194	0.219	-0.074	23.2 (33.9 vs 16.7)
Type 2 : Spacious and tall foot	-0.496	1.099	0.685	19.3 (23.6 vs 16.7)
Type 3 : Narrow and tall foot	-0.172	-0.853	0.456	34.2 (35.6 vs 33.3)
Type 4 : Short and flat foot	-0.522	0.124	-1.159	23.4 (6.9 vs 33.3)

3.2.4. Results of representative foot model

3.2.4.1 Manikin description

The procedures for making representative foot model was same to the method of representative hand manikins. The family of 5 representative Korean foot manikin is characterized as follows. In case of manikin 1, manikin 1 reflects very large foot which have long foot length, spacious foot breadth, and higher foot height. Manikin 2 is the foot which has higher foot height but short foot length. Manikin 3 shows the foot which has long foot length and but relatively small foot height and foot breadth. Manikin 4 reflects the foot which has short foot length, breadth and foot height. Manikin 5 shows the hand which has average of each foot dimension.

Table 3.17. The hypothetical hand manikins described in percentile format

Variables	**1**	**2**	**3**	**4**	**5**
PGL	99.2%	0.3%	91.0%	0.8%	50%
FL	99.2%	0.3%	90.8%	0.8%	50%
PMTL	98.8%	0.2%	92.3%	1.2%	50%
PMFL	97.3%	0.1%	93.7%	2.7%	50%
FB	99.3%	18.7%	65.6%	0.7%	50%
DFB	99.2%	19.1%	65.3%	0.8%	50%
BH	97.1%	99.6%	8.5%	2.9%	50%
IH	97.1%	99.5%	9.0%	2.9%	50%
IC	99.5%	64.1%	40.7%	0.5%	50%
BC	99.5%	51.8%	47.0%	0.5%	50%
MAH	94.8%	92.8%	21.9%	5.2%	50%

Table 3.18. The hypothetical foot manikins described in percentile format (in cm)

Variables	**1**	**2**	**3**	**4**	**5**
PGL	27.3	19.8	25.8	20.3	23.8
FL	27.4	19.9	25.9	20.4	23.9
PMTL	20.0	14.4	19.1	15.1	17.5
PMFL	17.2	12.1	16.8	13.3	15.2
FB	10.9	9.0	9.7	8.1	9.5
DFB	11.3	9.2	10.0	8.3	9.8
BH	4.1	4.4	2.9	2.7	3.4
IH	7.0	7.5	4.5	4.1	5.5
IC	28.2	24.5	23.5	19.5	23.9
BC	27.9	24.1	24.0	20.2	24.1
MAH	7.9	7.8	6.4	5.9	6.9

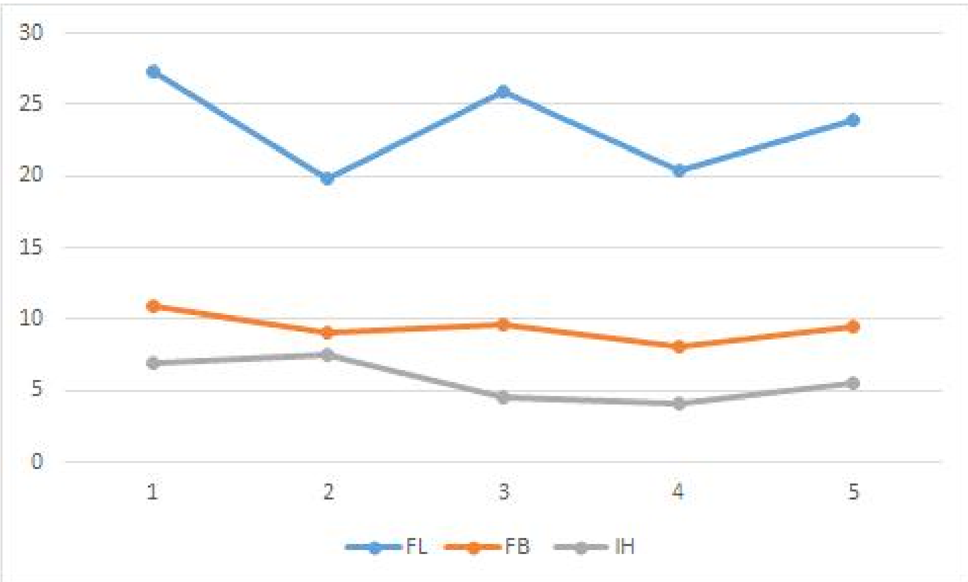


Figure 3.7. Size of each foot manikin (in cm)

3.2.5 Discussion

The measured foot size data for the Koreans subjects was compared to data from the previous studies to determine the characteristics that distinguish Korean foot from those of other nationalities (Goonetilleke, 1997; Kanchan 2012; Hislam, 2012; Zeybak,2008; Hemy, 2013). In case of Hongkong population, only male measurement data was reported and applied. According to Figure 3.8, Korean males and female have spacious foot breadth compared to other nationalities.

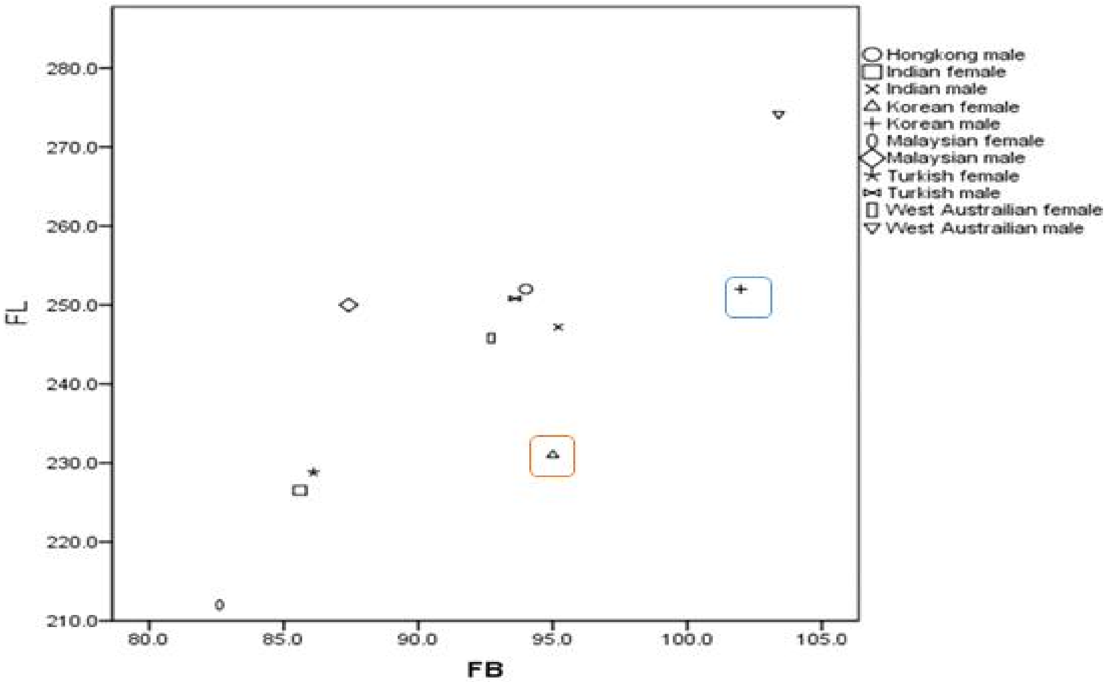


Figure 3.8. A comparison of the different foot shapes of various ethnicities

As explained above, we used three major factor scores to explain the foot shapes by applying a cluster analysis, and we distinguished four foot shape types based on the resulting dendrogram. Then, we analyzed the proportion of each type among the subjects. In males, narrow and tall foot (Type 1) were the most common, constituting 34.2% of all male subjects. Short and flat foot (Type 4) were the least common (6.9% of all male subjects). In contrast, short and flat fingers (Type 4) was the most common for female subjects (33.3% of all females). Thus, even though they belong to the same race, Korean males and females had significantly different foot shape type distributions (p value<0.001). A comparison of the foot shape between Korean males and females shows that males had longer foot shape (Type 1), while females had a more short and flat foot (Type 4). Thus, it is necessary to further subdivide the design parameters related to the length (for male) and height (for female) when developing a sizing system for shoes or pedals.

In case of representative foot model deducted by using boundary method, it was analyzed that the model encompass 95.4% of the population of the design. The result showed to satisfy 95% of the target population capacity. Thus, designing the sizes of interface related with hands by using representative hand model suggested at the current research would enable making interface allowing usage without inconvenience from the majority (95%) of South Koreans.

Chapter Ⅳ

Developing Estimation Model Using Hand and Foot Measurement Data

4.1 Sex Estimation Model

4.1.1.1 Sex Estimation Model Using Hand Dimension

In the cases of large natural disasters, terror, or crime scenes, the forensic anthropometry method has been utilized as a reliable means of confirmation of identity by using only a few body parts (Cattaneo & Baccino, 2002; Kanchan & Krishan, 2011). In recent years, the importance of this method has been highlighted and its accuracy has also been improving when combined with various statistical techniques (Cattaneo, 2007; Patil & Mody, 2005; Villa, Hansen, Buckberry, Cattaneo, & Lynnerup, 2013). Due to its time and cost-effectiveness and relatively accurate identification ability, forensic anthropometry with DNA analysis is widely used in many countries including Korea (Champod, Lennard, Margot, & Stoilovic, 2004; DeSilva, Flavel, & Franklin, 2014; Egli, Champod, & Margot, 2007). One of the most fundamental identifications in forensic anthropometry is sex determination, which could eliminate 50% of the cases.

Among many traces of body parts, hand prints are frequently found on a crime scene, and usually provide important clues in the investigation. The hand is composed of 27 bones and 15 joints, which provide important information such as length, breadth, circumference, and thickness of various hand dimensions. Some hand dimensions were found to have significant correlation with a human’s stature and weight. In the case of disasters or air crashes, a dismembered or fragmentary hand is commonly used to confirm a victim’s identity (Aboul-Hagag et al., 2011; Ishak et al., 2012a; Kanchan &

Krishan, 2011).

The previous studies discriminated the sex of subjects mainly based on the hand length and breadth. However, in an accident or incident area, it is not possible to measure hand length or hand breadth in many cases because the human body is usually damaged or fragmented. Thus, gender prediction using the detailed hand anthropometric method will be effective in such conditions. Moreover, the hand is a highly complex structure with 27 bones and 15 joints, and detailed measurements of the hand will therefore provide more information for sex identification. In this study, besides the length and breadth of fingers and palms, the detailed dimensional measurements such as breadth, length, thickness, and circumferences of finger joints, wrist, and unique features of the hand are considered. By applying statistical techniques, a sex determination method is proposed. Depending on the different ethnic groups, the sectioning point for sex determination was reported to differ (Aboul-Hagag et al., 2011; Ishak et al., 2012a; Kanchan & Krishan, 2011). Therefore, the sectioning point that has been derived from other nationalities would not be applicable to the Korean population. Through this study, which is the first empirical attempt at sex determination of Koreans by using hand dimensions, the author proposes reliable criteria that would be applicable in a forensic investigation.

4.1.1.2 Method

Data used in this study were gained from body measurements of the Size Korea Project organized by the National Agency for Technology and Standards Measurement, an institution for anthropometric survey in the Republic of Korea. The subjects were a total of 321 people (167 males and 154 females) who had no history of disease associated with the hand or spine. The subjects were same to the data set of Section 3.1.

A total of 29 variables including length, breadth, thickness, and circumference of fingers, palm, and wrist were measured as presented in Table 3 and Figure 1 (Aboul-Hagag et al., 2011; Ishak et al., 2012a; Kanchan & Krishan, 2011). To reduce the measurement errors, each investigator examined the dimension of one measurement variable. Digital calipers were used to measure the length, breadth, and thickness (stated accuracy ±0.1mm), while tape measures were used to measure the circumferences.

Table 4.1. Definition of hand measurement employed in this research

Hand dimension	Abbreviation	Definition
Hand length	HL	The distance from the middle of inter stylion to the tip of middle finger
Palm length	PL	The distance from the middle of inter stylion to the proximal flexion crease of the middle finger
Thumb; index; middle; ring; little finger length	1DL, 2DL, 3DL, 4DL, 5DL	The distance from proximal flexion crease of the finger to the tip of the respected finger
Hand breadth	HB	The distance from the most lateral point on the head of the 2D metacarpal to the most medial point on the head of 5D metacarpal
Maximum hand breadth	MHB	The distance from the most lateral point on the head of the 1D metacarpal to the most medial point on the head of 5D metacarpal with closing fingers
Wrist breadth	WB	The distance from the most lateral point on the wrist to the most medial point of wrist
Thumb; index; middle; ring; little finger proximal breadth	1D2B, 2D2B, 3D2B, 4D2B, 5D2B	The distance from the most lateral point on each finger proximal joint to the most medial point of each finger proximal joint
Index; middle; ring; little finger distal breadth	2D1B, 3D1B, 4D1B, 5D1B	The distance from the most lateral point on each finger distal joint to the most medial point of each finger distal joint
Hand thickness	HT	The distance from the back of the middle finger to the most medial point of palm
Maximum hand thickness	MHT	The maximum distance from the back of the hand to the most projected point of abductor pollicis brevis
Hand circumference	HC	The superficial distance around the edge of metacarpal
Maximum hand circumference	MHC	The maximum superficial distance around the edge of the hand with closing fingers
Wrist circumference	WC	The superficial distance around the edge of the wrist
Thumb; index; middle; ring; little finger proximal circumference	1D2C, 2D2C, 3D2C, 4D2C, 5D2C	The superficial distance around the edge of proximal joint in each finger

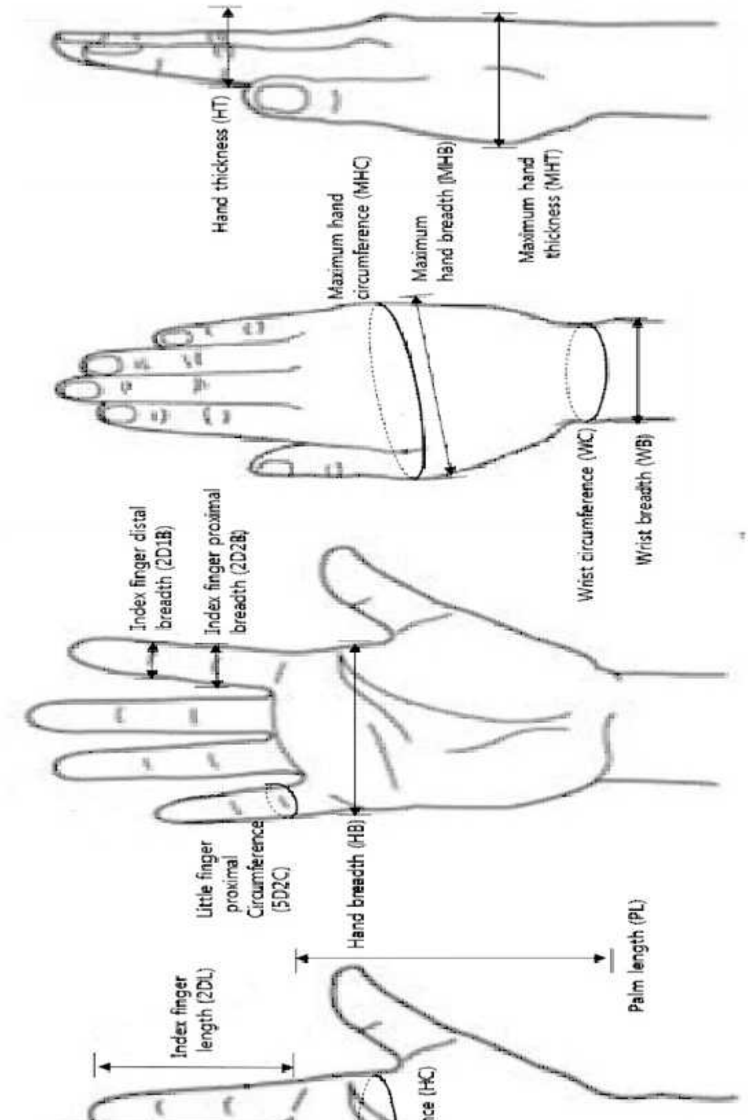


Figure 4.1. Various hand landmarks in human hand

All investigators were instructed of the measurement methods for at least 18 hours. When measuring, the subjects were asked to undress their top layer of clothing, sit down, and place their palms parallel to the measurement unit facing up and fully opened. Data values greater than ± 3σ from the mean were regarded as outliers, and the data were then compared to other body sizes. When the data had no relevance, it was removed.

The obtained hand dimension data were calculated and analyzed using SPSS 21. A descriptive statistic (mean, SD) was presented for each dimension. The body dimension differences between sexes were compared using a t-test. The accuracy of sex determination was derived using discriminant analysis (D.-I.Kim, Kim, Lee, & Han, 2013), and the accuracy of the method was confirmed using a cross validation method (Randomly selected 70% data for training set and 30% for validation set). Based on the demarking points, the genders were classified into males with higher values and females with lower values.

4.1.1.3 Result

Mean, SD, and range of hand dimensions are presented in Table 4.2. All dimensions, including length, breadth, thickness, and circumferences, appeared larger in males than in females, with statistical significance. The t-test results indicate that the maximum breadth and circumference of the hand show the greatest differences between sexes. On the other hand, the length of the index and little fingers shows a relatively small difference between male and female.

In order to evaluate the measured variables that determine sex most accurately, the accuracy according to a single variable was calculated (Table 4.3). The measured variables exhibited an average of more than 70% accuracy, and the maximum hand circumference (MHC) showed the highest accuracy of 88.6% for males and 89.6% for females.

Table 4.2. Descriptive statistics of mean ans SD in hand landmarks (in mm)

	Male (n=167)			Female (n=154)			T
	Mean	SD	Range	Mean	SD	Range	
HL	183.28	9.04	153.05-203.37	170.73	7.67	146.22-190.83	13.34
PL	105.06	4.98	90.06-115.77	97.38	4.57	83.1-113.54	14.35
1DL	61.23	3.94	49.53-72.48	56.08	3.49	45.84-64.43	12.35
2DL	70.48	4.33	55.49-81.08	66.26	4.28	55.89-75.24	8.76
3DL	78.59	4.68	63.82-91.41	73.51	4.27	61.19-82.46	10.14
4DL	74.28	4.70	56.80-85.03	69.22	4.31	54.19-80.39	10.03
5DL	59.00	4.46	43.56-70.55	54.53	4.56	38.62-66.93	8.88
HB	85.96	4.19	74.61-95.75	78.03	3.98	70.94-88.32	17.34
MHB	107.30	5.01	94.08-119.26	95.79	4.81	84.41-110.89	20.89
WB	61.42	3.01	54.03-69.01	55.43	3.52	48.76-66.09	16.43
1D2B	22.46	1.60	19.01-26.27	19.72	1.50	15.54-23.65	15.81
2D2B	20.57	1.15	16.79-24.51	18.32	1.22	14.79-21.30	16.91
3D2B	20.76	1.21	17.01-24.35	18.49	1.25	15.25-22.44	16.47
4D2B	19.58	1.13	16.18-23.55	17.28	1.23	14.76-20.10	17.48
5D2B	17.48	1.11	13.82-20.55	15.33	1.22	12.60-18.17	16.54
2D1B	18.09	1.19	15.08-22.68	16.15	1.22	13.13-19.22	14.49
3D1B	18.24	1.21	15.16-22.30	16.22	1.18	13.00-19.36	15.14
4D1B	16.86	1.14	13.82-20.27	14.95	1.14	12.45-18.33	14.98
5D1B	15.51	1.08	12.25-18.80	13.61	1.24	10.80-16.42	14.70
HT	27.66	2.06	21.43-38.86	24.69	1.79	21.00-30.92	13.72
MHT	49.12	4.05	38.12-62.35	42.16	3.74	34.52-58.85	15.96
HC	208.04	9.61	183.0-233.0	186.06	10.74	162.0-225.0	19.34
MHC	252.59	12.00	223.0-284.0	223.29	11.69	198.0-257.0	22.12
WC	175.80	10.91	156.0-254.0	156.24	8.95	137.0-185.0	17.47
1D2C	68.60	4.27	60.0-81.0	61.03	4.58	50.0-74.0	15.32
2D2C	64.86	3.71	55.0-77.0	58.24	4.05	48.0-72.0	15.26
3D2C	66.40	3.95	55.0-78.0	59.57	4.23	49.0-72.0	14.94
4D2C	62.06	3.85	52.0-77.0	55.62	4.00	47.0-66.0	14.66
5D2C	54.51	3.45	45.0-65.0	48.76	3.80	41.0-58.0	14.19

*** $P<0.001$ is significant

Table 4.3. Demarking points (in mm) of hand dimension in estimating sex and expected accuracy

	Variable	Demarking point	Accuracy (%)		Sex bias (%)
			Male	Female	
Length					
Function1	HL	♀<177.01<♂	75.4	76.6	-1.2
Function2	PL	♀<101.22<♂	77.8	81.8	-4.0
Function3	1DL	♀<58.66<♂	78.4	78.6	-0.2
Function4	2DL	♀<68.37<♂	65.9	70.1	-4.2
Function5	3DL	♀<76.05<♂	68.3	72.1	-3.8
Function6	4DL	♀<71.75<♂	70.7	72.1	-1.4
Function7	5DL	♀<56.77<♂	73.1	67.5	5.6
Breadth					
Function8	HB	♀<82.00<♂	83.2	85.7	-2.5
Function9	MHB	♀<101.55<♂	86.2	87.0	-0.8
Function10	WB	♀<58.43<♂	84.4	81.2	3.2
Function11	1D2B	♀<21.09<♂	79.6	81.8	-2.2
Function12	2D2B,	♀<19.45<♂	81.4	81.2	0.2
Function13	3D2B	♀<19.63<♂	82.6	81.8	0.8
Function14	4D2B	♀<18.43<♂	86.2	83.1	3.1
Function15	5D2B	♀<16.41<♂	83.8	80.5	3.3
Function16	2D1B,	♀<17.12<♂	79	78.6	0.4
Function17	3D1B	♀<17.23<♂	80.8	83.1	-2.3
Function18	4D1B	♀<15.91<♂	78.4	79.9	-1.5
Function19	5D1B	♀<14.56<♂	79.0	76.6	2.4
Thickness					
Function20	HT	♀<26.18<♂	76.0	82.5	-6.5
Function21	MHT	♀<45.64<♂	82.6	84.4	-1.8
Circumference					
Function22	HC	♀<197.05<♂	85.0	87.0	-2.0
Function23	MHC	♀<237.94<♂	88.6	89.6	-1.0
Function24	WC	♀<166.02<♂	83.2	88.3	-5.1
Function25	1D2C	♀<64.82<♂	83.2	79.9	3.3
Function26	2D2C	♀<61.55<♂	79.6	79.9	-0.3
Function27	3D2C	♀<62.99<♂	83.2	76.6	6.6
Function28	4D2C	♀<58.84<♂	80.2	76.6	3.6
Function29	5D2C	♀<51.64<♂	79.0	77.9	1.1

The highest accuracy of discrimination was followed by those predicted using the maximum hand breadth and the breadth of the second joint of the ring finger for males and using the wrist circumference, maximum hand breadth, and the maximum hand thickness for females. The demarking point was calculated from the average measurements from male and female subjects and indicated that males had the higher values and females had the lower values.

In order to derive a more accurate prediction model, group variables (length, breadth, thickness, and circumference) were combined and the stepwise method was followed. The discriminant analysis using variables related to the lengths showed the sex determination accuracy of 82.6%. When the four variables (PL, 1DL, 2DL, and 3DL) were used for the discriminant analysis, the accuracy was 83.2% with -4.9% bias (Table 4.4). In case of breadth related variables, the discriminant analysis yielded 88.4% accuracy by using the two variables (MHB and 5D2B). The determination accuracy of 87.2% was obtained when the thickness related variables (HT and MHT) were used. When MHC and WC, the two parameters of the circumference associated variables, were used for stepwise discriminant analysis, 89.4% accuracy was obtained. By using PL, MHT, and HB variables, which showed no significant difference according to age range, the discriminant model yielded 90.0% accuracy, which was the highest accuracy in this study.

Table 4.4. Discriminant analysis results using stepwise method

Variables		Coefficient		Canonical	Wilk's	Group	Sectioning	Accuracy (%)			Cross-validated (%)
		Unstandardized	Standardized	correlation	lambda	centroids	Point	Male	Female	Pooled	
PL		0.149	0.712	0.678	0.541	♂ 0.882	-0.038	80.8	85.7	83.2	81.9
1DL		0.159	0.593			♀-0.957					
2DL		-0.155	-0.669								
3DL		0.105	0.472								
	(constant)	-21.872									
MHB		0.160	0.786	0.772	0.404	♂ 1.158	-0.054	88.6	88.2	88.4	87.5
5D2B		0.275	0.319			♀-1.265					
	(constant)	-20.798									
HT		0.282	0.546	0.724	0.475	♂ 1.006	-0.043	88.0	86.4	87.2	86.3
MHT		0.181	0.707			♀-1.091					
	(constant)	-15.693									
MHC		0.065	0.774	0.791	0.374	♂ 1.239	-0.053	87.4	91.6	89.4	88.8
WC		0.034	0.343			♀-1.344					
	(constant)	-21.272									
PL		0.075	0.357	0.765	0.414	♂ 1.145	-0.004	91.0	88.9	90.0	89.1
MHT		0.131	0.511			♀-1.228					
HB		0.112	0.459								
	(constant)	-22.772									
2DL:4DL		31.34	1.000	0.128	0.984	♂ -0.123	0.006	67.1	40.3	54.2	54.2
	(constant)	-29.89				♀0.134					

4.1.1.4 Discussion

The purpose of this study is to determine reliable sex discriminators with various hand parts. All hand dimensions were greater with statistical significance in males than in females ($p < 0.001$). Therefore, all of the dimensions are possible sex indicators (D.-I.Kim, Kim, Lee, & Han, 2013). The single variables that showed highest determination accuracy were the maximum hand circumference (88.6%), the maximum hand breadth (86.2%) for males, and the maximum circumference (89.6%) and wrist circumference (88.3%) for females. The result of the study confirmed that the breadth and lengths of hand and palms can be used for sex determination in accordance with the results of the previous study by Ishak that showed 94% and 91.5% accuracy using hand breadth and lengths of West Australian subjects, respectively (Ishak et al., 2012). Similar studies on Indian subjects showed 89% and 85% accuracy, respectively (Kanchan & Rastogi, 2009). In the present study, the sex determination accuracy on Korean subjects based on hand breadth and length showed 85.7% and 76.8%, which are lower than the accuracy for Australian or Indian subjects. The possible reason is that the hand lengths of Koreans are 12mm and 16mm shorter than those of Australians and Indians for males, and 6mm and 12mm shorter for females, which resulted in greater overlapping of demarking points of males and females and consequently lowered the accuracy of sex determination of Korean subjects (Figure 3). Therefore, for sex determination based on the hand dimensions of Korean subjects, using hand dimensions other than hand length such as hand breadth and circumference may improve the accuracy (Figure 4.3).

While the previous studies mainly determined sex based on the length and breadth of the hand, this study attempted to discriminate sex by utilizing the thickness and circumference of hand parts.

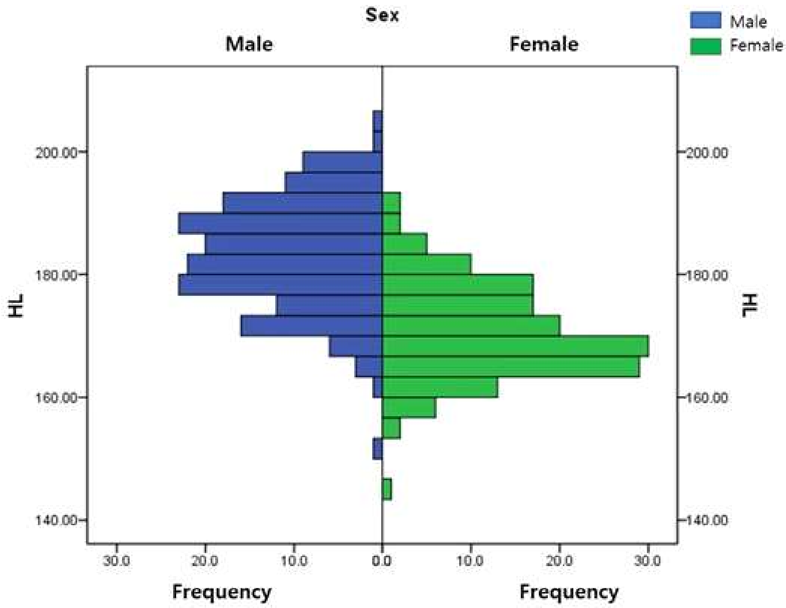


Figure 4.2. Hand length is a relatively unrelaible sex discriminator in Korean population (in mm)

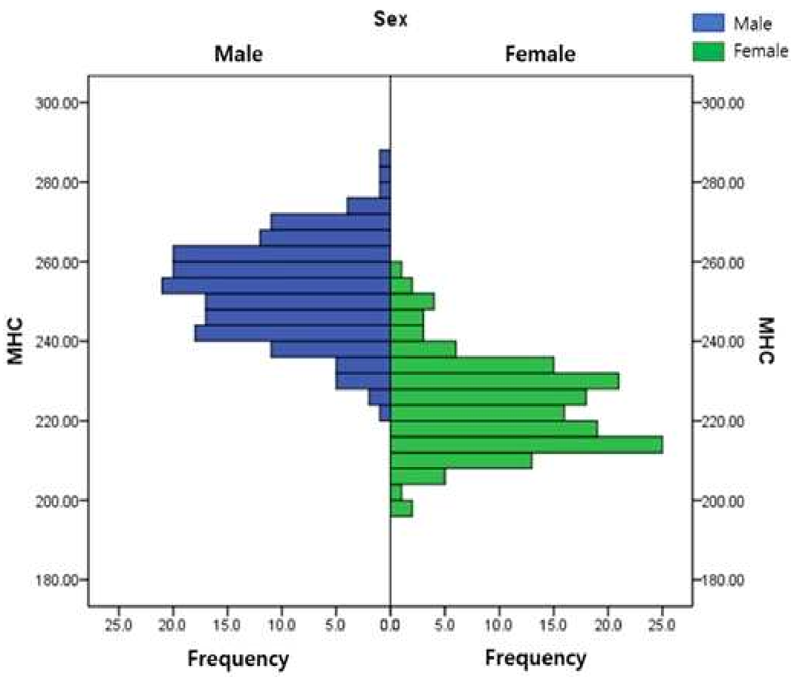


Figure 4.3. MHC is a reliable discriminator for sex estimation (in mm)

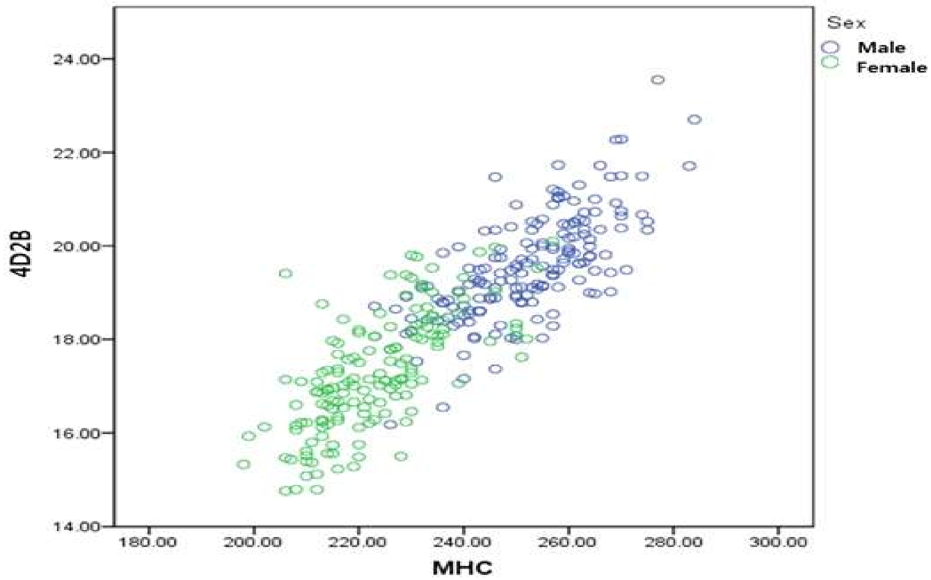


Figure 4.4. Circumference and breadth of various hand dimensions can be used for sex estimation (in mm)

The accuracy of the thickness and circumference of hand parts cannot be compared directly because there are few previous studies that applied breadth and circumference for sex determination. In this study, the breadth, circumferences, and thicknesses of hand parts generally showed higher accuracy than the lengths (Figures 4 and 5). A similar trend was observed in the study of Mahakkanukrauh in which an attempt was made to distinguish sex based on the breadths and lengths of metacarpals and phalanges (Mahakkanukrauh et al., 2013). Moreover, the sex determination using the breadth and circumference of each finger joint, which were not considered in previous studies, showed a minimum accuracy of 76% and maximum accuracy of 89.4% as a sex discriminator. Thus, an improved sex determination accuracy will be achieved when the breadth of finger joints and palm, the thickness of hand, and the circumferences of wrist are considered in addition to hand length and breadth.

The performance of sex determination using the hand anthropometrics seems to differ between different nationalities. Although Manning and

Kanchan proposed a method based on a 2D to 4D ratio and confirmed its reliability (Kanchan, Kumar, & Menezes, 2008; Manning et al., 2004), the method showed only 54.2% accuracy in the present study, which is not higher than the other indicators. This study result is similar to the result of Voracek's study (Voracek, 2009). The reason that hand lengths or 2D: 4D ratio-based sex determination accuracy in Korean subjects appeared lower than the other ethnic groups may be associated with the nationalities characteristics (Kanchan & Krishan, 2011). Overall, the Korean subjects showed short hand lengths and breadths, and small differences of 2D and 4D lengths between male and female groups compared to the West Australian and Indian subjects. Thus, the ethnic difference may have an impact on the accuracy of the methods proposed in the previous studies.

In this study, predictive accuracy when using hand parts for each age range group was compared (Table 4.5). Lower prediction accuracy was shown in 60-70 yrs old age group compared to the other age group due to a size difference in the phalange breadth. There was no significant difference depending on job types or resident area.

The result of this study is obtained by measuring only the Korean hand dimensions, who were born and raised in Korea. Therefore, when applied to other ethnic groups, the sectioning points derived in this study may not provide high accuracy because each ethnic group has different hand size variations.

Table 4.5. Sex estimation accuracy(%) using hand parts depending on age range

Variab les	20's~30's			40's~50's			60's~70's		
	Male	Fema le	Pool ed	Male	Femal e	Poole d	Male	Femal e	Poole d
HL	77.0	80.0	78.4	81.8	77.4	79.7	64.0	71.9	68.4
PL	75.0	81.4	77.8	80.3	82.3	81.3	72.0	84.4	78.9
1DL	78.9	76.7	77.9	75.8	74.2	75.0	68.0	77.4	73.2
2DL	65.8	68.3	66.9	68.2	69.4	68.8	72.0	71.9	71.9
3DL	65.8	73.3	69.1	72.7	79.0	75.8	60.0	62.5	61.4
4DL	68.4	74.6	71.1	72.7	75.8	74.2	72.0	68.8	70.2
5DL	65.8	61.7	64.0	81.5	69.4	75.6	72.0	65.6	68.4
HB	85.3	86.7	85.9	87.9	87.1	87.5	68.0	78.1	73.7
MHB	86.8	91.5	88.9	90.9	91.8	91.3	72.0	78.1	75.4
WB	84.2	81.7	83.1	90.9	88.7	89.8	76.0	71.9	73.7
1D2B	78.9	90.0	83.8	87.9	85.5	86.7	68.0	81.3	75.4
2D2B,	89.5	86.7	88.2	86.4	87.1	86.6	72.0	75.0	73.7
3D2B	89.5	86.7	88.1	86.4	83.9	85.2	68.0	81.3	75.4
4D2B	92.1	83.3	88.2	90.9	85.5	88.3	72.0	75.0	73.7
5D2B	88.2	83.3	86.0	90.9	75.5	88.2	80.0	68.8	73.7
2D1B,	76.3	86.7	80.9	89.4	85.5	87.5	72.0	71.9	71.9
3D1B	80.3	88.3	83.8	84.8	88.7	86.7	72.0	75.0	73.7
4D1B	81.6	85.0	83.1	84.8	85.5	85.2	64.0	71.9	68.4
5D1B	86.8	86.7	86.8	83.3	83.9	83.6	72.0	75.0	73.7
HT	78.9	88.3	83.1	83.3	87.1	85.2	60.0	68.8	64.9
MHT	86.8	86.7	86.8	86.4	82.3	84.4	76.0	84.4	80.7
HC	89.5	90.0	89.7	90.9	88.7	89.8	76.0	87.5	82.5
MHC	89.5	95.0	91.9	92.4	90.3	91.4	72.0	84.4	78.9
WC	84.2	85.0	84.6	87.9	88.7	88.3	76.0	90.6	84.2
1D2C	80.3	90.0	84.6	84.8	88.7	86.7	52.0	62.5	57.9
2D2C	80.3	90.0	84.5	90.9	87.1	89.1	76.0	71.9	73.7
3D2C	81.6	88.3	94.6	87.9	85.5	86.7	60.0	75.0	68.4
4D2C	73.7	81.7	77.2	87.9	87.1	87.5	72.0	75.0	73.7
5D2C	80.3	86.7	83.1	84.8	88.7	86.7	76.0	75.0	75.4

4.1.2.1 Sex Estimation Model Using Foot Dimension

Foot traces are frequently found in crime scene compared to other body parts, and often considered as important clues in the crime investigation. This is due to the fact that foot traces are highly relevant to the height of the suspects, and provide various numeric data from 26 bones, 33 joints and 19 muscles that composes this organ (Krishan et al., 2011). Furthermore, in Asian nations like Korea, China and Japan, people tend to take their shoes off when they enter residential areas. Naturally, it is highly likely to find bare foot traces when crime is committed in houses (Yi, 2002), which makes it crucial to study foot dimensions to identify the suspect of the case.

Previous studies mostly focused on foot length and breadth for their sex estimation. However, foot can provide various numeric data for investigation, because foot has many bones, muscles, and joints. Thus, this study incorporated other anthropometric measures such as distance from pternion to the 1st metatarsal and from pternion to the 5th metatarsal to determine sex of suspects. Also, other than different distance measurements, foot height, metatarsal height and other circumferential measurements are also considered as a potential sex prediction clues. Moreover, sex divergence of Korean feet shape, which has not been much studied so far, will be discussed to provide a novel prediction models regarding different sectioning points. Level of precision of each model will also be discussed.

4.1.2.2 Method

This study analyzes data from 3-D Korean Body Shape Measurement Project of KATS (Korean Agency for Technology and Standards). 575 adults in total (175 men and 400 women) participated for foot scanning. Mean age of male participants was 41.6 (minimum: 20, maximum: 69) and 38.4 for female participants (minimum: 20, maximum: 68). Feet of all the subjects were fully grown and not expected to grow further. Only the subject with no medical record about their feet or spines. This research has been approved by the research ethics committee of Seoul National University. All subjects were informed by written consent

Ten foot dimensions were selected for this research based on previous experiments (J. G. Hall et al., 2007; Standard, 2003; Zeybek et al., 2008) and ISO 7250 standards. (Table 4.6 and Figure 4.5) 3D scanner is used for rapid and precise measurement on diverse parts of feet. (Enfoot system, K&I Technology, South Korea). This scanner utilizes CCD camera and laser beam to generate 3D foot model, from which it can automatically extract physical information.

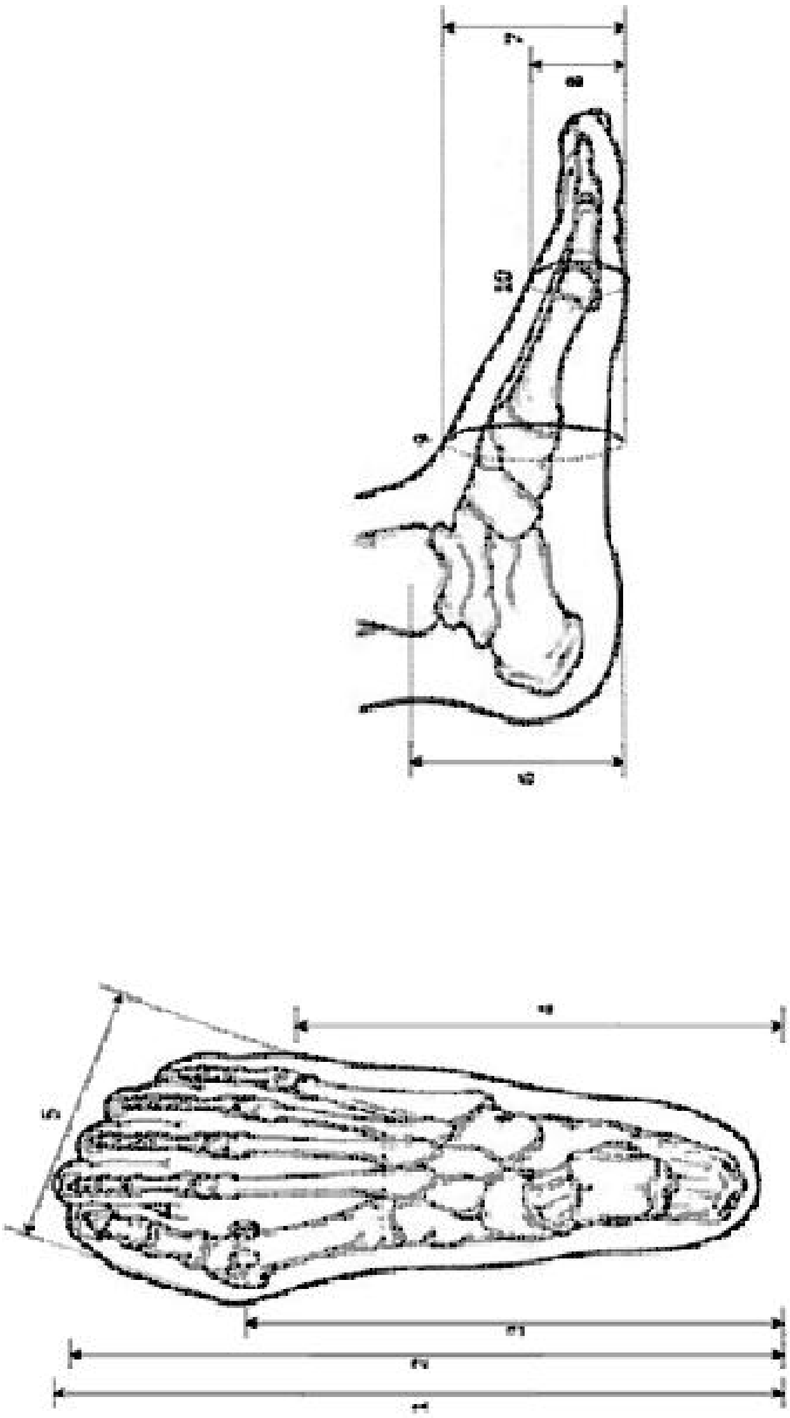


Figure 4.5. Various landmarks in foot dimension

No.	Foot dimensions	Abbreviation	Definition
1	Foot length	FL	The maximum distance from the pternion to the tip of longest toe
2	Pternion to great toe (length)	PGL	The distance from the pternion to the great toe
3	Pternion to first metatarsal (length)	PIML	The distance from the pternion to the most medial point on the head of the first metatarsal
4	Pternion to fifth metatarsal (length)	PEML	The distance from the pternion to the most lateral point on the head of fifth metatarsal
5	Breadth at the metatarsal	FB	The distance from the most medial point on the head of the first metatarsal to the most lateral point on the head of fifth metatarsal
6	Height at the lateral malleolus	MAH	The distance from the floor to the most prominent point on the later malleolus bone
7	Height at the navicular	NH	The distance from the floor to the most prominent point on the navicular bone
8	Height at the metatarsal	MH	The distance from the floor to the most prominent point on the head of the first metatarsal
9	Circumference at the navicular	NC	The superficial distance around the edge of the prominent point of navicular and the sole in the vertical direction
10	Circumference at the metatarsal	MC	The superficial distance around the edge of the metatarsal

Table 4.6. Definition of hand measurement employed in this research

Resolution of this device is less than 1mm. Subjects attached marker on their 1st, 5th metatarsal head, navicular height and prominent point in malleolus before they step on to the scanner. They are advised to put the left foot outside the scanner and put the right foot in the instrument, parallel to the other one and stay in a comfortable resting position. The right foot is supposed to stand still, straighten toward the front-side, with toes laid naturally.

Normal descriptive statistics (mean, SD, range) were analyzed to compare measurements from different dimensions, while difference of foot dimensions between two sex groups was compared by T-test. Discriminant analysis was performed in order to estimate accuracy on each variable. Stepwise discriminant analysis of group variables was also conducted to ensure higher prediction precision. The estimation accuracy was validated by cross validation (jack-knife). Randomly selected 70% data for training set and 30% for validation set. Measurements lower than demarking point were considered as women's and higher measurements were matched to men. All the statistical analysis was done with SPSS 21 Package.

4.1.2.3 Result

Normal descriptive statistics are described in Table 4.7. In all 10 foot dimensions, measurements from male participants were statistically significantly higher than the other group (p value<.001). The most distinguishable dimension was NC, which was 254.8mm for men and 229.4mm for women on average. Circumference at the metatarsal (MC) and Foot length (FL) are following it with second-largest differences between two groups. On the other hand, breadth at the metatarsal (FB), whose gap between sex group is as large as 7.2mm, had T-value of 10.06, and is found to have the smallest statistical difference compared to other dimensions.

Table 4.7. Descriptive statistic of mean (in mm) and SD in foot landmarks

Variable	Male (n=174)			Female (n=288)			T value
	Mean	SD	Range	Mean	SD	Range	
FL	251.6	12.3	223-288	231.4	10.2	201-267	18.202
PGL	251.3	12.3	223-288	231.3	10.2	201-267	17.965
PIML	184.1	9.2	159-214	170.2	7.9	149-193	16.638
PEML	159.3	8.9	133-189	147.9	8.2	80-108	14.166
FB	102.2	5.4	85-120	95.0	4.7	47-88	15.089
MAH	72.3	5.4	59-88	66.8	5.9	36-66	10.062
NH	61.3	5.4	51-74	51.9	6.2	21-41	16.682
MH	36.6	3.1	29-47	32.9	3.4	28-65	11.871
NC	254.8	12.1	218-305	229.4	10.8	198-267	23.478
MC	254.1	12.2	212-305	232.7	10.2	204-264	20.334

Table 4.8. Demarking points (in mm) of foot dimension in estimating sex and expected accuracy

	Variable	Demarking point	Accuracy (%)		Sex bias (%)
			Male	Female	
Length					
Function1	FL	♀<241.5<♂	78.2	86.8	-8.6
Function2	PGL	♀<241.3<♂	77.6	86.5	-8.9
Function3	PIML	♀<177.2<♂	74.1	83.3	-9.2
Function4	PEML	♀<153.6<♂	74.7	80.6	-5.9
Breadth					
Function5	FB	♀<98.6<♂	73.6	78.5	-4.9
Height					
Function6	MAH	♀<69.6<♂	66.7	71.2	-4.5
Function7	NH	♀<56.6<♂	78.2	77.8	0.4
Function8	MH	♀<34.8<♂	76.4	70.8	5.6
Circumference					
Function9	NC	♀<242.1<♂	86.2	89.2	-3.0
Function10	MC	♀<243.4<♂	81.0	84.4	-3.4

Single variables were analyzed to predict sex from data different dimensions and were tested for their precision rate (Table 4.8). Both sexes showed highest level of precision in circumference at the navicular (NC, function9), with breakpoint of 242.1mm. Precision rate of NC prediction was 86.2% for men and 89.2% for women when measurement larger than 242.1

is predicted to be a men's foot and smaller measure is predicted to be women's. In contrast, height at the lateral malleolus (MAH, function 6) showed the lowest precision rate (men: 66.7%, women: 71.2%). Prediction level differs the most in distance from pternion to first metatarsal (PIML, 9.2%) between two sex groups, while height at the navicular (NH) had the smallest difference. Among 10 variables, 8 were more precise in women than in men except for height at the navicular (NH) and height at the metatarsal (MH).

To acquire more precise data than that from single variables, height, length and circumference measures were combined and analyzed by discriminant analysis (Table 4.9). As a result, all the function showed precision level as high as 75%. Function 13, the combination of dual height and circumference measurements showed highly precise prediction with precision ratio of 89.2%, followed by function 11, the combination of height and breath variables and the combination of height variables (function 12). Analyzing all 10 variables with discriminant analysis using stepwise method, it turned out to show relatively high precision when FL, PIML, FB, NH, MH, NC and MC are incorporated (function 14, men: 89.1%, women: 92.7%). This was the most precise prediction among all models we suggested in this study, which showed 90.2% precision level in cross validation.

Table 4.9. Discriminant analysis results using stepwise method

Variables	coefficient: Unstandardized	coefficient: Standardized	Canonical correlation	Wilk's lambda	Group centroids	Accuracy (%): Men	Accuracy (%): Women	Accuracy (%): Pooled	Cross-validated (%)
Function11 (length & breadth)									
FL	0.070	0.778	0.679	0.539	♂ 1.228	78.2	86.8	83.5	82.0
FB	0.066	0.333			♀ -0.740				
(constant)	-23.328								
Function12 (height)									
MAH	0.055	0.317	0.632	0.600	♂ 1.104	81.6	75.3	77.7	76.5
NH	0.145	0.858			♀-0.633				
(constant)	-11.868								
Function13 (height & circumference)									
NH	0.084	0.498	0.763	0.417	♂ 1.517	89.1	89.2	89.2	88.9
MH	-0.082	-0.271			♀-0.916				
NC	0.056	0.634							
MC	0.024	0.264							
(constant)	-21.091								
Function14 (all)									
FL	0.020	0.216	0.802	0.356	♂ 1.725	89.1	92.7	91.3	90.2
PIML	0.044	0.374			♀-0.996				
FB	-0.127	-0.633							
NH	0.078	0.461							
MH	-0.081	-0.268							
NC	0.042	0.470							
MC	0.055	0.602							
(constant)	-24.825								

4.1.2.4 Discussion

The purpose of this study is to measure different dimensions of feet and formulate appropriate numeric variables for statistically meaningful analysis method to provide credential sex distinction index. According to T-test result discussed above, there are multiple measurement that are sexually divergent. Male feet dimensions were larger in all 10 variables than those of women and the difference was statistically significant. This tendency corresponds to the previous study done in Turkey, in which the researchers observed meaningful difference in FB and FL (Ozaslan et al., 2012). Likewise, Krauss reported significant sexual dimorphism in feet length and breadth of European subjects (Krauss et al., 2008), and Lee also mentioned that there are meaningful difference in FB, instep girth and height in Taiwanese adults (Y.-C. Lee & Wang, 2014). However, in contrast to Lee's observation that toe height does not provide statistically meaningful distinction between sexes, this study found out that MAH, NH and MH are all significantly different for Korean men and women. NC recorded the biggest difference of 25.4mm between men and women among all the dimensions. This is consistent with Lee's previous study which addressed NC as the most distinguishable measurement. It is assumed that the sexual dimorphism we found in this research is primarily due to the different growth hormone secretion patterns in puberty from preceding research (Bardin & Catterall, 1981).

FL has been a widely used measurement criteria, and it showed accuracy of 78.2% for men and 86.8% for women. For male subjects, FL prediction precision was highest in west Australians and lowest in Koreans. Female west Australians also showed the highest precision, followed by Korean and Indian women (Table 4.10).

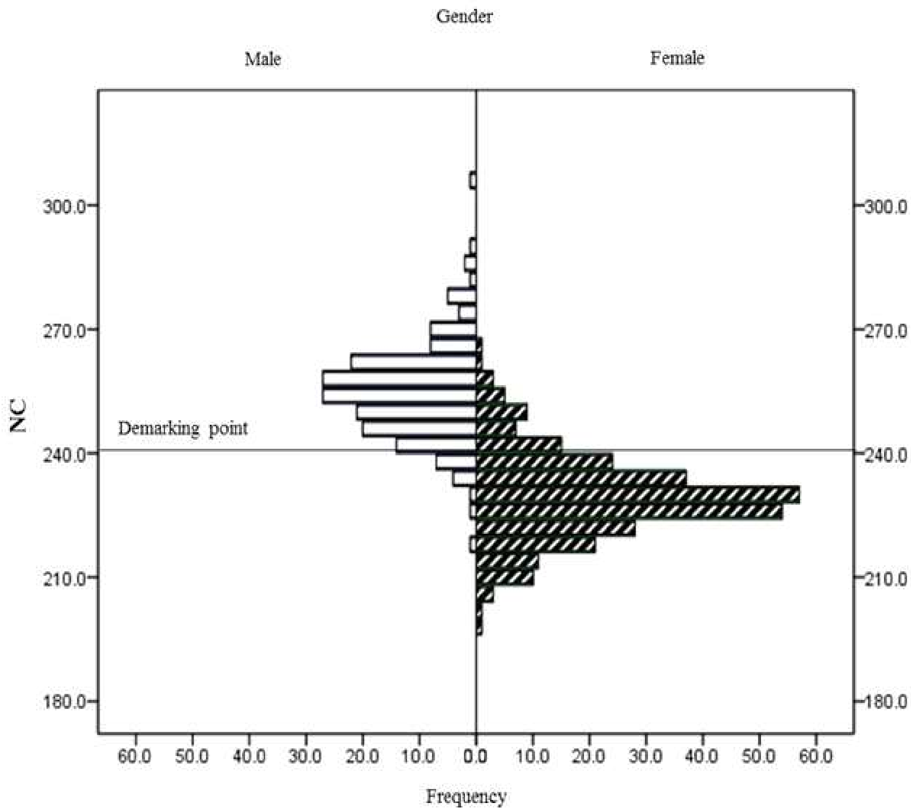


Figure 4.6. NC is a reliable sex discriminator in sex estimation

Table 4.10. Comparison of accuracies from different populations depending on foot dimensions

Dimension	Korean		West Australian (2013)		North Indian (2010)	
	Male	Female	Male	Female	Male	Female
FL	78.2	86.8	88.9	91.8	80.6	82.9
FB	73.6	78.5	81.1	85.5	80.6	84.0

Yet, foot breadth was less precise in predicting sex of Koreans than it is in other ethnic population. It was 73.6% for Korean men, which is 7.5% and 7.0% smaller than it is for west Australian men and Indian men. For women, the precision of FB is measured to be 78.5%, lower than it is in west Australian women and Indian women by 7.0% maximum. The reason is that while the sexual difference of FB was larger in other ethnic groups (Taiwanese: 10.2mm, west Australian: 10.7mm, Turkish: 10.6mm), Koreans' is as small as 7.2mm. There are wider overlapping range around the sectioning point for Korean, lowering the precision rate. Regarding comparison in between different variables, Koreans showed relatively low prediction precision in FB than FL, which is comparable to previous research studied west Australian feet (Hemy et al., 2013). On the other hand, FB was more precise than FL in Indian women in Sen’s preceding study (Table 4.10). In sum, it seems that there exist ethnic and sexual differences regarding how precise sex discrimination from feet dimension can be.

This study enhanced the precision of sex distinction by incorporating detailed foot dimensions like circumference and height, rather than focusing only on foot length and breadth as other previous studies had done. In both sexes, length variables (FL, PGL, PIML, and PEML) were highly precise, and thought to be provide useful information in foot print analysis for identifying suspects. In contrast, variables related to foot breadth and height (MAH, NH, MH) showed relatively lower precision rate, so it is recommended to utilize length variables in identifying suspects with their body parts.

Circumference at the navicular (NC) and circumference at the metatarsal (MC) are newly introduced in this study as an effective sex distinction index other than foot length (FL) and breadth (FB), which have been primarily investigated so far. NC and MC have large sexual difference on average and are also highly precise in predicting sex. Thus, along with FL, they are expected to be widely used as effective, fast sex identifying indices in natural disasters and terror scenes, where partial body parts are often used for victim identification.

It may be necessary to conduct identification by only utilizing erased part of the footprint or dismembered foot part in disasters in actual investigation. In such case, foot length or foot breadth is limited to measure.

Table 4.11. Sex estimation accuracy(%) using foot parts depending on age range

Variables	20's–30's			40's–50's			60's–70's		
	Male	Female	Pooled	Male	Female	Pooled	Male	Female	Pooled
FL	85.7	89.4	88.4	83.9	86.8	85.8	78	81.8	79.4
PGL	85.7	89.4	88.3	91.1	83.8	87.1	78	81.8	79.4
PMTL	84.4	86.4	85.8	83.9	86.8	85.5	75.6	77.3	76.2
PMFL	80.5	85.4	84.0	78.0	76.4	77.4	78.0	77.3	77.8
FB	83.1	82.3	82.5	85.7	79.4	82.3	82.9	77.3	81.0
BC	84.4	86.4	85.8	83.9	86.8	85.5	82.9	90.9	85.7
IC	88.3	88.4	88.4	87.5	95.6	91.9	90.2	99.9	93.7
IH	85.7	72.7	76.4	80.4	80.9	80.6	73.2	81.8	76.2
BH	81.8	73.7	76.0	69.6	69.1	69.4	75.6	68.2	73.0
MAH	68.8	74.2	72.7	75.0	77.9	76.6	73.2	81.8	76.2

Thus, it may be an alternative to use PIML or PEML instead of foot length or foot breadth. Because, PIML, PEML showed 74% or more of prediction accuracy for both men and women. In addition, PIML, PEML, the distance between the metatarsal and pternion, which is measured near the both end points of metatarsal, thus, loads happen to the joint when the suspect walks. It relatively makes clear marks. This will be benefits for foot print investigation using PIML or PEML.

In this study, determination accuracy when using foot parts for each age range group was deduced (Talbe 4.11). In FL and PGL variables, there was no certain difference depending on age range group. However, lower prediction accuracy was shown in 60-70yr old male and female groups because the size difference between males and females was relatively small in 60-70yrs old age group. There was no significant difference depending on job types or resident area.

This study is only focused on making standards for sex determination from Korean population. Thus, the accuracy from the functions from this study will be maintained only when it is applied for Korean or one ethnic group which have similar physical condition with Korean.

4.2 Stature Estimation Model

4.2.1 Stature Estimation Model Using Hand Dimension

4.2.1.1 Overview

In forensic research, anthropometrics, which uses body parts to estimate the physical characteristics of an individual, has served as a useful tool in reducing the amount of time and effort in confirmation of identity (Kanchan et al., 2012) When only a small part of a human body is found after a disaster or a scene of an incident, it is hard to predict stature by using the anatomical method, which reconstructs the entire body height with combing major body parts. In such a case, mathematical methods based on linear equations can be a reasonable solution. When applying a mathematical method, more diverse regression models that can predict the height of subjects will allow investigators to estimate their stature with a higher success rate and accuracy (Kanchan & Krishan, 2011). Among the various body parts, the hand is frequently found in crime scenes or disaster spots. In addition, the human hand is a complex structure consisting of 27 bones and 15 joints and possesses many biological features that can be used for stature estimation

Previous studies used hand lengths and breadths or hand and foot lengths as a variable for deriving a regression equation for stature estimation (Habib & Kamal, 2010). However, in some forensic investigation, it is impossible to measure hand length or breadth owing to some loss of damage to fingers. In such cases, it is not possible to predict height by using hand length or breadth. However, if prediction regression equations are available for different hand parts in addition to hand length and hand breadth, it will be possible to increase the success rate of stature estimation by using other regression models for diverse hand parts. Therefore in this study, phalange and finger lengths, as well as hand and wrist circumference and thicknesses were additionally used for stature estimation. In previous studies, it was reported that if the regression equations for one ethnic group are used for other races, prediction accuracy is lowered. Thus, it is urgent to derive regression formulas that can be applied to Korean people or ethnic groups similar to Koreans when a crime or an accident happens. We aim to identify possible criteria that would be applicable in forensic practices for Koreans. Moreover, the results of this study may be utilized not only in forensic practices, but also in other fields such as therapy, sports, and clothing design.

4.2.1.2 Method

Hand measurement data analyzed in this section was same to that of sex estimation model in section 4.1. The measurements included a total of 29 variables, indicated in Table 4.12 and Figure 4.7, some of which are lengths, breadths, thicknesses, and circumferences of fingers, phalanges, palms, and wrists. The measurements were carried out on the right hands of the subjects. Measurement procedures were same to that of sex estimation model in section 4.1

Average and standard deviations were calculated for each measured dimension by using SPSS 21. In order to identify the dimension differences between males and females, a t-test was conducted. To find the relationship between the various parts of the hand and height, their Pearson correlation coefficients were compared. The dimensions of various hand parts were used for obtaining a single regression, and the determination coefficient of a regression estimation equation (R^2) and standard error of estimate (S.E.E) were calculated. In addition, a multiple regression equation was derived via a stepwise method by combining different variables

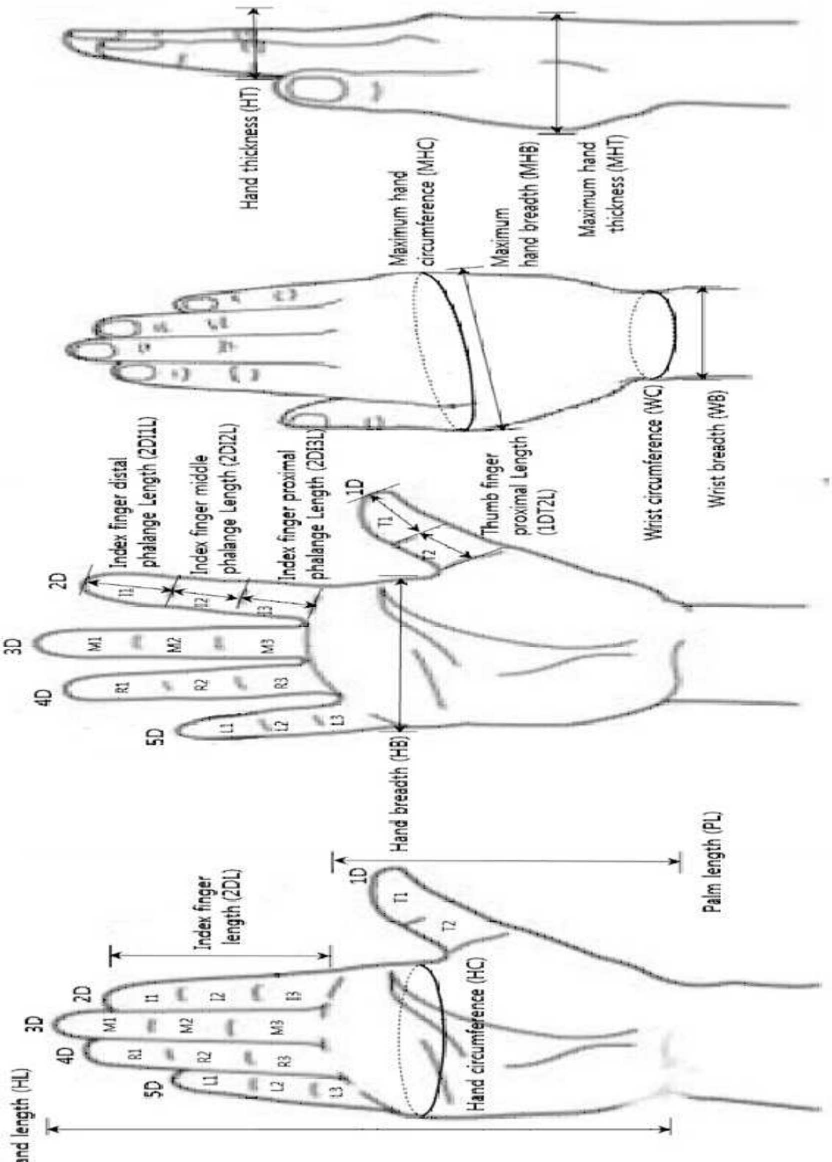


Figure 4.7. Various hand landmarks for stature estimation

Table 4.12. Definition of hand measurement for stature estimation

Type	Hand dimension	Abbreviation	Definition
Length	Hand length	HL	The distance from the middle of inter stylion to the tip of middle finger
	Palm length	PL	The distance from the middle of inter stylion to the proximal flexion crease of the middle finger
	Thumb; index; middle; ring; little finger length	1DL, 2DL, 3DL, 4DL, 5DL	The distance from the proximal flexion crease of the finger to the tip of the respected finger
	Thumb; index; middle; ring; little finger proximal phalange length	1DT2L, 2DI3L, 3DM3L, 4DR3L, 5DL3L	The distance from the proximal interphalangeal joint crease to metacarpophalangeal joint crease of each finger
	Thumb; index; middle; ring; little finger middle phalange length	2DI2L, 3DM2L, 4DR2L, 5DL2L	The distance from the distal interphalangeal joint crease to the proximal interphalangeal joint crease
	Index; middle; ring; little finger distal phalange length	1DT1L, 2DI1L, 3DM1L, 4DR1L, 5DL1L	The distance from the most forwarding projecting point on the tip of each finger to distal interphalangeal joint crease of each finger
Breadth	Hand breadth	HB	The distance from the most lateral point on the head of the 2D metacarpal to the most medial point on the head of 5D metacarpal
	Maximum hand breadth	MHB	The distance from the most lateral point on the head of the 1D metacarpal to the most medial point on the head of 5D metacarpal with closing fingers
	Wrist breadth	WB	The distance from the most lateral point on the wrist to the most medial point of wrist
Circumference	Hand circumference	HC	The superficial distance around the edge of metacarpal
	Maximum hand circumference	MHC	The maximum superficial distance around the edge of the hand with closing fingers
	Wrist circumference	WC	The superficial distance around the edge of the wrist
Thickness	Hand thickness	HT	The distance from the back of the middle finger to the most medial point of palm
	Maximum hand thickness	MHT	The maximum distance from the back of the hand to the most projected point of abductor pollicis brevis

4.2.1.3 Result

The t-test results pertaining to the descriptive statistics analysis the hand size (mean, SD) and differences for each dimension between males and females are listed in Table 4.13 The average values of all dimensions including stature were statistically much greater in males than in females. Except for the proximal phalange length of the index finger, all differences in the measured variables between males and females were found to be significant with a significance level of 0.001. Because of the size difference between males and females, the correlation coefficients and regression model need to be derived for both genders. The variable that showed the greatest difference between males and females was the maximum hand circumference (MHC) and the corresponding t-value was 22.12. Among hand dimensions associated with length, hand length (HL) and palm length (PL) showed the greatest t-values. Further, among finger length dimensions, the thumb showed the greatest t-value. Finally, among the breadth-related hand dimensions, the maximum hand breadth (MHB) showed the largest t-value (20.89).

The relationship between the measured variables and height for both genders were analyzed using the Pearson correlation coefficient (Table 4.11). Hand length was found to be the variable with the highest correlation to stature both in both males ($r = 0.628$) and females ($r = 0.534$). In male subjects, among the finger-related variables, middle finger length (3DL) showed the greatest correlation ($r = 0.549$) with height. In female subjects, ring finger length (4DL) showed the greatest correlation ($r = 0.465$) with height. Further, in male subjects, among the breadth and circumference variables, the maximum hand circumference ($r = 0.363$) showed a correlation of 0.3 or greater. In female subjects, the MHC correlation coefficient was the highest at 0.155. The remaining breadth and circumference dimensions were less relevant.

Table 4.13. Descriptive statistics for hand measurement (cm) in Korean male and female

Variable	Male (n=167)		Female(n=154)		T-test
	Mean	SD	Mean	SD	T value
Stature	169.6	6.35	155.6	6.5	14.04
Weight	70.6	10.41	55.5	8.5	15.13
HL	18.3	0.9	17.1	0.8	13.35
PL	10.5	0.5	9.7	0.5	14.33
1DL	6.1	0.4	5.6	0.4	12.30
2DL	7.0	0.4	6.6	0.4	8.76
3DL	7.9	0.5	7.4	0.4	10.15
4DL	7.4	0.5	6.9	0.4	9.95
5DL	5.9	0.4	5.5	0.5	8.80
1DT2L	2.9	0.3	2.7	0.3	5.63
2DI3L	2.3	0.2	2.3	0.2	1.95
3DM3L	2.7	0.2	2.5	0.2	4.51
4DR3L	2.4	0.2	2.3	0.2	3.74
5DL3L	1.8	0.2	1.7	0.2	3.95
1DT1L	3.4	0.2	3.1	0.2	12.41
2DI2L	2.1	0.2	2.0	0.2	5.14
3DM2L	2.5	0.2	2.4	0.2	5.25
4DR2L	2.3	0.2	2.2	0.2	5.29
5DL2L	1.6	0.2	1.5	0.2	4.28
2DI1L	2.6	0.2	2.3	0.2	10.70
3DM1L	2.7	0.2	2.5	0.2	10.67
4DR1L	2.8	0.2	2.5	0.2	10.83
5DL1L	2.5	0.2	2.3	0.2	10.09
HB	8.6	0.4	7.8	0.4	17.34
MHB	10.7	0.5	9.6	0.5	20.89
WB	6.1	0.3	5.5	0.4	16.43
HC	20.8	1.0	18.6	1.1	19.34
MHC	25.3	1.2	22.3	1.2	22.12
WC	17.6	1.1	15.6	0.9	17.47
HT	2.8	0.2	2.5	0.2	13.72
MHT	4.9	0.4	4.2	0.4	15.96

Table 4.14. Correlation between hand dimension and stature

Variable	Male	Female
HL	0.628**	0.534**
PL	0.592**	0.505**
1DL	0.390**	0.375**
2DL	0.507**	0.424**
3DL	0.549**	0.436**
4DL	0.487**	0.465**
5DL	0.395**	0.407**
1DT2L	0.384**	0.289**
2DI3L	0.383**	0.250**
3DM3L	0.367**	0.206*
4DR3L	0.330**	0.198*
5DL3L	0.237**	0.348**
1DT3L	0.259**	0.154
2DI2L	0.455**	0.392**
3DM2L	0.459**	0.331**
4DR2L	0.406**	0.372**
5DL2L	0.331**	0.299**
2DI1L	0.187*	0.201*
3DM1L	0.279**	0.329**
4DR1L	0.278**	0.304**
5DL1L	0.247**	0.198*
HB	0.385**	0.099
MHB	0.376**	0.145
WB	0.360**	0.090
HC	0.320**	0.096
MHC	0.363**	0.155
WC	0.213**	0.069
HT	0.111	0.023
MHT	0.161*	0.086

** Significant at 0.01 level (two tailed).
* Significant at 0.05 level (two

In this study, stature estimation was conducted using a regression equation, as was done in previous studies (Table 4.15 and Table 4.16). For male subjects, HL (R^2 = 0.398) and PL (R^2= 0.358), in that order, proved to be the greatest determining factors in the regression equation. The middle finger showed the highest accuracy (R^2 = 0.301) among finger lengths. Further, middle finger middle phalange length (3DM2L) showed the highest accuracy (R^2= 0.211) among phalange lengths. For female subjects, ring finger length showed the highest accuracy (R^2= 0.211). Although maximum hand circumference (MHC) showed the highest accuracy (R^2= 0.024) among other breadth, circumference, and thickness variables, the R^2 values for these variables were less than 0.02 and thus had less correlation with stature

To derive an accurate regression equation, various hand dimension variables were combined and a stepwise method was followed to form a multiple regression equation (Table 4.17). When hand, wrist, and palm lengths were used as variables for deriving a regression equation for all the subject (all males and females; n = 321), an R^2 value of 0.643 was obtained with an estimation error of 5.719 cm. For males, the combination of the hand length (HL), middle finger middle phalange length (3DM2L), palm length (PL) yielded an R^2 value of 0.425 with an average estimation error of 4.819 cm, which was the smallest estimation error of the regression equation found in this study. For females, the combination of hand length (HL), maximum hand breadth (MHB), middle-finger distal phalange length (3DM1L), and thumb-finger distal phalange length (1DT1L) yielded an R^2 value of 0.418 with an average estimation error of 5.080 cm.

Table 4.15 Linear regression equation for stature estimation from male hand dimension

Sex	Parameters	Regression Equation	R^2	S.E.E
Male	HL	S=88.051+4.451(HL)	0.398	4.954
	PL	S=88.814+7.693(PL)	0.358	5.116
	1DL	S=131.141+6.286(1DL)	0.152	5.877
	2DL	S=117.095+7.451(2DL)	0.258	5.500
	3DL	S=111.159+7.435(3DL)	0.301	5.337
	4DL	S=120.628+6.593(4DL)	0.238	5.574
	5DL	S=136.519+5.608(5DL)	0.154	5.871
	1DT2L	S=148.037+7.335(1DT2L)	0.148	5.895
	2DI3L	S=142.905+11.514(2DI3L)	0.148	5.894
	3DM3L	S=143.404+9.867(3DM3L)	0.135	5.939
	4DR3L	S=148.173+9.062(4DR3L)	0.110	6.021
	5DL3L	S=156.530+7.219(5DL3L)	0.057	6.199
	1DT1L	S=144.069+7.583(1DT1L)	0.068	6.163
	2DI2L	S=140.26+1.372(2DI2L)	0.207	5.667
	3DM2L	S=137.66+1.285(3DM2L)	0.211	5.655
	4DR2L	S=142.93+1.155(4DR2L)	0.165	5.818
	5DL2L	S=154.423+9.544(5DL2L)	0.111	6.021
	2DI1L	S=155.977+5.261(2DI1L)	0.035	6.271
	3DM1L	S=148.972+7.588(3DM1L)	0.080	6.124
	4DR1L	S=147.426+8.054(4DR1L)	0.078	6.132
	5DL1L	S=150.168+7.777(5DL1L)	0.062	6.182
	HB	S=119.99+5.882(HB)	0.150	5.865
	MHB	S=118.310+4.780(MHB)	0.142	5.913
	WB	S=122.925+7.600(WB)	0.130	5.955
	HC	S=125.651+2.112(HC)	0.102	6.049
	MHC	S=120.726+1.935(MHC)	0.133	5.944
	WC	S=147.695+1.246(WC)	0.046	6.236
	HT	S=160.147+3.416(HT)	0.112	6.345
	MHT	S=157.209+2.522 (MHT)	0.026	6.301

All coefficients are significant (P value<0.05)

Table 4.16 Linear regression equation for stature estimation from female hand dimension

Sex	Parameters	Regression Equation	R^2	S.E.E
Female	HL	S=78.992+4.482(HL)	0.285	5.469
	PL	S=86.414+7.097(PL)	0.255	5.587
	1DL	S=116.692+6.934(1DL)	0.141	6.015
	2DL	S=113.295+6.381(2DL)	0.180	5.859
	3DL	S=107.122+6.492(3DL)	0.190	5.821
	4DL	S=107.152+6.983(4DL)	0.211	5.709
	5DL	S=124.202+5.753(5DL)	0.166	5.909
	1DT2L	S=137.681+6.529(1DT2L)	0.083	6.211
	2DI3L	S=139.364+7.134(2DI3L)	0.063	6.263
	3DM3L	S=141.145+5.681(3DM3L)	0.043	6.329
	4DR3L	S=142.396+5.807(4DR3L)	0.039	6.341
	5DL3L	S=136.893+10.853(5DL3L)	0.121	6.084
	1DT1L	S=141.492+4.583(1DT1L)	0.024	6.392
	2DI2L	S=132.621+11.383(2DI2L)	0.154	5.95
	3DM2L	S=133.762+9.274(3DM2L)	0.110	6.103
	4DR2L	S=132.063+10.793(4DR2L)	0.138	6.005
	5DL2L	S=142.142+9.114(5DL1L)	0.090	6.045
	2DI1L	S=139.481+6.872(2DI1L)	0.040	6.337
	3DM1L	S=127.521+11.376(3DM1L)	0.108	6.108
	4DR1L	S=134.843+8.331(4DR1L)	0.092	6.144
	5DL1L	S=143.424+5.394(5DL1L)	0.039	6.340
	HB	S=143.086+1.605 (HB)	0.010	6.437
	MHB	S=136.755+1.961 (MHB)	0.021	6.432
	WB	S=146.373+1.667 (WB)	0.008	6.442
	HC	S=144.850+0.575 (HC)	0.009	6.439
	MHC	S=136.416+0.857 (MHC)	0.024	6.390
	WC	S=147.747+0.499 (WC)	0.005	6.453
	HT	S=153.544+0.812 (HT)	0.001	6.467
	MHT	S=149.321+1.485 (MHT)	0.007	6.445

All coefficients are significant (*P* value<0.05)

Table 4.17. Multiple regression equations for estimation of stature from hand dimension

Case	Regression (stepwise) equation	R^2	SEE
Pooled	S= 32.56+1.34(WC)+6.83(PL)+6.83(3DL)-5.13(3DM3L)	0.642	5.719
Male	S= 84.77+2.03(HL)+5.74(3DM2L)+3.17(PL)	0.425	4.819
Female	S= 90.77+5.42(HL)-2.92(MHB)+7.48(3DM1L)-5.94(1DT1L)	0.418	5.080

All coefficients are significant (*P* value<0.05)

4.2.1.4 Discussion

The purpose of this study was to estimate stature from various dimensions of the hand with enhanced accuracy. By conducting t-test, it was confirmed that there are differences between the fingers, phalanges, palms, and other major landmark features of male and female subjects. Hand parts that showed a greater difference between males and females do not indicate higher prediction accuracy. Among dimensions related to length, breadth, circumference, and thickness, the breadth-related dimension (MHB) or circumference related dimension (MHC) showed higher difference between males and females. However, length related variables (HL, PL) showed higher estimation accuracy than breadth related variables (HB, MHB), circumference related variables (MHC, WC), and thickness related variables (HT, MHT). This tendency is similar to that observed by Uhrova who studied the hand and foot lengths and breadths of Slovakian subjects. She reported that the hand breadth shows the greatest difference in male and female, however, hand length showed higher accuracy than hand breadth (Uhrová et al., 2013). For length-related dimensions, the hand length (HL) showed greater differences than phalange length between males and females; moreover hand length (HL) also showed higher accuracy than phalange length in stature estimation. These observations were similar to those reported by Habib (Habib & Kamal, 2010). He studied the hand and phalange lengths of Egyptian subjects for stature estimation, and reported that among the variables studied, hand length showed the greatest difference between males and females. Hand length also showed highest R^2 among the hand measurement variables. In these previous studies, researchers suggested that this hand size difference between males and females may have occurred from biological and social differences in their growth process (Bardin & Catterall, 1981).

With regard to the correlation between hand dimension variables and stature, the hand length (HL) showed the greatest correlation coefficient;

moreover, for almost all the variables, it was larger in males than in females. Among the five finger lengths, the middle finger length (3DL) showed the highest correlation with stature in males, and the ring finger length (4DL) showed the highest correlation with stature in females. Among the finger phalanges (proximal, middle, and distal), for both males and females, the middle phalange showed the highest correlation with stature. Further, among the phalanges, middle finger middle phalange (3DM2L) and index finger middle phalange (2DI2L) showed the highest correlations with stature in males and females, respectively. These result is similar to one of the results reported by Habib (Habib & Kamal, 2010): the middle finger showed the greatest correlation with stature. However, another result of his study that the phalange showed the greatest correlation with stature is different from the results found in the present study; Habib found that the ring finger proximal phalange and middle-finger proximal phalange showed the greatest correlation with stature in males and females, respectively. Therefore, in terms of the correlation between phalange length and stature, differences seem to exist between Korean and Egyptian races, as well as between the males and females of the two races.

The regression equations obtained using hand length (HL) showed the highest accuracy for both males and females, compared to those derived using various other hand dimension variables (Figure 4.8). The R^2 values for males and females obtained using regression equations based on the correlation coefficients were 0.398 and 0.285, respectively. These results demonstrated that the accuracy for Korean subjects was higher than that for Mauritius subjects (0.353), but lower than those for Turkish (0.552) and West Australian (0.532) subjects.

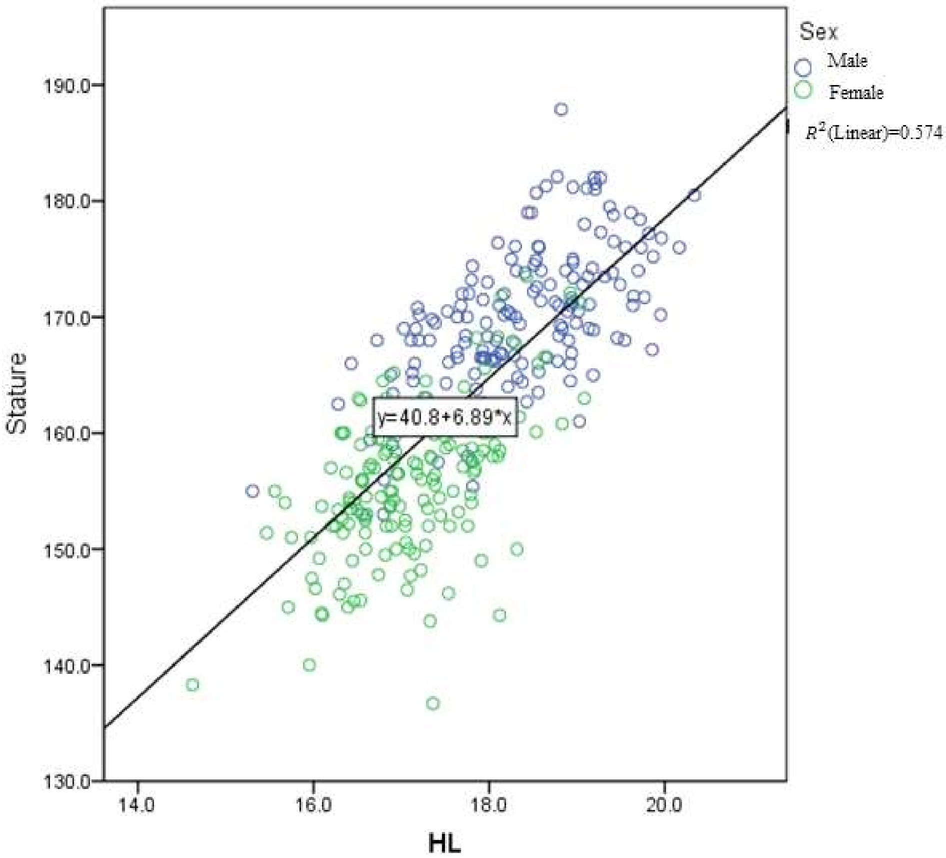


Figure 4.8. Relationship between stature (cm) and hand length (cm) among Korean population

For Korean females, the regression result found in the present study was 0.285; this value is lower than that for those of Mauritius (0.397), Turkish (0.503), and West Australian (0.476) females (Agnihotri et al., 2008 & Ozaslan et al., 2012) The different levels of accuracy for different races may be due to the different hand sizes or statures of these races. On the basis of the data reported in the literature (total of 17 case studies), the correlation coefficient between the hand size and R^2 was obtained to be 0.126, and the correlation coefficient between stature and R^2 was 0.211 (Kanchan et al., 2012 ; Habib & Kamal, 2010 ;Agnihotri, 2008; Ozaslan et al., 2012). Therefore, a correlation between the hand size and R^2 in addition to the correlation between stature and R^2, was suggested (Table 4.18). For Korean subjects, because of their small hand sizes and stature compared to other races, to obtain more accurate estimation, hand dimension variables other than hand length should be considered when configuring the multiple regression equation. By formulating the multiple regression equation, higher estimation accuracy was obtained. The regression equation based on the wrist circumference (WC), palm length (PL), middle finger length (3DL), and middle finger proximal phalange length (3DM3L) of both males and females together yielded an R^2 value of 0.642. For male subjects, middle finger middle phalange length (3DM2L), hand length (HL) and the palm length (PL) yielded an R^2 value of 0.425; this value is higher than that reported for Slovakian subjects (0.40) obtained using hand breadth and length (Uhrová et al., 2013). For female subjects, hand length (HL), maximum breadth of hand (MHB), middle finger distal phalange length (3DM1L) and thumb distal phalange length (1DT1L) exhibited an R^2 value of 0.418; this value is higher than that for Slovakian female subjects (0.34).

For stature estimation using hand information, length information was found to be the most relevant. Circumference, thickness, and breadth were consistently less accurate than length in both males and female subjects. In particular for females, these variables showed R^2 values less than 0.024, which is not suitable for estimation. These results are consistent with that reported by Ahmed and Uhrova; hand length shows higher correlation with stature than breadth., Therefore for stature estimation, the use of dimensions associated with length, such as lengths of hand, palm, fingers and phalanges, will enhance prediction accuracy. In this study, it was also verified whether the regression equations obtained from other ethnic groups can be applied to Korean subjects. Consequently, the estimation using the equation obtained from West Australian subjects showed mean differences of 11.65cm and 13.75 cm from the actual heights of Korean male and female subjects, respectively (Ishak et al., 2012); these values are significantly larger than the estimation error found in the present study (for males: 4.81cm; for females: 5.08cm).

In this study, R^2 when using hand parts for each age range group was compared. There was no tendency depending on age range for males. However, higher R^2 was shown in 20-30yrs old age group for females than in 40-50yrs and 60-70yrs old age groups. There was no significant difference depending on job types or resident area.

This result may imply that the regression equation may be exclusive to an ethnic group from which that it was drawn. Therefore, the results of the present study may only be applicable to racial groups that have physical features similar to those of Koreans.

Table 4.18**.** Comparison between mean of stature, hand length, hand breadth and their correlation coefficients(r) from previous studies

Author	**Year**	**Country**	**Mean stature**		**Mean HL**		**Mean HB**		**R between stature and HL**	
			Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Krishan	2007	India	168.2	155.7	18.2	16.8	8.1	7.3	0.60	0.69
Arun	2008	Mauritius	173.9	159.5	18.8	17.2	8,5	7.5	0.59	0.74
Sahar	2010	Egypt	174.6	160.0	19.2	17.6	-	-	0.70	0.50
Nasir	2011	India	167.8	-	17.7	-	8.3	-	0.56	-
Ishak	2012	Australia	178.5	163.7	19.5	17.6	9.1	7.9	0.73	0.69
Ozaslan	2012	Turkey	172.4	162.0	19.2	17.9	8.2	7.5	0.57	0.30
Altayeb	2013	Sudan	175.1	160.3	19.2	17.3	7.9	7.0	0.60	0.62
Petra	2014	Slovak	179.5	166.3	18.7	17.2	8.5	7.6	0.63	0.58

Table 4.19 Stature estimation accuracy(R^2) using hand parts depending on age range

Variables	20’s~30’s		40’s~50’s		60’s~70’s	
	Male	Female	Male	Female	Male	Female
HL	0.463	0.440	0.308	0.358	0.390	0.228
PL	0.481	0.470	0.209	0.259	0.341	0.220
3DL	0.328	0.403	0.195	0.172	0.410	0.260
4DL	0.273	0.335	0.212	0.138	0.328	0.150
HB	0.256	0.060	0.136	0.114	0.111	0.024

4.2.2 Stature Estimation Model Using Foot Dimension

4.2.2.1 Overview

In forensic identification, evidence in the form of a footprint could provide much more useful information than other body parts. This is because foot length has a positive correlation with stature. Furthermore, at almost all crime scenes there are footprints (Kanchan et al., 2012; Kanchan et al., 2010). Especially, in most Asian countries such as Korea, Japan, and China, people take off their shoes indoors (Yi. 2002) Thus, in case of an indoor crime, the bare foot plays a key role in profiling a suspect. In addition, a foot has 26 bones, 33 joints, and 19 muscles, all of which provide various data pertaining to body profiles. All of this information can be used for identifying gender, weight, height, and age, all of which effectively decrease the pool of potential criminal suspects. Previous studies proved the importance of forensic information when it comes to the foot. However, there were few studies that focused on the applicability of Korean foot dimensions in forensic science.

Therefore, in this study, it will be useful for profiling stature and body condition from measurement data from certain foot dimensions such as heel, metatarsal edge, instep, metatarsal, and lateral malleolus. Thus, in addition to foot length and breadth measurement data, which are frequently featured in previous studies, this research provides a valuable regression model based on specific data such as dimensions pertaining to the instep, metatarsal, and lateral malleolus. Besides, there has been little practical research done using Koreans' foot measurements suitable for practical application to meet medicolegal standards. Previous research reported that stature estimation equations derived from one race or group of races have lower accuracy when applied to other ethnic groups (Y.-C. Lee & Wang, 2014), and most of the stature estimation formulas were derived in West Asia and Africa. Thus, it is an urgent work to develop stature estimation equations for Korean and other ethnic groups that have similar characteristics. For these reasons, the authors expect to this research to provide, not only for use in forensic medicine, a body of information for use by the fashion industry and by medical appliance and sports equipment manufacturers.

4.2.2.2 Method

This research used the results of a 3D features measurement project (Size Korea Project) of the Korea Technology Standards Institute. The sample for stature estimation model was taken from 575 subjects (175 male and 400 females). In the study, based on the prior research and ISO 7250 standard (Standard, 2003), 10 features of foot dimensions were finally selected, as in Table 4.20 and Figure 4.9. Measurement tools and procedures were same to those of sex estimation model case in section 4.1.

Data of 461 participants' foot dimensions were performed by using a statistical package of SPSS 21, then the averages and deviations of each dimension were provided. The t-test was applied to compare gender differences in each dimension. Moreover, Pearson's correlation coefficients were computed to identify correlations of various foot measurements with height. Multivariate regressions were performed using the data for the various measurements. And for comparing prediction accuracy among prediction models, the coefficient of determination (R^2) and standard error of estimate (S.E.E) were used. Additionally, a stepwise method that drew a regression equation by combining various variables was used.

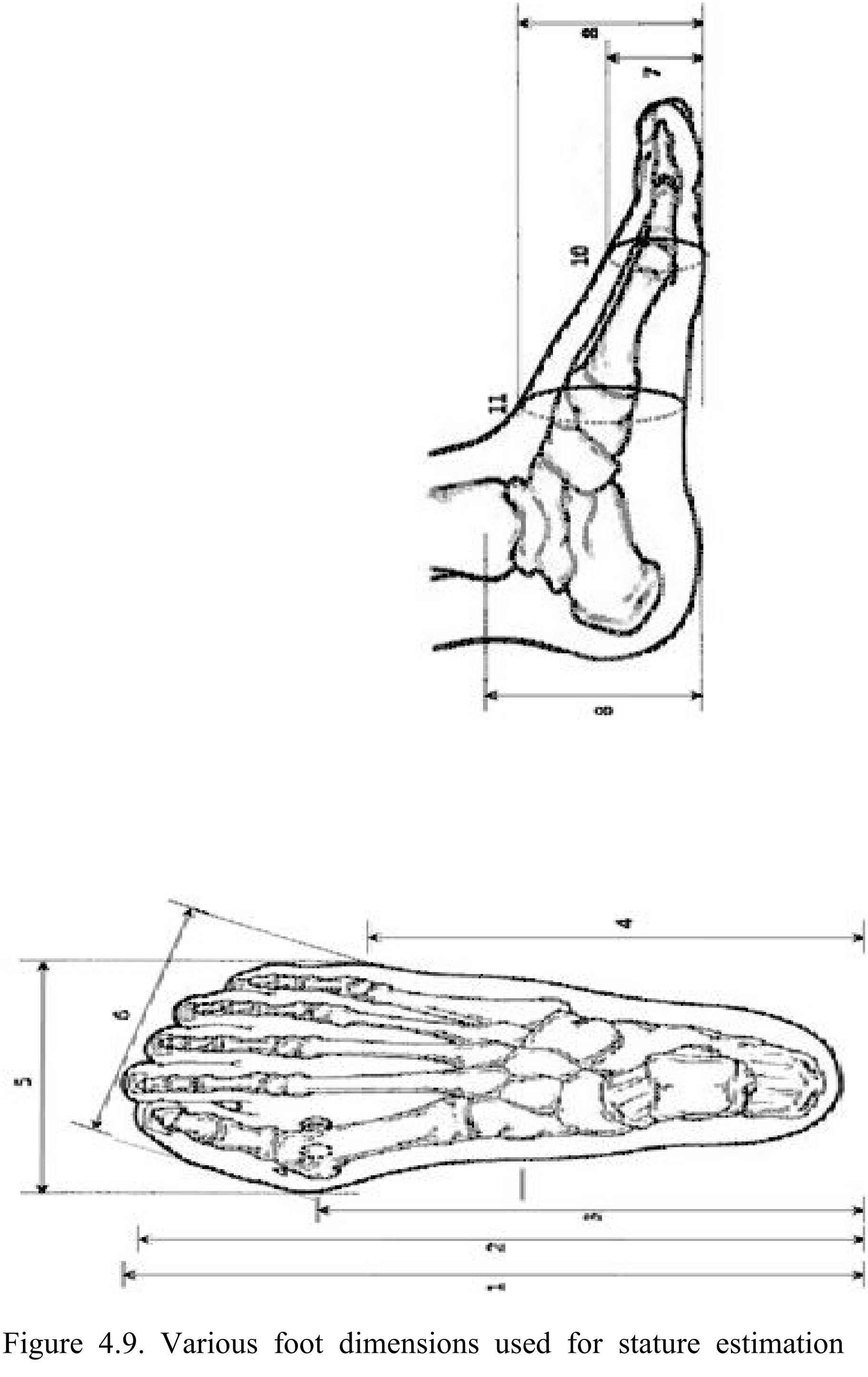


Figure 4.9. Various foot dimensions used for stature estimation

Table 4.20. Definition of various foot measurement for stature estimation

No.	Foot dimensions	Abbreviation	Definition
1	Foot length	FL	The maximum distance from the pternion to the tip of longest toe
2	Pternion to great toe (length)	PGL	The distance from the pternion to the great toe
3	Pternion to first metatarsal tibiale (length)	PMTL	The distance from the pternion to the most medial point on the head of the first metatarsal(tibiale)
4	Pternion to fifth metatarsal fibulare (length)	PMFL	The distance from the pternion to the most lateral point on the head of fifth metatarsal(fibulare)
5	Breadth at the metatarsal	FB	The distance from the most medial point on the head of the first metatarsal to the most lateral point on the head of fifth metatarsal
6	Diagonal breadth at the metatarsal	DFB	The distance from the most medial point on the head of the first metatarsal to the most lateral point on the head of fifth metatarsal
7	Height at the ball(metatarsal)	BH	The distance from the floor to the most prominent point on the head of the first metatarsal
8	Height at the instep(navicular)	IH	The distance from the floor to the most prominent point on the navicular bone
9	Height at the lateral malleolus	MAH	The distance from the floor to the most prominent point on the later malleolus bone
10	Circumference at ball(metatarsal)	BC	The superficial distance around the edge of the metatarsal
11	Circumference at instep(navicular)	IC	The superficial distance around the edge of the prominent point of navicular and the sole in the vertical direction

Table 4.21. Descriptive statistics of subjects

	Variable	Male (n=175)		Female(n=286)		T-test
		Mean	SD	Mean	SD	T
	Stature	169.7	6.6	159.7	5.3	17.0
1	FL	25.2	1.2	23.1	1.0	17.0
2	PGL	25.1	1.2	23.1	1.0	18.0
3	PMTL	18.4	0.9	17.0	0.8	16.6
4	PMFL	15.9	0.9	14.8	0.8	14.2
5	FB	9.9	0.5	9.2	0.5	15.3
6	DFB	10.2	0.5	9.5	0.5	15.1
7	BH	3.7	0.3	3.3	0.3	11.9
8	IH	6.1	0.5	5.2	0.6	17.3
9	MAH	7.2	0.5	6.7	0.6	10.1
10	BC	25.4	1.2	23.3	1.0	20.3
11	IC	25.5	1.2	22.9	1.1	23.5

Table 4.22. Correlation coefficient between foot dimension and stature

No.	Variable	Male	Female
1	FL	0.753**	0.433**
2	PGL	0.742**	0.433
3	PMTL	0.675**	0.393**
4	PMFL	0.666**	0.334**
5	FB	0.544**	0.224**
6	DFB	0.503**	0.224**
7	BH	0.140	0.016
8	IH	0.051	-0.006
9	MAH	0.494**	0.069
10	BC	0.331**	0.212**
11	IC	0.328**	0.222**

** Significant at 0.01 level (two tailed).
* Significant at 0.05 level (two tailed

4.2.2.3. Results

Descriptive statistics (mean, SD) were calculated, and the results of t-test (difference in the measurements of each foot part between males and females) are shown in Table 4.21. Statistically, some of the foot measurements from males were relatively bigger than the corresponding measurements for females (*p* value <0.001). Thus, in order to get more accuracy, a regression model needs to be derived for each gender. For men, the circumference at instep (IC) was the maximum measurement with the dimension of 25.5cm, while the height at the ball (BH) was measured at 3.7 cm as the minimum. For women, the maximum and minimum measurements were the circumference at ball (BC) at 23.3cm and the height at the ball (BH) at 3.3 cm. The most different variables between male and female was circumference at instep (IC). The men's average was 25.5cm, and the women's average was 22.9cm. The t value was 23.5. On the other hand, height at the lateral malleolus (MAH) variable shows a small difference (0.5cm) between male and female, and its t value was 10.1, which showed the least differences in foot dimensions.

Correlation between subjects' height and measurement values were analyzed by comparing the Pearson correlation coefficient (Table 4.22). Among all of the variables, foot length (FL) showed the highest relationship in males (r=0.753) and females (r=0.433). On the other hand, height at the instep (IH) was less relevant to height. Males' length variables such as FL, PGL, PMTL and PMFL indicated more than 0.6 in the correlation coefficient, and female was more than 0.3. Considering all parts of the foot, males' correlation coefficient are all in excess of the females' coefficients. But for the height at the ball

(BH) and height at the instep (IH), the correlations were statistically significant for all foot part dimensions (p<0.01). Furthermore, only females' instep heights (IH) suggested a negative correlation coefficient, yet it was not statistically significant. For relative variables of length, among FL, PGL, PMTL and PMFL, the correlation coefficient of foot length (FL) was the highest. For breadth-related variables, between foot breadth (FB) and diagonal breadth at the metatarsal (DFB), FB was at the highest. And for height-related variables among height at the ball (BH), height at the instep (IH), and height at the lateral malleolus (MAH), MAH had the highest correlation.

Tables 4.23 and 4.24 show regression equations for stature estimation. For men, prediction accuracy was the highest when the regression equation involved foot length (R^2=0.567),and the SEE (±4.332cm) was the lowest. However, the height at the instep (IH) had the lowest prediction accuracy. Length-related variables FL, PGL, PMTL, and PMFL all indicated R^2>0.4,and SEE between 4.3~4.9cm. Nevertheless, the height-related variables of BH and IH's R^2 was less than 0.014, and also SEE was±6.5cm which indicate comparatively poor predictability. For women, foot length (FL) had the highest prediction accuracy and the lowest SEE (R^2=0.434,SEE=±4.152 cm). For length-related variables FL, PGL, PMTL, PMFL the R^2's were over 0.108 and SEE was between 4.8~5.0cm. Height at the instep(IH) had the lowest correlation coefficient and R^2 was also the lowest,0.003. In this study, by the stepwise method, multiple regression was performed using various combinations of variables (Table 4.25).

Table 4.23 Linear regression equations for stature estimation (cm) from male foot dimension

Sex	Parameters	Regression Equation	R^2	S.E.E
Male	FL	S=68.7+4.015(FL)	0.567	4.332
	PGL	S=70.5+3.948(PGL)	0.548	4.414
	PMTL	S=81.3+4.803(PMTL)	0.452	4.858
	PMFL	S=91.7+4.891(PMFL)	0.440	4.914
	FB	S=99.4+7.090(FB)	0.292	5.525
	DFB	S=107.3+6.094(DFB)	0.253	5.692
	BH	S=158.7+2.997(BH)	0.014	6.520
	IH	S=165.9+0.620(IH)	0.003	6.577
	MAH	S=126.2+6.012(MAH)	0.239	5.726
	BC	S=124.5+1.780(BC)	0.104	6.215
	IC	S=124.3+1.782(IC)	0.102.	6.222

All coefficients are significant (*P* value<0.05)

Table 4.24. Linear regression equations for stature (cm) estimation from female foot dimension

Sex	Parameters	Regression Equation	R^2	S.E.E
Female	FL	S=74.1+3.673(FL)	0.434	4.152
	PGL	S=107.3+2.263(PGL)	0.185	4.825
	PMTL	S=114.1+2.677(PMTL)	0.152	4.922
	PMFL	S=127.4+2.180(PMFL)	0.108	5.046
	FB	S=135.3+2.646(FB)	0.047	5.217
	DFB	S=135.6+2.531(DFB)	0.047	5.217
	BH	S=158.7+0.251(BH)	0.003	5.353
	IH	S=159.9-0.050(IH)	0.003	5.353
	MAH	S=155.5+0.623(MAH)	0.001	5.341
	BC	S=133.8+1.113(BC)	0.041	5.232
	IC	S=134.4+1.102(IC)	0.046	5.220

All coefficients are significant (*P* value<0.05)

Table 4.25. Multiple regression equations for estimation (cm) of stature from foot dimension

Case	Regression (stepwise) equation	R^2	SEE
Pooled	S= 69.9+3.582(FL)+1.961(MAH)	0.600	4.802
Male	S= 60.5+3.526(FL)+2.5825(MAH)	0.608	4.110
Female	S= 61.8+3.397(FL)+2.973(MAH)	0.494	3.937

All coefficients are significant (*P* value<0.05)

When multiple regression was practiced for both males and females by the use of footlength (FL) and height at the lateral malleolus(MAH), the R-squared value for the regression model was 0.600 and SEE indicated ±4.802cm. For men, by FL and MAH, the R^2 improved to 0.608, and SEE was ±4.110cm. In this research, this was the highest R^2 and the lowest SEE. For females, by using FL and MAH, R^2 became 0.494, and SEE was ±3.937cm.

4.2.2.4 Discussion

The purpose of this research is to develop a trustworthy estimation model by using measurements of various foot parts. Standard deviations and average were calculated from measurements of participants' feet. In addition, the study calculated the differences between men and women, which determined that the circumference at the instep (IC) and the circumference at ball (BC) were the most different foot dimensions. These results seemed similar to the results of Lee's research that studied the feet of Taiwanese men and women (Y.-C. Lee & Wang, 2014). However, the variables most different between the genders (IC, BC) showed weak prediction accuracy and correlation coefficients with stature.

Among various foot parts, the present research results match those of prior researchers who found that FL is strongly related to heights. In Zeybek's research with 249 Turkish subjects, FL for men produced r=0.749; for women, r=0.678 (Zeybek et al., 2008). That research also revealed a strong co-relationship of the length with the foot breadth, malleolus height, and navicular height. Hemy's research of course showed that FL's relationship with height had higher correlation compared to FB and foot heel breadth (Hemy et al., 2013). Additionally, the correlation coefficient for FL was higher than coefficient for the measurements between the foot heel and the toe tips. Therefore, based on the outcome of prior research and this study, FL is the most accurate foot dimension among other trial foot dimensions.

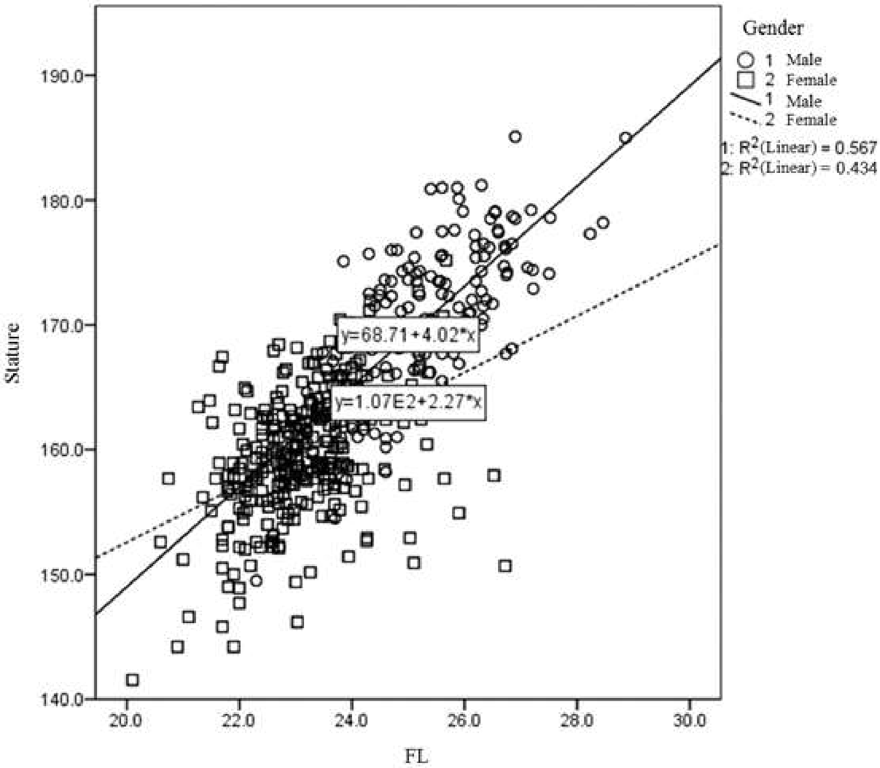


Figure 4.10. Scatter graph and trend ine showing the relation between FL and stature in Korean population

In this research, using various foot-part measurements, a regression model was derived for estimating heights, wth allowances for gender. The regression model using only FL was shown to be the most reliable predictor. For men the R^2 was 0.567; for women, 0.188 (Figure 4.10). With these measurements it was possible to draw comparisons with other regression models of the prior studies that were created for other nationalities, also involving only the FL. The regression model for men in this study showed an R-squared of 0.567 and a SEE of ±4.332cm. The R^2 of the regression model with the FL alone for Korean females was 0.185. This was lower than the same statistics of the same model applied to Malaysians (0.572), West Australians(0.544), Turkish subjects(0.549), and Indians(0.197).

In this research, there was a gap of prediction accuracy with the regression equation for foot length alone, with regard to gender differences. The R^2 for men was 0.567, which is higher than for almost any other e thnic group; female's R^2 for women was 0.185, which was lower than that for anyother ethnic group. These results showed, as compared to prior research (Table 4.26), that for Korean males foot length prediction accuracy was higher than that for Indian, Turkish, West Australian, and Egyptian subjects. However, for Korean females the accuracy was less than that for Indian, Turkish, West Australian, and Egyptian subjects. There could be several reasons for this. First, the Korean research participants differed by age more than did the subjects in the foreign groups. Additionally, because many younger Korean females have had the tendency to put on high heels and pointed shoes, which may cause variation of features of the foot, the foot measurements could be relatively smaller (S. Jung, Lee, Boo, & Park, 2001). That may affect prediction accuracy.

For estimating height based on the foot, it was better to use length-related variables such as FL, PGL, PMTL, PMFL rather than variables of breadth and height. This result was similar to the findings of Zeybek's research with Turkish subjects in which foot length (FL) was the most effective variable with which to create a prediction model (Zeybek et al., 2008).

Table 4.26. Comparison of stature, foot length, R^2 and S.E.E from previous studies

Author	Year	Country	Stature		Foot length		R^2		S.E.E	
			Male	Female	Male	Female	Male	Female	Male	Female
This study	2015	South Korea	169.7	159.7	25.2	23.1	0.565	0.434	4.33	4.15
Zeybak	2008	Turkey	174.1	161.6	25.6	23.0	0.459	0.549	-	-
Fawzy	2010	Egypt	-	-	24.8	-	0.293	-	3.55	-
Hisham	2012	Malaysia	166.0	156.7	22.2	21.2	0.422	0.572	4.46	3.50
Kanchan	2012	India	174.6	156.9	24.1	22.1	0.395	0.197	4.16	5.57
Hemy	2013	West Australia	178.4	163.6	27.3	24.5	0.485	0.544	5.10	4.84

Furthermore, the research on West Australians also showed that a regression model based solely on foot length had better predictability than one based on breadth. With regard to variables of breadth alone, foot breadth (FB) had higher accuracy than diagonal breadth at the metatarsal (DFB). And in for height-related variables, height at the lateral malleolus (MAH) showed the highest accuracy. Variables of circumference, for which all of the R^2 were between 0.041 and 0.104, had lower prediction accuracy so that using circumference in stature estimation cannot be recommended. Overall, when various foot dimensions were used for estimating height, the use of FL, PGL, PMTL, and PMFL will provide higher accuracy than variables of circumference and height.

Table 4.27. Stature estimation accuracy(R^2) using foot parts depending on age range

Variables	20's~30's		40's~50's		60's~70's	
	Male	Female	Male	Female	Male	Female
FL	0.402	0.460	0.419	0.397	0.708	0.556
MAH	0.068	0.114	0.086	0.092	0.258	0.092
FB	0.237	0.103	0.230	0.063	0.064	0.044

In this study, R^2 when using foot parts for each age range group was calculated (Table 4.27). Higher R^2 was shown in 60-70 yrs old age group than in other age range group for males. There was no tendency depending on age range for females. No significant difference was shown depending on job types or resident area.

This research focused on only the Korean population. Thus, the accuracy of these formulas will be maintained only when applied for to Korean or similar ethnic groups that have similar physical characteristics. Although all of the subjects were asked to stand while maintaining balance on both feet, the imbalance may affect measurement. These can be considered to be some limitations on the accuracy of this research.

4.3 Weight Estimation Model

4.3.1 Overview

It is very important to estimate the weight of a patient and prescribing an appropriate dose of medicine according to that weight in Emergency Medical Service (E.M.S.) (Anglemyer, Hernandez, Brice, & Zou, 2004; W. L. Hall, Larkin, Trujillo, Hinds, & Delaney, 2004). When excessive or insufficient dose of medicine or injection is prescribed, the status of a patient may worsen or result in severe side effects. It is therefore crucial to predict a patient’s weight accurately (Kahn, Oman, Rudkin, Anderson, & Sultani, 2007). While it is possible to accurately weigh a patient who is conscious and can get on a scale by him/herself, doctors and nurses prescribes medicine on the site according to an estimated weight of the patient if the patient is unconscious, having speech disorders, or if there are no scales at the site of an accident. However, previous studies have reported that prediction of patients’ weights by doctors and nurses are inaccurate in many cases, (Corbo, Canter, Grinberg, & Bijur, 2005) which may lead to critical consequences (Bootman, Wolcott, Aspden, & Cronenwett, 2006). In order to prevent such outcomes, there are various methods of estimating weight precisely, one of which is a method using anthropometrics.

However, existing studies mainly applied anthropometrics limited to abdomen, thighs and feet areas of the body. In cases of patients who have lost parts of their bodies and patients with severe injuries on their abdomens or thighs at the site of an accident, it is common that measurements of such body parts are impossible. In these situations, measurements of various parts of patients’ hands could work as indexes for predicting patients’ body weights, or at least act as a supplement for other weight estimation models. In this regard, our study aims to analyze hand measurement data of males and females, and derive a linear regression equation model for estimating body weights of males and females using a combination of major hand measurements as variables.

4.3.2 Method

The author utilized the Korean hand measurement project data from Size Korea. Body dimension data of 5195 people (2750 male, 2445 female) were used. All subjects were adults aged over 20 with fully grown body. Average age of males were 42.4 (minimum 20, maximum 70), and average age of females were 46.5 (minimum 20, maximum 75). All subjects were of the same race, born and grown in Korea, and no subjects had any history of spine disorder.

In this study, 9 variables including circumference of certain part of whole body was defined in Table 4.28 and Figure 4.11 (J.G. Hall et al., 2007). In order to minimize inter-observer error, one measurer took charge of one variable and measured each variable for all subjects. Subjects' body were measured with anthropometric tapeline for circumference. Each subject was easily stand with balanced stance. After marking standard points on his/her body with a marker, the superficial distance around the edge of those standard points were measured. Body weight was weighed in kilograms. After each subject stepped on the center of a scale with his/her shoes and coats taken off, the scale value was acquired.

Normal descriptive statistics (average and standard deviation) was calculated. A correlation coefficient was calculated to find out the correlation between each variables and body weight. Linear regression was used to identify how accurately each variable predicts body weight. Moreover, multiple regression was conducted by means of stepwise method in order to improve the accuracy of body weight estimation, using combinations of variables. Each regression equation calculated and showed the Standard Error of Estimate (SEE) for predicting deviation of estimated value from the actual body weight. All statistical analysis was performed using SPSS 21.

Table 4.28. Definition of the body measurement employed in this research with reference

No	Body dimension	Abbreviation	Definition
1	Head circumference	HEC	The superficial distance passing eyelid and projecting point on back of the head
2	Neck circumference	NEC	The superficial distance around the edge of the upper part of the neck
3	Breast circumference	BREC	The superficial distance around the edge of the breast at the height of nipple
4	Upper arm circumference	UPPEC	The superficial distance around the edge of the upper arm at the height of arm pit
5	Elbow circumference	ELBOC	The superficial distance around the edge of the elbow
6	Wrist circumference	WC	The superficial distance around the edge of the wrist
7	Thigh circumference	THIC	The superficial distance around the edge of the middle part of thigh
8	Calf circumference	CAC	The maximum superficial distance around the edge of calf
9	Ankle circumference	ANC	The superficial distance around the edge passing heel and navicular

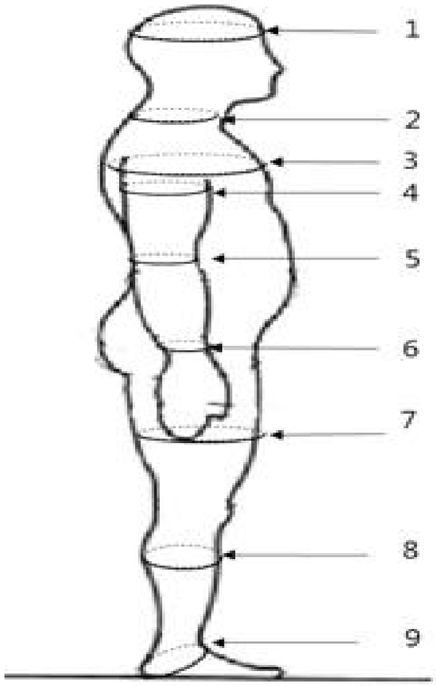


Figure 4.11 Various landmarks in body dimension for weight estimation

4.3.3 Results

Averages and standard deviations of each body measurements in males and females are shown in Table 4.29. In the male group, average height was 170.6 centimeters (SD 6.4) and average body weight was 71.1 kg (SD 10.0). In the female group, average height was 157.3cm (SD 5.9) and average body weight was 56.2kg (SD 7.7). Correlation coefficients between measurements of each body dimension and body weight are shown in Table 2.

In males and females, breast circumference (BREC) showed the highest correlation with body weight. Among the upper body, BREC showed the highest correlation with body weight in males and female. In case of lower body, thigh circumference(CHIC) showed the highest correlation with body weight. On the other hand, head circumference (HEC) showed the least correlation with body weight in males and females.

Table 4.29. Descriptive statistics for body measurement (cm) and correlation coefficient between body measurement and body weight in Korean male and female

Variable	Male (n=2750)		Female(n=2445)		R	
	Mean	SD	Mean	SD	Male	Female
Stature	170.6	6.4	157.3	5.9	0.456**	0.236**
Weight	71.1	10	56.2	7.7	-	-
HEC	57.1	1.5	54.9	1.5	0.481**	0.313**
NEC	37.5	2.2	32.4	1.9	0.692**	0.739**
BREC	92.9	6.6	88.2	7.9	0.862**	0.823**
UPPEC	30.4	2.7	27.1	2.8	0.787**	0.805**
ELBOC	29.0	2.1	25.6	2.0	0.711**	0.720**
WC	16.8	0.9	15.2	0.9	0.643**	0.682**
THIC	51.3	4.4	48.1	3.8	0.847**	0.746**
CAC	37.7	2.8	34.3	2.4	0.829**	0.742**
ANC	26.0	1.3	23.4	1.2	0.671**	0.649**

** Significant at 0.01 level (two tailed).

4.3.3.2 Regression Analysis

Body weight was estimated by using various variables (Table 4.30). When using one variable for predicting body weight, using breast circumference (BREC) reduced SEE the most (±5.202 kg) and resulted in the highest R^2 (0.742) in males. In females, using breast circumference (BREC) reduced SEE the most (±4.398 kg), yielding the highest R^2 (0.677). In both males and females, it was shown that using BREC was more accurate with lesser S.E.E than using other body measurement variables (Table 4.30).

In this study, in order to improve prediction accuracy, we conducted multiple regressions combining several hand measurement variables, using stepwise method (Table 4.31). In males, using the variables, thigh circumference (THIC) and breast circumference (BREC) resulted in R^2 value of 0.863. With the breast circumference (BREC) and calf circumference (CAC), the regression model shows R^2 value of 0.848 in females. All regression coefficients of the equations above were statistically significant ($p<0.001$).

Table 4.30. Linear regression equation for weight estimation from body dimension (in Kg and cm)

Sex	Parameters	Regression Equation	R^2	S.E.E
Male	HEC	W= 3.24 (HEC)-113.7	0.231	8.985
	NEC	W= 3.17 (NEC)-47.7	0.479	7.493
	BREC	W= 1.34 (BREC)-53	0.742	5.202
	UPPEC	W= 3.04 (UPPEC)-21.3	0.619	6.323
	ELBOC	W= 3.55 (ELBOC)-31.9	0.506	7.201
	WC	W= 7.43 (WC)-53.5	0.413	7.846
	THIC	W= 1.99 (THIC)-31.1	0.717	5.446
	CAC	W= 3.04 (CAC)-43.3	0.687	5.731
	ANC	W= 5.22 (ANC)-64.6	0.450	7.595
Female	HEC	W= 1.67 (HEC)-35.3	0.098	7.356
	NEC	W= 2.94 (NEC)-38.7	0.545	5.221
	BREC	W= 0.80 (BREC)-14.6	0.677	4.398
	UPPEC	W= 2.19 (UPPEC)-3.318	0.648	4.597
	ELBOC	W= 2.84 (ELBOC)-16.4	0.519	5.372
	WC	W= 5.63 (WC)-29.5	0.465	5.667
	THIC	W= 1.51 (THIC)-16.5	0.556	5.157
	CAC	W= 2.41 (CAC)-26.4	0.551	5.190
	ANC	W= 4.24 (ANC)-42.7	0.421	5.892

All coefficients are significant (*P* value<0.05)

Table 4.31. Multiple regression equations for estimation of stature from hand dimension (in Kg)

Case	Regression (stepwise) equation	R square	SEE
Pooled	W = 2.25(CAC)+0.68(BREC) -78.8	0.860	4.413
Male	W = 0.82(BREC)+1.13(THICC) -63.1	0.863	3.790
Female	W = 0.6(BREC)+1.5(CAC) -48.2	0.848	3.016

All coefficients are significant (*P* value<0.05)

4.3.4 Discussion

The goal of this study is to predict the actual body weight using body measurement data. In males, almost all variables showed correlation coefficient(r) of over 0.481. In females, r value was over 0.313. Therefore, when predicting the body weight, it is recommended to use breast circumference (BREC) rather than using other body circumference.

The author compared the reliability of this study with the result of previous studies. The estimation error, which is the variance between estimated value predicted by the single linear regression equation of this study and the actual average, was ±5.20kg in males and ±4.39kg in females. The variable with the highest correlation with body weight was breast circumference (R=0.742 for males and R=0.677 for females). When comparing the reliability of weight estimation, the rate of predicting the weight within 10% and 20% of the actual weight was frequently used in previous studies 10% is the commonly acceptable margin of weight error cited in the literature for anticoagulants and thrombolytic((Lin et al., 2009 & Lorenz et al., 2007). Lorenz, who conducted a study comparing body weight estimation of surgeons based on patients' appearances and anthropometric estimation method using circumference of abdomen, waist and hip, showed that the surgeons' estimation and the anthropometric method had accuracy of 60% and 93.7%, respectively, for predicting the weight within 10% of the actual weight. Comparing Lorenz's study results and our study, where the rate of estimating the body weight within 10% and 20% of the actual weight value was 94.0%, 99.9% respectively, we can infer that anthropometric method using BREC, THICC, and CAC is more accurate than the surgeons' estimation and present similar reliability level of Lorenz's anthropometric estimation method. Lin also estimated American patient's weight by using middle arm circumference and knee height. In his research, the anthropometric method using middle arm circumference and knee height predicted weight within 10% accuracy of American patient's weight in 74% of male patients. In females, the method estimated weight within 10% accuracy of patient's actual weight in 65% of patients. Comparing Lin's result with this study, anthropometric method using BREC, THICC, and CAC showed higher prediction accuracy within 10% of actual weight, R^2 and lower S.E.E (Lin et al., 2009).

One limitation in this anthropometric study was that the only Korean who was born and raised in South Korea were measured in the sample. We focused only one single ethnic group. In previous studies, anthropometric estimation accuracy was lowered depending on different races. Therefore, in the case of other ethnic group, the prediction accuracy of the regression model of this study will be lower. However, in case of the ethnic group which have similar physical characteristics to Korean, the regression models for this study can be applied to the group.

Chapter V

Evaluating Estimation Model

5.1 Comparison with other nationalities

The estimation performance of developed model have been evaluated by comparing with previous studies. In sex estimation model using hand measurement, the model for west Australian showed the highest accuracy in males and females. Model using the hand size of South Koreans were 5% lower in accuracy in comparison with Indians, and 15% lower in accuracy in comparison with west Australians. The cause of the difference came from the differing hand shape in accordance with the ethnic groups. However, the difference in the average length of hands between male and female were more than 20mm in west Australians or Indians. In case of South Koreans, the difference was 13mm, and in the case of width, the difference was only 7mm. Therefore, the research may deduct that the accuracy got lowered from the mix of male and female around sectioning point separating male and female as the difference of the length and the width of hands between male and female is small.

In a model separating the gender by using the sizes of parts of the feet, the estimation accuracy of the model deducted from west Australians was the highest. The estimation model deducted from South Korean group showed accuracy similar to the accuracy from the model deducted from Indians.

In case of a model predicting heights, the reliability of the model was compared with R^2 and S.E.E. In case of height estimation model using hands, the model compared with a model deducted from Indians and Egyptians. When using Hl, the male subject had comparatively higher estimation accuracy, but when using HB, the accuracy was lower than the models of other ethnic groups. In case of female, the estimation accuracy was lower than the models deducted from two ethnic groups.

In the height estimation using feet, male showed higher estimation accuracy compared with other ethnic groups. However, in case of female, the accuracy was lower than other ethnic groups. When looking at the result, in case of South Korean female, it is recommended for the researcher to predict while considering size of other parts rather than only using FL or FB when conducting stature estimation by using the size of feet.

In case of weight estimation model, ratio estimating weight within 10% boundary is usually used as a standard for evaluating reliability, the Lorenz's research targeting U.S citizens showed ratio of 93.7%, and the Lin's research conducted targeting U.S. citizens deducted ratio of 74%. Estimation ratio within 10% of the model deducted from the research targeting Koreans showed 94% similarity with the accuracy of the research model targeting U.S. citizens.

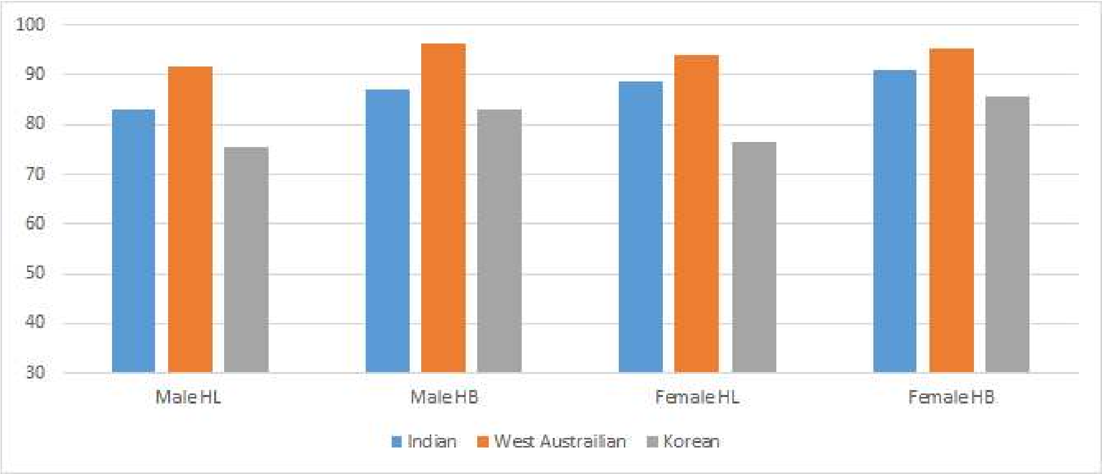


Figure 5.1. Prediction accuracy comparison using hand dimension with other nationalities

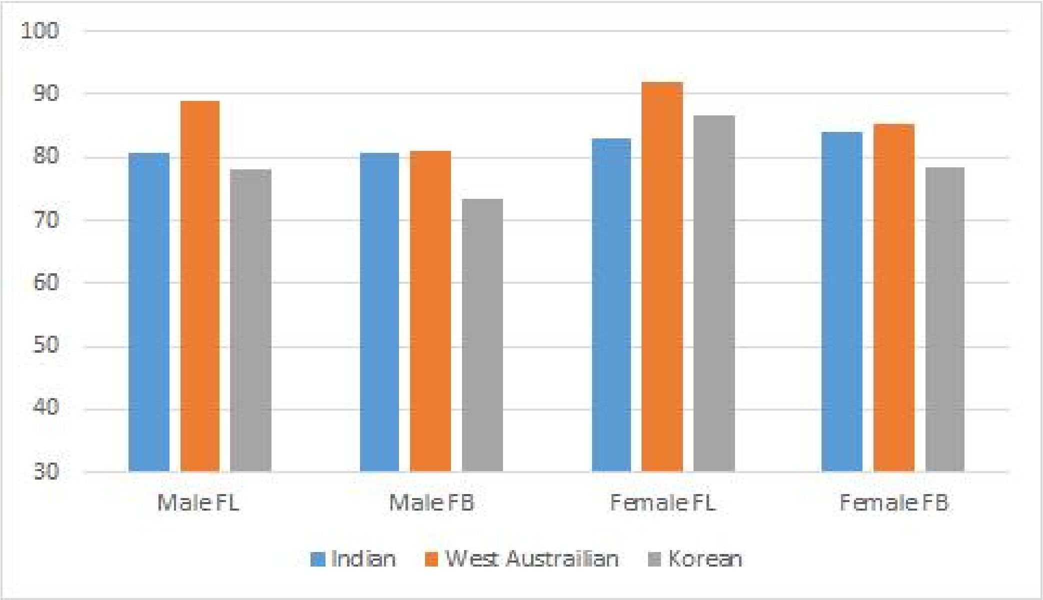


Figure 5.2. Prediction accuracy comparison using foot dimension with other nationalities

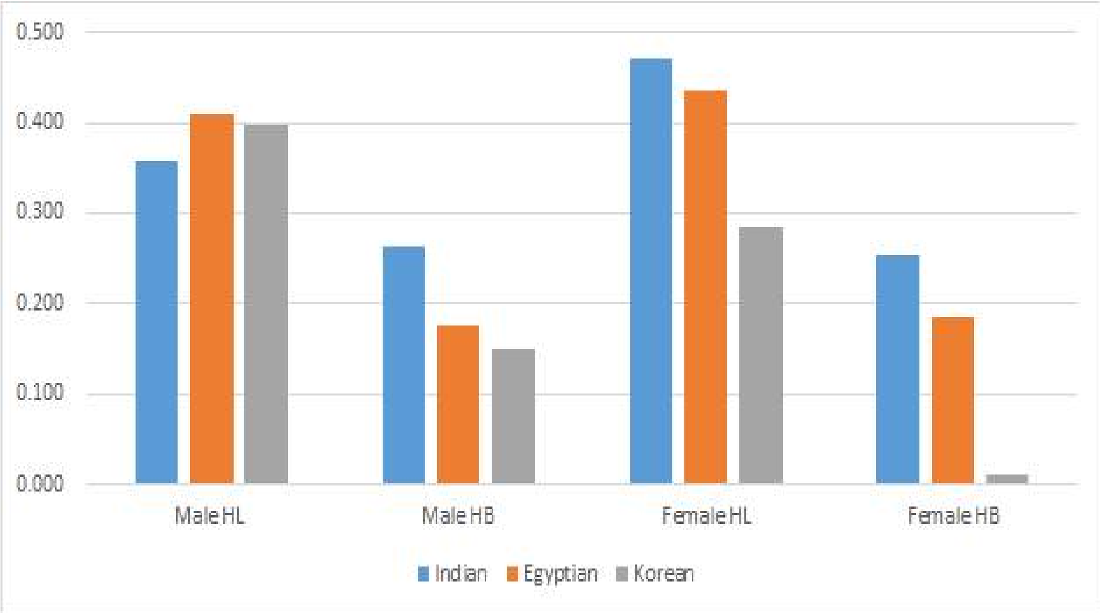


Figure 5.3. Prediction accuracy (R^2) comparison using hand dimension with other nationalities

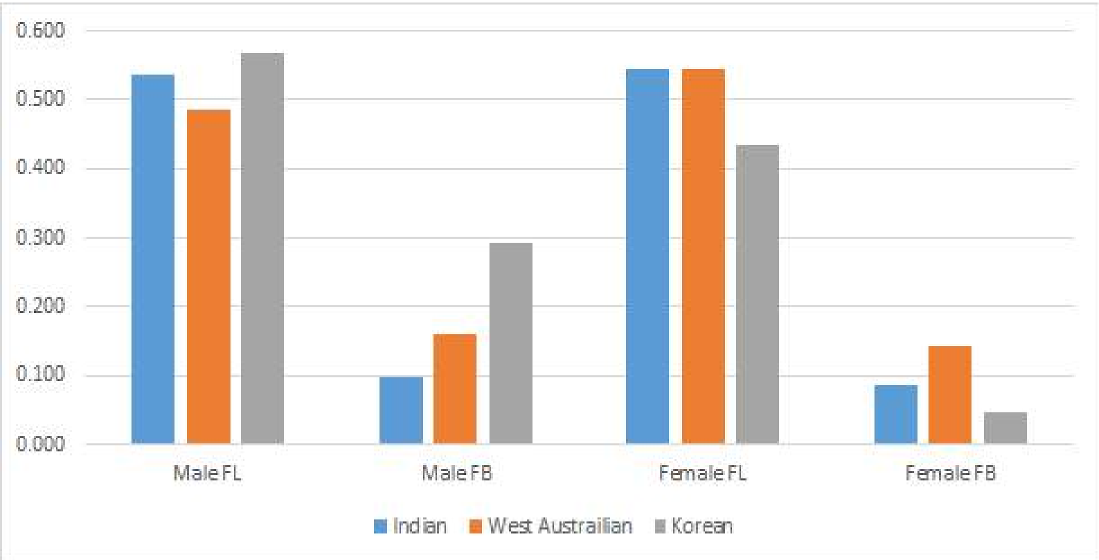


Figure 5.4. Prediction accuracy (R^2) comparison using foot dimension with other nationalities

5.2 Reliability of Models

On the body size measurement project samples (Male 150, Female 150) conducted targeting Koreans for the verification of reliability of sex estimation model, the estimation accuracy was compared by applying the current model (sex estimation model using HL and HB, sex estimation model using FL and FB).

As a result of the application to the new sample group, the sex estimation model using hand size showed more than 70.3% of estimation accuracy on both genders. Sex estimation model using feet size also showed more than 75% of estimation accuracy on both genders. Therefore, the application of the model to other Korean groups would secure a certain level of reliability.

Bland Altman Plot was drawn for the verification of reliability of stature estimation model (Table 5.6, 5.6 and 5.7). Bland Altman refers to a graphical method showing the difference between the calculated values through the two measurement methods. In case of the estimation model using hand size, the research found the cases of enlargement of estimation errors when the height is too small (under 163cm) on (Figure A) or when the subject are too big (over 180cm) at the estimation of the stature using HL of male. In case of female, the estimated height estimated through the model was smaller than the actual height as the height got bigger. Thus, the difference between the actual height and estimated height became positive (+).

In case of estimation using the size of feet, the male showed regular deviation regardless of the height. In case of female, also regular deviation regardless of the height was observed and there was no tendency on deviation. Multiple regression in model showed higher accuracy than single model result.

In case of weight estimation model, the numbers of subjects were too many, so the Bland Altman Plot was drawn by selecting 300 males and females at random. Female subjects showed more accuracy in estimation than male subjects, and the research could find out that the female subjects were comparatively estimating in more accurate manner regardless of their weight.

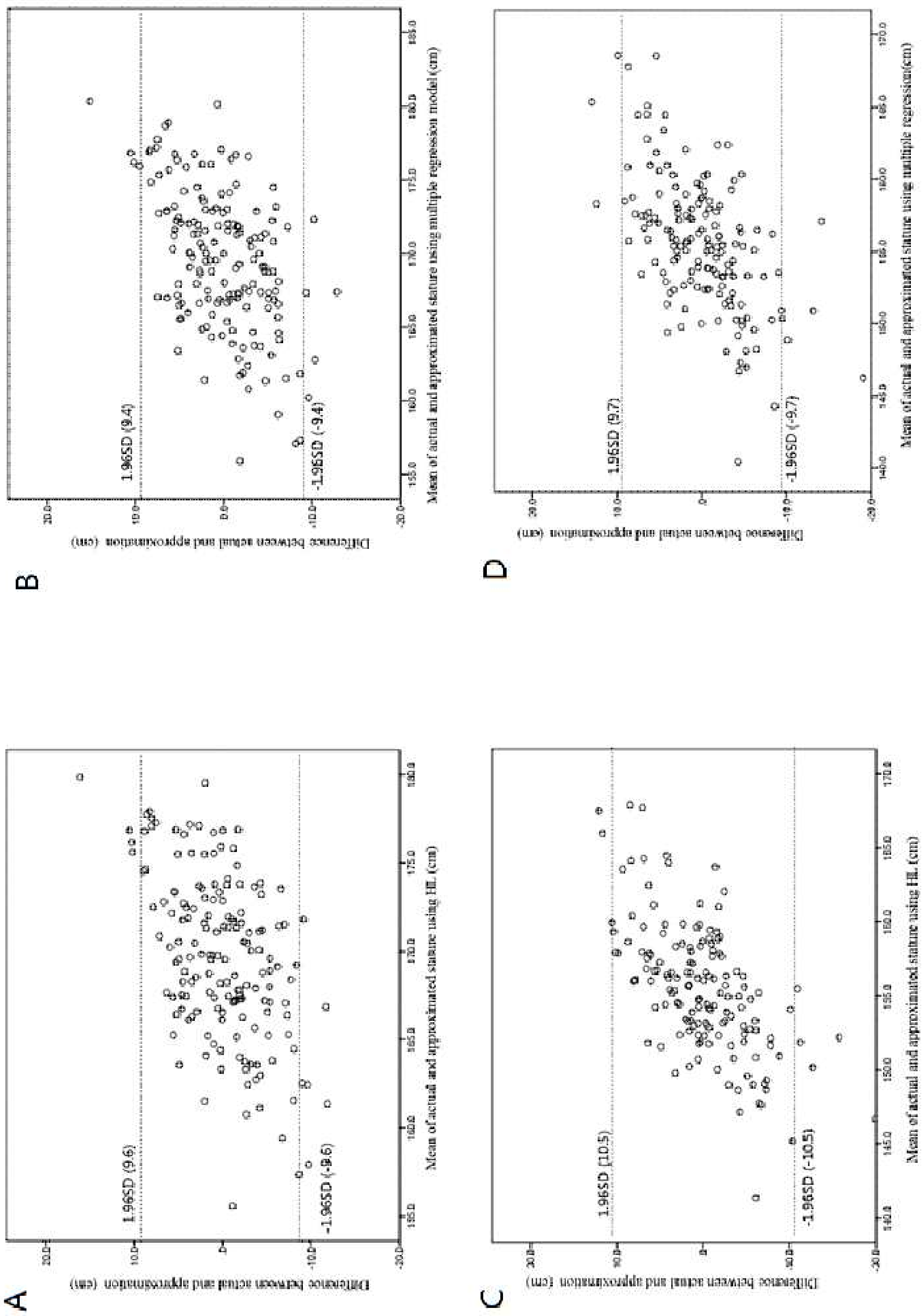


Figure 5.5. Bland-Altman plots showing reliability of the regression model using hand dimension (A, B: male; C, D: female)

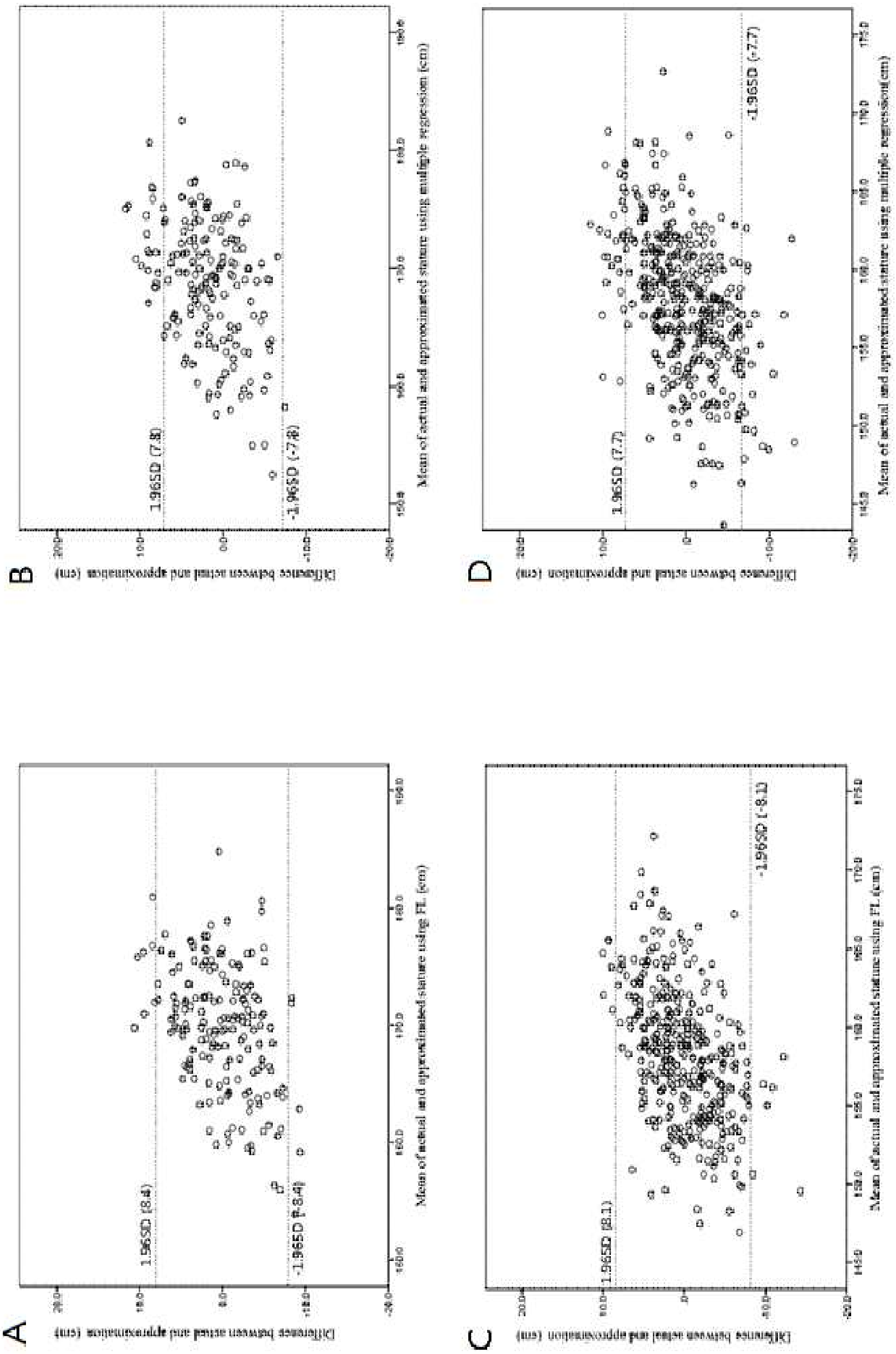


Figure 5.6. Bland-Altman plots showing reliability of the regression model using foot dimension (A, B: male; C, D: female)

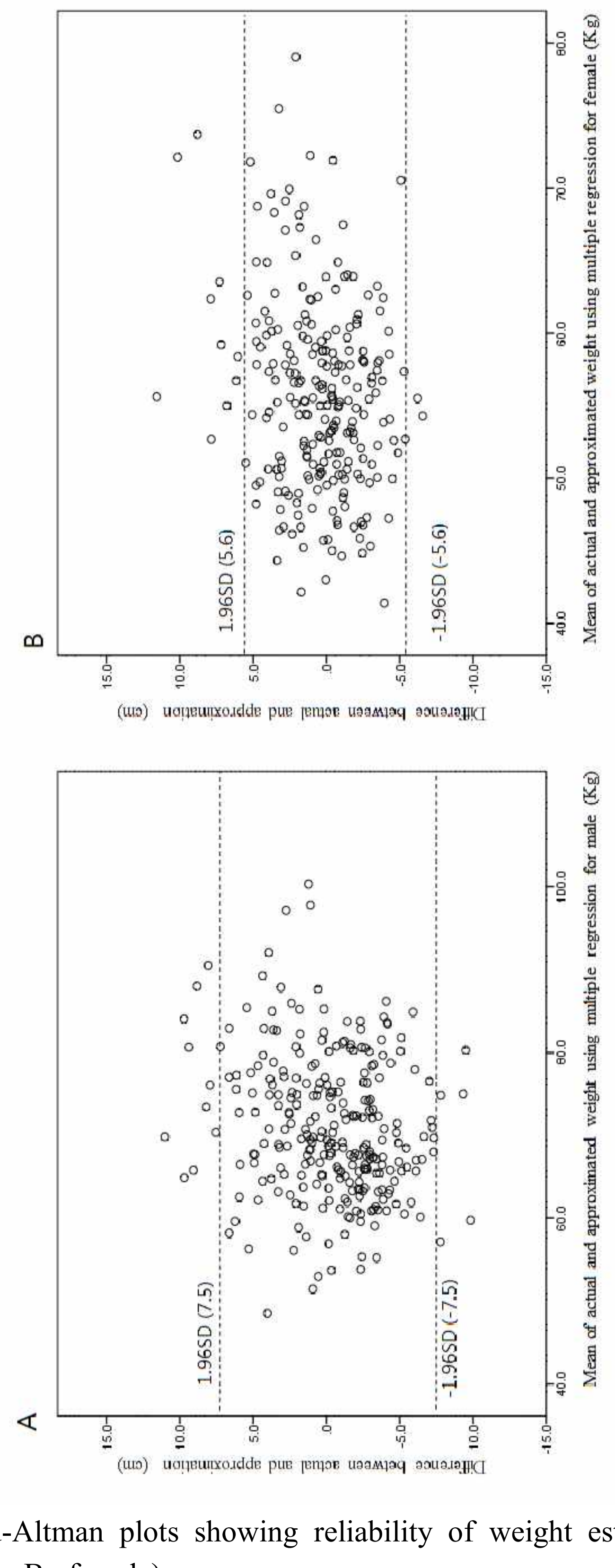


Figure 5.7. Bland-Altman plots showing reliability of weight estimation model (A: male; B: female)

When stature estimation model is used in forensic investigation, excessively large SEE will not be able to narrow down the possible list of the presumptive identification. In order to understand the usefulness of this model, it was analyzed how much percent of population can be specified by this model. When using hand length for stature estimation, SEE was 4.9cm for males and 5.4cm for females. If the estimated stature is 166cm, at least 52% of population can be restricted. If the estimated stature is under 153cm or over 178cm, the presumptive list can be limited to 10 percent of population (Figure 5.8). In case of regression model for females, if the estimated stature is 156cm, at least 63 percent of population can be specified (Figure 5.9). If the estimate stature is under 144cm or over 167cm, the presumptive group was get restricted to 10% of total population.

When using foot length for stature estimation, SEE was 4.3cm for males and 4.1cm for females (Figure 6.0 and 6.11). If the estimated stature is 166cm, at least 47% of population can be restricted. If the estimated stature is under 154cm or over 178cm, the presumptive list can be limited to 10 percent of population. In case of regression model for females, if the estimated stature is 156cm, at least 51 percent of population can be specified. If the estimate stature is under 146cm or over 167cm, the presumptive group was get restricted to 10% of total population.

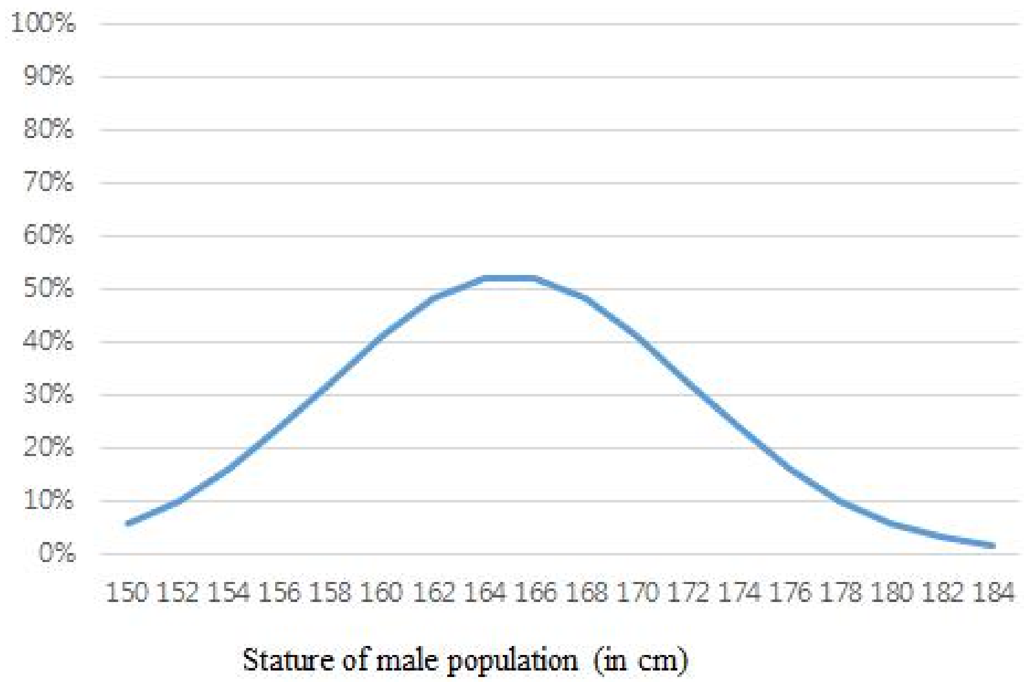


Figure 5.8. Restricted percent of male population depending on stature using HL

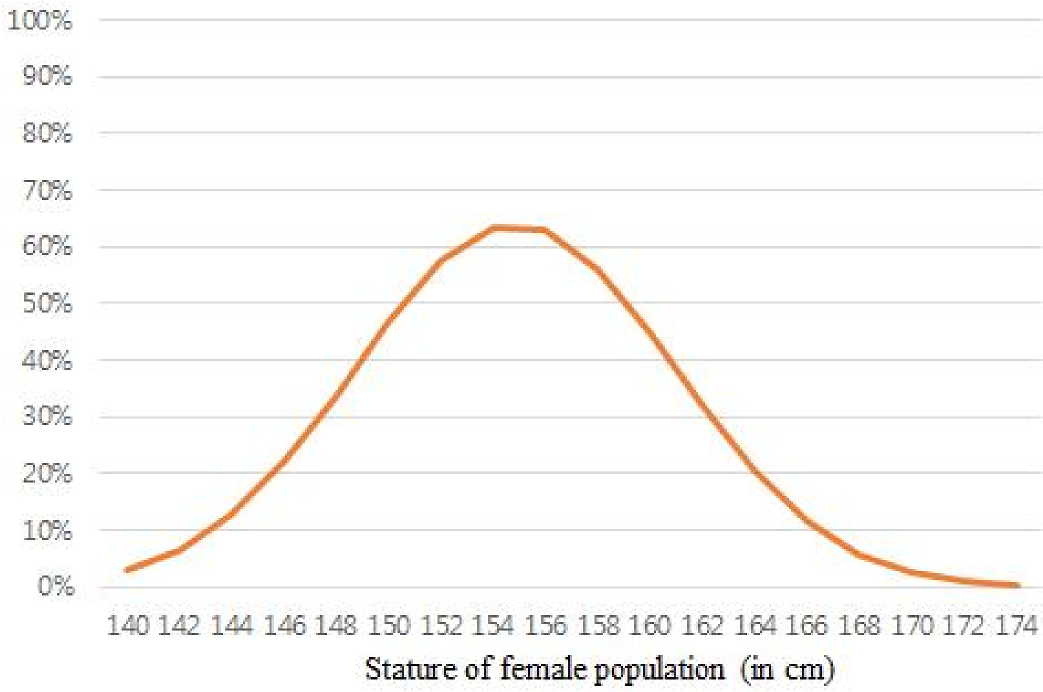


Figure 5.9. Restricted percent of female population depending on stature using HL

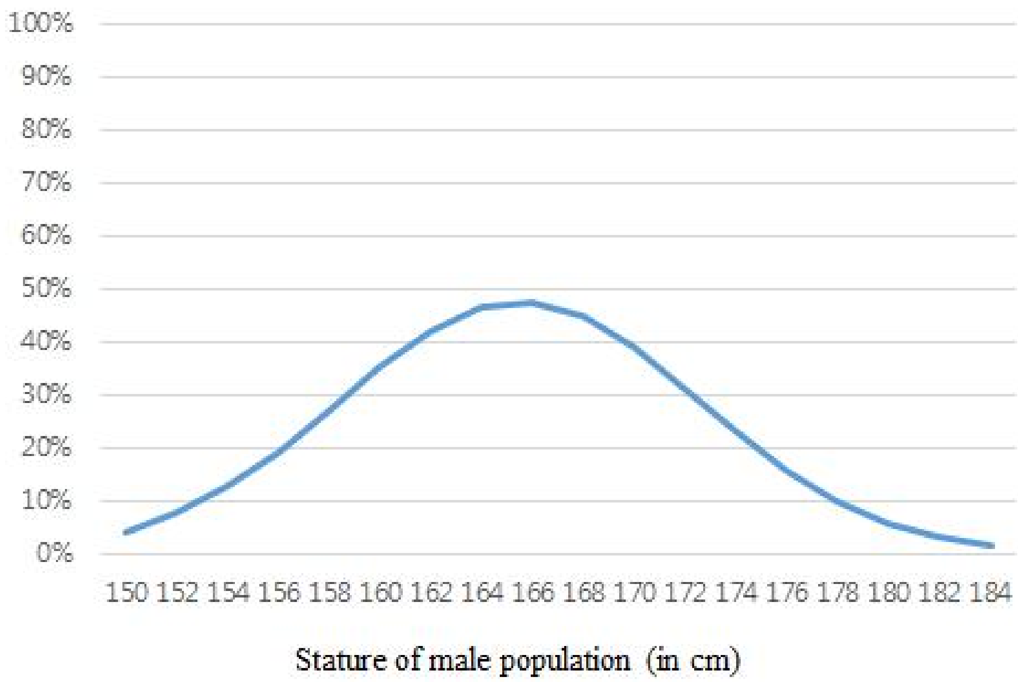


Figure 6.0. Restricted percent of male population depending on stature using FL

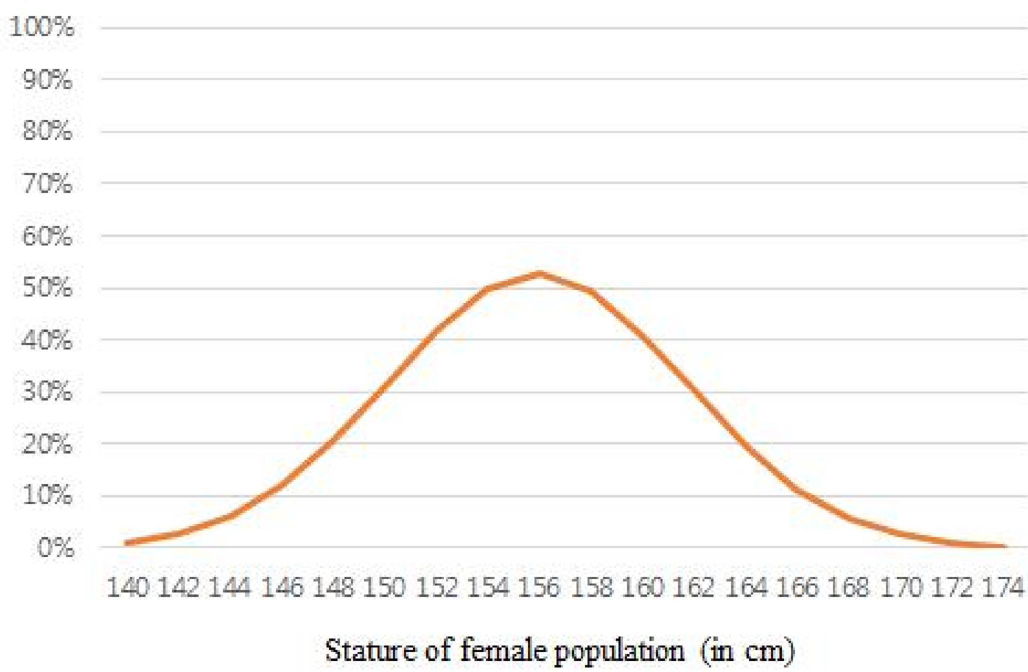


Figure 6.1. Restricted percent of female population depending on stature using FL

Chapter Ⅵ

Applying Measurement Data for User Interface

6.1 Case Study Ⅰ: Smartphone User Interface

6.1.1 Overview

Recently, many companies have attempted to develop better android user interface(UI) (Böhmer & Krüger, 2013). Unlike the Android is designed to be developed by there are already dozens of launchers which play important role in Android UI. Facebook has launched a "Facebook Home" in April last year, however, user satisfaction was low. The cause of that UI made without consideration users' usage pattern and ergonomic condition. Furthermore, the main function of the smartphone is calling, the calling function should be prioritized, however, the Facebook home no longer to call at the first depth of the screen and the buttons was placed in hard position to touch with one hand (Ackerman, 2013). Frequently used menus were also located in the upper position of the screen. This might users inconvenience. Thus, it is very urgent to identify how users touch the phone and understand how they use the screen because design interface induce user’s inconvenience.

In this study, we aim to analyze the physical characteristics of Korean users in touching screen and the be identified. Then, the will be verified by the actual app arrangement of mobile phone users in order to confirm that the area is frequently used in users screen.

6.1.2 Method

The flow of this study is as follows. i) The usage posture of smart phone was observed. ii) In order to identify the sweet spot for the phone screen touch, anthropometric dimension data of Korean people was utilized and subjective evaluation test on touching inconvenience was conducted. iii) The spot was compared with actual app arrangement locations in order to verify its validity.

6.1.2.1 Posture analysis

Mock-ups of android phone (4.3 inch) frequently used in South Korea were given to 40 users living in the metropolitan area, mainly using right hand, and having more than 3 years of experiencing smartphone. The users were than allowed to freely touch the 21 points often used in UI. The users were directed to conduct touching on the 21 points while holding the phone with the most frequently used grip when using only one hand. Identical task were conducted when using both hands. The grips of the users were shot while the location of the thumb touching the screen, the number of fingers holding the mobile phone, and the location of the right corner of the mobile phone were being identified. The postures of the users when using a single hand and both hands were examined and classified

Figure 6.1. Posture analysis when touching smart phone screen with one hand or both hand

6.1.2.2 Ergonomic analysis with hand anthropometry

Most of the mobile phone users use the one hand or both hands when they grip their mobile phone. Thus, it is important to identify the anthropometric dimension associated with the hand in order to find area that can be touched easily. According to the result of pilot test and expert interview, the length of thumb and thumb proximal phalange, thumb spreading angle were determined to be important dimensions. 300 subject's hand anthropometry data from the Size Korea project data was utilized (Table 6.1). The length of the thumb was defined by the distance from the proximal flexion crease of thumb to the tip of the thumb, and the length of the thumb proximal phalange was defined by the distance from the proximal interphalangeal joint crease to metacarpophalangeal joint crease of thumb (Figure 1). The subjective discomfort when touching smartphone screen was measured by utilzing smart phone mock up (4.3 inch). 40 subject who have been used smartphone for more than 3 years participated the evaluation test. The subjects were asked to touch randomly selected point among 21 points on the screen, then they evaluated discomfort with likert scale(1point : very easy to touch, 4point : normal, 7point: very hard to touch).

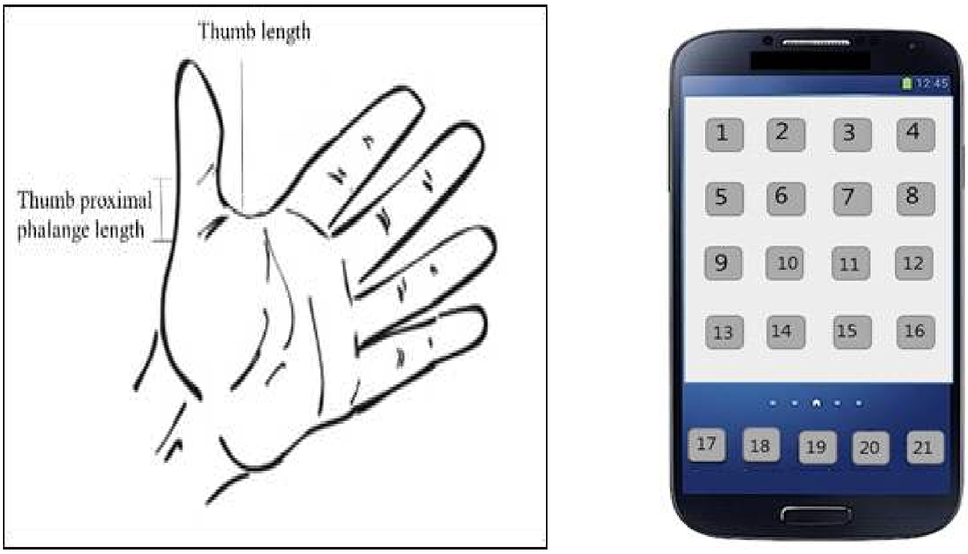


Figure 6.2. Anthropometric dimensions and smartphone mock up

6.1.2.3 User survey

Total of 80 participants using android phones and living in Seoul metropolitan area joined the survey. The age of participant varied from 15 to 55 years old. For convenience of the smartphone launcher users, the survey was conducted via a mobile Web pages. Prior to the survey (appendix), a full explanation of the launcher and purpose of the study was provided to the participants. Questions about usage pattern and frequently used apps were asked. Lastly, we asked the participants to upload a file of a captured screenshots of their home screen currently in use, then we analyzed them with heat map method in order to find out how sweet spot is used in actual users' screen. Microsoft Excel 2013 was used to create the heat map.

6.1.3 Results

6.1.3.1 Posture analysis

To identify how the users grip their mobile phones, pictures of 40 users' grip posture (one hand and both hand) were taken. The grips of the users were separated into two parts. First, using a lower grip when using a single hand, the users support the weight of the mobile phone with the little finger, holds the left edge of the mobile phone with the middle finger and the ring finger, locates the right corner of the mobile phone on the adductor pollicis, and the thumb locates on the bottom part. When conducting upper grip, the users held the right corner of the mobile phone by using four fingers, and located the right corner of the mobile phone on palmaris brevis. On the current research targeting the Korean users, distribution ratios of upper grip and lower grip were 67% and 33% each. In case of both hand usage, the posture with the lower corner of the phone contacting the adductor pollicis of right and left hand was most common(68%). Thus, these common posture was used for ergonomic analysis.

When they grip their phone with one hand, the posture with the lower right corner of the mobile phone contacting the adductor pollicis of right hand while touching screen by thumb, was the most frequent (62%).

6.1.3.2 Ergonomic analysis

The thumb-related dimensions derived from hand anthropometry data are listed in the following table. In the length of thumb and thumb phalange, the male's length was statistically and significantly greater than female's length. The length of the thumb was 67.4mm for 95th percentile male and 53.7mm for 5th percentile male. In case of female, it was 67.4mm and 50.6mm respectively.

Table 6.1. Anthropometric dimension for Korean users

Gender	**Percentile**	**TL**[a]	**TPL**[b]	**TSA**[c]
Male	5	53.7	23.5	47.0°
	95	67.4	34.8	79.5°
Female	5	50.6	23.0	44.0°
	95	61.6	32.0	76.0°
Pooled	5	51.1	23.2	44.5°
	95	66.0	34.3	79.5°

TL: Thumb length, TPL: Thumb proximal phalange length, TSA: Thumb spreading angle

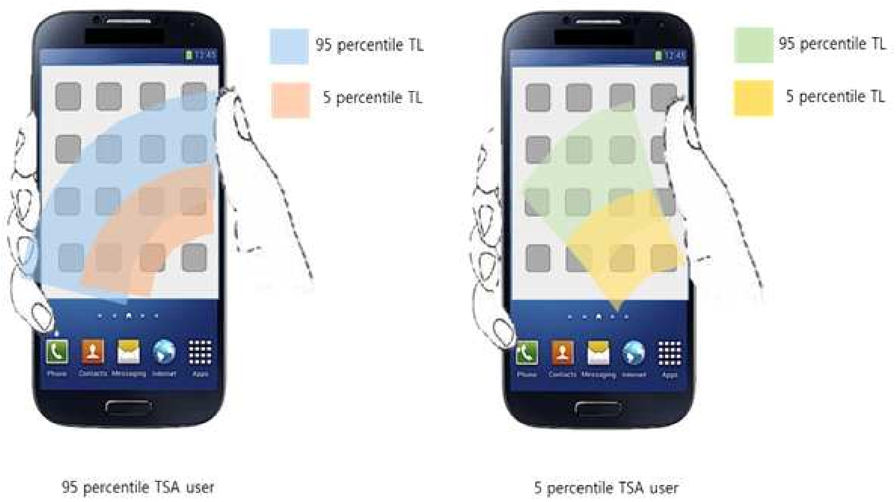


Figure 6.3. Upper grip Korean user's comfort touching zone

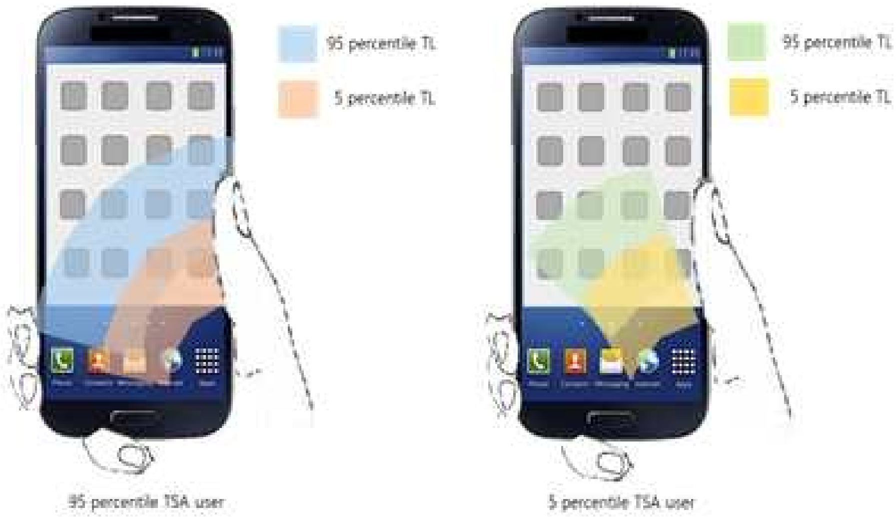


Figure 6.4. Lower grip Korean user's comfort touching zone

In order to investigate the sweet spot of Korean population, the dimension criteria of mobile phone refers to the one of the most prevalently used phone in Korea, Samsung Galaxy S3(4.3 inch). Among the touchable area for thumb, the lower part of the first interphalangeal joint is excluded because the joint should be bended more than 90 degrees (flexion) for thumb to reach the area, which could lead to muscle fatigue and inconvenience. In upper grip, blue and green-shade area is a touchable area for 95th percentile Korean users. In case of TSA and TL 95th percentile user, it was found that they could touch more than 8 positions when they grip the phone with one hand (Figure 2). On the other hand, in case of TSA and TL 5th percentile, it seems that they can touch only two positions without changing the grip. In upper grip, the users were hard to touch dock bar without changing grip posture. In lower grip, TSA and TL 95th percentile users can touch many positions located in lower and right corner of the screen. They can also touch dock bar without changing grip posture. Subjective discomfort was compared depending on line and column (4X4). By the result of ANOVA, significant difference was observed in 1st, 2nd, 3rd line (*p* vlaue <0.001). The discomfort of 1st lne shows higher discomfort compared to other lines(*p* vlaue <0.001). Regarding columns, the discomfort of 1st column were significantly different from that of 2nd column (*p* vlaue <0.05). The discomfort of 1st line and column shows the highest discomfort, but 3rd line and column shows the lowest discomfort.

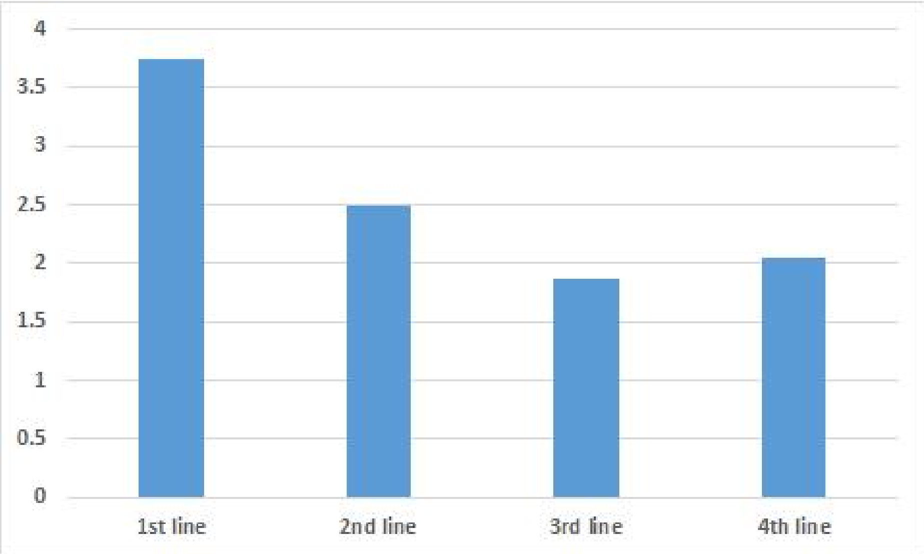


Figure 6.5. Subjective touching discomfort depending on line

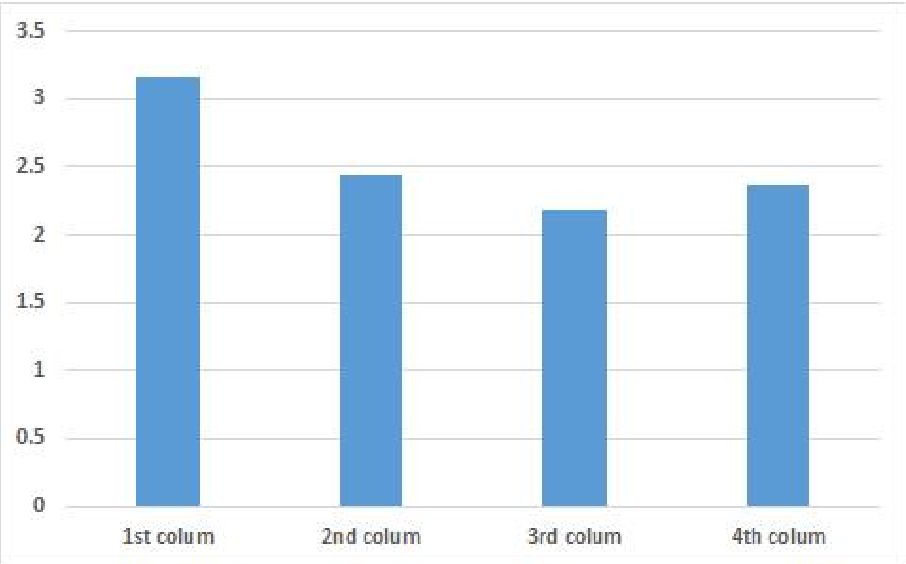


Figure 6.6. Subjective touching discomfort depending on column

Figure 6.7 Subjective discomfort rating comparison depending on the number of used hands

Figure 6.8 Subjective discomfort rating comparison depending on the grip types

Considering anthropometric properties of upper grip users and lower grip users, point number 15 (Middle of the screen) was the spot expected for easy touching with a single hand without changes in the wrist or grip of South Korean users.

ANOVA was conducted to understand the difference in discomforts in accordance with the grip pattern. There were statistically meaningful differences in point 1, 2, 3, 12, 15, 16, 17, 18, 19, and 20 between upper grip and lower grip. When analyzing with (P value<0.05) heat map, the upper grip users were discomforted mostly on the touching of the right edge of the home bar, and the lower grip users were discomforted mostly on the touching of upper-right part of the home bar.

ANOVA analysis for the discovery of the differences in discomforts with the usage of a single hand and both hands showed statistically meaningful difference at point 1, 2, 3, 5, 6, 9, 10, 13, and 17. (p value<0.05) The analysis using the heat map showed easy touching at the middle of the screen and the middle part of the home bar (Minimum 1 point, Maximum 6 points). Touching the middle and the left and the right side part of the screen became easy when using both hands. (Minimum 1.6 points, Maximum 4.4 points)

When using both hands, there were statistically meaningful differences at point 3 and 5 between upper grip and lower grip (P value<0.05). When analyzing heat map, the degree of discomforts from touching was lower than the case of the usage of a single hand in all areas. (Minimum 1.3, Maximum 3.8)

6.1.3.3 User survey

80 people of 2:1 male to female ratio responded to the questionnaires. The range of ages are 20's (44.9%), 30's (44.9%), 40s (6.1%) and 50's (4.1 %). The ratio of 20's and 30's were high because they are the primary

smartphone users. Participant's occupation ratio was followed: office workers (49.0%), housewives (38.8%), students (8.2 %), and others (4.1 %). The distribution of the duration of smartphone usage varies also. 21 of 50 people (41.8%) used their smartphone for less than a year, 3 people used theirs for 1-2 years (6.0 %), and 19 people (38.9%) used theirs more than three years.

Kakaotalk app (free messaging app) was most frequently used the app for smartphone users (63.3%), Facebook followed the next (14.3%) as the second. The tendency of placements for the most habitually used apps was anlayzed using heat map analysis (Figure 6.9).

It seems that users prefer to locate frequently used apps around a specific area (home button, the lower-left corner of the screen, lower right, right-center) to facilitate their touching action effortlessly. This tendency was consistent with the results of ergonomic analysis. However, user seldom placed frequently used apps in point 11. It is assumed that many users used photographs of landscapes and family wallpapers so they placed frequently used apps on the edge of the screen in order to allow full view of the landscape or face.

Figure 6.9. Frequency of placement of frequently used apps on the user’s smart phone home screen

Placement of frequently used apps in the lower left of the screen may be influenced by their mental model. User were accustomed to windows menu bar of PC located in lower left side of screen. Such mental model may affect them to place frequently used apps on lower left side. This phenomenon can be explained by using Fitts law. When frequently used apps were located on the center of screen, although touching with thumb may be easy, the reaction time to touch becomes slow because it needs accurate touch. Thus, users may place their frequently used apps on left side of lower part of screen because it enables them to touch apps quickly by reducing reaction time.

6.1.4. Discussion

Throughout this study, the easily touchable area, also known as sweet spot, for Korean people was derived by ergonomic analysis and the frequently used apps of Koreans were identified via a user survey. It was also confirmed that how users allocate and arrange their apps on mobile screens along with their personalization tendencies through analyzing the screen shots of mobile phones which users provided. According to the ergonomic analysis, it was noticeable that the number of apps which 5th percentile female could touch is merely 30% of what the 95th percentile male could. Therefore, when designing a mobile phone interface icons, the icons or buttons - which should be touched frequently, need to be located on the sweet spot, the easily touchable area (common part of the 5th percentile and the 95 percentile users touchable area) for users with various lengths of thumbs.

In this study, using a heat map, we analyzed where the users place their apps via a quantitative method. In case of the right handed users, the frequently used the app are mostly located in the lower center. This tendency was consistent with ergonomic analysis of this study, which is also similar to the studies of Kromer and Bomber (Böhmer & Bauer, 2010). They reported that the users place significant icons in the lower part of the screen. Respect to Karson's study (Böhmer & Bauer, 2010; Böhmer & Krüger, 2013), he reported that users can touch the central portion of the screen easily with minimal errors. So, we expected many users to place their frequently used apps on the spot. Although Karson's results (Karlson, Bederson, & Contreras-Vidal, 2006; Parhi, Karlson, & Bederson, 2006) were confirmed in Shin's or Fukazawa's results that more important icon is placed in the center and arranged in the bottom right order from the top left, users' favorite icons from this study was not in the center; the favorite icon allocations in this study disagreed their result (Fukazawa, Hara, Onogi, & Ueno, 2009; Shin, Hong, & Dey, 2012). Frequently used apps or icons were mainly placed in the lower center and the left side of the screen in particular. The reason why the users placed in this way may be affected by ergonomic convenience. Hence, it is determined to be located on the lower center of the screen.

Moreover, the frequently used apps seemed to be arranged on the left side, possibly due to the easier noticeability in case of new notifications on left side when considering the gaze path of the users.

Many of the users have their wallpaper, especially family photos, in landscape orientation so they place important or frequently used icons at the edge or corner of their mobile screens in order to maximize the full view of the landscape image. In Karson's research (Karlson et al., 2006; Parhi et al., 2006), the left and right corners of the screens were classified as the place where it is hard to touch and causes errors. However, many users placed their favorite apps in the corner of their screens for customization of their mobile screens.

Android UI guideline considering the physical convenience of the users was deducted from the result of the current research. First, in case of UI of the program mainly used by female users, it is good to place the frequently-used button on point 11, 12, and 15 on the lower right corner by considering the length of the thumb of the female users. Also, in case of UI of a program expecting frequent usage of a single hand, it is recommended to place the most frequently used button on point 7, 10, 11 and 15. In case of a program expecting frequently usage of both hands, user's convenience could be promoted by placing frequently used button on point 10, 11, 14, and 15. Moreover, in case of the usage of a single hand by the upper grip user, the location of a keyboard should be relocated, or new format of UI for upper grip user is required as the usage is discomforting from the positioning of the android keyboard at the home bar section of UI. In case of lower grip user, it is recommended to avoid the placement of main menus and buttons on the 1st line, and is recommended to place them on the lower section as the touching the 1st line section is discomforting. In case of home bar, it would be easier for the users to conduct touching if the frequently used buttons or applications are placed at the middle rather than at the edge of the right section.

6.2 Case Study Ⅱ : F-16 Cockpit

6.2.1 Overview

Republic of Korea Air Force is conducting operation by accepting various local weaponries, but for the aircrafts which are the core of the military strength of the air force, aircrafts manufactured in United States or Europe are mainly used (S.J. Lee, 1987). The cockpits of such aircrafts are designed to suit the body shape of westerners. The air force is conducting the selection process by setting the limit of height, sitting height, and weight when selecting pilots by reflecting design properties of imported aircrafts (Gregory Franklin Zehner, 2000; Gregory F Zehner & Oh, 1993). However, the design size of cockpit differs with the types of the imported aircrafts, and when considering that the physical properties of South Koreans vary from person to person, even the pilots with the body size suiting the current selection standard of the air force pilots would feel discomforts when piloting aircrafts (Gregory Franklin Zehner, 2000; Gregory F Zehner & Oh, 1993). For example, a pilot with a lower sitting height compared with the normal height may have a limit on the securement of sight from the low eye-level, and a pilot with short lower body might have problem operating full rudder or full brake requiring a piloting by applying strength at the tiptoe. Therefore, the current research tries to conduct research on the total percentage of the usage by current pilots of the air force without discomforts in the aspect of anthropometric design when considering the design size of the cockpit of F-16 aircraft which is the representative aircraft imported from United States and one of the main model of the current air force.

6.2.2 Method

6.2.2.1 Anthropometric Variables

To investigate the accommodation level of aircraft cockpit, anthropometric variables used in the investigation of accommodation level at the existing researches were collected (Gregory F Zehner & Oh, 1993). Also, identification on the core piloting devices and the controlling movements of the relevant controlling devices directly linked with safety at emergency situations and ground control was conducted through interviewing the pilots with more than 10 years of aviation career (Table 6.2).

Table 6.2. Participants of expert interview

Number	Gender	Career
1	Male	Instructor pilot, F-16 pilot for 11yrs
2	Male	Instructor pilot, F-16 pilot for 10yrs
3	Male	Instructor pilot, F-16 pilot for 10yrs
4	Male	Test pilot, F-4 pilot for 10yrs
5	Male	Test pilot, F-4 pilot for 7yrs
6	Male	4 Aircraft Leader, F-16 pilot for 6yrs
7	Male	4 Aircraft Leader, F-16 pilot for 6yrs
8	Male	Wingman, F-16 pilot for 3yrs
9	Male	F-16 Engineer, F-16 engineer for 12yrs
10	Female	Instructor pilot for 5yrs

The subjects of the measurement of 5 basic accommodations were selected through expert interview. Photos were taken on the piloting postures of pilots, and the controlling motion of core controlling device was also analyzed. T.O of the F-16 aircraft was referred for the design size of the aircraft.

Operating posture is different from person to person. In this study, emergency ejection postures and postures for enduring positive or adverse g force which were described in flight manuals were considered. The standard posture was derived with consideration of wearing G suit, locking of harness reels of shoulder and knee, which assume mobility of pilot on seat is limited.

6.2.2.2 Test sample

The current research used Size Korea's body measurement data as a test sample. The research selected 1,000 adult males and 200 adult females satisfying body standard (Height: 162.5cm ~ 195cm, maximum amount of weight per height, sitting height: 86.5cm ~ 101.5cm) used for the selection of pilots in the Republic of Korea Air Force among the adult males and females of a certain age group (25~50 yrs old) of current air force pilots.

6.2.3 Result

6.2.3.1 Anthropometric Variables

Through the postures reported from the existing researches and through the expert interview, 6 accommodation level measurement postures were selected (Table 6.3).

The first posture is the basic controlling posture for piloting an aircraft, and the posture may be hard for identification of other aircrafts within the major external obstacles and formation as the eye-level is located below the glare shield in case of a pilot with low height. The second posture concerns whether the hands of the pilot touch the switch within the cockpit or not. In case of a pilot with short arm, the pilot may feel discomforts in controlling the major switches. The third posture requires the usage of feet for controlling pedals when controlling rudder in the air or controlling full brake on the ground. In case of a pilot with short lower body, the pilot may feel discomforts from fully stepping on the rudder or brake, and the response speed may become slow. The fourth posture concerns whether the hands of the pilot touch the farthest point within the range of movement of throttle when the pilot controls the throttle for maximum output during take-off or flight in the cockpit. In case of a pilot with short arm length, the pilot may feel discomforts during flight as the posture has to be changed if the arm does not touch the point. The fifth posture is to confirm whether the pilot may turn his or her head from side to side while wearing a helmet for the confirmation of the aircrafts on the right and the left side within the formation by looking at the outside during flight. In case of a pilot with tall height, the pilot may undergo difficult situation from turning the head from side to side as the helmet touches the canopy. The sixth posture is to confirm whether the lower body of the pilot may safely get ejected or not during ejection. In case of a pilot with long lower body, the pilot may suffer injury as the knee part touches the cockpit structure during ejection (Gregory F Zehner & Oh, 1993).

Table 6.3. Anthropometric variable for F-16 Cockpit

No	Posture	Anthropometric variables
1	Basic operation posture	Sitting eye height
2	Basic operation posture (reach to switch)	Arm length
3	Rudder or brake control posture	Combo leg (Buttock knee length + sitting knee height)
4	Full throttle control posture	Half span(Arm length+chest breadth/2)
5	Turning head posture	Sitting height
6	Ejection posture	Buttock knee length

6.2.2.2 Test sample statistics

The descriptive statistics of anthropometric variable of the test sample used in the current research are as follows (Table 6.3 and 6.4).

In all variables, males were bigger in statistical manner than females (p value<0.05). The average height males were 172cm, and the average height of females were 165cm.

Table 6.4. Test sample statistics

Anthropometric Variables	Male		Female	
	Mean	SD	Mean	SD
Stature	172.4	5.1	165.1	2.4
Weight	73.6	10.3	57.4	7.4
Sitting eye height	82.1	2.8	77.9	1.8
Chest breadth	31.2	2.0	28.4	1.7
Arm length,	58.3	2.6	55.6	2.0
Buttock knee length	56.0	2.9	53.3	1.8
Sitting knee height	44.5	2.5	42.9	1.4

Table 6.5. The size range of anthropometric variables

Anthropometric Variables	Male			Female		
	Mean	**Max**	**Min**	**Mean**	**Max**	**Min**
Sitting eye height	82.1	90.4	73.2	77.9	83.0	74.6
Arm length	58.3	66.1	50.0	55.6	59.9	50.7
Combo leg	100.6	118.0	89.9	96.3	102.0	91.3
Half span	73.9	83.5	65.8	73.3	76.2	63.4
Sitting height	93.2	101.2	86.6	89.7	95.5	86.6
Buttock knee length	56.0	65.3	46.0	53.3	58.0	49.4

6.2.2.3 Accommodation percentage

In case of the first posture (Figure 6.10), the pilot may not see the exterior part of the cockpit and receives lower visual field through the glare shield when the eye-level of the pilot is below 75cm. This makes it hard for the pilot to identify nearby obstacles during landing or ground control, and may cause discomforts in identifying nearby aircrafts during formation flights. In case of the second posture (Figure 6.11), discomforts during flight may be caused as the pilot has to lean one’s upper body during the operation of various switches within the aircraft if the arm length of the pilot is shorter than 49cm.

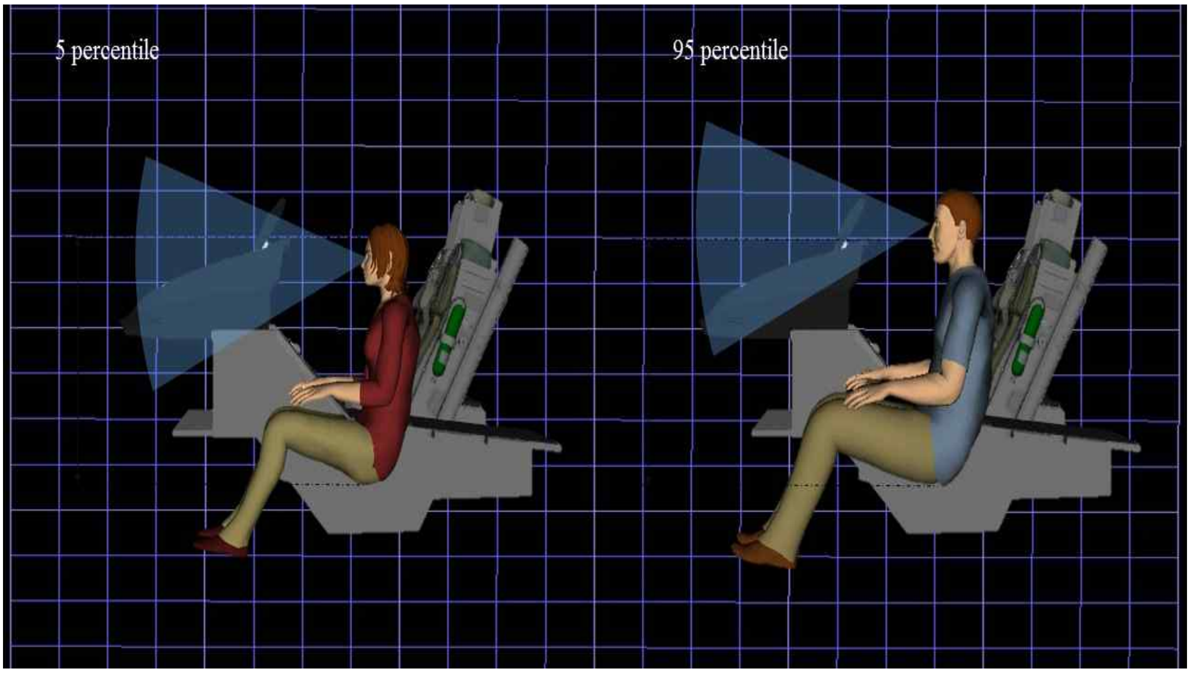


Figure 6.10. Posture 1 : sitting eye height (5 percentile vs 95 percentile)

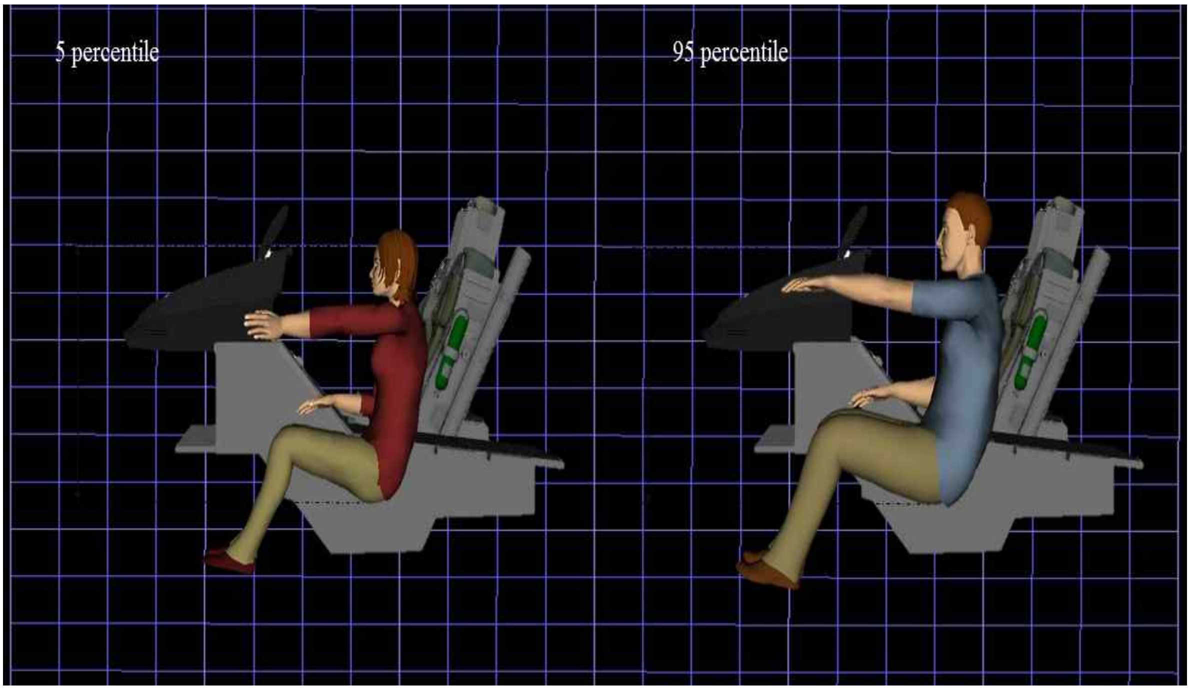


Figure 6.11. Posture 2 : arm length (5 percentile vs 95 percentile)

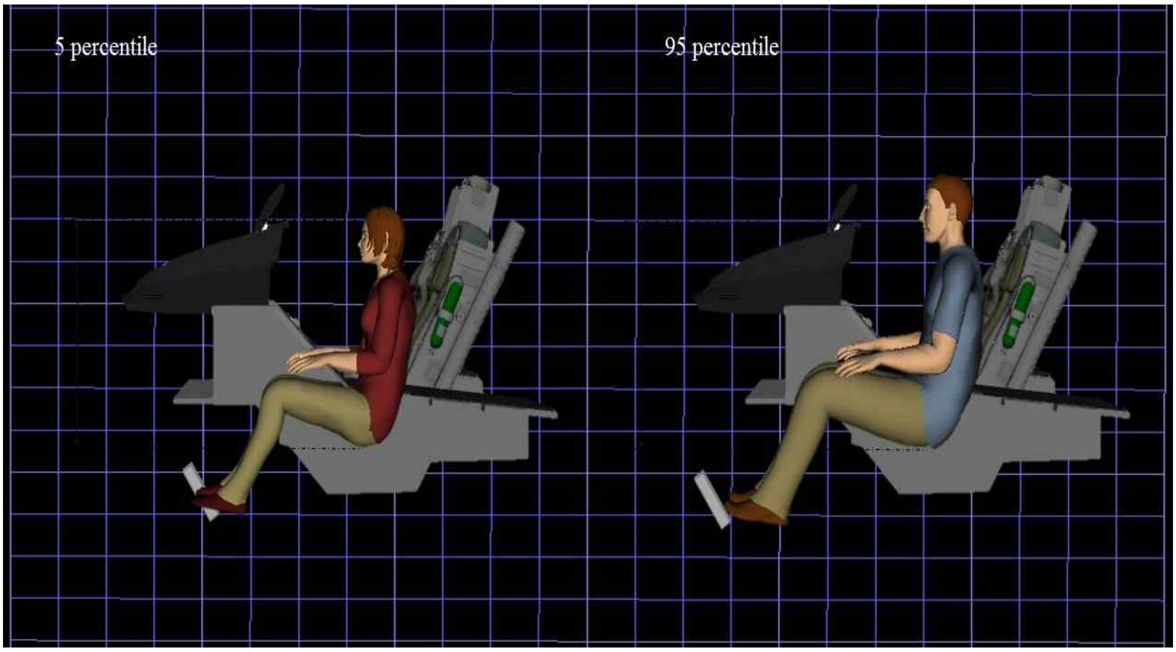


Figure 6.12. Posture 3 : combo leg (5 percentile vs 95 percentile)

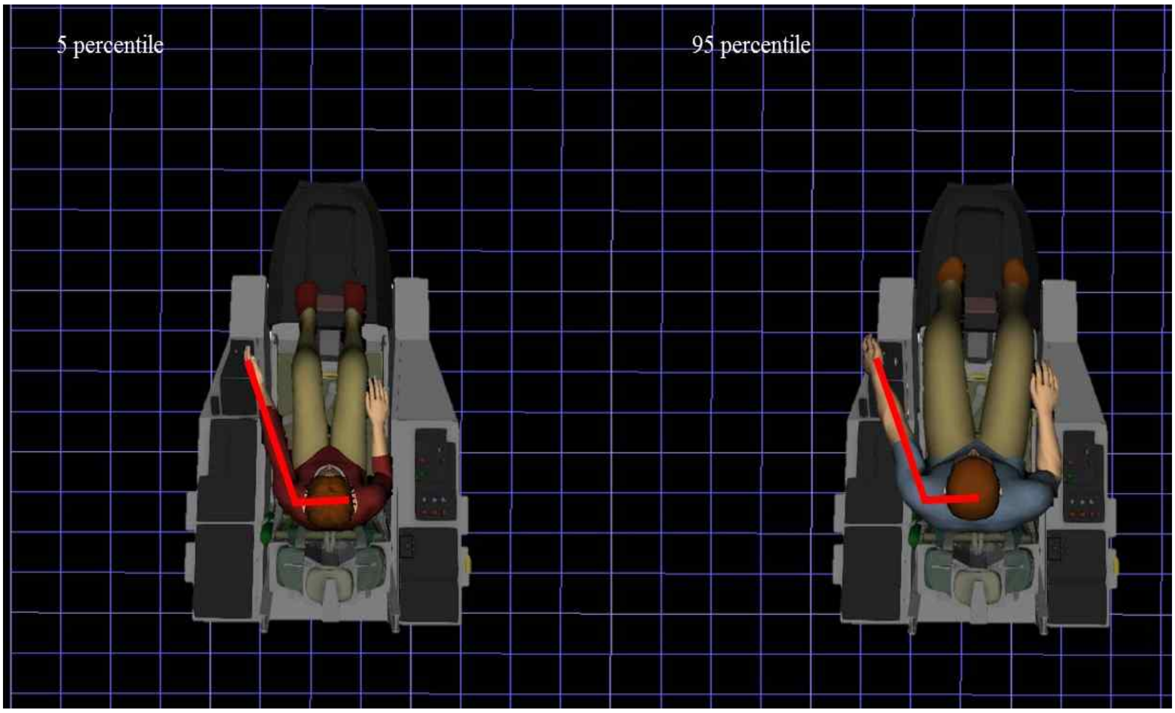


Figure 6.13. Posture 4 : half span (5 percentile vs 95 percentile)

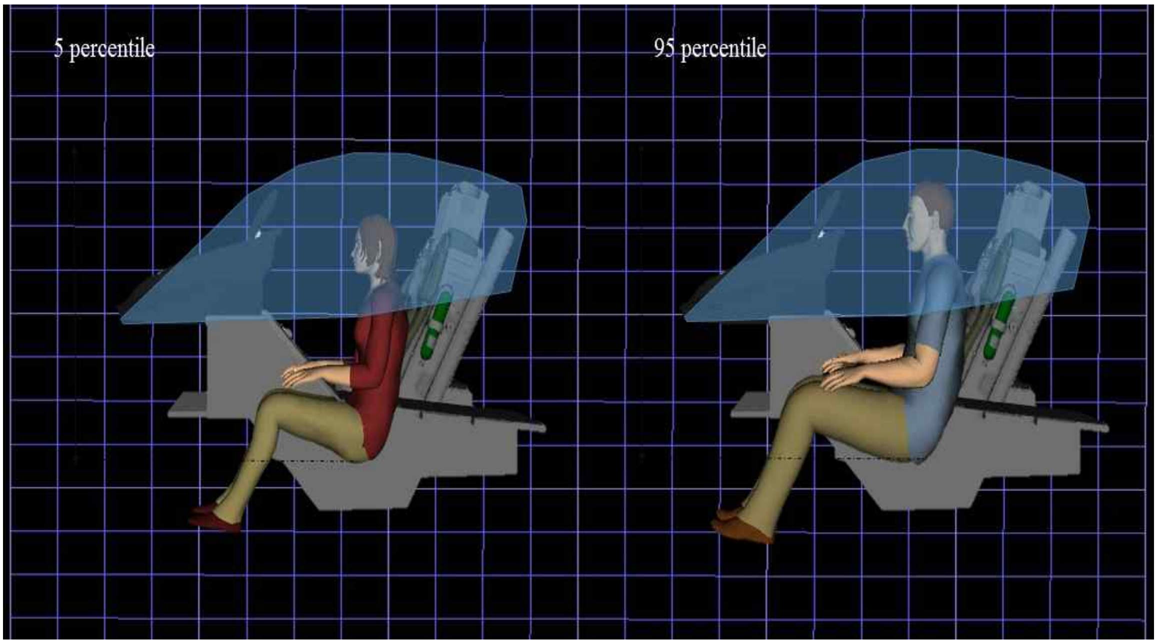


Figure 6.14. Posture 5 : sitting height (5 percentile vs 95 percentile)

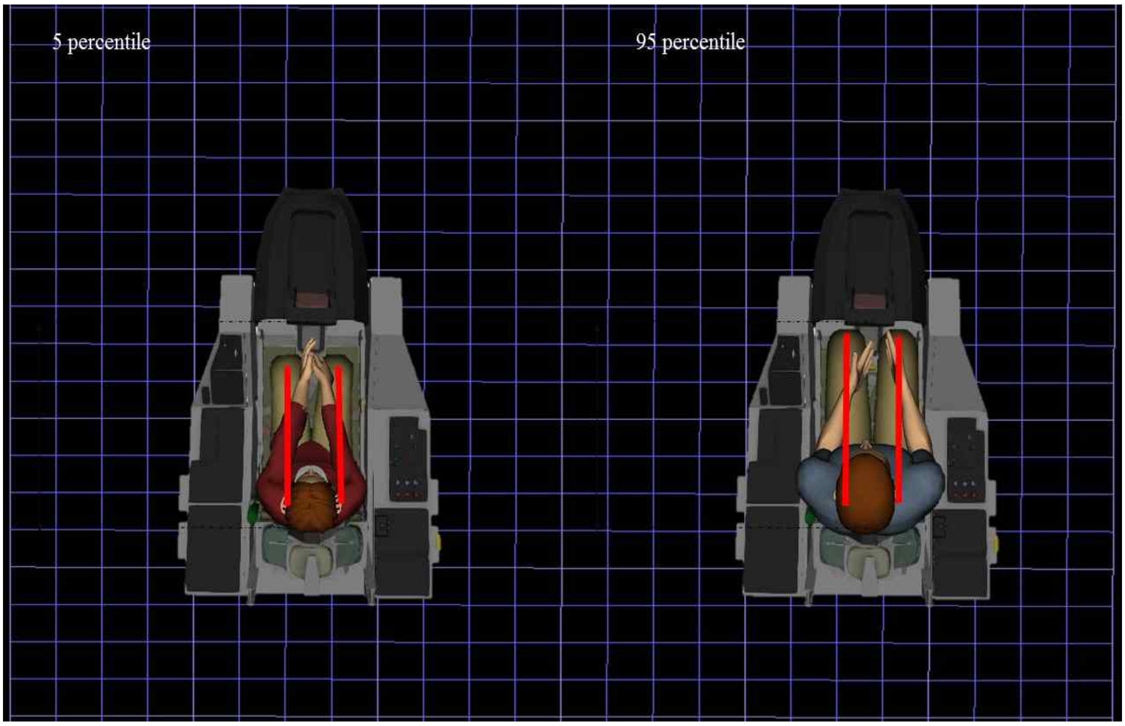


Figure 6.15. Posture 5 : buttock knee length (5 percentile vs 95 percentile)

Also, touching the switch may not be easy during an inverted flight or during receiving high level of acceleration gravity. In case of the third posture (Figure 6.12), maximum usage of the rudder pedal may be hard for the pilot as the heel touches the middle part of the pedal if the length of the lower body is shorter than 95cm in the sitting posture. Also, the pedal controlling time may increase. In case of the fourth posture, the pilot conducts full-throttle if maximum level of acceleration is required during take-off of flight. Allowing this required the hands of the pilot to touch the maximum point of throttle controlling range. Controlling could be conducted without discomforts if the half span (1/2 of the length of arm and width of chest) is longer than 60.5cm. In case of fifth posture (Figure 6.14), the aircraft safety regulation regulates that the prevention of bumping to the canopy during ejection can only be realized if the clearance between the upper part of the canopy and the upper part of the helmet is more than 8cm. Therefore, maintenance of head to canopy clearance when wearing a helmet, and free rotation of head can be achieved only if the sitting height of the pilot is lower than 100.8cm when considering the thickness of the helmet (1.9cm). In case of the sixth posture (Figure 6.15), the knee of the pilot may suffer injury from touching the structure of the cockpit during ejection if the buttock knew length of the pilot is bigger than 68.8cm. Therefore, the buttock knew length of pilots should be smaller than 68.8cm for the prevention of such injuries.

The research analyzed how many percentages of the test sample personnel satisfied the accommodation standards determined above by using the test sample data (Table 6.6). In case of the first posture, 95% of the males and 90% of the females satisfied the standard, and analyzed that 10% of the female pilots with small sitting height would have difficulties in securing the visual field. In case of the second posture, males and females both satisfied 100%, and analyzed that there will be no big discomforts in touching the controlling button for both genders. In case of the third posture, it was analyzed that 11.6% of the male pilots and 27.5% of the female pilots with short lower body would feel discomforts in controlling the rudder pedal or brake pedal. In case of the fourth posture, it was analyzed that the male pilots and female pilots would feel no discomforts in using the throttle from the minimum point to the maximum point. In case of fifth posture, 1 subjects among 1,000 male test samples seem to have concerns over the freedom of the rotation of the head as the head touches the canopy. In case of the sixth posture, both genders seemed to have enough clearance for ejection without injuries on the lower body during ejection.

Table 6.6. Accommodation limit and percentage of each posture

Postures	Male		Female	
	Limit	**Accommodation**	**Limit**	**Accommodation**
Basic operation posture 1	>76.0cm	95.0%	>76.0cm	90.0%
Basic operation posture 2	>49cm	100%	>49cm	100%
Rudder control posture	>95.0cm	88.4%	>95.0cm	72.5%
Full throttle control posture	>60.5cm	100%	>60.5cm	100%
Turning head posture	<100.8cm	99.9%	<100.8cm	100%
Ejection posture	<68.8cm	100%	<68.8cm	100%

6.2.4 Discussion

The purpose of the current research was to understand the degree of potential discomforts of South Koreans who have different physical properties than the westerners when the South Korean pilots use the aircrafts produced while suiting the body type of westerners The above mentioned result of the research was able to conduct comparison (Table 6.7) with the accommodation level research case of F-16 on the United States pilots conducted by Zehner (Gregory F Zehner & Oh, 1993).

Table 6.7. Comparison with US pilot population

Postures	Korean			U.S.A		
	Limit	Accommodation		Limit	Accommodation	
		Male	Female		Male	Female
Basic operation posture 1	>76.0cm	95.0%	90%	>76.0cm	87.6%	65.6%
Basic operation posture 2	>49cm	100%	100%	>49cm	100%	100%
Rudder control posture	>95.0cm	88.4%	72.5%	>95.0cm	100%	100%
Full throttle control posture	>60.5cm	100%	100%	>60.5cm	100%	100%
Turning head posture	<100.8cm	99.9%	100%	<100.8cm	99.8%	100%
Ejection posture	<68.8cm	100%	100%	<68.8cm	100%	100%

After confirming the accommodation level on the 6 different postures of F-16 aircraft conducted in South Korea and United States, South Korean pilots showed higher level of accommodation level at first posture than the United States pilot group. This can be understood from the properties of South Koreans having higher ratio on the upper body among the body ratio compared with the westerners. It seems that the pilots do not feel discomforts from the posture number 2, 4, and 5 as the pilots from both nations showed 100% of accommodation level. However, in case of posture 3, the Unites States pilots all had 100% accommodation level whereas the accommodation level of South Korean group had 88.4% and 100% contrasting to the United States pilot group. The cause of the difference seems to come from the small lower-body ratio in comparison with the height of South Koreans when comparing with the U.S. citizens. Therefore, engineered improvement is required for the removal the discomforts from the operation of rudder by pilots with short lower body. The pilots may feel less discomforting if a mechanical system of a pedal is improved for the placement of the pedal or the rudder within the cockpit, or if a method allowing the touching of the legs through the placement of foothold is suggested

6.3 Case Study Ⅲ : K-2 Rifle Control Unit

6.2.1 Overview

K-2 rifle is most frequently used in the Korea military. The rifle was produced from 1982, most widely distributed, and used in many troops of the army, navy, and air force. K-2 rifle was designed while considering the body size of the South Korean male of 1970s, and was used without big discomforts for decades. However, with the females' enlistment increased recently, and the westernization of the body type of South Koreans, the users with various hand sizes started to operate K-2 rifle. Various discomforts may arise from the situation (Aghazadeh & Mital, 1987; Meagher, 1987; Sekulova et al., 2015). For example, some female soldiers with short hand length or short finger may have discomforts of bending the wrist or re-grasping the grip as the hand does not touch the control button of the rifle. Therefore, the current research evaluates whether the control part of the K-2 rifle currently used in the military may be used without discomforts or not in the aspect of ergonomic aspect when considering recent body size of the soldiers of Korea military, and tries to estimate the accommodation level.

6.3.3.1 Anthropometric variable

To investigate the accommodation level of the interface of K-2 rife, anthropometric variable used in the investigation of accommodation level/evaluation of interface was collected from existing researches (Table 6.8, and Figure 6.17). Through interviews with experts having rich experience in shooting K-2 rifle, discomforting points about the K-2 were collected, and the order of shooting the K-2 rifle, and the information on commonly-used hand gestures were also collected. Test sample data set was same to that of section 3.1 (Table 6.7)

Table 6.8. Participants of expert interview

Number	Gender	Career
1	Male	Shooting instructor for 10yrs in military
2	Male	Shooting instructor for 5yrs in military
3	Male	Shooting experience for 6yrs in military
4	Female	Master's degree in ergonomics, shooting experience for 10yrs
5	Male	Master's degree in ergonomics, shooting experience for 8yrs
6	Male	Shooting experience for 5yrs in military

Figure 6.17. K-2 rifle control unit

3.3.2 Application of representative hand manikins

To confirm whether the interface of the controlling part of the K-2 rifle may accommodate 95% of adult Koreans or not, hand manikin deducted from Chapter 3 which accommodates 95% of Koreans was applied. By using Jack which is visual ergonomic program, 9 hand manikins representing the hands of Koreans are produced. The manikins are to be gripped with 3D model of K-2 rife, and identified whether the control units like trigger touch the finger or button, or create collision during operation or not.

6.3.4 Result

Through the controlling part of the rifle studied on the existing researches and expert interviews, accommodation levels on 5 control units were measured. The first trigger guard prevents accidental discharge by protecting the trigger. The second trigger is the lever allowing the shooting, and is controlled by the index finger of the right hand. The third selector lever is a lever for the conversion of the safety selector lever into safe or auto, and is controlled by the thumb of the left hand. The fourth MRB (magazine release button) is a button used for the removal of magazine, and is controlled by pressing with a thumb. The fifth handle is a part for gripping the gun, and the handle is gripped with the middle finger, ring finger, and little finger.

6.3.4.1 Test sample statistic

The descriptive statistic of anthropometric variable used in the current research is as follows.

Table 6.9. Test sample statistic

Anthropometric Variables	Male			Female		
	Mean(SD)	Min	Max	Mean(SD)	Min	Max
Thumb finger length	61.2(3.9)	49.5	72.4	56.0(3.4)	45.8	64.4
Index finger length	70.4(4.3)	55.4	81.8	66.2(4.2)	55.8	75.2
Hand breadth	85.9(4.1)	74.6	95.7	78.0(3.9)	70.3	88.3
Center of wrist to root digit 2	113.1(5.6)	97.2	128.8	104.8(5.2)	90.0	122.9

Table 6.10. 5 percentile and 95 percentile value of anthropometric dimensions

Gender	Variable	Percentile	Size (mm)
Male	Thumb finger length	5	53.3
		95	67.5
	Index finger length	5	63.6
		95	78.5
	Hand breadth	5	78.6
		95	92.3
	Center of wrist to root digit 2	5	103.2
		95	121.8
Female	Thumb finger length	5	50.5
		95	61.6
	Index finger length	5	58.5
		95	73.6
	Hand breadth	5	71.6
		95	86.1
	Center of wrist to root digit 2	5	95.8
		95	113.6

Table 6.11. Anthropometric variables used for this research

No	Control unit	Anthropometric variables
1	Triger guard	Index finger length+ Center of wrist to root digit 2
2	Triger	Index finger length+ Center of wrist to root digit 2
3	Selector level	Thumb finger length
4	MRB	Index finger length+ Center of wrist to root digit 2
5	Handle length	Hand breadth

6.3.4.2 Accommodation analysis with representative manikins

The result of the analysis on the accommodation level by using manikin family showed that the k-2 rifle does not accommodate 95% of South Koreans (Table 6.12). In case of manikin number 1, 2, and 3, the collision of trigger guard and the thumb was observed as the thumb was long. Also, as the hand breath was longer than the length of the handle, some fingers deviated from the grip. Thus, the strength of the grip got weaker, and discomforts aroused from the circumstance. In case of manikin number 4, 7, and 8, the manikins represented the users with short length of hands or short fingers. Discomforts are expected as the users have to bend their wrists or hold the grip again for touching MRB when rapidly replacing the magazine as MRB does not touch the thumb. When judging based on the above result, it seems that 95% of the South Korean users cannot use the controlling part of the K-2 rifle without discomforts.

Table 6.12 Accommodation test result using hand manikins

No.	Triger guard	Triger	Selector level	MRB	Handle length
1	*	O	O	O	Δ
2	*	O	O	O	Δ
3	*	O	O	O	Δ
4	O	O	O	X	O
5	*	O	O	O	O
6	O	O	O	O	O
7	O	O	O	X	O
8	O	X	O	X	O
9	O	O	O	O	O

MRB : Magazine release button

Nomenclature
O: Fingers reach on control unit or grip handle easily
Δ: Fingers reach on control unit or grip handle with difficulties
X: Finger does not reaches on button or control unit
*: Collision happens when pressing trigger

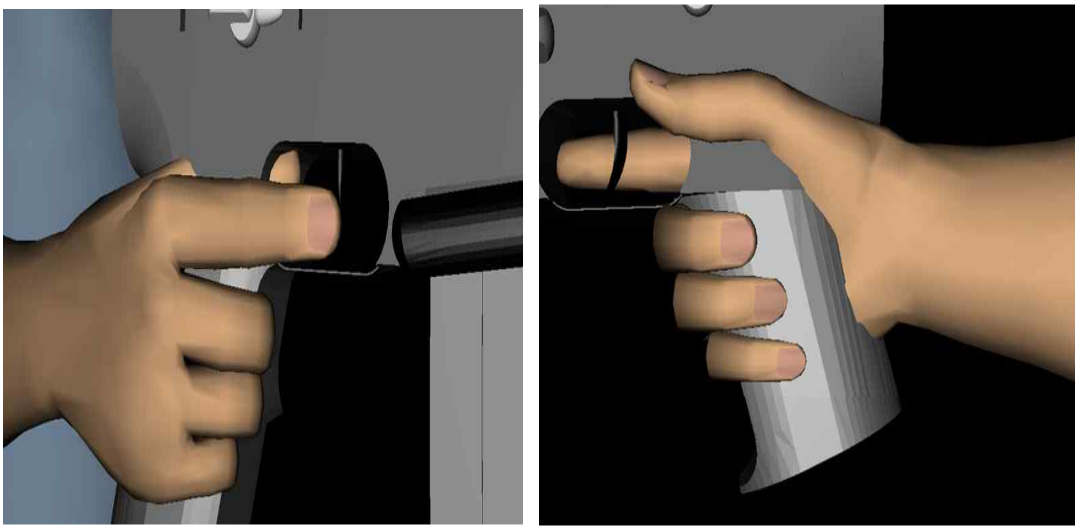


Figure 6.18. Accommodation test using visual modeling software(JACK)

6.3.4.3 Accommodation percentage

Accommodation level of K-2 rifle is shown in Table 6.13. In case of trigger guard, collision of the index finger and the trigger guard is expected when controlling the trigger if the length from the index finger and the center of the wrist to the thumb root is more than 185mm. It is estimated that 60.5% of male, and 94.2% of female will use without discomforts. In order for the trigger to touch the finger, the length from the index finger and the center of the wrist to the index finger route should be over 143mm. Males showed 100% of accommodation percentage while it was estimated that about 0.9% of females will not be able to touch trigger in neutral wirst position. Selector level can only be touched if the length of the thumb is more than 40mm, and 100% of both genders were accommodated. In case of MRB, touching MRB without change in wrist or grip posture is possible only when the length from the index finger and the center of the wrist to the index finger route is over 175mm. 82.6% of male, and 27.9% of female were accommodated. Some fingers deviate from the grip when gripping if the handle length is over 90m, and it was estimated that about 15.6% of the males with huge hand width would undergo such discomforts.

Table 6.13. Accommodation level of K-2 rifle control unit

Postures	Male		Female	
	Limit	Accommodation	Limit	Accommodation
Trigger guard	<185mm	60.5%	<185mm	94.2%
Trigger	>143mm	100%	>143mm	99.1%
Selector level	>40mm	100%	>40mm	100%
MRB	>175mm	82.6%	>175mm	27.9%
Handle length	<90mm	84.4%	<90mm	100%

6.3.4.4 Discussion

The purpose of the research is to estimate the level of usage without discomforts by South Koreans considering the controlling part of the K-2 rifle currently used in the military and the size of the hands of South Koreans. In case of national defense weaponry system, the accommodation research considering anthropometric dimension lacked, and there were only few research cases. However, the research was able to compare with the firearm ergonomic analysis conducted by Sekulova (Sekulova, 2015). Sekulova used the hand length and hand breadth of the Germans, South Koreans, and U.S. citizens for the estimation of the accommodation of rifles to produce new rifle of Czech. The research analyzed that the touching on the blot catch would cause discomforts if the South Koreans show 5 percentile. The research was conducted targeting K-2 rifle. In case of K-2 rifle, the MRB switch was designed to be far away from the trigger, and it was estimated that the touching would be hard for 72.1% of females. The current research estimated that the discomforts from the collision between the index finger and the trigger guard from the trigger guard would be big in case of male under the comparison between two genders. In case of females, it was estimated that the discomforts would be big as the index finger does not touch the MRB switch. Therefore, when producing Korean-type rifle, the controlling part of the rifle should be designed for the female soldiers with short hand length and finger to touch the MRB with ease by designing the location of the MRB to be closer to the trigger while designing the length of the trigger guard to be longer by considering the length of hand an finger of South Korean males.

Moreover, the current research analyzed and evaluated the accommodation level by using hand manikin on the controlling part of K-2 rifle. By using hand manikin, average hand length, hand width, and sizes of other hand parts used in the evaluation of usability were reflected, and provided strength of rapid judgment over the accommodation level of weaponry system. Especially, when using with visual modeling programs including JACK, it was useful as the analysis on the user’s posture, distance to the controlling part, level of reach, and eye direction of the user could be conducted within a single screen.

People with various body types and body sizes are entering the Korean military from the recent increase in the number of female soldiers, westernization of the body size of Koreans, and increase in the number of enlistment of children of various ethnic groups. However, as the existing weaponries are used without change, discomforts from using the weaponry system is increasing. To response to such changes, it is required to recognize the importance of anthropometric design process previously neglected during the development of weaponry system, and design the weaponry system by reflecting the process.

Chapter Ⅶ

Discussion and Conclusion

7.1 Summary of Finding

This study described an identification of Korean physical characteristics, development for estimation model, and evaluation of user interface. Through, this study, the proposed sex, stature, weight estimation models using various hand or foot dimension, which to the best of my knowledge is the first attempt at Korean forensic anthropometry. The proposed models were validated by comparing to other nationalities cases. Summary of findings can be described into three main points.

First, physical properties of hands and feet of South Koreans were identified. Major factors determining the shape of South Koreans (Width of hand, length of palm, and length of fingers) were identified, and classified the hand shapes into four types. Compared to other ethnic groups, the research identified that the males and females of South Koreans have wider hand width than other ethnic groups. Moreover, representative hand manikin size accommodating 95% of South Koreans was deducted by using boundary condition method. In case of feet, major factors determining the shape of feet of Koreans (foot length, foot breadth, foot height) were identified by analyzing feet size data of Korean peopole, and four clusters were identified by using cluster analysis. Also, feet manikin size representing the 95% of the feet size of Koreans was deducted.

Second, Human properties(sex, stature, weight) estimation models using hand or foot dimensions were developed. This research determined sex by using discriminant analysis on 29 diversified hand parts. Highest level of accuracy was shown when using the maximum hand circumference, and variables related with width and circumference showed higher estimation accuracy than the length. Feet dimensions also were utilized to estimate the gender by using discriminant analysis, and navicular circumference showed the highest estimation accuracy (86.2%). In case of stature estimation model, stature was estimated by using linear regression model using the hand or foot parts with high relevance with stature. Hand length showed the highest level of accuracy R^2(male : 0.678, female : 0.534). Among various parts of feet, feet length showed the highest level or accuracy, and for the R^2 (male : 0.567, female : 0.188). The weight estimation model has developed using the circumference of 9 parts of the hands, feet and upper or lower body. The level of accuracy was the highest when using the breast circumference (R^2=0.742).

Third, ergonomic evaluation on the interface of smart phone, F-16 aircraft cockpit, and K-2 rifle was conducted by using measurement data of hands and feet. In smart phone case study, the holding grips of the users were separated into two parts (upper and lower grip). The distribution ratios of upper grip and lower grip were 67% and 33% each. Considering Korean people's hand size, the center of the screen was the most comfort area for touching screen. The upper grip users were discomforted mostly on the touching of the right edge of the home bar, and the lower grip users were discomforted mostly on the touching of upper-right part of the home bar.

For F-16 cockpit case study, the evaluation was conducted to find out whether the Korean pilots may use the cockpit without discomforts for 6 major piloting postures, and it was expected that the discomforts may arise as 11.6 % of the male pilots and 27.5% of the female pilots could not operate full brake/rudder with their feet or had to additionally change postures for their feet to operate the full brake/rudder.

In case of K-2 rifle interface, 9 hand manikins was utilized to evaluate accommodation level of K-2 rifle control unit. It was expected that 39.6% of the males would have collision of finger on the trigger guard when controlling the trigger as they have long finger. In case of 72.1% female soldiers, it was expected that they would feel discomforts as the index finger does not touch the switch on the controlling part of the rifle.

7.2 Contribution

The current research was able to make several major contributions in theoretical and practical aspects.

First, the research identified the key factors determining the properties of hands and feet of South Koreans, compared the factors with other ethnic groups, and identified the properties of hands and feet of South Koreans. Hand and foot manikin deducted from the reflection could be used for basic material in designing the products for easier usage by South Koreans when producing hand tool, handle, shoes, and pedal.

Second, the current research expanded the area of hand and foot anthropometry research focused on the product development within the industry, and allowed the usage of body measured value in forensic area and emergency medical science area. Anthropometry researches of forensic area are active and vibrant in foreign settings, but there were only few researches in South Korea using the body measured data. Therefore, the current research used the body measured data and deducted a research result usable in forensics and emergency medical science. Deducted sex separation indicators, height and weight estimation models may be used to understand the identity of estimated person in the field of forensics and emergency medical science, or used for precise estimation of the weight of emergency patients.

Third, the current research evaluated the interface of the current national defense weaponry system by using the South Korean’s body measured data in the anthropometric design process perspective, and deducted improvements for the designing of more comfortable interface for South Koreans. The methods and improvements used in the current research may be used for advanced research and reference when developing or adopting future national defense weaponry system.

7.3 Limitation and Further Research

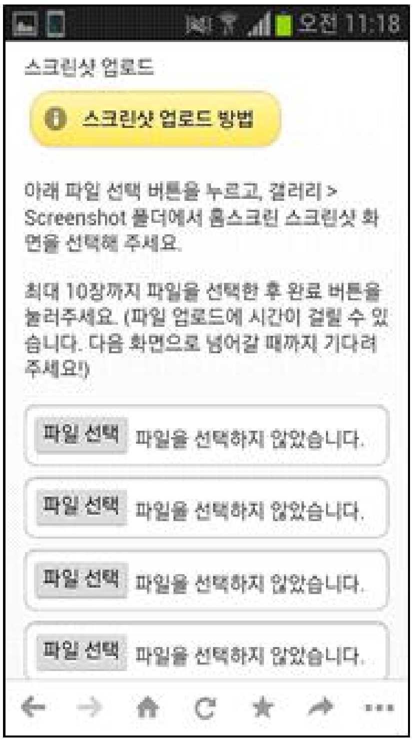
There are several limitations in the current research, and the limitations are as follows.

First, the current research mainly evaluated the product in the anthropometric aspect. For example, when evaluating the smartphone, UI, aircraft seat, and the controlling part of a gun in the case study, the interface was evaluated by only having the usability of the touch while considering the size of the touching body part. However, other elements including the error rate and performance time had to be evaluated while the interface had to be easy for touching (Sanders & McCormick, 1987). For example, even if the touching a certain part of a smartphone is easy, particular caution is required when using the relevant part if the error rate is high when conducting touch. Therefore, the current research evaluated the interface by using the fulfillment of the body size. However, for more objective interface evaluation, other usability elements other than comfortable touching considering body size has to be considered for comprehensive judgment.

Second, the research only considered the static size of hands and feet. However, hand and feet have various movements as the freedom is bigger than other body parts. The properties may provide differences in the size of hands and feet parts in accordance with posture. The research could not cover the differences in the dynamic changes of hand and feet size. Therefore, future researches shall consider the dynamic changes in the size of parts of hands, measure the sizes under various movements, and develop estimation model using the measurement.

Appendix

Web questionaries



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국문초록

인간은 손과 발을 사용하여, 인터페이스를 조작하며, 이를 통해 기계를 인간의 의도대로 조작하거나 각종 도구들을 사용하게 된다. 따라서 인간이 사용하기 편한 인터페이스를 설계하기 위해서는 손과 발에 대한 치수정보에 기초한 제품과 시스템 설계가 중요하다. 또한 손과 발은 많은 근육, 뼈, 관절로 구성되어 다양한 치수정보를 제공해주는데 이러한 정보는 인터페이스 설계 뿐만 아니라 법의학, 응급의학 분야에서도 폭 넓게 이용되고 있다.

본 연구의 목적은 한국인의 손과 발의 신체적 특성을 식별하고, 손과 발의 치수 정보를 이용하여 성, 신장, 무게 같은 인체 특성을 추정하는 모델을 개발하는 것이다. 또한 이러한 인체 특성과 인체 측정치를 실제 우리 생활에서 자주 사용되는 인터페이스 (전자제품, 국방 무기체계_에 적용하여 제품이 어느 정도의 사용자들이 불편함 없이 사용할 수 있는지 평가하고 예측하는 것이다.

첫째, PhaseⅠ에서는 한국인 손과 발의 신체적 특징을 파악하였다. 사이즈코리아에서 제공받은 성인 321명의 손 치수 정보로부터 한국인 손의 형상을 결정짓는 주요 인자 (손 너비, 손바닥 길이, 손가락 길이)를 식별하고, 한국인 손의 형상을 네가지로 분류하였다. 타민족과 비교시 한국인은 타민족에 비해 남성 여성 모두 손 너비가 넓은 특징을 식별하였다. 또한 Boundary condition method를 이용하여 한국인 95%를 수용할 수 있는 대표 손 마네킨 치수를 도출하였다. 발의 경우에도 461명의 발 치수 데이터를 분석하여 한국인 발의 형상을 결정하는 주요 인자(발길이, 발너비, 발 높이)를 식별하고 군집분석을 이용하여 네가지 군집을 식별하였다. 또한 한국인 95%의 발 치수를 대표할 수 있는 발 마네킨 치수를 도출하였다.

둘째, PhaseⅡ에서는 신체 측정치를 이용하여 성, 신장, 무게를 예측하는 통계적 모델을 개발하였다. 손에서 측정할 수 있는 29개의 측정 변수에 대해 판별 분석을 이용하여 남녀로 구분하였다. 최대 손둘레 이용

시에 가장 높은 정확도를 보였으며, 길이 보다는 너비, 두레 관련 변수의 예측정확도가 높았다. 발 역시 10개의 발 부위 치수 정보를 이용하여 판별분석을 이용하여 성별을 예측하였으며 발등에서의 둘레 (Navicular circumference)가 가장 높은 예측 정확도(86.2%)를 나타냈다. 신장 예측은 손과 발의 여러 부위중 키와 상관이 높은 부위들을 이용하여 회귀분석을 사용하여 신장이 예측되었다. 남녀모두 손길이 이용시 가장 정확도가 높았으며 회귀식의 R^2는 남성은 0.678, 여성은 0.534였다. 발의 여러 부위들 중에는 발길이가 가장 높은 정확도를 나타내었으며, R^2는 남성은 0.567, 여성은 0.188의 정확도를 나타냈다. 무게예측 모델은 손, 발 및 몸통의 9개 부위 둘레 길이를 이용하여 회귀 분석을 사용하여 모델을 개발하였다. 가슴둘레 이용시에 가장 정확도가 높았다. ($R^2 = 0.742$)

셋째, Phase III에서는 Phase I 의 결과와 손과 발의 측정치를 이용하여 스마트폰, F-16 항공기 좌석, K-2 소총의 인터페이스에 대한 인간공학적 평가를 실시하였다. 주로 anthropometric 관점에서 4.3인치 안드로이드 스마트폰에서 주로 사용되는 21개 UI 지점에 대하여 불편도를 평가하고, 신체치수를 고려시 터치하기 쉬운 지점들을 식별하였다. F-16 cockpit에서는 6개의 주요 조종 자세에 대해 한국인 조종사들이 불편감 없이 사용할 수 있는지를 평가하였고 남성 조종사중 11.6%, 여성 조종사중 27.5%가 full brake 사용시에 발이 닿지 않거나 발을 닿기 위해 추가로 자세를 변화 시켜야 하므로, 불편함을 겪을 것으로 예상되었다.

본 연구결과는 향후 한국인을 위한 인터페이스 설계시 연구자와 엔지니어에게 도움을 줄 수 있을 것으로 기대한다. 본 연구에서 이용된 통계적 방법들과 분석도구들은 본 연구에서 평가된 스마트폰, 항공기, 총 이외에도 다른 제품과 시스템의 인터페이스를 평가하고 개선하는 데에도 활용 될 수 있을 것이다.