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An anthropometric survey of Korean hand and hand shape types

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ABSTRACT

Some tools or interfaces designed not to fit the size of individuals make users experience discomfort and lower productivity. Previous studies on hands tend to focus only on measuring lengths of various hand parts and reporting the distribution of these measurements. In order to overcome this, we aim to distinguish major factors that determine hand shapes and categorize the hand shapes of Koreans. 321 people (167 males and 154 females) enrolled as subjects of this study by their own will. 21 hand dimensions including length, breadth, and circumference of the hand were measured. T-value and correlation coefficients were compared to identify the difference of measurement values and the relation between hand measurements and heights. Factor and cluster analysis was conducted to identify hand shape types of Korean. Descriptive statistics of Korean hand dimension were presented. 78.3% of the variance of hand shape was explained by 3 major factors (factor 1: hand breadth, factor 2: palm length, factor 3: finger length). We also distinguished 4 hand shape types and found that wide hand and short finger type (type 1) was the most common in males, but narrow hand and short finger type was the most common in females. Korean males and females had wider hands and shorter fingers than the people of 8 other nations. We expect products and interfaces to be designed based on these understandings on the characteristics of Korean hands that the result of our study suggests.

1. Introduction

People control machines in everyday life by interacting with interfaces that have been designed, and they also use various hand tools to carry out the corresponding tasks. Frequently, tools or interfaces are not designed to conform to the size of the user's hands, and in such cases, users can experience discomfort that eventually results in a decrease in productivity (Aghazadeh and Mital, 1987; Karunanithi et al., 2001; Goonetilleke, 1998; Rok Chang et al., 1999). Modern industry has become increasingly prosperous due to international trade, and many companies are now manufacturing more and more products for worldwide consumption (Okunribido, 2000). However, it will be difficult to produce goods that will satisfy consumers in any given nation if information on the size of their bodies is not thoroughly investigated (Xiao et al., 2005). Thus, anthropometry, which is used to obtain the exact size of diverse body parts, has recently become more and more important for product manufacturing and various other service fields (Goonetilleke et al., 1997; Witana et al., 2006).

Our hands are two of the most frequently used body parts. They are composed of 27 bones and 15 joints each and contain more measurement information than any of the other body parts. Certain products, such as hand tools, should be designed based on these measurements. Many previous studies have focused on the importance of mapping and measuring the human hand, and several prior studies have measured the dimensions of the hand. For example, Davies measured 28 hand landmarks on 92 Europeans, compared the hand sizes of different ethnic groups, and found that the hand parts of European females were, on the whole, significantly smaller than those of their West Indian counterparts (Davies et al., 1980). Of the various parts, the width at the tip of middle finger exhibited the greatest difference across different ethnic groups.

Okunribido measured 18 hand landmarks on 37 Nigerian farmworkers (Okunribido, 2000) and found a significant difference with other regions. For example, the proximal phalange length of the middle finger and the little finger was significantly smaller than that of their counterparts in Hong Kong, United States and Europe. In addition, the depth of the little finger and the middle finger in Nigerian females was reported to be about 25% thicker than those of their Hong Kong counterparts. However, the cause for these differences has not been thoroughly investigated.

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Imrhan measured the hand dimensions of 40 Bangladeshi males (Imrhan et al., 2006), and these dimensions were then compared to those of Mexican and Vietnamese males (Imrhan and Contreras, 2005). Most of the hand dimensions of the Bangladeshi men were significantly smaller than those of the Mexican men, with the most significant difference being the depth at the proximal joint of the little finger. Prado-lu measured the head, chest, foot and hand size of workers from the Philippines and reported the hand length, breadth, and circumference as well as the wrist circumference (Del Prado-Lu, 2007). Mandahawi measured the landmarks on the hands of 235 Jordanian people. The percentile for the dimensions of each hand part for the 235 Jordanians are presented and compared to those of their Bangladeshi, Nigerian, and Vietnamese counterparts (Mandahawi et al., 2008). In the depth-related hand parts, the dimensions for the Jordanian males were significantly larger than those for the Hong Kong males, and Jordanian women had a significantly greater size in terms of the finger breadth and depth-related variables than their UK counterparts.

Instead of only measuring size, many case studies have also derived the shape of different body parts. Clerke measured the hand dimensions of 232 Australians teenagers, and then used the hand width and length ratio to identify three hand shape types (long, average, square) (Clerke et al., 2005). Fallahi defined the hand shape as the ratio of the hand width to the hand length and then found a difference in the grip strength that depended on the shape of the subjects' hands (Fallahi and Jadidian, 2011). Park identified five factors to describe the body shape of the obese Koreans, and the factor scores were used to classify their body shapes into four types (Park and Park, 2013). Kouchi analyzed the hand dimensions of Japanese subjects in order to obtain a representative Japanese hand model. She conducted a factor analysis and identified 7 factors that explain the variability in the hand size to then derive digital 3D hand model from the boundary conditions of the hand dimensions (Kouchi et al., 2005).

A number of studies have used body size measure to provide guidelines for hand tools. Kwon identified three key hand dimensions to design gloves (length, circumference, and breadth) from among 70 different dimensions. He concluded that greater size options should be provided for males due to the greater variability in the size of the male hand (Chae et al., 2004). Ki reported on five hand measurements that represent the characteristics of Korean hands (Sang ho and Doyoung, 2012), including hand length, middle finger length, hand circumference, hand breadth and hand thickness. He also used regression analysis to provide details on the hand part dimensions corresponding to the length of people's hands. This study was intended to provide a main reference point to produce gloves and hand tools for Korean users. Chang proposed garden tools (shovel, rake, and hoe) to suit a user as a result of ergonomic studies on tool handles (Rok Chang et al., 1999). In addition, many studies on hand tool guidelines have also been conducted (Tichauer and Gage, 1977; Meagher, 1987). These studies have argued that incorrect hand tools may result in cumulative disorders, so to increase user satisfaction, the design of hand tools should provide more diversity in sizing options than the standard “one size fits all” approach that is currently used.

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. 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, we include 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 and to categorize the hand shapes that are found within the Korean population. Ultimately, we expect the results of our study to be used as baseline data to design and develop products related to hands.

2. Method

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 1.

2.2. Measurement

In this study, all 27 hand dimensions that were common among previous studies were measured, as defined in Fig. 1 and Table 2 (García-Cáceres et al., 2012; Hall et al., 2007; Cakit et al., 2014). 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 h of training in an anthropometric measurement.

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

Table 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		Occupation	
	20's	30's	40's	50′	>60's	Urban	Rural	Office job	Production
Male	20.4%	20.4%	20.4%	19.2%	19.8%	69%	31%	59%	41%
Female	20.1%	20.1%	20.1%	19.6%	20.1%	58%	48%	55%	45%

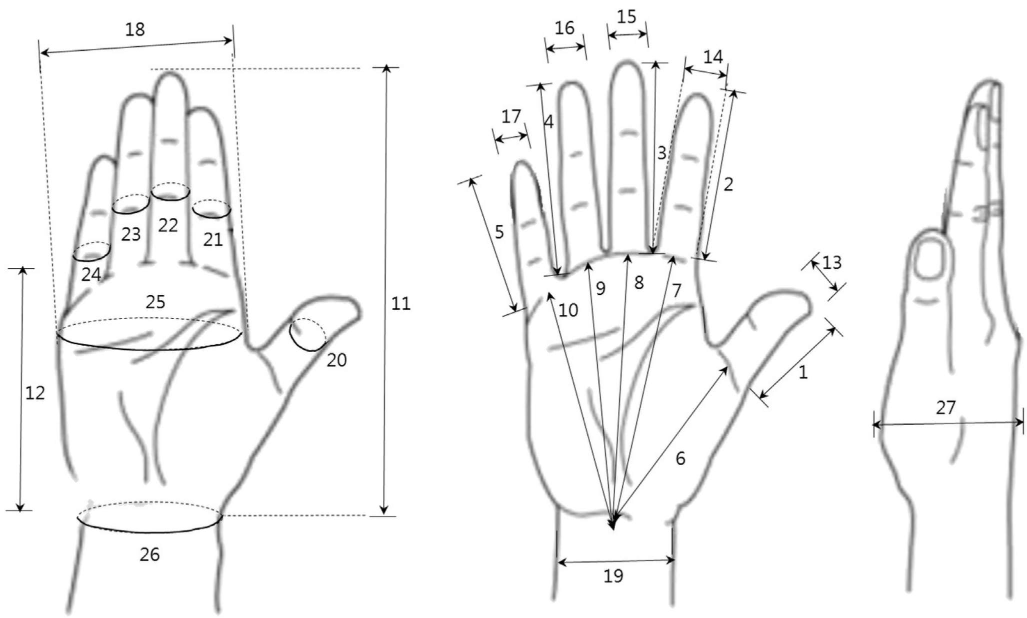


Fig. 1. Hand dimensions.

Table 2
Definition of hand dimensions (García-Cáceres et al., 2012; Hall et al., 2007; Cakit et al., 2014).

	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	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
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

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.

3. Results

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 ($p < 0.001$). 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

Table 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 test (using $\alpha = 0.05$ level of significance).
* Indicates statistically significant using $\alpha = 0.05$ level of significance.
** Indicates statistically significant using $\alpha = 0.01$ level of significance.
PIP: Proximal interphalangeal.

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. Table 4 shows the percentile values (5th, 50th and 95th) of each hand measurement in males and in females, and the extreme values (the 5th, 95th percentile values) are suggested for use in hand tool production.

3.2. Factor and clustering 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 (Appendix). 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 (Chae et al., 2004). 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).

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 5). We verified that these four groups were significantly different from one another through the use of ANOVA ($p < 0.05$).

4. 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

Table 4
Percentile values for Korean males and females (in mm).

Hand dimensions	Male			Female		
	5th	50th	95th	5th	50th	95th
Fingertip to root digit 1	53.4	61.5	67.6	50.5	56.2	61.6
Fingertip to root digit 2	63.6	70.5	78.5	58.5	66.0	73.6
Fingertip to root digit 3	71.3	78.6	86.6	66.7	73.5	81.4
Fingertip to root digit 4	66.7	74.3	82.2	62.6	69.1	76.2
Fingertip to root digit 5	51.1	59.6	65.8	45.4	54.7	61.6
Center of wrist crease to root digit 1	71.3	79.5	87.9	65.3	72.8	79.9
Center of wrist crease to root digit 2	103.2	113.4	121.8	95.8	104.7	113.7
Center of wrist crease to root digit 3	102.8	112.6	121.9	97.0	104.1	114.6
Center of wrist crease to root digit 4	98.0	108.4	117.5	92.9	99.4	109.4
Center of wrist crease to root digit 5	89.3	99.8	109.0	84.7	91.2	100.7
Hand length	168.3	183.2	197.6	159.6	169.4	184.5
Palm length	96.7	105.1	113.2	89.7	97.1	105.1
Breadth at PIP joint of digit 1	19.8	22.5	25.2	17.3	19.4	22.3
Breadth at PIP joint of digit 2	18.8	20.4	22.5	16.5	18.3	20.5
Breadth at PIP joint of digit 3	18.8	20.7	22.7	16.4	18.4	20.4
Breadth at PIP joint of digit 4	18.0	19.5	21.5	15.3	17.1	19.4
Breadth at PIP joint of digit 5	15.6	17.5	19.1	13.2	15.3	17.3
Hand breadth at metacarpals	78.7	85.9	92.3	71.6	77.6	86.1
Wrist breadth	55.7	61.6	66.0	50.1	55.5	62.1
Circumference at PIP joint of digit 1	61.4	68.0	76.0	54.0	61.0	70.0
Circumference at PIP joint of digit 2	60.0	64.0	71.6	52.0	58.0	65.0
Circumference at PIP joint of digit 3	60.0	67.0	73.0	54.0	59.0	68.0
Circumference at PIP joint of digit 4	56.0	62.0	68.0	49.7	55.0	63.0
Circumference at PIP joint of digit 5	49.0	55.0	60.0	42.0	49.0	55.2
Wrist circumference	159.8	175.0	192.8	143.7	155.5	174.5
Hand depth	42.2	49.0	55.4	36.9	41.8	48.1

Table 5
Cluster mean factor scores (Centroid position) for four hand types.

Hand types	Cluster mean factor scores			Relative frequencies (%)
	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 15.6)
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)

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 (Imrhan and Contreras, 2005; Mandahawi et al., 2008; Cakit et al., 2014; Greiner, 1991). Korean males tended to have thicker hands than Turkish, Jordanian and Mexican males (Table 6). Likewise, Korean females had shorter finger and hand lengths but greater wrist and metacarpal breadth and circumference than Turkish females

Table 6
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 7
Summary data of hand dimensions (Mean ± SD) of Korean females and other populations (in mm).

Hand dimension	Korean	Turkish	American	European	Indian	Nigerian
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	74.2 ± 5.4
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	54.2 ± 4.9
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	17.8 ± 1.9
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		14.5 ± 1.7
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	175.0 ± 11.0
Hand breadth at metacarpals	78.0 ± 4.0	69.9 ± 3.2	83.1 ± 4.4	77.2 ± 4.7	68.0 ± 5.1	75.7 ± 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 7). Among Korean, Indian, Turkish and American females, Americans had the longest hand and finger length (Clerke et al., 2005; Sang ho and Doyoung, 2012; Cakit et al., 2014; Greiner, 1991; Nag et al., 2003). 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 (Tables 8 and 9), 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. 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 substantial than 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 and Hreljac,

Table 8
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 9
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*

* Indicates statistically significant using $\alpha = 0.05$ level of significance.

2004; Blackwell et al., 1999). 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 7–8 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-

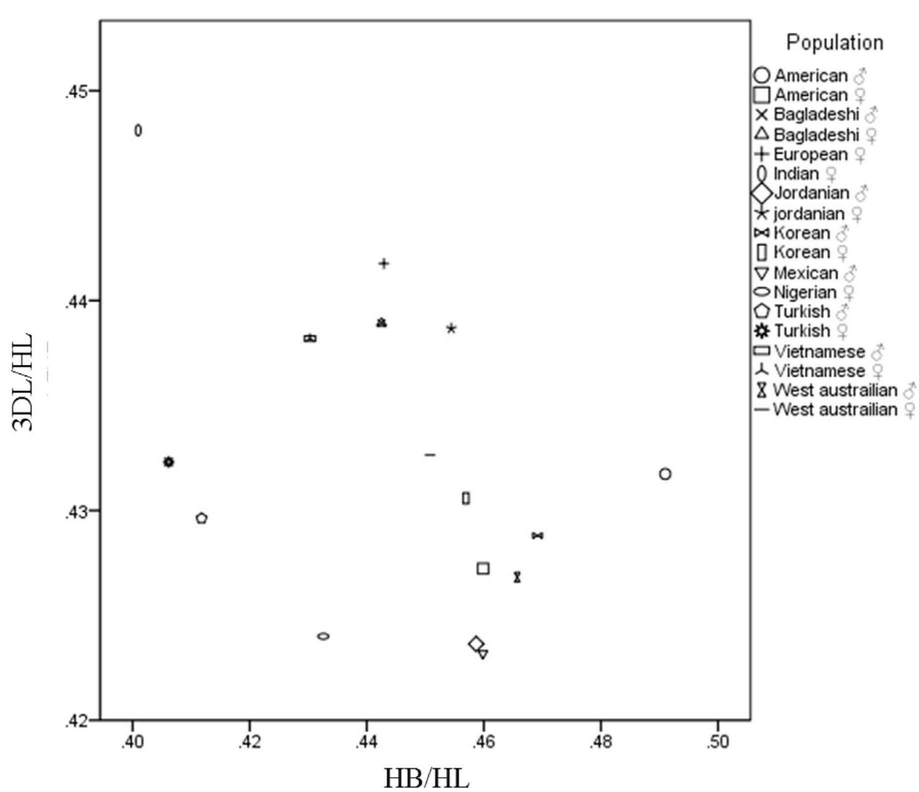
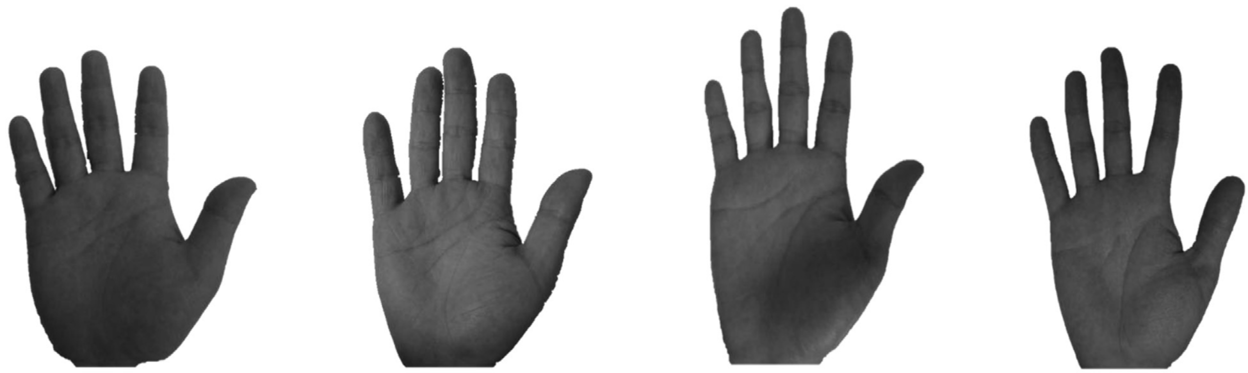


Fig. 2. A comparison of the different hand shapes of various ethnicities.



(a) Type 1 :Spacious hand and short finger (b) Type 2 : Short palm but above average finger (c) Type 3: Long palm and finger (d) Type 4 :Narrow hand and short finger

Fig. 3. Images representing the four hand types.

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. We added the results for the 10 previous studies (from 11 nations) to the results of our study (Okunribido, 2000; Imrhan et al., 2006; Mandahawi et al., 2008; Nag et al., 2003; Greiner, 1991; Ishak et al., 2012). Then, we 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 (Fig. 2). 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, we used three major factor scores to explain the hand shapes by applying a cluster analysis, and we distinguished four hand shape types (Fig. 3) based on the resulting dendrogram. Then, we 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 ($p < 0.001$). Previous studies have attributed this difference to biological and social differences (Bardin and Catterall, 1981; Widyanti et al., 2015; Khadem and Islam, 2014).

5. Conclusion

This study provided anthropometric data for Korean hands as well as the distribution of the values measured for each hand part. 27 hand anthropometric dimensions were listed with the mean, standard deviation, and percentile values. The statistical tests showed significant differences not only between Korean male and female hand dimensions, but also between Koreans and other nationalities. The result thus showed that distinguishing characteristics exist in the hands of Koreans when compared to those of other races in that the hand breadth is wider and the finger length is shorter. This study, three key factors were determined to explain the variability in the Korean hand shape, and the hand shapes were classified into four types according to their distinct shape characteristics. We therefore expect that products and interfaces can be designed based on this understandings of the characteristics of Korean hands by following the results that are provided herein.

Appendix

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

(continued on next page)

(*continued*)

Hand dimension	Factor and factor loadings			Communality
	1	2	3	
Breadth 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

References

Aghazadeh, F., Mital, A., 1987. Injuries due to handtools: results of a questionnaire. Appl. Ergon. 18, 273–278.
Bardin, C.W., Catterall, J.F., 1981. Testosterone: a major determinant of extra genital sexual dimorphism. Science 211, 1285–1294.
Berguer, R., Hreljac, A., 2004. The relationship between hand size and difficulty using surgical instruments: a survey of 726 laparoscopic surgeons. Surg. Endosc. Other Interv. Tech. 18, 508–512.
Blackwell, J.R., Kornatz, K.W., Heath, E.M., 1999. Effect of grip span on maximal grip force and fatigue of flexor digitorum superficialis. Appl. Ergon. 30, 401–405.
Cakit, E., Durgun, B., Cetik, O., Yoldas, O., 2014. A survey of hand anthropometry and biomechanical measurements of dentistry students in Turkey,. Hum. Factors Ergon. Manuf. Serv. Ind. 24, 739–753.
Chae, K.O., Hyo, J.k., Sun, S.M., Heecheon, R., Heeeun, K., 2004. Determination and application of key dimensions for a sizing system of glove by analyzing the relationshiops between hand anthropometri. J. Erfonomics Soc. Korea 23, 25–38.
Clerke, A.M., Clerke, J.P., Adams, R.D., 2005. Effects of hand shape on maximal isometric grip strength and its reliability in teenagers. J. Hand Ther. 18, 19–29.
Davies, B., Abada, A., Benson, K., Courtney, A., Minto, I., 1980. A comparison of hand anthropometry of females in three ethnic groups. Ergonomics 23, 179–182.
Del Prado-Lu, J.L., 2007. Anthropometric measurement of Filipino manufacturing workers. Int. J. Ind. Ergon. 37, 497–503.
Fallahi, A., Jadidian, A., 2011. The effect of hand dimensions, hand shape and some anthropometric characteristics on handgrip strength in male grip athletes and non-athletes. J. Hum. Kinet. 29, 151–159.
García-Cáceres, R.G., Felknor, S., Córdoba, J.E., Caballero, J.P., Barrero, L.H., 2012. Hand anthropometry of the Colombian floriculture workers of the Bogota plateau. Int. J. Ind. Ergon. 42, 183–198.
Goonetilleke, R.S., 1998. Designing to minimize discomfort. In: Ergonomics in Design, Citeseer.
Goonetilleke, R.S., Ho, E.C.F., So, R.H., 1997. Foot anthropometry in Hong Kong. In: Proceedings of the ASEAN 97 Conference, pp. 81–88.
Greiner, T.M., 1991. Hand anthropometry of US army personnel. In: DTIC Document.
Hall, J.G., Allanson, J.E., Gripp, K.W., Slavotinek, A.M., 2007. Handbook of Physical Measurements. Oxford University Press New York.
Imrhan, S., Contreras, M., 2005. Hand anthropometry in a sample of Mexicans in the US-Mexico border region. In: Proceedings of the XIX Annual Occupational Ergonomics and Safety Conference, Las Vegas, NV, pp. 589–593.
Imrhan, S., Sarder, M., Mandahawi, N., 2006. Hand anthropometry in a sample of Bangladesh males. In: Proceedings of the Eighth Annual Industrial Engineering Research Conference, Clearwater, FL, pp. 15–18.
Ishak, N.-I., Hemy, N., Franklin, D., 2012. Estimation of stature from hand and handprint dimensions in a Western Australian population. Forensic Sci. Int. 216, 199. e191–199. e197.
Karunanithi, R., Tajuddin, A., Kathirvel, K., 2001. Study on anthropometric dimensions of agricultural workers. J. Inst. Eng. India Agric. Eng. Div. 82, 13–19.
Khadem, M.M., Islam, M.A., 2014. Development of anthropometric data for Bangladeshi male population. Int. J. Ind. Ergon. 44, 407–412.
Kouchi, M., Miyata, N., Mochimaru, M., 2005. An analysis of hand measurements for obtaining representative Japanese hand models, in, SAE Technical Paper.
Mandahawi, N., Imrhan, S., Al-Shobaki, S., Sarder, B., 2008. Hand anthropometry survey for the Jordanian population. Int. J. Ind. Ergon. 38, 966–976.
Meagher, S.W., 1987. Tool design for prevention of hand and wrist injuries. J. Hand Surg. 12, 855–857.
Nag, A., Nag, P.K., Desai, H., 2003. Hand anthropometry of Indian women. Indian J. Med. Res. 117, 260–269.
Okunribido, O.O., 2000. A survey of hand anthropometry of female rural farm workers in Ibadan, Western Nigeria,. Ergonomics 43, 282–292.
Park, W., Park, S., 2013. Body shape analyses of large persons in South Korea. Ergonomics 56, 692–706.
Rok Chang, S., Park, S., Freivalds, A., 1999. Ergonomic evaluation of the effects of handle types on garden tools. Int. J. Ind. Ergon. 24, 99–105.
Sang ho, K., Doyoung, K., 2012. Classification and identification of Korean hand shapes based on anthropometric hand data analysis. J. Korea Saf. Manag. Sci. 14, 75–85.
Tichauer, E., Gage, H., 1977. Ergonomic principles basic to hand tool design. Am. Ind. Hyg. Assoc. J. 38, 622–634.
Widyanti, A., Susanti, L., Sutalaksana, I.Z., Muslim, K., 2015. Ethnic differences in Indonesian anthropometry data: evidence from three different largest ethnics. Int. J. Ind. Ergon. 47, 72–78.
Witana, C.P., Xiong, S., Zhao, J., Goonetilleke, R.S., 2006. Foot measurements from three-dimensional scans: a comparison and evaluation of different methods,. Int. J. Ind. Ergon. 36, 789–807.
Xiao, G., Lei, L., Dempsey, P.G., Lu, B., Liang, Y., 2005. Isometric muscle strength and anthropometric characteristics of a Chinese sample. Int. J. Ind. Ergon. 35, 674–679.