American Journal of Engineering and Applied Sciences

Original Research Paper

Hand Anthropometric Data for Saudi Arabia Engineering Students of Aged 20-26 Years at King Khalid University

[1,2]**Mohamed A.A. Mansour**

[1]*Department of Industrial Engineering, College of Engineering, Zagazig University, Zagazig, Al-Sharkia 44519, Egypt*
[2]*King Khalid University, Abha, Asser, 394, Kingdom of Saudi Arabia*

Article history
Received: 14-06-2016
Revised: 23-09-2016
Accepted: 27-09-2016

Corresponding Author:
Mohamed A.A. Mansour
Department of Industrial Engineering, College of Engineering, Zagazig University, Zagazig, Al-Sharkia 44519, Egypt and
King Khalid University, Abha, Asser, 394, Kingdom of Saudi Arabia
Email: momansor@kku.edu.sa

Abstract: Anthropometric data plays a significant role in the effective and accurate design of various devices and machines. The inclusion of anthropometric data helps ensure that devices or machines are safe, user-friendly and highly productive and efficient. In this study, 56 hand dimensions based on 266 Saudi Arabian inter-university adult males aged 20-26 years are described in terms of statistics, bivariate correlations and multivariate regression models for predicting hand anthropometric dimensions. All hand dimensions were measured using the correct instruments and techniques. The statistics reported are the minimum, maximum, mean, standard deviation, percentiles (1st, 5th, 50th, 95th and 99th), normality, skewness and kurtosis. Bivariate correlations and multiple regression models are tabulated. The 56 hand dimensions of Saudi adult males are presented for use by the designers of hand tools and equipment. Most hand dimensions are positively correlated at a 0.01/0.05 level of significance. Thirteen multiple regression models were developed for estimating hand length from other hand dimensions with coefficient determination factors ranging from 0.881 to 0.962. In addition, multiple regression equations for estimating hand dimensions from hand length and breadth/fist circumference were developed. The information in this paper will be useful for ergonomic design and the modifications of hand tools, personal protective equipment, workstations and interface systems imported into Saudi Arabia to reduce human error and improve public health.

Keywords: Saudi Arabia, Hand Anthropometry, Bivariate Correlation, Hand Tool Design, Multivariate Regression Models

Introduction

The current state of the Saudi Arabian economy reveals a notable growth in the importation of machinery, vehicles, hand tools and other items manufactured in both developed and undeveloped countries. These items are designed according to the anthropometry of foreign populations, not for the Saudi population. This can be attributed to the lack of information in the literature and government databases. This mismatch between imported man-machine systems and Saudi anthropometry produces undesirable effects such as occupational disease and accidents (Okunribido, 2000; Syuaib, 2015). Aghazadeh and Mital (1987) estimated that over 260,000 injuries per year are due to worker-tool mismatches in the USA. The unavailability of properly designed machines and equipment decreases work performance and increases the chance of work injuries (Botha and Bridger, 1998).

Anthropometric data are a collection of the human body's dimensions and are used in physical anthropometry, apparel sizing and forensics. In addition, anthropometric data are applied in ergonomics to specify the physical dimensions of equipment, the workplace and furniture.

The advent of technology has completely evolved the way in which people communicate: from pigeons and telephone/telegraph/post to mobile phones (Ismaila *et al*., 2013; Jain, 2012; Ismaila, 2009). Today, young people use a particular type and style of mobile phone to improve their self-presentation. They prefer bigger screens with big keypads and large font displays as well as advanced touch screen handsets (Dianat *et al*., 2013). Thus, it is an important task to obtain and analyze hand anthropometric data for students aged between 20 and 26.

While conducting this research, it was noted both that some users with long fingers find it difficult to use mobile devices while typing text messages and 96% of Saudi participants have more than one mobile. Therefore, there is a great need for a hand anthropometry database to analyze the finger and hand size of users so as to make these hand devices more user-friendly. The generalized dimensions of a user's hand between the ages of 20 and 26 will help develop accurate hand devices. Hence, the purpose of this study is to analyze the hand anthropometric data of students between the ages of 20 to 26.

Related Work

According to Abeysekers and Shahnavaz (1989), a significance difference in anthropometric dimensions among populations leads to a mismatch between imported products/tools and people in other countries. For example, a European adjustable helmet did not properly fit 40% of heads in Sri Lanka. The availability of anthropometric data is one of the most important factors for designing man-machine systems that have greater interaction ability and safety as well as higher performance and productivity (Lewis and Narayan, 1993).

Anthropometric data for the Saudi Arabian population are to some degree limited in the literature. A few researchers have emphasized the effect of cardiovascular performance on the anthropometric growth of school boys and girls (Noweir *et al*., 2001; Al-Hazzaa, 1990). Alrashdan *et al*. (2014) gathered 32 body dimensions and the weight of 152 female students, aged 18-25 years, from different female campuses in Riyadh, the capital of Saudi Arabia. They considered hand length and width and presented anthropometric tables, comparing the dimensions of Saudi females with those of Western and Asian populations. In addition, to the best of our knowledge, there is no anthropometric database available for Saudi Arabians from the Saudi Arabia Standards Organization.

There are data for different populations in the Middle East; for instance, there are data for Jordanians (Mohammad, 2005), static anthropometry for Iranians (Dianat *et al*., 2013; Mirmohammadi *et al*., 2016), anthropometry for the design of Bahraini school furniture (Mokdad and Al-Ansari, 2009) and anthropometric measurements of Turkish adults (Ali and Arslan, 2009). Various hand anthropometry studies have been performed to develop anthropometric databases, design machinery and hand tools, study the variations existing in ethnic sub-populations for comparative study and study hand performance. The populations in these studies were industrial workers, adult civilians, farmers (García-Cáceres *et al*., 2012), university students, primary school students and adult military personnel. The number of hand dimensions' ranges from one to 86 dimensions, the sample size ranges from 23 to 2,387 subjects and age ranges from five to 11 years for students and 15 to 80 years for adults. Some hand anthropometric data are available in the literature for nations such as the UK, Sweden, Spain, Colombia, Thailand, Jordan, Nigeria, Norway, the USA, China and Sri Lanka.

Some studies point out the importance of anthropometric data for machine design. Wagner (1988) compiled data on 20 hand dimensions for pianists and pointed out the significance of these measurements for keyboard design. Nag *et al*. (2003) described data for 51 hand dimensions from 95 Indian women in their study of ergonomic hand tool design. Mandahawi *et al*. (2008) collected data on 24 hand dimensions relevant to tool design for 115 men and 120 women from four Jordanian cities and compared this data with those of other populations. Research on this topic includes the work done by Kar *et al*. (2003), Meagher (1987; 1989, Schmidtke (1984) and Norris and Wilson (1997).

In addition to these studies, some research that is relevant to the design of hand tools for various nationalities has been published. Davies *et al*. (1980a) described 28 hand dimensions for female industrial workers from the UK to evaluate the standards of machine guards. Imrhan and Contreras (2005) described 23 hand dimensions based on two samples consisting of 25 men and 25 women for Mexicans living near the USA border including workers, university students and home helpers. Buchholz *et al*. (1992) and Buchholz and Armstrong (1991) studied the interaction of handle size and shape with kinematics and hand anthropometry.

Other studies focused on developing an anthropometric database for various developed and undeveloped countries and comparisons among ethnic sub-populations. Okunribido (2000) conducted an anthropometric survey measuring 18 dimensions of the right hand in 37 female rural farm workers living in Ibadan, Western Nigeria. The statistics for collecting data were compared with those for females from the UK, Hong Kong and the USA using data from other published studies. He concluded that the Nigerian female hand is wider and thicker, but shorter than that of their foreign counterparts. Davies *et al*. (1980b) compared 28 hand anthropometric dimensions based on a sample of 92 subjects for three ethnic groups. Greiner (1991) collected data about 86 hand dimensions for USA Army personnel.

Cakit *et al*. (2012) conducted a hand survey and biomechanical measurements of dentistry students in Turkey. Thirty-three hand dimensions were measured and described using statistical measures for 92 male and 73 female students studying at dentistry faculty and compared with Thai, Indian, Malaysian, British, Jordanian, Nigerian, Mexican, Bangladesh and Vietnamese populations. Kember *et al*. (1981) conducted a hand anthropometric survey of UK workers for 12 dimensions. Sutjana *et al*. (2008) measured 46 body dimensions, which includes seven hand measurements, of 127 medical students in Indonesia and calculated the mean and standard deviations, as well as the 5th, 50th and 95th percentiles.

Abeysekera and Shahnav (1988) measured 85 anthropometric body measurements and derived another five for 724 Sri Lankan workers. They compared hand length, hand width and both measurements with other populations such as those of Western Europe, West India, India (Punjab), Hong Kong China, the UK, Japan, Africa/Sudan, Sri Lanka, Sweden and Egypt. Ahn *et al*. (2016) studied the effect of grip curvature and hand anthropometry for the unimanual operation of touch screen handheld devices. Irwin and Radwin (2008) estimated the internal biomechanical loads of the hand from external loads and finger lengths that were themselves estimated from measured hand length and breadth. They found that hand anthropometric measurements, especially palm width, are better predictors of hand strength than stature and body weight. An important implication of the above discussion is that hand anthropometry must be known for any target population for whom hand tools and other manual devices are to be designed.

Courtney (1984) carried out a hand anthropometric study of on a sample of 100 Hong Kong Chinese female workers and summarized 23 hand dimensions, comparing the results with data from the UK, Japan and the USA. The study indicated significant differences for age and ethnic group. Further, Claudon (2000) discussed how poor ergonomic hand tool design is a well-known factor contributing to biomechanical stresses and increasing the risk of cumulative trauma and carpal tunnel syndrome disorders. Bures *et al*. (2015) developed a hand anthropometric database for the Czech population and Obi (2016) developed a hand anthropometry survey for rural farm workers in Southeastern Nigeria.

Abeysekera and Shahnavaz (1989) noted that the potentially harmful effects of ignoring anthropometric differences among populations may manifest, for example, when a developing nation imports equipment from a developed nation because the latter tends to design their equipment based on the anthropometric data on their own population. Reliable data on the association between hand injuries or disorders and hand anthropometry are almost absent in developing countries. According to Kar *et al*. (2003), the continued reliance on muscular power for tool use, in developing countries and the widespread use of hand tools that do not fit hands properly results in health, safety and task performance problems. Further information on the relevant anthropometric dimensions of the populations of importing countries for equipment design may help reduce these problems. Limited work has addressed hand anthropometry data for the populations of developing countries (Abeysekera 1988; Imrhan *et al*., 2006; 2009; Chandra *et al*. 2011).

The reviewed literature indicates that no research focusing on hand anthropometry for the Saudi Arabian people has yet been conducted. Hence, the present study is the first comprehensive hand anthropometric study in general for Saudi Arabians and in particular for engineering students. This paper presents the results of a hand anthropometric study of a sample of 266 male adults enrolled in engineering programs at King Khalid University (KKU). A bivariate correlation analysis and multivariate regression model for predicting hand length is estimated in this article. The results of this study are expected to influence the design and choice of hand tools imported into Saudi Arabia and provide the impetus for more anthropometric studies on Saudi people that relate to the design of equipment and other activities.

Materials and Methods

Subjects

The anthropometric data for 266 male participants were collected during the winter of 2015 at KKU, Abha, Aseer Region, Kingdom of Saudi Arabia. The participants were engineering students from various provinces in Aseer, which is in the southwest of the Kingdom. The subjects were enrolled on a voluntary basis in this research. All had normal physical health and were free of any medical contraindications. The average and standard deviation for the height, weight and age of the male subjects were (166.95, 7.59) cm, (65.57, 8.23) kg and (22.89, 0.98) years, respectively. Knowledge related to diseases, which affects the characteristics of anthropometric data, was considered an exclusion criterion, as identified by Malina and Bushang (1984).

Hand Dimensions

All measurements were conducted on right-handed individuals based on a performance index greater than 0.85 according to Annett (1970). Fifty-six hand dimensions were measured, as specified in Fig. 1 and Table 1, according to Garrett (1970) and Ermacova *et al*. (1985).

Instruments

A 60-inch anthropometric tape, finger circumference gauge model F00575, large anthropometer model 01290 and small anthropometer model 01291 were used. All instruments were produced by the Lafayette Instrument Company (USA).

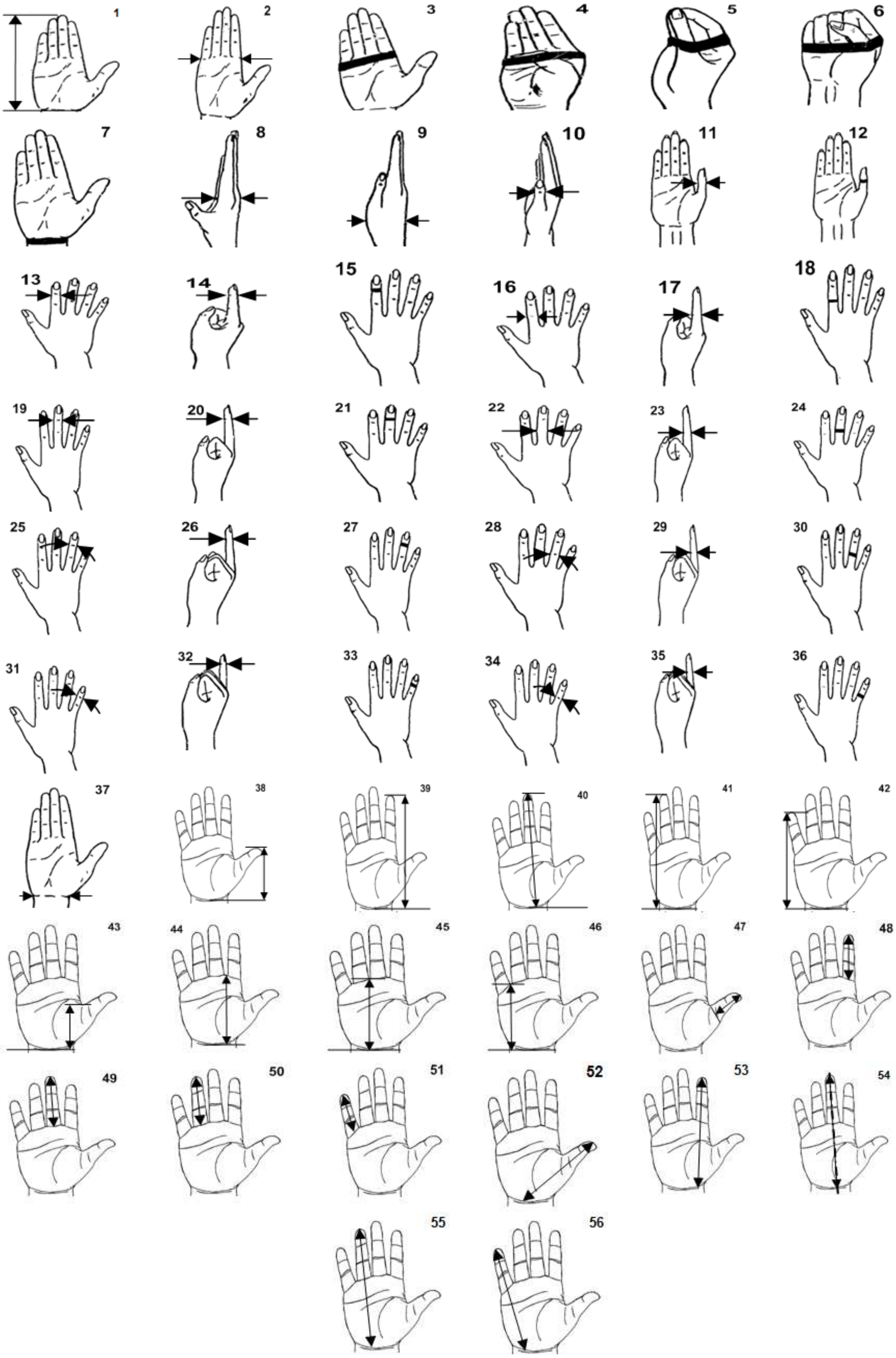

Fig. 1. Hand dimensions measured in the study

Table 1. Descriptive statistics of 56 hand anthropometric dimensions

		Range				Percentiles							
Code	Dimension	Min	Max	Mean	SD	1st	5th	50th	95th	99th	SW	Sk	Ku
D1	Hand length	16.06	20.24	17.87	0.78	16.09	16.59	17.90	19.16	19.81	0.68	0.04	–0.24
D2	Hand breadth at metacarpal	6.69	8.66	7.67	0.35	6.90	7.08	7.69	8.26	8.55	0.73	–0.01	0.04
D3	Hand circumference at metacarpal	16.46	20.60	18.63	0.74	16.79	17.25	18.63	19.83	20.36	0.56	–0.11	0.11
D4	Hand circumference at metacarpal, minimum	17.97	24.62	21.30	1.12	18.81	19.52	21.32	23.26	23.96	0.92	0.12	–0.12
D5	Hand circumference, fingertips even	19.46	25.50	22.48	1.08	19.71	20.62	22.56	24.15	24.98	0.39	–0.20	0.00
D6	Fist circumference	21.77	27.49	24.75	1.15	22.31	22.90	24.77	26.75	27.38	0.19	0.12	–0.43
D7	Wrist circumference	12.90	16.61	14.92	0.66	13.45	13.85	14.93	15.99	16.49	0.79	–0.03	–0.20
D8	Hand thickness, metacarpal 3	2.26	3.23	2.76	0.17	2.30	2.48	2.76	3.05	3.18	0.71	–0.07	0.16
D9	Hand depth, thenar pad	4.15	6.12	5.12	0.37	4.24	4.47	5.12	5.74	6.00	0.80	–0.07	–0.03
D10	Digit 1: Interphalangeal joint breadth	1.56	2.25	1.89	0.12	1.61	1.71	1.89	2.09	2.15	0.83	0.06	–0.05
D11	Digit 1: Interphalangeal joint depth	1.35	1.94	1.65	0.11	1.39	1.50	1.65	1.84	1.91	0.40	0.12	–0.13
D12	Digit 1: Interphalangeal joint circumference	4.67	6.42	5.59	0.30	4.81	5.11	5.59	6.12	6.29	0.70	0.08	–0.03
D13	Digit 2: Distal interphalangeal joint breadth	1.31	1.79	1.53	0.10	1.32	1.38	1.53	1.69	1.75	0.15	0.11	–0.55
D14	Digit 2: Distal interphalangeal joint depth	1.00	1.49	1.22	0.08	1.03	1.08	1.23	1.35	1.44	0.67	0.02	–0.05
D15	Digit 2: Distal interphalangeal joint circumference	3.84	5.25	4.43	0.25	3.87	4.00	4.45	4.84	4.96	0.16	–0.05	–0.35
D16	Digit 2: Proximal interphalangeal joint breadth	1.55	2.06	1.81	0.09	1.60	1.67	1.82	1.97	2.03	0.52	0.03	–0.39
D17	Digit 2: Proximal interphalangeal joint depth	1.40	1.85	1.62	0.09	1.41	1.48	1.61	1.77	1.83	0.69	0.13	–0.26
D18	Digit 2: Proximal interphalangeal joint circumference	4.75	6.04	5.39	0.26	4.79	4.97	5.39	5.82	6.02	0.48	0.03	–0.36
D19	Digit 3: Distal interphalangeal joint breadth	1.27	1.72	1.53	0.09	1.35	1.38	1.53	1.66	1.71	0.06	–0.17	–0.44
D20	Digit 3: Distal interphalangeal joint depth	1.04	1.55	1.31	0.09	1.09	1.16	1.31	1.47	1.52	0.46	0.00	–0.13
D21	Digit 3: Distal interphalangeal joint circumference	3.91	5.18	4.48	0.25	3.94	4.06	4.49	4.88	5.10	0.48	0.02	–0.32
D22	Digit 3: Proximal interphalangeal joint breadth	1.60	2.09	1.83	0.09	1.63	1.67	1.83	1.97	2.07	0.34	0.12	–0.30
D23	Digit 3: Proximal interphalangeal joint depth	1.41	1.94	1.66	0.10	1.42	1.49	1.66	1.82	1.90	0.55	–0.04	–0.38
D24	Digit 3: Proximal interphalangeal joint circumference	4.81	6.24	5.48	0.24	4.94	5.09	5.47	5.88	6.10	0.79	0.16	–0.06
D25	Digit 4: Distal interphalangeal joint breadth	1.18	1.68	1.43	0.09	1.22	1.28	1.43	1.57	1.61	0.81	–0.02	–0.23
D26	Digit 4: Distal interphalangeal joint depth	1.01	1.55	1.25	0.09	1.04	1.09	1.25	1.39	1.48	0.66	0.11	0.02
D27	Digit 4: Distal interphalangeal joint circumference	3.65	4.81	4.21	0.24	3.68	3.85	4.21	4.61	4.77	0.20	0.14	–0.41
D28	Digit 4: Proximal interphalangeal joint breadth	1.45	1.95	1.68	0.09	1.46	1.53	1.69	1.83	1.89	0.48	–0.05	–0.26
D29	Digit 4: Proximal interphalangeal joint depth	1.33	1.87	1.57	0.10	1.34	1.40	1.56	1.75	1.80	0.65	0.09	–0.26
D30	Digit 4: Proximal interphalangeal joint circumference	4.55	5.64	5.10	0.23	4.58	4.72	5.09	5.50	5.61	0.21	0.06	–0.47
D31	Digit 5: Distal interphalangeal joint breadth	1.10	1.56	1.31	0.09	1.12	1.16	1.30	1.44	1.51	0.23	0.11	–0.27
D32	Digit 5: Distal interphalangeal joint depth	0.88	1.36	1.13	0.08	0.91	0.99	1.13	1.26	1.33	0.96	–0.04	0.03
D33	Digit 5: Distal interphalangeal joint circumference	3.28	4.48	3.85	0.23	3.32	3.50	3.85	4.24	4.45	0.30	0.16	–0.23
D34	Digit 5: Proximal interphalangeal joint breadth	1.21	1.66	1.45	0.09	1.23	1.30	1.46	1.59	1.63	0.28	–0.17	–0.25
D35	Digit 5: Proximal interphalangeal joint depth	1.16	1.65	1.39	0.08	1.21	1.26	1.39	1.52	1.58	0.64	0.05	–0.19
D36	Digit 5: Proximal interphalangeal joint circumference	3.91	4.99	4.46	0.23	3.96	4.08	4.45	4.85	4.95	0.06	0.09	–0.70
D37	Wrist breadth	4.88	6.58	5.81	0.32	4.94	5.25	5.81	6.31	6.54	0.66	–0.14	–0.14
D38	Digit 1:Height, perpendicular to wrist crease	6.37	10.98	8.56	0.84	6.62	7.12	8.59	9.98	10.39	0.67	–0.09	–0.19
D39	Digit 2:Height, perpendicular to wrist crease	14.17	18.64	16.34	0.84	14.22	14.85	16.37	17.62	18.12	0.56	–0.17	–0.23
D40	Digit 3:Height, perpendicular to wrist crease	15.41	19.41	17.56	0.79	15.58	16.12	17.62	18.90	19.32	0.59	–0.13	–0.22
D41	Digit 4:Height, perpendicular to wrist crease	14.03	18.21	16.29	0.81	14.23	15.00	16.28	17.68	18.14	0.64	–0.02	–0.18
D42	Digit 5:Height, perpendicular to wrist crease	10.56	15.03	12.94	0.83	11.00	11.60	12.95	14.40	14.93	0.91	0.04	–0.24
D43	Crotch 1 height	4.37	7.16	5.68	0.58	4.44	4.72	5.70	6.71	7.02	0.32	0.10	–0.35
D44	Crotch 2 height	8.34	11.44	9.80	0.60	8.44	8.78	9.77	10.81	11.40	0.60	0.08	–0.19
D45	Crotch 3 height	8.09	11.20	9.78	0.57	8.46	8.92	9.78	10.73	11.10	0.55	0.03	–0.19
D46	Crotch 4 height	7.07	10.10	8.67	0.59	7.21	7.74	8.66	9.66	9.96	0.52	0.03	–0.27
D47	Digit 1: Length, fingertip to crotch level	4.32	6.66	5.35	0.46	4.42	4.59	5.31	6.16	6.39	0.21	0.18	–0.36
D48	Digit 2: Length, fingertip to crotch level	5.76	8.29	6.82	0.46	5.84	6.03	6.85	7.62	7.83	0.24	0.06	–0.26
D49	Digit 3: Length, fingertip to crotch level	6.64	9.06	7.78	0.48	6.76	6.98	7.77	8.56	8.83	0.08	0.03	–0.58
D50	Digit 4: Length, fingertip to crotch level	5.95	8.75	7.32	0.47	6.16	6.60	7.30	8.16	8.37	0.84	0.06	–0.01
D51	Digit 5: Length, fingertip to crotch level	4.38	6.55	5.44	0.40	4.57	4.80	5.42	6.13	6.44	0.51	0.19	–0.20
D52	Digit 1: Length, total, tip to wrist crease	8.96	13.69	10.95	0.96	9.02	9.19	10.96	12.61	13.45	0.05	0.17	0.10
D53	Digit 2: Length, total, tip to wrist crease	14.35	18.59	16.59	0.83	14.83	15.12	16.57	18.05	18.44	0.29	–0.06	–0.35
D54	Digit 3: Length, total, tip to wrist crease	15.43	20.06	17.61	0.77	15.92	16.27	17.62	18.86	19.72	0.25	–0.02	0.00
D55	Digit 4: Length, total, tip to wrist crease.	14.63	19.17	16.74	0.80	14.79	15.37	16.75	18.07	18.63	0.94	0.01	–0.11
D56	Digit 5: Length, total, tip to wrist crease	12.18	16.96	14.59	0.87	12.61	13.13	14.61	16.11	16.54	0.86	–0.04	–0.16

Procedure

The procedures used to carry out the measurements were in accordance with the NASA-1024 guidelines. A rest of 10 min was given to subjects between measurement sessions. All measurements were taken daily in the afternoon between 13:00–15:00 h. The subject's age was documented by the registered date of birth within their university registration files. Furthermore, subjects of the study were requested to provide written consent. Confidentiality of data was assured and all participants were informed that the data would only be used for the stated purpose of the survey. The field study was approved by the ethics review board of the Engineering College in February 2016. The board was established in 2014 at King Khalid University. Breadth, length and thickness were measured with an anthropometer and circumferences were measured with anthropometric tape. A training program was designed for those responsible for collecting the data. It was provided over two weeks, three times/week, twice a day for 60 min separated by 30 min of rest. The program included modules about anatomy, body landmarks and measurement instrument use and techniques. Five trials were carried out to evaluate each dimension and the overall mean value was noted.

Statistical Analysis

The collected data was comprehensively screened and cleaned. Initially, we collect data for 280 students. After missing values and outliers were removed, the final set of data consisted of 266 data measurements. The normality assumption for the 56 variables representing the measured hand dimensions was investigated in this study. For each anthropometric dimension, the following standard descriptive statistics were determined from directly measured dimensions: minimum, maximum, mean, Standard Deviation (SD), percentiles (1st, 5th, 50th, 95th and 99th), Shapiro-Wilk's normality test (SW) at $p > 0.05$, skewness (Sk) and kurtosis (Ku). In addition, Pearson's product moment correlation coefficient and its significance were used to find the correlations among the measured variables. Multivariate regression models were developed to estimate each hand dimension from the other hand dimensions. The statistical analysis was conducted using of computerized statistical analysis software (IBM SPSS Statistics for Windows 21). To indicate statistical significance, 5% and 1% levels of probability were used.

Results

Sample Characteristics

Table 1 presents the descriptive statistics of the 56 hand dimensions for Saudi university adult males at KKU. The table shows that hand dimensions were approximately normally distributed based on the values of SW, Sk and Ku.

Bivariate Correlation

The Pearson product-moment correlation coefficient was used to establish relationships among hand dimensions. The bivariate correlations reported in Table 2 indicate a significant positive correlation between most of the hand dimensions, which was consistent with Chandra *et al*. (2011). The white cells in Table 2 indicate a correlation is significant at 0.01 level (two-tailed), the shaded cells indicate a correlation significant at the 0.05 level (two-tailed) and a bordered cell indicates that the correlation is not significant.

Constructing Regression Models

In order to construct the regression models for each hand with the anthropometric dimension as a dependent variable and all other dimensions as independents, SPSS was set up to use stepwise linear regression models with a probability of $F = 0.05$, a removal probability of 0.10 and to include a constant in the equation option. Comprehensive regression modeling to estimate the hand length from other hand dimensions was conducted and the results are presented in Table 3. Table 4 provides 56 multiple regression models for estimating each hand dimension in terms of hand length and hand breadth with R^2.Furthermore, Table 5 provides 56 multiple regression equations in terms of hand length and fist circumference.

Thirteen regression models were determined using SPSS to define the relationship between hand length and the other 55 hand dimensions, as shown in Table 3. These models have a Variance Inflation Factor (VIF) of less than 10 or tolerance greater than 0.2, which indicates that they are free from multicollinearity. The models are defined in terms of their parameters, standardized and un-standardized coefficients, significance and collinearity statistics (as tolerance and VIF). Column 1 in Table 3 lists the regression model number, which is the number of independent variables in the model. Column 2 lists the constant terms and the significant independent variables. For example, model 1 includes constant term C and one independent variable named D54, which corresponds to dimension 54 in the collected data set, while model 2 includes constant term C and two independent variables, D54 and D40. Columns 3 and 4 present the unstandardized coefficients of the model in terms of B and SE values, while Column 5 presents the standardized coefficients. The B values represent the regression coefficients and the SE values represent the standard errors of the coefficients. Standardized regression coefficients (Beta), t and the two-tailed probability of t (Sig.) are given in columns 6 and 7. Columns 8 and 9 list the tolerance for the variables (Tol.) and VIF of collinearity while Column 10 gives the models' coefficient of determination (R^2).

Table 3 indicates that the R^2 values for the developed models range from 0.881 to 0.962 and all models are adequate. Model 1, which is calculated as Hand length = 1.31+0.94 × "total tip to wrist crease" is estimated from un-standardized coefficients in Column 3. The model estimated from standardized coefficients in Column 5 is calculated as Hand length = 0.94 × "total tip to wrist crease." The collinearity is measured in terms of Tol and VIF values. For this model, Tol> 0.2 and VIF < 10, so the model is free from multicollinearity. We note that the R^2 value increases from 0.881 to 0.962 for the models with 1 to 13 independent variables. The maximum R^2 value is achieved by the model with 13 independent variables. The results listed in Table 4 and 5 show that the prediction of hand dimensions from hand length and breadth was better than predicting from hand length and fist circumference based on comparing the values of R^2.

DOI: 10.3844/ajeassp.2016.877.888

Table 2. Pearson's correlation coefficient between the different hand anthropometric measurements

Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
2	0.51	1
3	0.5	0.86	1
4	0.33	0.65	0.67	1
5	0.49	0.67	0.66	0.59	1
6	0.53	0.69	0.67	0.59	0.7	1
7	0.44	0.65	0.69	0.53	0.46	0.54	1
8	0.23	0.35	0.42	0.36	0.41	0.35	0.34	1
9	0.29	0.39	0.35	0.41	0.39	0.49	0.39	0.31	1
10	0.34	0.45	0.45	0.17	0.41	0.48	0.44	0.4	0.31	1
11	0.21	0.47	0.46	0.37	0.36	0.34	0.42	0.39	0.23	0.56	1
12	0.32	0.53	0.52	0.3	0.44	0.47	0.49	0.46	0.32	0.9	0.84	1
13	0.3	0.53	0.52	0.34	0.34	0.44	0.44	0.43	0.28	0.55	0.47	0.58	1
14	0.13	0.37	0.35	0.34	0.37	0.36	0.45	0.43	0.21	0.49	0.51	0.59	0.54	1
15	0.25	0.52	0.5	0.37	0.38	0.44	0.48	0.49	0.28	0.58	0.54	0.64	0.9	0.81	1
16	0.42	0.59	0.58	0.41	0.5	0.53	0.51	0.41	0.33	0.58	0.5	0.62	0.67	0.51	0.66	1
17	0.29	0.39	0.36	0.4	0.33	0.54	0.4	0.31	0.47	0.42	0.36	0.45	0.46	0.47	0.51	0.45	1
18	0.43	0.57	0.54	0.45	0.49	0.62	0.51	0.41	0.46	0.6	0.5	0.63	0.62	0.55	0.65	0.85	0.8	1
19	0.31	0.51	0.53	0.35	0.41	0.42	0.44	0.5	0.3	0.62	0.54	0.68	0.72	0.55	0.72	0.59	0.42	0.58	1
20	0.29	0.51	0.47	0.44	0.45	0.43	0.47	0.44	0.33	0.43	0.48	0.54	0.52	0.75	0.66	0.48	0.47	0.53	0.56	1
21	0.34	0.56	0.56	0.42	0.48	0.46	0.5	0.52	0.34	0.61	0.59	0.7	0.69	0.71	0.77	0.61	0.47	0.63	0.89	0.84	1
22	0.3	0.49	0.5	0.38	0.35	0.4	0.49	0.51	0.25	0.45	0.44	0.52	0.56	0.51	0.6	0.65	0.37	0.58	0.55	0.52	0.61	1
23	0.35	0.4	0.35	0.32	0.32	0.47	0.33	0.27	0.36	0.46	0.4	0.49	0.47	0.44	0.5	0.43	0.74	0.66	0.47	0.48	0.52	0.35	1
24	0.39	0.54	0.49	0.42	0.4	0.52	0.48	0.46	0.38	0.55	0.5	0.61	0.64	0.58	0.68	0.65	0.69	0.76	0.62	0.61	0.69	0.8	0.82	1
25	0.29	0.51	0.48	0.33	0.39	0.48	0.45	0.43	0.3	0.58	0.43	0.58	0.68	0.52	0.69	0.61	0.42	0.57	0.69	0.52	0.68	0.49	0.48	0.59	1
26	0.31	0.48	0.52	0.42	0.43	0.44	0.53	0.39	0.32	0.48	0.48	0.55	0.56	0.6	0.64	0.52	0.42	0.53	0.56	0.68	0.7	0.44	0.47	0.55	0.55	1
27	0.33	0.56	0.55	0.41	0.46	0.52	0.53	0.47	0.33	0.6	0.49	0.64	0.69	0.64	0.75	0.63	0.44	0.61	0.71	0.68	0.79	0.54	0.53	0.64	0.91	0.83	1
28	0.3	0.54	0.51	0.42	0.37	0.46	0.58	0.4	0.37	0.52	0.47	0.57	0.53	0.41	0.52	0.62	0.43	0.59	0.55	0.45	0.57	0.69	0.38	0.65	0.58	0.44	0.59	1
29	0.18	0.22	0.19	0.27	0.28	0.28	0.21	0.26	0.21	0.31	0.32	0.35	0.31	0.48	0.42	0.37	0.51	0.51	0.4	0.52	0.51	0.34	0.64	0.61	0.29	0.43	0.38	0.25	1
30	0.32	0.5	0.46	0.43	0.41	0.47	0.5	0.43	0.36	0.54	0.51	0.59	0.52	0.58	0.6	0.63	0.58	0.69	0.61	0.61	0.68	0.67	0.64	0.79	0.54	0.55	0.61	0.77	0.78	1
31	0.17	0.33	0.38	0.13	0.27	0.42	0.3	0.37	0.14	0.59	0.37	0.55	0.54	0.37	0.52	0.51	0.33	0.48	0.59	0.3	0.53	0.4	0.33	0.43	0.61	0.45	0.61	0.36	0.24	0.37	1
32	0.31	0.48	0.55	0.31	0.42	0.49	0.45	0.36	0.32	0.54	0.42	0.56	0.52	0.51	0.57	0.48	0.39	0.51	0.61	0.64	0.7	0.4	0.45	0.52	0.5	0.74	0.68	0.41	0.37	0.48	0.51	1
33	0.24	0.44	0.48	0.23	0.38	0.5	0.41	0.41	0.2	0.63	0.44	0.62	0.6	0.5	0.62	0.56	0.41	0.56	0.68	0.49	0.67	0.46	0.44	0.53	0.66	0.63	0.72	0.44	0.34	0.49	0.9	0.8	1
34	0.28	0.5	0.5	0.39	0.41	0.49	0.48	0.47	0.26	0.56	0.39	0.56	0.55	0.46	0.56	0.63	0.36	0.58	0.55	0.47	0.57	0.57	0.35	0.56	0.57	0.41	0.57	0.68	0.27	0.61	0.49	0.43	0.54	1
35	0.3	0.3	0.28	0.27	0.33	0.37	0.34	0.22	0.32	0.47	0.4	0.49	0.4	0.48	0.47	0.48	0.49	0.54	0.48	0.46	0.51	0.32	0.53	0.5	0.43	0.48	0.5	0.35	0.48	0.55	0.35	0.47	0.46	0.36	1
36	0.35	0.48	0.48	0.41	0.45	0.52	0.51	0.44	0.35	0.62	0.48	0.63	0.57	0.55	0.61	0.68	0.5	0.68	0.6	0.56	0.65	0.53	0.52	0.63	0.6	0.54	0.64	0.63	0.44	0.69	0.5	0.54	0.59	0.83	0.78	1
37	0.26	0.52	0.55	0.42	0.42	0.44	0.73	0.31	0.27	0.41	0.4	0.46	0.29	0.43	0.37	0.47	0.31	0.45	0.39	0.48	0.48	0.4	0.2	0.34	0.36	0.42	0.44	0.42	0.25	0.44	0.27	0.36	0.34	0.43	0.32	0.46	1
38	0.53	0.21	0.25	0.18	0.22	0.25	0.13	0.02	0.13	0.12	0.07	0.1	0.2	-.01	0.13	0.23	0.25	0.28	0.08	0.06	0.08	0.08	0.29	0.23	0.10	0.14	0.13	0.21	0.06	0.16	0.06	0.09	0.06	0.09	0.13	0.16	-.14	1
39	0.81	0.46	0.46	0.36	0.5	0.52	0.32	0.2	0.25	0.33	0.25	0.32	0.35	0.12	0.27	0.45	0.34	0.47	0.27	0.2	0.26	0.23	0.36	0.35	0.28	0.28	0.29	0.32	0.18	0.31	0.17	0.25	0.23	0.28	0.27	0.35	0.07	0.77	1
40	0.92	0.52	0.49	0.33	0.53	0.56	0.39	0.24	0.25	0.4	0.28	0.38	0.35	0.17	0.3	0.47	0.31	0.48	0.35	0.29	0.37	0.31	0.37	0.41	0.34	0.31	0.37	0.34	0.23	0.37	0.23	0.31	0.27	0.32	0.33	0.41	0.17	0.6	0.89	1
41	0.87	0.53	0.48	0.3	0.48	0.56	0.4	0.24	0.25	0.44	0.35	0.44	0.35	0.21	0.31	0.46	0.33	0.48	0.39	0.34	0.41	0.31	0.4	0.42	0.4	0.36	0.42	0.34	0.27	0.39	0.26	0.35	0.32	0.34	0.36	0.43	0.21	0.48	0.81	0.93	1
42	0.72	0.41	0.39	0.23	0.37	0.5	0.34	0.19	0.15	0.37	0.33	0.4	0.32	0.21	0.31	0.37	0.26	0.38	0.33	0.3	0.34	0.28	0.33	0.35	0.3	0.36	0.36	0.21	0.25	0.31	0.24	0.32	0.31	0.29	0.36	0.39	0.2	0.29	0.62	0.76	0.86	1
43	0.55	0.23	0.19	0.07	0.12	0.22	0.12	0.03	0.05	0.21	0.15	0.21	0.29	0.02	0.2	0.28	0.21	0.3	0.18	0.07	0.16	0.11	0.31	0.26	0.13	0.15	0.15	0.19	0.08	0.18	0.15	0.15	0.16	0.18	0.21	0.27	-.20	0.8	0.71	0.63	0.58	0.47	1
44	0.75	0.39	0.36	0.27	0.38	0.41	0.24	0.10	0.12	0.27	0.26	0.28	0.27	0.04	0.18	0.36	0.2	0.34	0.25	0.10	0.21	0.16	0.28	0.27	0.19	0.2	0.21	0.24	0.05	0.19	0.18	0.023	0.22	0.27	0.25	0.33	-.02	0.61	0.82	0.81	0.75	0.65	0.77	1
45	0.77	0.41	0.41	0.28	0.41	0.46	0.3	0.13	0.14	0.31	0.29	0.33	0.26	0.07	0.2	0.36	0.18	0.33	0.28	0.17	0.26	0.24	0.3	0.31	0.24	0.24	0.26	0.27	0.14	0.26	0.21	0.26	0.26	0.29	0.26	0.35	0.07	0.52	0.77	0.82	0.81	0.71	0.67	0.91	1
46	0.77	0.42	0.42	0.27	0.4	0.48	0.37	0.19	0.13	0.38	0.29	0.37	0.34	0.14	0.27	0.41	0.2	0.36	0.3	0.26	0.31	0.29	0.32	0.35	0.31	0.34	0.36	0.3	0.13	0.28	0.23	0.34	0.29	0.35	0.27	0.4	0.16	0.42	0.71	0.81	0.85	0.82	0.59	0.83	0.87	1
47	0.68	0.32	0.33	0.19	0.29	0.36	0.33	0.15	0.12	0.28	0.2	0.27	0.16	0.11	0.15	0.22	0.18	0.25	0.25	0.22	0.27	0.19	0.28	0.28	0.22	0.19	0.23	0.2	0.11	0.20	0.14	0.22	0.19	0.27	0.2	0.29	0.22	0.31	0.51	0.64	0.63	0.55	0.35	0.51	0.57	0.57	1
48	0.61	0.4	0.36	0.26	0.33	0.38	0.24	0.18	0.17	0.16	0.13	0.18	0.16	0.05	0.12	0.27	0.16	0.3	0.2	0.22	0.25	0.19	0.21	0.24	0.16	0.17	0.18	0.2	0.16	0.24	0.09	0.2	0.15	0.27	0.17	0.26	0.2	0.3	0.45	0.54	0.54	0.43	0.33	0.44	0.47	0.46	0.42	1
49	0.73	0.53	0.51	0.4	0.44	0.47	0.41	0.25	0.21	0.23	0.21	0.26	0.29	0.12	0.23	0.35	0.26	0.34	0.26	0.26	0.27	0.32	0.29	0.36	0.26	0.27	0.31	0.29	0.15	0.29	0.16	0.26	0.21	0.28	0.22	0.29	0.25	0.39	0.59	0.67	0.62	0.53	0.37	0.51	0.55	0.56	0.51	0.42	1
50	0.71	0.44	0.42	0.25	0.38	0.4	0.31	0.2	0.19	0.24	0.15	0.24	0.2	0.05	0.14	0.31	0.26	0.34	0.2	0.21	0.22	0.21	0.28	0.29	0.19	0.19	0.22	0.2	0.13	0.22	0.18	0.26	0.23	0.19	0.2	0.22	0.13	0.41	0.58	0.65	0.59	0.48	0.4	0.53	0.54	0.52	0.45	0.45	0.57	1
51	0.52	0.29	0.26	0.2	0.28	0.34	0.27	0.06	0.22	0.26	0.17	0.24	0.18	0.07	0.13	0.23	0.27	0.32	0.13	0.17	0.16	0.10	0.28	0.24	0.10	0.16	0.13	0.27	0.14	0.24	0.08	0.17	0.13	0.16	0.24	0.23	0.18	0.31	0.46	0.51	0.48	0.39	0.31	0.43	0.44	0.41	0.4	0.36	0.36	0.35	1
52	0.68	0.27	0.29	0.25	0.31	0.33	0.3	0.19	0.22	0.25	0.11	0.21	0.15	0.13	0.15	0.33	0.2	0.33	0.24	0.2	0.26	0.24	0.24	0.29	0.23	0.21	0.24	0.28	0.15	0.27	0.13	0.19	0.16	0.25	0.26	0.32	0.19	0.38	0.55	0.64	0.6	0.44	0.39	0.53	0.54	0.56	0.47	0.39	0.48	0.49	0.33	1
53	0.86	0.48	0.47	0.35	0.47	0.49	0.42	0.25	0.29	0.31	0.24	0.32	0.32	0.18	0.28	0.41	0.28	0.42	0.27	0.28	0.32	0.29	0.34	0.38	0.29	0.3	0.33	0.3	0.2	0.33	0.17	0.27	0.21	0.28	0.29	0.35	0.26	0.47	0.71	0.8	0.76	0.62	0.46	0.61	0.63	0.64	0.58	0.59	0.63	0.64	0.44	0.6	1
54	0.94	0.49	0.48	0.32	0.48	0.51	0.45	0.22	0.29	0.32	0.19	0.29	0.33	0.14	0.27	0.42	0.28	0.42	0.3	0.27	0.32	0.3	0.32	0.37	0.31	0.3	0.33	0.31	0.18	0.32	0.17	0.29	0.23	0.25	0.3	0.33	0.27	0.52	0.79	0.88	0.82	0.68	0.51	0.69	0.7	0.72	0.65	0.54	0.68	0.67	0.47	0.62	0.8	1
55	0.88	0.49	0.47	0.32	0.45	0.48	0.41	0.22	0.29	0.27	0.19	0.27	0.28	0.15	0.25	0.36	0.31	0.4	0.26	0.32	0.33	0.29	0.36	0.39	0.29	0.33	0.33	0.28	0.24	0.34	0.14	0.31	0.22	0.26	0.29	0.33	0.22	0.5	0.74	0.82	0.78	0.64	0.49	0.63	0.65	0.67	0.59	0.55	0.67	0.62	0.45	0.61	0.78	0.83	1
56	0.77	0.46	0.48	0.28	0.44	0.44	0.4	0.18	0.23	0.29	0.18	0.28	0.25	0.12	0.21	0.36	0.23	0.37	0.3	0.24	0.31	0.26	0.27	0.31	0.26	0.24	0.27	0.22	0.12	0.24	0.17	0.28	0.22	0.25	0.21	0.27	0.26	0.39	0.64	0.73	0.66	0.55	0.41	0.59	0.59	0.61	0.58	0.5	0.57	0.57	0.41	0.55	0.66	0.77	0.68	1

Correlation is significant at the 0.01 level (2-tailed; white cells). Correlation is significant at the 0.05 level (2-tailed). Correlation is not significant

Table 3. Coefficients for hand length regression models

		Unst. Co.	St. Co.				Collinearity		
	Model	B	SE	Beta	*t*	*Sig.*	Tol	VIF	R^2
1	C	1.31	0.37		3.49	0.00			0.881
	D54	0.94	0.02	0.94	44.23	0.00	1.00	1.00	
2	C	0.57	0.30		1.87	0.06			0.925
	D54	0.56	0.04	0.56	15.92	0.00	0.23	4.30	
	D40	0.43	0.03	0.44	12.44	0.00	0.23	4.30	
3	C	0.35	0.27		1.27	0.20			0.940
	D54	0.45	0.03	0.44	13.01	0.00	0.19	5.13	
	D40	0.33	0.03	0.34	10.20	0.00	0.20	4.90	
	D55	0.23	0.03	0.24	8.17	0.00	0.27	3.65	
4	C	0.29	0.25		1.16	0.25			0.949
	D54	0.39	0.03	0.39	12.12	0.00	0.18	5.43	
	D40	0.28	0.03	0.28	8.91	0.00	0.19	5.25	
	D55	0.18	0.03	0.19	6.83	0.00	0.26	3.90	
	D53	0.16	0.02	0.18	6.83	0.00	0.29	3.39	
5	C	0.35	0.25		1.43	0.15			0.952
	D54	0.40	0.03	0.40	12.62	0.00	0.18	5.44	
	D40	0.19	0.04	0.19	5.01	0.00	0.12	8.11	
	D55	0.18	0.03	0.19	7.11	0.00	0.26	3.90	
	D53	0.17	0.02	0.18	7.29	0.00	0.29	3.41	
	D45	0.13	0.03	0.10	3.97	0.00	0.32	3.17	
6	C	0.52	0.25		2.10	0.04			0.954
	D54	0.39	0.03	0.39	12.62	0.00	0.18	5.46	
	D40	0.18	0.04	0.18	4.73	0.00	0.12	8.20	
	D55	0.18	0.03	0.18	6.88	0.00	0.25	3.94	
	D53	0.16	0.02	0.17	6.96	0.00	0.29	3.47	
	D45	0.12	0.03	0.09	3.84	0.00	0.31	3.18	
	D52	0.05	0.01	0.06	3.18	0.00	0.55	1.80	
7	C	0.46	0.24		1.90	0.06			0.956
	D54	0.39	0.03	0.39	12.70	0.00	0.18	5.47	
	D40	0.18	0.04	0.18	4.89	0.00	0.12	8.20	
	D55	0.17	0.03	0.17	6.62	0.00	0.25	3.99	
	D53	0.14	0.02	0.15	6.09	0.00	0.27	3.68	
	D45	0.11	0.03	0.08	3.61	0.00	0.31	3.20	
	D52	0.05	0.01	0.06	3.27	0.00	0.55	1.80	
	D48	0.09	0.03	0.05	3.23	0.00	0.63	1.60	
8	C	0.48	0.24		2.01	0.05			0.958
	D54	0.37	0.03	0.37	12.26	0.00	0.18	5.61	
	D40	0.17	0.04	0.18	4.77	0.00	0.12	8.24	
	D55	0.15	0.03	0.16	6.13	0.00	0.24	4.10	
	D53	0.14	0.02	0.15	5.88	0.00	0.27	3.71	
	D45	0.11	0.03	0.08	3.57	0.00	0.31	3.21	
	D52	0.05	0.01	0.06	3.32	0.00	0.55	1.80	
	D48	0.09	0.03	0.05	3.32	0.00	0.63	1.60	
	D49	0.09	0.03	0.06	3.16	0.00	0.49	2.05	

DOI: 10.3844/ajeassp.2016.877.888

Table 3. Continue

9	C	0.91	0.28		3.27	0.00			0.959
	D54	0.37	0.03	0.37	12.18	0.00	0.18	5.64	
	D40	0.19	0.04	0.19	5.27	0.00	0.12	8.49	
	D55	0.16	0.02	0.16	6.35	0.00	0.24	4.11	
	D53	0.14	0.02	0.15	6.00	0.00	0.27	3.71	
	D45	0.10	0.03	0.08	3.31	0.00	0.31	3.24	
	D52	0.05	0.01	0.06	3.48	0.00	0.55	1.81	
	D48	0.09	0.03	0.06	3.49	0.00	0.63	1.60	
	D49	0.10	0.03	0.06	3.35	0.00	0.49	2.06	
	D30	–0.13	0.05	–0.04	–2.91	0.00	0.84	1.19	
10	C	0.72	0.29		2.51	0.01			0.960
	D54	0.35	0.03	0.35	11.58	0.00	0.17	5.87	
	D40	0.20	0.04	0.21	5.65	0.00	0.11	8.73	
	D55	0.16	0.02	0.17	6.54	0.00	0.24	4.12	
	D53	0.13	0.02	0.14	5.82	0.00	0.27	3.74	
	D45	0.11	0.03	0.08	3.55	0.00	0.31	3.27	
	D52	0.05	0.01	0.06	3.40	0.00	0.55	1.81	
	D48	0.09	0.03	0.05	3.37	0.00	0.62	1.61	
	D49	0.09	0.03	0.06	3.11	0.00	0.48	2.08	
	D30	–0.18	0.05	–0.06	–3.67	0.00	0.70	1.43	
	D37	0.09	0.04	0.04	2.42	0.02	0.72	1.40	
11	C	0.69	0.28		2.44	0.02			0.961
	D54	0.34	0.03	0.34	11.05	0.00	0.16	6.06	
	D40	0.20	0.04	0.21	5.70	0.00	0.11	8.73	
	D55	0.16	0.02	0.17	6.57	0.00	0.24	4.12	
	D53	0.12	0.02	0.13	5.45	0.00	0.26	3.82	
	D45	0.11	0.03	0.08	3.51	0.00	0.31	3.27	
	D52	0.04	0.01	0.05	3.25	0.00	0.55	1.82	
	D48	0.09	0.03	0.05	3.24	0.00	0.62	1.61	
	D49	0.08	0.03	0.05	2.72	0.01	0.47	2.13	
	D30	–0.18	0.05	–0.05	–3.69	0.00	0.70	1.43	
	D37	0.09	0.04	0.04	2.65	0.01	0.71	1.41	
	D50	0.08	0.03	0.05	2.57	0.01	0.49	2.03	
12	C	0.75	0.28		2.65	0.01			0.961
	D54	0.33	0.03	0.33	10.83	0.00	0.16	6.13	
	D40	0.22	0.04	0.22	5.97	0.00	0.11	8.92	
	D55	0.16	0.02	0.17	6.72	0.00	0.24	4.13	
	D53	0.12	0.02	0.13	5.44	0.00	0.26	3.82	
	D45	0.11	0.03	0.08	3.64	0.00	0.30	3.28	
	D52	0.04	0.01	0.05	2.73	0.01	0.52	1.91	
	D48	0.09	0.03	0.05	3.46	0.00	0.61	1.63	
	D49	0.09	0.03	0.06	3.12	0.00	0.45	2.23	
	D30	–0.16	0.05	–0.05	–3.12	0.00	0.66	1.52	
	D37	0.13	0.04	0.05	3.29	0.00	0.59	1.71	
	D50	0.09	0.03	0.05	2.89	0.00	0.48	2.09	
	D02	–0.09	0.04	–0.04	–2.07	0.04	0.44	2.26	
13	C	0.66	0.28		2.32	0.02			0.962
	D54	0.33	0.03	0.33	10.83	0.00	0.16	6.14	
	D40	0.22	0.04	0.22	6.11	0.00	0.11	8.95	
	D55	0.16	0.02	0.17	6.70	0.00	0.24	4.14	
	D53	0.12	0.02	0.13	5.32	0.00	0.26	3.84	
	D45	0.11	0.03	0.08	3.57	0.00	0.30	3.28	
	D52	0.04	0.01	0.05	2.72	0.01	0.52	1.91	
	D48	0.10	0.03	0.06	3.65	0.00	0.61	1.64	
	D49	0.09	0.03	0.06	3.06	0.00	0.45	2.24	
	D30	–0.26	0.07	–0.08	–3.63	0.00	0.33	3.08	
	D37	0.14	0.04	0.06	3.53	0.00	0.58	1.73	
	D50	0.08	0.03	0.05	2.88	0.00	0.48	2.09	
	D02	–0.10	0.04	–0.05	–2.46	0.01	0.42	2.37	
	D24	0.14	0.07	0.04	2.00	0.05	0.33	3.03	

Table 4. Multiple regression equations in terms of hand length and hand breadth

	Model coefficients			Model accuracy			Model coefficients			Model accuracy	
Dim.	Constant	D_1	D_2	R^2	SE	Dim.	Constant	D_1	D_2	R^2	SE
D1	0.000	1.000	0.0000	1.000	0.000	D29	0.955	0.012	0.052	0.057	0.098
D2	0.000	0.000	1.000	1.000	0.000	D30	2.297	0.026	0.304	0.254	0.201
D3	3.879	0.080	1.737	0.737	0.381	D31	0.682	–0.001	0.083	0.112	0.080
D4	5.311	0.003	2.077	0.418	0.854	D32	0.140	0.010	0.105	0.238	0.073
D5	3.871	0.274	1.789	0.482	0.781	D33	1.567	0.005	0.287	0.197	0.205
D6	3.986	0.362	1.865	0.513	0.807	D34	0.453	0.004	0.121	0.253	0.075
D7	4.272	0.119	1.112	0.441	0.497	D35	0.653	0.021	0.046	0.119	0.770
D8	1.285	0.016	0.156	0.127	0.161	D36	1.596	0.042	0.276	0.249	0.201
D9	1.424	0.056	0.353	0.163	0.339	D37	2.177	–0.003	0.481	0.268	0.274
D10	0.528	0.023	0.125	0.217	0.104	D38	–1.046	0.619	–0.190	0.290	0.707
D11	0.591	–0.005	0.150	0.233	0.094	D39	0.117	0.837	0.165	0.662	0.487
D12	1.769	0.026	0.437	0.286	0.285	D40	0.127	0.910	0.151	0.856	0.302
D13	0.350	0.006	0.140	0.281	0.082	D41	–0.830	0.842	0.270	0.765	0.392
D14	0.605	–0.009	0.102	0.146	0.078	D42	–1.337	0.736	0.247	0.517	0.580
D15	1.607	–0.007	0.386	0.270	0.216	D43	–1.292	0.441	–0.118	0.309	0.485
D16	0.412	0.019	0.138	0.367	0.075	D44	–0.592	0.571	0.024	0.559	0.399
D17	0.722	0.014	0.084	0.166	0.080	D45	–0.589	0.562	0.024	0.597	0.365
D18	1.491	0.065	0.358	0.354	0.211	D46	–1.910	0.564	0.067	0.290	0.376
D19	0.499	0.007	0.118	0.266	0.073	D47	1.571	0.468	–0.049	0.460	0.335
D20	0.235	0.005	0.127	.258	0.079	D48	–0.275	0.325	0.167	0.383	0.364
D21	1.176	0.023	0.378	0.321	0.205	D49	–1.371	0.383	0.299	0.560	0.321
D22	0.747	0.009	0.120	0.242	0.080	D50	–0.809	0.397	0.134	0.511	0.328
D23	0.543	0.026	0.085	0.191	0.090	D51	0.580	0.257	0.035	0.267	0.342
D24	2.138	0.049	0.321	0.305	0.204	D52	–3.007	0.902	–0.282	0.468	0.701
D25	0.400	0.004	0.124	0.264	0.074	D53	–0.499	0.898	0.134	0.750	0.418
D26	.177	0.010	0.116	0.240	0.080	D54	0.725	0.828	0.039	0.881	0.267
D27	1.143	0.017	0.362	0.317	0.195	D55	0.005	0.880	0.131	0.784	0.372
D28	0.550	0.004	0.138	0.295	0.76	D56	–1.723	0.881	0.373	0.606	0.547

Table 5. Multiple regression equations in terms of hand length and fist circumference

	Model coefficients			Model accuracy			Model coefficients			Model accuracy	
Dim.	Constant	D_1	D_6	R^2	SE	Dim.	Constant	D_1	D_6	R^2	SE
D1	0.000	1.000	0.000	1.000	0.000	D29	0.897	0.006	0.023	0.082	0.097
D2	1.742	0.091	0.164	0.500	0.246	D30	2.480	0.029	0.085	0.230	0.205
D3	6.231	0.189	0.365	0.479	0.537	D31	0.611	0.009	0.035	0.185	0.077
D4	6.788	0.035	0.561	0.351	0.903	D32	0.173	0.009	0.032	0.240	0.074
D5	4.195	0.232	0.571	0.506	0.763	D33	0.501	0.011	0.103	0.250	0.199
D6	0.000	0.000	1.000	1.000	0.000	D34	0.511	0.003	0.035	0.238	0.076
D7	5.649	0.179	0.179	0.245	0.321	D35	0.600	0.016	0.021	0.150	0.076
D8	1.335	0.013	0.048	0.127	0.161	D36	1.592	0.031	0.093	0.277	0.272
D9	1.094	0.018	0.150	0.239	0.323	D37	2.641	0.013	0.118	0.197	0.287
D10	0.525	0.018	0.042	0.239	0.103	D38	–1.346	0.604	–0.036	0.287	0.708
D11	0.818	0.006	0.029	0.118	0.100	D39	–0.288	0.801	0.093	0.671	0.481
D12	2.169	0.039	0.110	0.227	0.269	D40	–0.062	0.891	0.068	0.860	0.298
D13	0.506	0.012	0.033	0.202	0.086	D41	–0.901	0.827	0.096	0.769	0.389
D14	0.655	–0.009	0.030	0.134	0.079	D42	–2.089	0.675	0.120	0.534	0.570
D15	2.001	0.007	0.093	0.192	0.228	D43	–1.206	0.452	–0.048	0.311	0.484
D16	0.533	0.023	0.035	0.308	0.079	D44	–0.640	0.567	0.013	0.559	0.399
D17	0.583	0.001	0.041	0.249	0.074	D45	–0.816	0.544	0.035	0.600	0.364
D18	1.456	0.049	0.124	0.401	0.203	D46	–2.204	0.539	0.050	0.596	0.373
D19	0.641	0.013	0.026	0.186	0.077	D47	–1.784	0.394	0.003	0.459	0.336
D20	0.369	0.011	0.030	0.191	0.083	D48	0.013	0.340	0.030	0.376	0.366
D21	1.627	0.042	0.085	0.227	0.219	D49	–0.800	0.414	0.047	0.535	0.330
D22	0.898	0.016	0.026	0.169	0.085	D50	–0.469	0.418	0.013	0.504	0.330
D23	0.489	0.019	0.034	0.236	0.087	D51	0.372	0.240	0.031	0.272	0.341
D24	2.318	0.051	0.091	0.285	0.207	D52	–3.667	0.864	–0.033	0.462	0.705
D25	0.484	0.006	0.034	0.288	0.077	D53	–0.382	0.902	0.034	0.750	0.418
D26	0.274	0.013	0.030	0.199	0.082	D54	0.697	0.924	0.016	0.881	0.267
D27	1.404	0.022	0.097	0.270	0.202	D55	0.385	0.903	0.008	0.782	0.374
D28	0.695	0.010	0.033	0.216	0.081	D56	–1.174	0.843	0.028	0.600	0.550

Discussion

The descriptive statistics given in this study can be considered a basis for developing a comprehensive anthropometric database. Additionally, for the values of SW, Sk and Ku, 98.23% of the collecting readings of the 56-dimensional variable fit to a normal curve because of the data cleaning procedure adopted for the data set.

All correlation coefficients between the 56 hand dimensions were positively related except for the relationship between "Digit 1: Height, perpendicular to wrist crease" and "Digit 2: Distal inter-phalangeal joint depth," which is negative, but near to zero. Further, 93.89% of the coefficients are significant at a level of 1%. In addition, 3.25% of coefficients are significant at the level of 5% and all the remaining coefficients (2.86%) were found to have no significance.

The results of the current study show that 29.80% of the correlation coefficients ($0.50 < r \leq 1.00$) show a strong relationship between hand dimensions, 2.05% of correlation coefficients ($0.30 \leq r < 0.50$) are moderately correlated and 68.15% of correlation coefficients ($0.00 \leq r < 0.30$) are poorly correlated. In addition, the mean correlation coefficient is 0.40, indicating that there is a moderately significant correlation between hand dimensions.

The average R^2 of the prediction models is 0.948, which indicates a good linear relationship between hand dimensions. Thus, the designers of man-machine systems and hand tools used by the age range in this study can use the statistics and prediction equations presented in this work. The prediction equations illustrated in Tables 4 and 5 could be deployed for predicting 56 hand dimensions with 95% confidence by evaluating hand breadth, fist circumference and hand length. The average R^2 for estimating all hand dimensions from hand length and hand breadth is 0.396, in contrast to that of estimating all hand dimensions from hand length and fist circumference, which is 0.383.

Conclusion

Fifty-six hand measurements of Saudi Arabian adult males, aged 20-26 years, who were enrolled in engineering programs at KKU were collected and summarized. The data was then analyzed using correlation and multiple regression. These data will be of great value for designing new products, hand tools, workstations, gloves (Hsiao *et al*., 2015), personal protective equipment for engineering students and other practical applications, especially user-friendly man-machine systems. This is the first ever large-scale hand anthropometric measurement of engineering students in Saudi Arabia and it will be a considerable contribution to the anthropometric data of Saudi Arabia. In addition, this study provides a bivariate correlation analysis using Pearson's correlation coefficient to measure the relationship between the 56 hand dimensions at 0.01 and 0.05 significance levels. The analysis shows positive significant correlations among all dimensions except for between "Digit 1: Height, perpendicular to wrist crease" and "Digit 2: Distal inter-phalangeal joint depth." Furthermore, the study provides multivariate regression models for estimating any hand dimension from all other hand dimensions and 13 regression models for estimating hand length.

A natural expansion of this work is to investigate the interaction between the collected hand measurements and physical abilities of the hand such as gripping strength. A larger sample size in terms of gender, age range, region and other occupational groups should be investigated to obtain proper anthropometric data for the ergonomic design of practical man-machine systems in Saudi Arabia. In addition, we could expand this work by conducting a survey to compare the hand anthropometric characteristics of Saudi people with other populations or use this data to create biomechanical hand models.

Acknowledgement

The author is very grateful to the Department of Industrial Engineering, College of Engineering, King Khalid University, Kingdom of Saudi Arabia for providing all facilities to carry out the field study. Finally, the author would like to thank the reviewers for their helpful and constructive comments that helped improving the manuscript.

Ethics

The field study was approved by the review board established in 2014 at the College of Engineering at King Khalid University that responsible for human measurement and in accordance with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

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