Anthropometric and Biomechanical Characteristics on Body Segments of Koreans

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Abstract This paper documents the physical measurements of the Korean population in order to construct a data base for ergonomic design. The dimension, volume, density, mass, and center of mass of Koreans whose ages range from 7 to 49 were investigated. Sixty-five male subjects and sixty-nine female subjects participated. Eight body segments (head with neck, trunk, thigh, shank, foot, upper arm, forearm and hand) were directly measured with a Martin-type anthropometer, and the immersion method was adopted to measure the volume of body segments. After this, densities were computed by the density equations in Drillis and Contini (1966). The reaction board method was employed for the measurement of the center of mass. Obtained data were compared with the results in the literature. The results in this paper showed different features on body segment parameters comparing with the results in the literature. The constructed data base can be applied to statistical guideline for product design, workspace design, design of clothing and tools, furniture design and construction of biomechanical models for Korean. Also, they can be extended to the application areas for Mongolian.

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Keywords: body segment, dimension, volume, density, mass, center of mass

Introduction

Anthropometric and biomechanical data are important because they can be applied to many practical areas. Since the characteristics of race, sex, and age are important factors for the statistical guideline for product design, workspace design, design of clothing and tools, furniture design, construction of biomechanical models, etc., the physical measurements of the human body are required to describe these characteristics.

In the past, researchers have relied on cadaver-based approach in doing their studies (Dempster, 1955; Clauser et al., 1969; Chandler et al., 1975). Recently, however,

researchers began to develop alternative approaches for living subjects instead of cadavers. New technologies including magnetic resonance imaging (MRI) based method (Martin et al., 1989; Mungiole and Martin, 1990), computerized tomography (CT) based method (Ackland et al., 1988; Huang and Suarez, 1983; Huang and Wu, 1976; Rodrigue and Gagnon, 1983), mathematical modeling (Hanavan, 1964), photogrammetry (Kaleps et al., 1984; Jensen, 1978), and gamma mass scanning (Brooks and Jacobs, 1975), have been used to overcome the limitations of the cadaver-based approach.

In this study, the immersion method was adopted because it allows for low measurement cost, availability, easy experimental design, and the simple calculation of the density and mass of the human body. Also, there has been very little data to date regarding young males, women, and non-Caucasian in the literature (see Mungiole and Martin, 1990). Therefore, the investigation of the dimension, volume, density and mass of Korean males and females whose ages range from 7 to 49 will present useful data for ergonomic design. The obtained data will be compared with the results by Dempster (1955), and Chandler et al. (1975).

Methods

Subjects

In this study, 65 male and 69 female volunteer subjects were recruited from primary schools, secondary schools and companies in Daejeon city. An advertisement for recruiting was appeared in a regional newspaper. According to Kim et al. (1997), the distribution of dimensions and weights of population in Daejeon city was not much different from that of dimensions and weights of population in Korea. The subjects ranged from age 7 to 49. For each sex, the subjects were divided into 5 groups: primary school students, secondary school students, and those in their twenties, thirties, and forties. There were no significant preference differences between age groups. In Table 1, means and standard deviations of statures and weights of the subjects are presented according to sex and age with sample size.

Table 1 Statures and weights of subject groups (unit: cm)

Item / Group		Male			Female		
		Mean	S.D	n	Mean	S.D	n
Stature	(7-13) yrs.	144.75	9.34	14	134.83	14.13	17
	(14-19) yrs.	168.22	7.82	13	158.53	5.28	8
	(20-29) yrs.	172.64	5.64	18	159.94	4.78	14
	(30-39) yrs.	170.56	4.51	13	160.93	5.13	15
	(40-) yrs.	166.9	4.67	7	156.19	5.55	15
Weight (kg)	(7-13) yrs.	39.18	10.26	14	31.29	8.36	17
	(14-19) yrs.	58.82	6.94	13	52.86	4.41	8
	(20-29) yrs.	68.2	8.16	18	48.99	6.38	14
	(30-39) yrs.	68.81	6.49	13	56.44	6.48	15
	(40-) yrs.	67.91	4.1	7	55.78	7.13	15

(a)

(b)

(c)

Fig. 1 Apparatuses for immersion method.

Volume measurement

Eight body segments (head with neck, trunk, thigh, shank, foot, upper arm, forearm, and hand) were measured. In order to measure the volume of each body segment, the immersion method was employed by using Archimedes's principle. Four types (type I through type IV) of apparatuses were designed (see Fig. 1). The volume of each apparatus was 849750 cc, 77270 cc, 11400 cc and 5000 cc, respectively. Figure 2 shows portions of body segments being immersed so that the volume of each body

Fig. 2 Portions of body segments immersed.

segment could be measured.

The procedure of volume measurement was as follows. First, enough water was poured into the apparatus. The volume was checked (there is a -1 mm error on reading notch marks). Next, the body segment being measured was immersed in water and the change in the volume was measured. At that time, subject wore swimming suit only. The difference indicates the volume of body segment to measure. Only the right parts of body segments were measured since it was assumed that the bodies were symmetric. Also, BTPS (body temperature and pressure saturated with water vapor) was ignored. Detailed procedure to compute the volume of each body segment is presented in Appendix A.

Density and mass calculation

The mass of each body segment could not be obtained directly because living subjects participated in this study. According to Drillis and Contini (1966), there is a method to calculate the densities of body segments using the

Fig. 3 Designed reaction board.

density of whole body. They presented linear regression equations between whole body density and each body segment density. In this study, these linear regression equations were used to compute the density of each body segment since Lim et al. (1993) reported that there was no significant difference (less than 2 kg) between actual body weight and estimated body weight even though the equations by Drillis and Contini (1966) were employed.

In order to obtain the mass of each body segment, the density of each body segment was multiplied by the volume of the corresponding body segment obtained by the immersion method.

Center of mass measurement

For the measurement of the center of mass, the reaction board method was employed since it allows to check the reaction change. The reaction board consisted of a rigid board mounted on a scale at one end and a pivot point at the other end. Figure 3 represents the designed reaction board.

Five types of postures on the reaction board were developed to measure the center of mass. Figure 4 shows postures on the reaction board. Each posture from Fig. 4 (a) to Fig. 4 (e) was designed for the center of mass of the whole body, forearm with hand, upper arm and forearm with hand, shank with foot, and thigh and shank with foot, respectively.

As mentioned earlier, since living subjects were used in this study, it is difficult to obtain the exact center of mass of each body segment. Instead of obtaining the center of mass on each body segment, the centers of masses on five body segment combinations were investigated. In order to arrive at an accurate estimation, the procedure in Winter (1979) was used for the calculation of the center of mass. Great attention was given on the exact postures of the subjects for obtaining precise data.

Fig. 4 Postures on reaction board.

Results

Eight body segments were directly measured with a Martin-type anthropometer. For the definition of body segments, see Dempster (1955) and Clauser et al. (1969). Means and standard deviations of anthropometric measurements for the subjects are shown in Appendix B (Table B1). Figure 5 represents linear regression models and correlation coefficients between weight and the volume of the whole body in each group.

The mean volumes of body segments according to age and sex are shown in Appendix B (Table B2). Also, the densities of body segments according to sex and age are presented in Appendix B (Table B3). The obtained density results were compared with Dempster (1955), and Chandler et al. (1975). Both the densities of right and left body segments in Dempster (1955) were averaged.

Given their densities and volumes, the masses of body segments can be obtained. The masses of particular body segments are shown in Appendix B (Table B4). Mass differences between whole body and actual weight imply that some estimation errors on masses of body segments existed. In order to validate the proposed method, we employ t-test in terms of real weights and estimated weights of subjects according to age and sex. Table 3 shows the test results of mean differences between real weights and estimated weights.

Mass proportions of each body segment represented as a percentage of the weight of the whole body are shown in Appendix B (Table B5). The obtained centers of masses of particular body segments are presented in Appendix B (Table B6). The values in Table B6 denote percentage from proximal end.

Fig. 5 Linear regression models between weight and volume.

Table 2 Comparisons of body segments densities (unit: kg/l)

Body Segment	Dempster	Chandler et al.	Park et al.
Upper arm	1.070	0.997	1.049
Forearm	1.125	1.043	1.115
Hand	1.155	1.079	1.129
Thigh	1.050	1.018	1.047
Shank	1.090	1.059	1.081
Foot	1.095	1.073	1.088

Discussion

In dimension measurements, as expected, the results were quite different from studies in which Caucasians were the subjects (see Table B1). These results were compatible with the article presented by Nakanishi and

Nethery (1999).

According to Fig. 5, volume and weight are highly correlated. However, designers need to note the subjects between 14 and 19 because there are several subjects who have large deviation from the values by regression equation comparing with other groups.

There are noticeable factors in the results of volume measurements (see Table B2). The mean weights and volumes of male subjects between 20 and 49 are almost the same. However, for subjects in their twenties, the volumes of thigh and foot are more than other groups. The subjects in their thirties have more volume on head with neck and less on shank comparing with other groups. The volume of the forearm segment decreases as age increases.

The mean weight and whole body volume of female subjects in their twenties are less than those of other female adult subjects. The volumes of head with neck,

Table 3 Tests of equality of means between real and estimated weights

group	n	real weight	estimated weight	difference	P
all	134	53.9903 – 14.3134	53.9136 – 14.0493	0.0707	0.967
male	65	60.1646 – 13.9361	59.9928 – 13.7346	0.1718	0.944
female	69	48.1739 – 12.1305	48.1986 – 11.8340	0.0246	0.990
7–13 (all)	31	34.8548 – 9.9430	35.1823 – 9.7075	0.3274	0.896
7–13 (male)	14	39.1786 – 10.2625	39.3486 – 10.1482	0.1700	0.965
7–13 (female)	17	31.2941 – 8.3648	31.7512 – 8.0821	0.4571	0.872
14–19 (all)	21	56.5524 – 6.6714	56.4024 – 6.6860	0.1500	0.942
14–19 (male)	13	58.8231 – 6.9404	58.7015 – 6.9222	0.1215	0.965
14–19 (female)	8	52.8625 – 4.4107	52.6663 – 4.4504	0.1962	0.931
20–29 (all)	32	59.7938 – 12.1413	59.6994 – 11.9812	0.0944	0.975
20–29 (male)	18	68.2000 – 8.1635	67.9906 – 8.0405	0.2094	0.939
20–29 (female)	14	48.9857 – 6.3817	49.0393 – 6.3409	0.0536	0.982
30–39 (all)	28	62.1821 – 8.9434	61.8032 – 8.8637	0.3789	0.874
30–39 (male)	13	68.8077 – 6.4924	68.3277 – 6.4715	0.4800	0.852
30–39 (female)	15	56.4400 – 6.4837	56.1487 – 6.4680	0.2913	0.903
40– (all)	22	59.6409 – 8.4923	59.5118 – 8.3066	0.1291	0.960
40– (male)	7	67.9143 – 4.1010	67.6343 – 4.2051	0.2800	0.902
40– (female)	15	55.7800 – 7.1256	55.7213 – 6.8950	0.0587	0.982

Mean – SD.

trunk, foot, forearm, and hand of subjects in their twenties are less than other adult groups. However, it is interesting to note that the volume of shank is the most compared with any other group, and the volume of upper arm is the most except for one group (subjects in their thirties).

The densities of body segments of subjects in primary schools (age from 7 to 13) are less than those of other groups as showed in Table B3. It is noticeable that there are much density differences between male subjects whose ages are greater than 13. For female subjects, there is a trend that density increases until age 19 and then decreases. However, density increases again when the ages of female subjects are greater than forty. According to obtained results, body segments can be divided into three groups based on density. The densities of forearm and hand are above average. However, the densities of thigh, upper arm and shank are below average.

According to Table 2, the obtained density results are between the results of Dempster (1955), and Chandler et al. (1975). In order to obtain more precise densities of body segments, CT or MRI based approaches will be needed even though they require expensive equipment and high costs.

Based on the results in Table 3, it is concluded that real weights and estimated weights of subjects were not significantly different. There were not many errors on the estimation of the mass of each body segment and the obtained results can be supported by Lim et al. (1993). Before testing equality of means, Levene's test was adopted to check the equality of variance. In all cases, equal variances were assumed based on the test results.

According to the results in Table B4, subjects in the primary school have significantly less mass than any other

groups on all body segments. However, from age 14 to age 49, there are not many mass differences between groups. Generally, male subjects have higher mass proportions of body segments than those of female subjects. However, the mass proportions of thigh for female subject groups are greater than those for male subject groups (see Table B5).

For the body segments of thigh and shank with foot, and shank with foot, female subjects in primary school have higher percentages from proximal end than male subjects in primary school (see Table B6). For any other body segments, male subjects had higher percentages from proximal end than female subjects. It is interesting to note that the subjects in their forties, primary school and secondary school students have greater percentages from proximal end than other subjects.

Conclusion

This paper presented dimensions, volumes, densities, masses and centers of body segments of Koreans according to sex and age. The one hundred twenty five participating subjects were divided into ten groups, the groups being based on sex and age.

Eight body segments were directly measured with Martin-type anthropometer and the immersion method was adopted to measure the volume of body segments. Following this, densities were computed using the density equations in Drillis and Contini (1966). For the measurement of center of mass, the reaction board method was employed. Obtained results showed different features on body segment parameters comparing with the results in the literature.

Appendix A. Volume measurement procedure

1. Whole body volume
 - (1) Record initial water level (a) of type I apparatus.
 - (2) Immerse the whole body to water (see Fig. 2 (a)).
 - (3) Record changed water level (b).
 - (4) Whole body volume = $(b - a) \cdot (\text{the base area of apparatus})$
2. Foot volume
 - (1) Record initial water level (a) of type III apparatus.
 - (2) Immerse foot to water (see Fig. 2 (g)).
 - (3) Record changed water level (b).
 - (4) Foot volume = $(b - a) \cdot (\text{the base area of apparatus})$
3. Shank volume
 - (1) Record initial water level (a) of type II apparatus.
 - (2) Immerse shank and foot to water (see Fig. 2 (d)).
 - (3) Record changed water level (b).
 - (4) Shank volume = $\{(b - a) \cdot (\text{the base area of apparatus})\} - (\text{foot volume})$
4. Thigh volume
 - (1) Record initial water level (a) of type II apparatus.
 - (2) Immerse thigh, shank and foot to water (see Fig. 2 (c)).
 - (3) Record changed water level (b).
 - (4) Thigh volume = $\{(b - a) \cdot (\text{the base area of apparatus})\} - (\text{shank volume}) - (\text{foot volume})$
5. Hand volume
 - (1) Record initial water level (a) of type IV apparatus.
 - (2) Immerse hand to water (see Fig. 2 (h)).
 - (3) Record changed water level (b).
 - (4) Hand volume = $(b - a) \cdot (\text{the base area of apparatus})$
6. Forearm volume
 - (1) Record initial water level (a) of type IV apparatus.
 - (2) Immerse upperarm, forearm and hand to water (see Fig. 2 (f)).
 - (3) Record changed water level (b).
 - (4) Forearm volume = $(b - a) \cdot (\text{the base area of apparatus}) - (\text{hand volume})$
7. Upper arm volume
 - (1) Record initial water level (a) of type II apparatus.
 - (2) Immerse forearm and hand to water (see Fig. 2 (e)).
 - (3) Record changed water level (b).
 - (4) Upper arm volume = $(b - a) \cdot (\text{the base area of apparatus}) - (\text{forearm volume}) - (\text{hand volume})$
8. Trunk volume
 - (1) Record initial water level (a) of type I apparatus.
 - (2) Immerse forearm and hand to water (see Fig. 2 (b)).
 - (3) Record changed water level (b).
 - (4) Trunk volume = $(b - a) \cdot (\text{the base area of apparatus}) - 2 \cdot (\text{thigh volume} + \text{shank volume} + \text{foot volume} + \text{upper arm volume} + \text{forearm volume} + \text{hand volume})$

Appendix B. Data sets of Korean population

Table B1 Anthropometric measures of body segments (unit: cm)

Item / Group		Male			Female		
		Mean	S.D	n	Mean	S.D	n
Cervical height	(7-13) yrs.	121.74	9.18	14	112.67	12.29	17
	(14-19) yrs.	142.68	7.0	13	134.39	4.67	8
	(20-29) yrs.	145.23	5.2	18	135.26	4.17	14
	(30-39) yrs.	144.42	4.29	13	135.88	4.5	15
	(40-) yrs.	141.49	4.57	7	131.81	5.15	15
Trochanter height	(7-13) yrs.	72.36	6.14	14	66.88	7.63	17
	(14-19) yrs.	81.9	6.14	13	77.84	2.78	8
	(20-29) yrs.	82.94	3.53	18	77.24	2.8	14
	(30-39) yrs.	81.14	3.67	13	76.35	3.53	15
	(40-) yrs.	78.7	2.87	7	74.25	3.58	15
Lateral femoral epicondyle height	(7-13) yrs.	40.8	4.07	14	35.69	4.92	17
	(14-19) yrs.	44.95	2.7	13	41.73	2.62	8
	(20-29) yrs.	44.29	2.16	18	42.03	2.66	14
	(30-39) yrs.	45.19	2.65	13	40.35	2.71	15
	(40-) yrs.	43.5	2.77	7	39.46	1.51	15
Acromion to olecranon length	(7-13) yrs.	26.5	1.99	14	24.8	2.72	17
	(14-19) yrs.	30.3	1.1	13	29.96	1.45	8
	(20-29) yrs.	42.87	1.83	18	38.94	2.2	14
	(30-39) yrs.	41.46	2.06	13	40.07	1.86	15
	(40-) yrs.	42.11	3.88	7	39.5	1.5	15
Olecranon to fingertip length	(7-13) yrs.	36.86	2.81	14	33.9	2.82	17
	(14-19) yrs.	42.38	2.69	13	40.28	1.71	8
	(20-29) yrs.	42.87	1.83	18	38.94	2.2	14
	(30-39) yrs.	41.46	2.06	13	40.07	1.86	15
	(40-) yrs.	42.11	3.88	7	39.5	1.5	15
Acromion to fingertip length	(7-13) yrs.	63.36	4.56	14	58.78	5.27	17
	(14-19) yrs.	72.68	3.29	13	70.24	2.7	8
	(20-29) yrs.	72.47	2.8	18	67.99	2.75	14
	(30-39) yrs.	72.47	2.8	13	68.97	2.87	15
	(40-) yrs.	71.76	4.39	7	67.71	2.87	15

Table B2 Volumes of body segments (unit: l)

Segment / Group		Male		Female	
		mean	S.D	mean	S.D
Wholebody	(7–13) yrs.	39.48	10.31	32.37	8.10
	(14–19) yrs.	56.23	5.77	51.36	5.75
	(20–29) yrs.	65.04	8.39	47.85	7.73
	(30–39) yrs.	65.75	5.99	55.83	6.33
	(40–49) yrs.	64.7	3.36	53.80	7.64
Head + Neck	(7–13) yrs.	4.77	0.98	4.59	1.88
	(14–19) yrs.	5.39	1.41	5.26	1.52
	(20–29) yrs.	5.45	1.21	4.66	1.05
	(30–39) yrs.	6.16	1.45	5.54	1.27
	(40–49) yrs.	5.66	1.99	5.43	1.34
Trunk	(7–13) yrs.	18.94	5.24	15.24	4.18
	(14–19) yrs.	26.55	2.81	24.52	5.26
	(20–29) yrs.	32.08	4.94	22.52	4.41
	(30–39) yrs.	34.83	3.61	27.60	3.42
	(40–49) yrs.	34.07	3.36	28.36	4.97
Thigh	(7–13) yrs.	3.96	1.76	3.57	1.18
	(14–19) yrs.	5.83	1.21	5.79	0.91
	(20–29) yrs.	6.69	1.41	5.37	1.20
	(30–39) yrs.	6.17	1.10	6.08	1.21
	(40–49) yrs.	6.12	1.09	5.51	1.00
Shank	(7–13) yrs.	1.59	0.41	1.40	0.50
	(14–19) yrs.	2.66	0.39	2.24	0.20
	(20–29) yrs.	2.69	0.60	2.31	0.47
	(30–39) yrs.	2.42	0.45	2.22	0.46
	(40–49) yrs.	2.82	0.86	1.94	0.45
Foot	(7–13) yrs.	0.72	0.17	0.64	0.11
	(14–19) yrs.	0.89	0.09	0.74	0.08
	(20–29) yrs.	0.93	0.12	0.70	0.16
	(30–39) yrs.	0.97	0.12	0.72	0.11
	(40–49) yrs.	0.87	0.08	0.72	0.16
Upper arm	(7–13) yrs.	0.84	0.23	0.75	0.30
	(14–19) yrs.	1.48	0.35	1.13	0.22
	(20–29) yrs.	1.78	0.41	1.25	0.42
	(30–39) yrs.	1.54	0.37	1.28	0.39
	(40–49) yrs.	1.39	0.30	1.06	0.29
Forearm	(7–13) yrs.	0.55	0.15	0.42	0.11
	(14–19) yrs.	0.83	0.09	0.68	0.11
	(20–29) yrs.	0.92	0.12	0.61	0.12
	(30–39) yrs.	0.90	0.13	0.71	0.11
	(40–49) yrs.	0.90	0.09	0.68	0.11
Hand	(7–13) yrs.	0.24	0.05	0.19	0.04
	(14–19) yrs.	0.36	0.05	0.30	0.03
	(20–29) yrs.	0.37	0.04	0.26	0.04
	(30–39) yrs.	0.38	0.03	0.29	0.05
	(40–49) yrs.	0.38	0.03	0.31	0.05

Table B3 Densities of body segments (unit: kg/l)

Segment / Group		Male		Female	
		mean	S.D	mean	S.D
Wholebody	(7–13) yrs.	0.993	0.037	0.965	0.055
	(14–19) yrs.	1.045	0.034	1.034	0.062
	(20–29) yrs.	1.050	0.021	1.03	0.055
	(30–39) yrs.	1.047	0.032	1.011	0.038
	(40–49) yrs.	1.050	0.032	1.048	0.049
Thigh	(7–13) yrs.	1.008	0.026	0.987	0.033
	(14–19) yrs.	1.044	0.024	1.036	0.043
	(20–29) yrs.	1.047	0.015	1.033	0.038
	(30–39) yrs.	1.045	0.022	1.021	0.026
	(40–49) yrs.	1.047	0.022	1.046	0.034
Shank	(7–13) yrs.	1.036	0.029	1.011	0.038
	(14–19) yrs.	1.077	0.026	1.068	0.049
	(20–29) yrs.	1.081	0.017	1.060	0.041
	(30–39) yrs.	1.078	0.025	1.054	0.032
	(40–49) yrs.	1.081	0.025	1.079	0.039
Foot	(7–13) yrs.	1.044	0.029	1.023	0.042
	(14–19) yrs.	1.085	0.026	1.076	0.048
	(20–29) yrs.	1.088	0.017	1.068	0.040
	(30–39) yrs.	1.086	0.024	1.060	0.031
	(40–49) yrs.	1.088	0.024	1.095	0.033
Upper arm	(7–13) yrs.	1.000	0.032	0.980	0.046
	(14–19) yrs.	1.045	0.029	1.035	0.057
	(20–29) yrs.	1.049	0.018	1.029	0.048
	(30–39) yrs.	1.047	0.027	1.016	0.032
	(40–49) yrs.	1.049	0.027	1.048	0.042
Forearm	(7–13) yrs.	1.041	0.048	1.005	0.071
	(14–19) yrs.	1.109	0.044	1.095	0.080
	(20–29) yrs.	1.115	0.028	1.089	0.071
	(30–39) yrs.	1.111	0.041	1.065	0.049
	(40–49) yrs.	1.115	0.041	1.113	0.064
Hand	(7–13) yrs.	1.030	0.065	0.981	0.095
	(14–19) yrs.	1.120	0.058	1.101	0.107
	(20–29) yrs.	1.129	0.037	1.094	0.095
	(30–39) yrs.	1.123	0.055	1.062	0.065
	(40–49) yrs.	1.128	0.055	1.126	0.086

Table B4 Masses of body segments (unit: kg)

Segment / Group		Male		Female	
		mean	S.D	mean	S.D
Weight	(7-13) yrs.	39.18	10.26	31.29	8.36
	(14-19) yrs.	58.82	6.94	52.81	4.41
	(20-29) yrs.	68.20	8.16	48.99	6.38
	(30-39) yrs.	68.81	6.49	56.44	6.48
	(40-49) yrs.	67.91	4.10	56.21	7.19
Wholebody	(7-13) yrs.	40.88	10.57	35.17	8.77
	(14-19) yrs.	58.87	6.52	53.15	5.44
	(20-29) yrs.	66.77	7.70	51.13	6.97
	(30-39) yrs.	69.01	6.28	58.99	6.35
	(40-49) yrs.	67.99	3.64	56.41	8.53
Thigh	(7-13) yrs.	3.99	1.78	3.52	1.19
	(14-19) yrs.	6.10	1.36	5.99	0.89
	(20-29) yrs.	6.99	1.41	5.52	1.12
	(30-39) yrs.	6.45	1.18	6.22	1.29
	(40-49) yrs.	6.42	1.19	5.73	1.09
Shank	(7-13) yrs.	1.65	0.44	1.42	0.54
	(14-19) yrs.	2.87	0.44	2.39	0.22
	(20-29) yrs.	2.90	0.65	2.44	0.47
	(30-39) yrs.	2.61	0.48	2.33	0.49
	(40-49) yrs.	3.05	0.92	2.11	0.47
Foot	(7-13) yrs.	0.75	0.18	0.65	0.13
	(14-19) yrs.	0.96	0.11	0.79	0.08
	(20-29) yrs.	1.01	0.13	0.74	0.16
	(30-39) yrs.	1.05	0.14	0.76	0.12
	(40-49) yrs.	0.94	0.09	0.78	0.16
Upper arm	(7-13) yrs.	0.84	0.23	0.74	0.32
	(14-19) yrs.	1.56	0.39	1.17	0.21
	(20-29) yrs.	1.87	0.43	1.27	0.38
	(30-39) yrs.	1.61	0.38	1.29	0.38
	(40-49) yrs.	1.47	0.34	1.11	0.29
Forearm	(7-13) yrs.	0.57	0.16	0.43	0.12
	(14-19) yrs.	0.93	0.12	0.74	0.1
	(20-29) yrs.	1.03	0.14	0.66	0.11
	(30-39) yrs.	0.99	0.17	0.76	0.12
	(40-49) yrs.	1.01	0.12	0.76	0.12
Hand	(7-13) yrs.	0.25	0.05	0.19	0.05
	(14-19) yrs.	0.40	0.06	0.33	0.04
	(20-29) yrs.	0.42	0.05	0.29	0.05
	(30-39) yrs.	0.43	0.04	0.31	0.05
	(40-49) yrs.	0.43	0.05	0.35	0.06

Table B5 Mass proportions of body segments (unit: %)

Segment / Group		Male		Female	
		mean	S.D	mean	S.D
Thigh	(7-13) yrs.	9.87	1.99	10.77	2.16
	(14-19) yrs.	10.32	1.36	11.39	1.93
	(20-29) yrs.	10.48	1.58	11.25	1.76
	(30-39) yrs.	9.33	1.12	10.95	1.42
	(40-49) yrs.	9.48	1.86	10.25	1.92
Shank	(7-13) yrs.	4.26	0.77	4.37	1.11
	(14-19) yrs.	4.89	0.53	4.54	0.44
	(20-29) yrs.	4.25	0.74	4.89	0.78
	(30-39) yrs.	3.81	0.67	4.08	0.83
	(40-49) yrs.	4.47	1.21	3.74	0.57
Foot	(7-13) yrs.	1.96	0.35	2.16	0.40
	(14-19) yrs.	1.64	0.16	1.50	0.19
	(20-29) yrs.	1.49	0.19	1.49	0.27
	(30-39) yrs.	1.54	0.23	1.34	0.16
	(40-49) yrs.	1.39	0.13	1.39	0.23
Upper arm	(7-13) yrs.	2.07	0.42	2.33	0.78
	(14-19) yrs.	2.62	0.43	2.25	0.45
	(20-29) yrs.	2.73	0.49	2.57	0.55
	(30-39) yrs.	2.33	0.41	2.28	0.53
	(40-49) yrs.	2.15	0.44	1.96	0.37
Forearm	(7-13) yrs.	1.45	0.12	1.37	0.10
	(14-19) yrs.	1.58	0.13	1.39	0.12
	(20-29) yrs.	1.51	0.17	1.34	0.12
	(30-39) yrs.	1.45	0.21	1.35	0.14
	(40-49) yrs.	1.48	0.13	1.35	0.12
Hand	(7-13) yrs.	0.65	0.11	0.61	0.08
	(14-19) yrs.	0.69	0.09	0.63	0.13
	(20-29) yrs.	0.61	0.07	0.58	0.07
	(30-39) yrs.	0.63	0.06	0.56	0.12
	(40-49) yrs.	0.63	0.05	0.63	0.12

Table B6 Centers of masses (unit: %)

Segment / Group		Male		Female	
		mean	S.D	mean	S.D
Foot + Shank + Thigh	(7-13) yrs.	45.3*	0.08	48.6	0.18
	(14-19) yrs.	51.7	0.09	45.9	0.08
	(20-29) yrs.	47.7	0.09	42.7	0.09
	(30-39) yrs.	43.1	0.11	41.9	0.10
	(40-49) yrs.	44.7	0.09	43.7	0.09
Foot + Shank	(7-13) yrs.	46.2	0.09	50.6	0.11
	(14-19) yrs.	51.8	0.06	48.9	0.09
	(20-29) yrs.	50.9	0.09	44.8	0.11
	(30-39) yrs.	44.2	0.12	45.1	0.11
	(40-49) yrs.	46.2	0.09	46.6	0.19
Hand + Forearm + Upper arm	(7-13) yrs.	48.3	0.11	48.2	0.12
	(14-19) yrs.	41.9	0.08	43.1	0.09
	(20-29) yrs.	40.2	0.08	39.0	0.07
	(30-39) yrs.	42.8	0.07	40.4	0.09
	(40-49) yrs.	45.6	0.08	45.3	0.11
Hand + Forearm	(7-13) yrs.	50.6	0.11	50.6	0.13
	(14-19) yrs.	43.9	0.08	38.8	0.13
	(20-29) yrs.	42.7	0.09	41.5	0.08
	(30-39) yrs.	45.6	0.08	42.4	0.09
	(40-49) yrs.	47.3	0.08	47.3	0.12

*percentage from proximal end.

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