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Body shape analyses of large persons in South Korea

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Despite the prevalence of obesity and overweight, anthropometric characteristics of large individuals have not been extensively studied. This study investigated body shapes of large persons (Broca index ≥ 20, BMI ≥ 25 or WHR > 1.0) using stature-normalised body dimensions data from the latest South Korean anthropometric survey. For each sex, a factor analysis was performed on the anthropometric data set to identify the key factors that explain the shape variability; and then, a cluster analysis was conducted on the factor scores data to determine a set of representative body types. The body types were labelled in terms of their distinct shape characteristics and their relative frequencies were computed for each of the four age groups considered: the 10s, 20s–30s, 40s–50s and 60s. The study findings may facilitate creating artefacts that anthropometrically accommodate large individuals, developing digital human models of large persons and designing future ergonomics studies on largeness.

Practitioner Summary: This study investigated body shapes of large persons using anthropometric data from South Korea. For each sex, multivariate statistical analyses were conducted to identify the key factors of the body shape variability and determine the representative body types. The study findings may facilitate designing artefacts that anthropometrically accommodate large persons.

Keywords: obesity; overweight; anthropometry; body shape; body type

1. Introduction

The prevalence of obesity and overweight has been increasing worldwide for the last few decades (James 2004; Prentice 2006; Caballero 2007). In South Korea, which is considered one of the leanest countries, more than 30% of its adult population was estimated to be obese or overweight (body mass index [BMI] $\geq 25\,\mathrm{kg/m^2}$) in 2005 (South Korea Ministry of Health and Social Affairs 2006), and this represented a 1.6 times increase from the incidence rate 10 years before. Owing to the steady increases, obese and overweight (hereafter, 'large' for the sake of brevity) persons have become the majority of population in multiple countries. Flegal et al. (2010) and Allender and Rayner (2007) reported that up to 70% of the population in the USA and the UK were large.

Despite the worldwide prevalence, however, the physical condition of obesity and overweight (hereafter, simply 'largeness') has not been extensively researched in ergonomics (Williams and Forde 2009; Buckle and Buckle 2011). It was mostly in the recent years that ergonomists identified largeness as an engineering design issue and began to investigate its ergonomics implications (Fontaine et al. 2002; Matrangola et al. 2008; Xu, Mirka, and Hsiang 2008; Park et al. 2009; Singh, Park, and Levy 2009; Singh et al. 2009; Park et al. 2010; Chambers et al. 2010; Matrangola and Madigan 2011; Miller, Matrangola, and Madigan 2011). Currently, many knowledge gaps seem to exist concerning the ergonomics implications of largeness.

One of the knowledge gaps in the ergonomics for the large is the lack of understanding of large persons' anthropometric characteristics, especially, their body shapes. Although the human body morphology has been studied in different contexts (Sheldon, Stevens, and Tucker 1940; Stunkard, Sorenson, and Schulsinger 1983; Singh 1993; Robinette 1998; Connell et al. 2006), few studies seem to have investigated the body shapes of large persons from an ergonomics perspective. To the authors' best knowledge, only one prior study by Nam, Park, and Jung (2007) analysed body shapes of large males; no ergonomics or engineering anthropometry studies seem to have investigated body shapes of large females or large persons of both sexes. The medical community uses two shape descriptors, apple and pear, to describe large individuals' body shapes. Apple-shaped individuals are described as accumulating subcutaneous and visceral fat in the abdominal area; pear-shaped persons are described as accumulating subcutaneous fat in the lower part of the abdominal wall and the gluteofemoral region. The apple and pear classification is known to be medically useful as it helps to understand the risks of largeness-associated health problems (Björntorp 1987; Kissebah and Krakower 1994; Lemieux

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and Despres 1994; Arner 1997). However, this binary classification may be too simplistic to be useful for engineering design applications. At present, some fundamental questions remain unanswered due to the lack of relevant research studies. They include the following:

- What is the extent of the inter-individual body shape variability among large individuals?
- What are the key anthropometric variables that explain the body shape variability among large persons?
- What are the representative body shapes (referred to as 'body types') of large individuals and their shape characteristics?
- What are the relative frequencies of the body types? Does the body type composition vary across different age groups?

The current knowledge gap needs to be addressed for multiple reasons: first, the knowledge on the key anthropometric variables and representative body types of large persons can help designers create various artefacts that provide adequate anthropometric accommodations to the population and, thus, enhance comfort, safety and user satisfaction during man–artefact interactions (Rasband 1994; Eynard, Fubini, and Masali 2000; Fontaine et al. 2002; Devarajan and Istook 2004; Yokota 2005). Second, an understanding of the key anthropometric variables and representative body types may provide a basis for developing digital human models (Chaffin 2001, 2005) and physical test dummies that represent the large population. Third, the knowledge on the representative body types may help ergonomists in designing future research studies on largeness. Certain research studies on largeness, for example, studies on large individuals' joint ranges of motion (Park et al. 2010) or body segment parameters (Matrangola et al. 2008; Chambers et al. 2010), may benefit from considering different body types.

The objective of this study was to: (1) determine the key anthropometric factors that explain the shape variability among large persons, (2) identify and characterise the representative body types of large individuals and (3) determine the relative frequencies of the body types for different age groups. To achieve the research goal, this study analysed large sets of static anthropometric data from the latest South Korean nationwide anthropometric survey, the SizeKorea project (Korean Agency for Technology and Standards 2004). The two sex groups were studied separately considering the significant sexual dimorphism in humans.

2. Method

The anthropometric data used in this study originated from the SizeKorea project, which is the latest nationwide anthropometric survey in South Korea. It aimed to support product design activities in various industrial sectors, including clothing, automobile, furniture and consumer electronics, by providing relevant anthropometric data to designers (Korean Agency for Technology and Standards 2004). A total of 19,700 South Koreans from 0 to 90 years of age were measured from April 2003 to November 2004 and a large-scale anthropometry database was created on the basis of the measurements. The items measured from each participant included 119 static body dimensions.

Two data sets, the male and female data sets, were prepared by identifying large individuals from the SizeKorea anthropometry database and gathering their body dimensions data. This study employed the data preparation scheme proposed by Nam, Park, and Jung (2007), which analysed large males' body shapes using the data from the SizeKorea database. Thus, the male data set is identical to the data set used by Nam, Park, and Jung (2007).

In identifying large individuals, only those who were aged between 10 and 69 yearswere considered, as many product design activities target this segment of the population. Three known largeness indexes, Broca index, BMI and waist-to-hip ratio (WHR), were utilised to define large individuals (National Research Council (US) Committee on Diet and Health 1989). The indexes are described in Table 1.

A large individual was defined as one who satisfied any one of the following conditions: Broca index ≥ 20, BMI ≥ 25 or WHR > 1.0. A total of 1444 males and 1327 females were identified from the SizeKorea database using this criterion. The large individuals were segmented into four age groups: the 10s, 20–30s, 40s–50s and 60s. For each sex, Table 2 provides the number of large individuals in each age group.

For each sex, the anthropometric data set was constructed by compiling body dimensions data of the large individuals. In doing so, only part of the 119 static body dimensions measured during the SizeKorea project were considered. Five

Table 1. Three largeness indexes.

Broca index = 100 × (actual weight − standard weight)/standard weight where standard weight = 0.9 × (stature [in cm] − 100)
Body mass index = body weight (in kg)/height squared (m^2)
Waist-to-hip ratio = waist circumference/hip circumference

Table 2. The number of large individuals in each age group.

	10s	20s–30s	40s–50s	60s	Total
Male	366	523	390	165	1444
Female	271	269	441	346	1327

ergonomics and industry domain experts participated in the selection of body dimensions. The selection criteria used were: (1) the dimensions reflect the body shape changes due to body fat accumulation or muscle mass changes and (2) the dimensions be relevant to design applications in the clothing, furniture, automobile and consumer electronics industries. A total of 33 and 36 body dimensions were selected for males and females, respectively (Table 3). The dimensions were of four types: widths, circumferences, depths and surface lengths. Graphical and video illustrations of the body dimensions and their measurement methods can be found at http://sizekorea.kats.go.kr/. Each individual's body dimensions data were normalised with respect to stature. The use of stature-normalised anthropometric data enabled describing and comparing individuals' body shape characteristics in a manner independent of stature.

Table 3. Body dimensions selected for body shape analyses.

Variable type(#)	Variables
Widths (8)	Chest breadth Bust breadth Waist breadth (omphalion) Hip width Biacromial breadth Elbow to elbow breadth Waist breadth (natural indentation) Hip breadth (sitting)
Circumferences (males: 13; females: 14)	Chest circumference Bust circumference Waist circumference (natural indentation) Waist circumference (omphalion) Hip circumference Midthigh circumference Knee circumference Calf circumference Ankle circumference Armscye circumference Upper arm circumference Trunk circumference Neck circumference^{M} Underbust circumference^{F} Wrist circumference^{F}
Depths (males: 6; females: 5)	Bust depth Hip depth Buttock-abdomen depth (sitting) Waist depth (natural indentation)^{M} Armscye depth^{M} Abdominal depth (sitting)^{M} Chest depth (standing)^{F} Body depth (standing)^{F}
Surface lengths (males: 5; females: 8)	Waist front length (omphalion) Interscye (front) Waist back length (natural indentation) Biacromion length Cervical to waist length Interscye fold (front)^{F} Crotch length (natural indentation)^{F} Back interscye fold (length)^{F}

Note: ^{M}= Males only; ^{F}= Females only.

Table 4. The factor analysis result for the male data set.

Anthropometric dimension (stature-normalised)	Factors and factor loadings: Factor 1 Waist and abdomen	Factor 2 Leg	Factor 3 Upper arm	Factor 4 Torso surface	Factor 5 Biacromial breadth	Communality
Abdominal depth (sitting)	0.93	0.06	0.09	0.03	0.05	0.87
Waist circumference (natural indentation)	0.93	0.11	0.17	0.21	0.04	0.94
Waist circumference (omphalion)	0.92	0.23	0.14	0.04	0.02	0.92
Waist depth (natural indentation)	0.92	−0.07	0.18	0.04	0.01	0.88
Buttock-abdomen depth (sitting)	0.89	−0.02	0.05	0.08	−0.02	0.81
Waist breadth (natural indentation)	0.78	0.14	0.22	0.33	0.14	0.80
Waist breadth (omphalion)	0.76	0.37	0.23	−0.02	0.07	0.78
Midthigh circumference	0.02	0.86	0.24	−0.13	0.01	0.82
Calf circumference	0.07	0.85	0.17	−0.03	0.04	0.77
Knee circumference	0.27	0.82	(0.08	−0.12	−0.07	0.78
Armscye depth	0.06	0.17	0.83	0.03	0.08	0.74
Upper arm circumference	0.26	0.19	0.76	0.06	0.19	0.72
Armscye circumference	0.31	−0.02	0.74	0.14	0.00	0.66
Waist back length (natural indentation)	0.10	−0.20	0.04	0.89	0.09	0.85
Cervical to waist length	0.21	−0.06	0.14	0.87	0.12	0.84
Biacromion length	0.05	0.10	0.06	0.05	0.92	0.86
Biacromial breadth	0.06	−0.11	0.15	0.15	0.89	0.85
% total variance explained (cumulative)	33.41	14.79	12.61	10.54	10.18	81.53

Note: The shaded regions in Table 4 indicate the anthropometric dimensions with significant factor loadings for each factor.

For each sex, a factor analysis was conducted on the corresponding anthropometric data set. The orthogonal varimax rotation method was employed (Hair et al. 1995; Johnson and Wichern 1998). The body dimensions with communalities less than 0.5 were removed during the factor analysis process. Also, the body dimensions with multiple loadings on all factors were either removed if the interpretation of meaning was difficult or were placed with the factors that are conceptually most closely related (Hair et al. 1995). The factor analysis reduced the original set of stature-normalised body dimensions into a smaller set of new composite variables called factors. The factors represent the key anthropometric variables that explain most of the body shape variability in the data set. Each large individual's body shape was represented in terms of the factors' values (factor scores). Such factor score-based body shape representation is more concise, and thus, more interpretable than the representation using the original body dimensions. Each factor was standardised with a mean of 0 and a standard deviation of 1, which further facilitated interpreting individuals' body shapes – if a male has a factor score greater than zero for a certain factor representing stature-normalised size of a body part, it indicates that he is above the average of the entire male group for that variable. Similarly, a negative factor score indicates a below-average size.

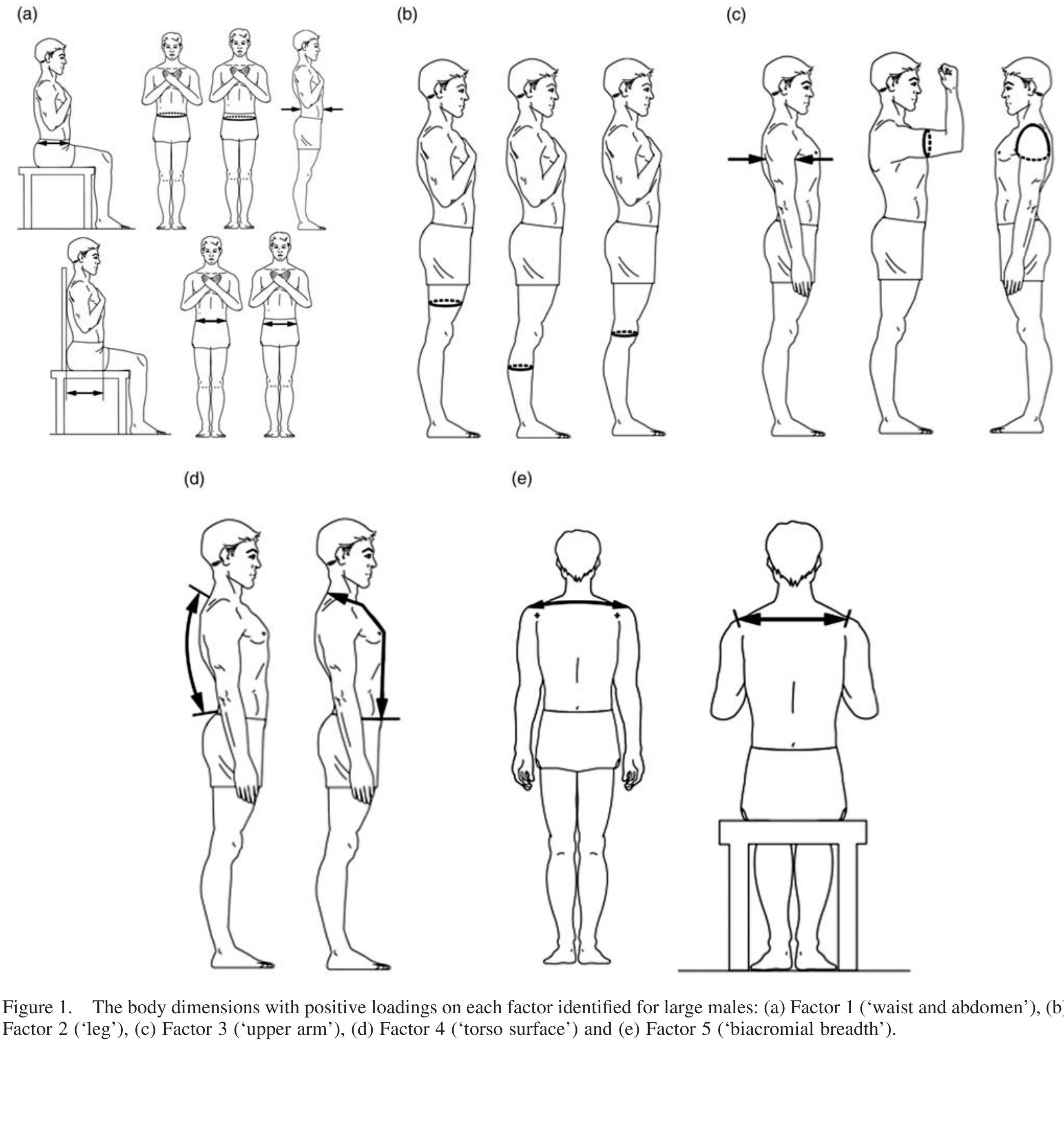

Figure 1. The body dimensions with positive loadings on each factor identified for large males: (a) Factor 1 ('waist and abdomen'), (b) Factor 2 ('leg'), (c) Factor 3 ('upper arm'), (d) Factor 4 ('torso surface') and (e) Factor 5 ('biacromial breadth').

Table 5. Cluster mean factor scores (centroid position) for each of the four male body types.

		Cluster mean factor scores					
		Factor 1: Waist and abdomen	Factor 2: Leg	Factor 3: Upper arm	Factor 4: Torso surface	Factor 5: Biacromial breadth	Relative frequencies (% total sample)
Body type	Body Type 1	0.7626[c]	1.0741[c]	0.8794[c]	0.4885[b]	0.3838[c]	10.10%
	Body Type 2	−0.1820[a]	0.7716[b]	−0.4770[a]	−0.3974[a]	−0.5495[a]	26.68%
	Body Type 3	0.0770[b]	−0.4731[a]	−0.3619[a]	1.0850[c]	0.1782[b]	23.21%
	Body Type 4	−0.1318[a]	−0.5624[a]	0.2877[b]	−0.4734[a]	0.1592[b]	40.01%

[a, b, c]The SNK test result.

Following the factor analyses, a cluster analysis was conducted for each sex using the corresponding factor scores data set. The Ward's method was employed (Johnson and Wichern 1998). The Euclidean distance between two individuals' factor score vectors (vectors consisting of factor scores) was utilised as a measure of dissimilarity. The cluster analysis was for grouping the individuals in the data set into clusters of individuals similar in body shape (factor score vector); such clusters can be considered as representing distinct body types. The Ward's method is a hierarchical clustering algorithm that iteratively joins similar entities to form clusters. Thus, the number of clusters continually decreases over iterations. In this study, the body shape classifications consisting of 3–6 body types were considered to be practically useful for the intended product design applications. To select one particular classification within that range, the widely used cubic clustering criterion (CCC) and pseudo Hotelling T^2 were employed (Hair et al. 1995).

For each sex, the selected body shape classification was evaluated as to whether its body types (clusters) significantly differ from one another in body shape characteristics. To do so, for each factor, a one-way analysis of variance (ANOVA) with post-hoc Student-Neuman–Keuls (SNK) multiple comparison tests were conducted to compare the cluster mean factor scores of the body types.

For each sex, the identified body types' shape characteristics were delineated based on their cluster mean factor scores. Also, each body type was graphically illustrated using a three-dimensional body scan image of an actual individual representative of the body type. Finally, the body type composition, that is, the relative frequencies of the body types, was determined for each of the four age groups considered.

3. Results

3.1. The male data set

The factor analysis result for the male data set is provided in Table 4. Five factors (Factors 1–5) were identified, which collectively accounted for 81.53% of the total variance.

Factor 1 showed positive loading with various circumference, breadth and depth dimensions in the waist and abdomen area (Table 4; Figure 1(a)). It was labelled the 'waist and abdomen' factor. Factor 2 exhibited positive loading with three circumference dimensions in the upper and lower leg areas (Table 4; Figure 1(b)). It was labelled the 'leg' factor. Factor 3 showed positive loading with depth and circumference variables in the armscye and upper arm area (Table 4; Figure 1(c)); it was labelled the 'upper arm' factor. Factor 4 showed positive loading with surface length variables defined in the anterior and posterior sides of the torso (Table 4; Figure 1(d)), and thus, was named as the 'torso surface' factor. Finally, Factor 5 was characterised with positive loading with biacromion length and biacromial breadth (Table 4; Figure 1(e)). It was named as the 'biacromial breadth' factor.

The clustering analysis results are provided in Table 5. Among the multiple possible classifications with three–six clusters generated by the Ward's method, the one with four clusters (thus, four body types) was selected based on the CCC and pseudo Hotelling T^2 (Hair et al. 1995).

For each of the four body types (clusters), Table 5 provides its five cluster mean factor scores (Factors 1–5), which collectively represent the cluster centroid position in the five-dimensional space. Note that each factor score is standardised with a mean of 0 and a standard deviation of 1.

The four body types were found to significantly differ from one another in body shape characteristics – one-way ANOVAs indicated that for each of the five factors, the cluster mean factor scores of the four body types were statistically not the same ($p < 0.000$). The results from the SNK tests are shown in Table 5 using alphabetic superscripts. For each factor, mean factor scores with different alphabetic superscripts are significantly different at $\alpha = 0.05$. Table 5 also provides the relative frequencies of the four body types in the entire male sample.

The four body types were given short verbal descriptors based on their cluster mean factor scores shown in Table 5:

- *Body Type 1:* All of the five cluster mean factor scores of Body Type 1 were greater than zero. Furthermore, among the four body types, it has the highest cluster mean factor scores for Factors 1, 2, 3 and 5 and has the second highest for Factor 4. Body Type 1 is thus labelled the 'large everyway' type.
- *Body Type 2:* Body Type 2 is characterised by four below-average (negative) cluster mean factor scores for Factors 1, 3, 4 and 5 and one above-average score for Factor 2. Body Type 2 is labelled the 'small figure but above-average legs' type.
- *Body Type 3:* Body Type 3 was labelled the 'large torso surface' type as its cluster mean factor score for the torso surface factor (Factor 4) is notably higher than zero by more than one standard deviation.
- *Body Type 4:* Among the four body types, Body Type 4 has the lowest cluster mean factor scores for Factors 2 (leg) and 4 (torso surface). Body Type 4 was labelled the 'small legs and small torso surface' type.

Note that the verbal descriptors above describe the body types with respect to the mean of the entire large male sample. Thus, 'small' and 'large' in the verbal descriptors mean 'small' and 'large' in comparison with the mean of the large male sample.

The four male body types are graphically illustrated in Figure 2; for each body type, an actual individual whose factor score vector is close to the cluster centroid was identified and his three-dimensional whole body laser scan image was obtained from the anthropometric database.

Table 6 provides the composition of the four male body types for each of the four age groups considered (the 10s, 20s–30s, 40s–50s and 60s). For each age group, the relative frequencies of the body types are provided. A χ^2 test for independence indicated a strong association between body type and age group ($p < 0.000$).

3.2 The female data set

The factor analysis result for the female data set is provided in Table 7. Three factors (Factors 1–3) were identified, which collectively accounted for 74.10% of the total variance.

Factor 1 showed positive loading with various circumference, depth and breadth dimensions in the entire torso area and even armscye circumference (Table 7; Figure 3(a)). It was labelled the 'torso' factor. Factor 2 showed positive loading with circumference and breadth dimensions in the lower body areas (Table 7; Figure 3(b)) and was labelled the 'lower body' factor. Factor 3 named as the 'biacromial breath' factor showed positive loading with biacromial breadth and biacromion length (Table 7; Figure 3(c)).

The clustering analysis results are provided in Table 8. The classification with four clusters (thus, four body types) was selected based on the CCC and pseudo Hotelling T^2 (Hair et al. 1995).

For each of the four body types (clusters), Table 8 provides its three cluster mean factor scores (Factors 1–3). The four body types were found to significantly differ from one another in body shape characteristics – one-way ANOVAs indicated that for each of the three factors, the cluster mean factor scores of the four body types were statistically not the same ($p <$ 0.000). The results from the SNK tests are shown in Table 8 using alphabetic superscripts ($\alpha = 0.05$). Table 8 also provides the relative frequencies of the four body types in the entire female sample.

The four body types were given short verbal descriptors based on their cluster mean factor scores (Table 8):

- *Body Type 1:* Among the four body types, Body Type 1 has the highest cluster mean factor score for Factor 1. It has the second lowest for Factor 3. Body Type 1 is labelled the 'large torso and below-average shoulder width' type.
- *Body Type 2:* Among the four body types, Body Type 2 has the highest cluster mean factor score for Factor 3 and the second lowest for Factor 2. Body Type 2 is labelled the 'wide shoulder and below-average lower body' type.
- *Body Type 3:* Body Type 3 was labelled the 'small torso and large lower body' type as it has the lowest cluster mean factor score for Factor 1 and the highest for Factor 2.
- *Body Type 4:* All of the three cluster mean factor scores were negative for Body Type 4. Moreover, Body Type 4 has the lowest cluster mean factor scores for Factors 2 and 3 and the second lowest for Factor 1. Body Type 4 is thus labelled the 'small figure' type.

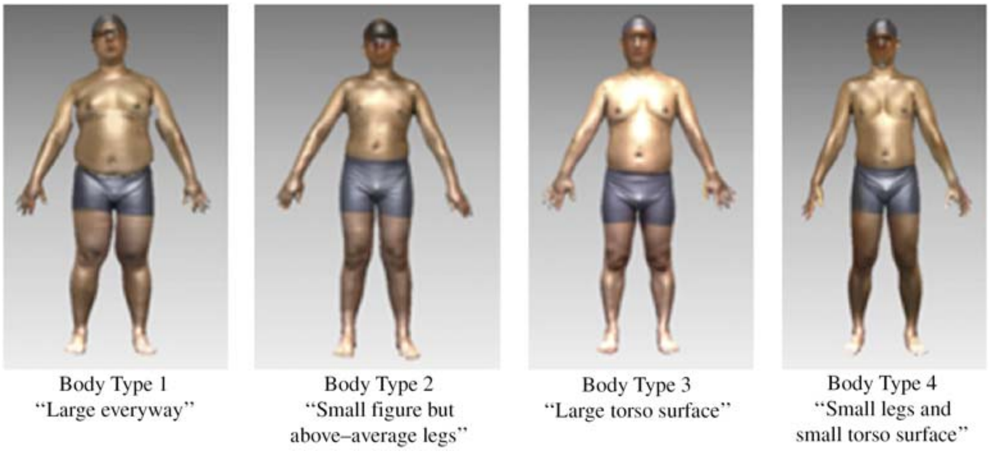

Figure 2. Body scan images representing the four male body types.

Table 6. The composition of the four male body types for each age group.

		Age group			
		10s	20s–30s	40s–50s	60s
Body type	Large everyway (Type 1)	13.25%	10.66%	9.09%	3.90%
	Small figure but above-average legs (Type 2)	68.07%	15.90%	8.82%	15.58%
	Large torso surface (Type 3)	2.41%	22.54%	36.36%	38.31%
	Small legs and small torso surface (Type 4)	16.27%	50.91%	45.72%	42.21%
	Total	100%	100%	100%	100%

Note that again, the above-mentioned verbal descriptors describe the body types with respect to the mean of the entire large female sample.

The four female body types are graphically illustrated in Figure 4 using body scan images of representative individuals.

Table 9 provides the composition of the four female body types for each of the four age groups considered (the 10s, 20s–30s, 40s–50s and 60s). A χ^2 test for independence indicated a strong association between body type and age group ($p < 0.000$).

4. Discussion

This study investigated body shapes of large persons using static anthropometric data from the SizeKorea project – the data were collected from April 2003 to November 2004. Large persons were identified from the anthropometric database using a criterion based on three largeness indexes: Broca index ≥ 20, BMI ≥ 25 or WHR > 1.0. For each sex, an anthropometric data set was prepared by compiling the large individuals' stature-normalised body dimensions data. Width, circumference, depth and surface length variables were considered. A factor analysis was performed on the data set to identify the key factors that explain the body shape variability. Then, a cluster analysis was conducted on the factor scores data to determine

Table 7. The factor analysis result for the female data set.

	Factors and factor loadings			
Anthropometric dimension	Factor 1 Torso	Factor 2 Lower body	Factor 3 Biacromial breadth	Communality
Waist circumference (natural indentation)	0.94	0.08	0.05	0.88
Waist circumference (omphalion)	0.91	0.14	0.03	0.86
Bust circumference	0.91	0.17	0.18	0.90
Bust depth	0.89	0.13	0.11	0.83
Waist breadth (natural indentation)	0.88	0.15	0.10	0.80
Underbust circumference	0.87	0.10	0.15	0.78
Body depth (standing)	0.85	0.13	−0.03	0.75
Waist breadth (omphalion)	0.85	0.22	0.07	0.78
Chest circumference	0.85	0.24	0.26	0.84
Bust breadth	0.83	0.18	0.21	0.77
Buttock-abdomen depth (sitting)	0.83	0.07	0.09	0.71
Chest depth (standing)	0.79	0.10	0.05	0.63
Trunk circumference	0.73	0.24	0.07	0.59
Elbow to elbow breadth	0.68	0.26	0.24	0.58
Armscye circumference	0.66	0.25	0.09	0.50
Midthigh circumference	0.11	0.88	0.14	0.81
Calf circumference	0.07	0.88	0.17	0.81
Knee circumference	0.16	0.88	−0.07	0.80
Hip breadth (sitting)	0.24	0.72	0.26	0.65
Biacromial breadth	0.23	0.12	0.89	0.85
Biacromion length	0.12	0.19	0.88	0.82
% total variance explained (cumulative)	48.53	16.67	8.90	74.10

Note: The shaded regions in Table 7 indicate the anthropometric dimensions with significant factor loadings for each factor.

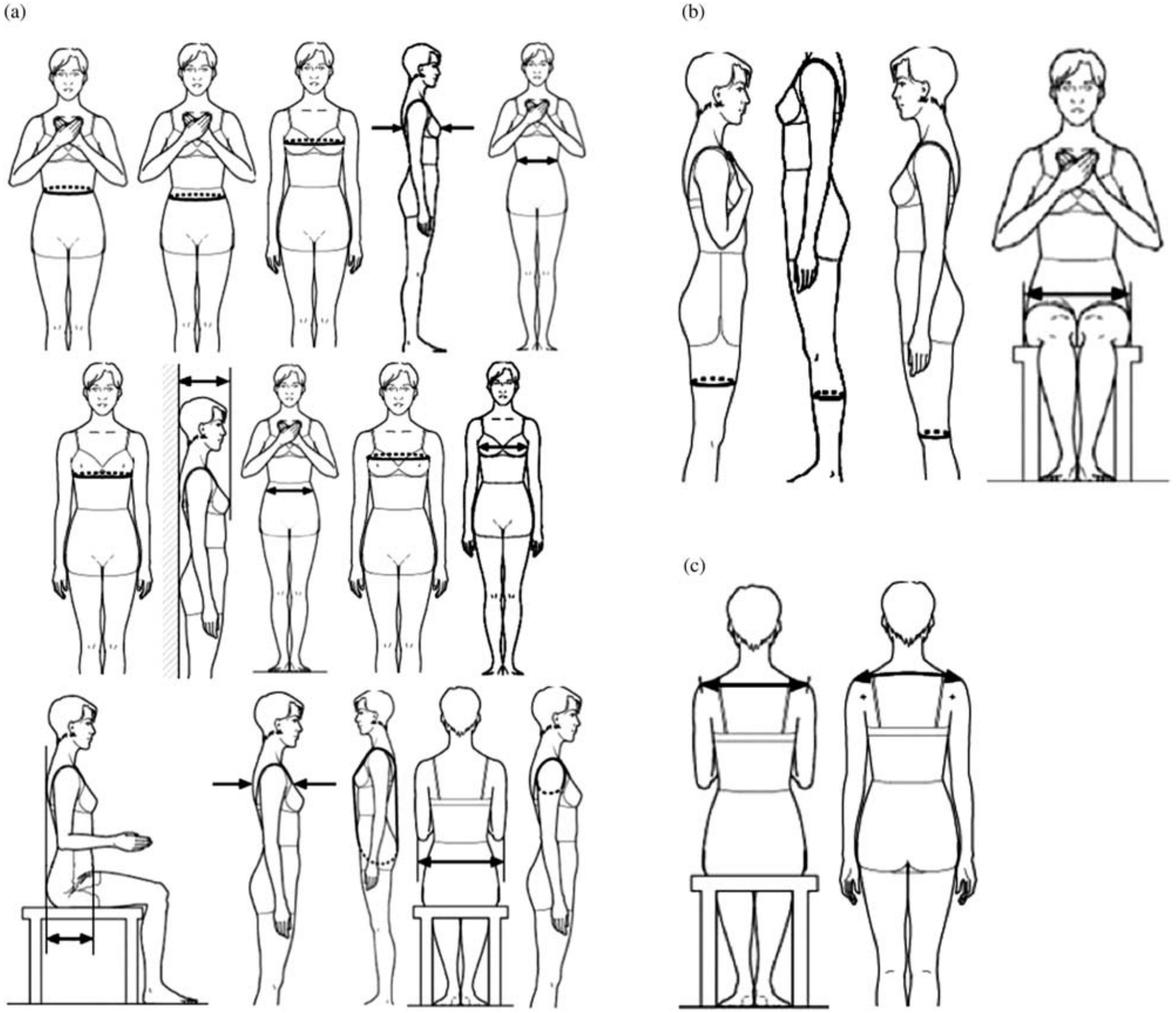

Figure 3. The body dimensions with positive loadings on each factor identified for large females: (a) Factor 1 ('torso'), (b) Factor 2 ('lower body') and (c) Factor 3 ('biacromial breadth').

Table 8. Cluster mean factor scores (centroid position) for each of the four female body types.

		Cluster mean factor scores			Relative frequencies (% total sample)
		Factor 1: Torso	Factor 2: Lower body	Factor 3: Biacromial breadth	
Body type	Body Type 1	1.1151[d]	0.1375[c]	−0.4820[b]	25.93%
	Body Type 2	0.1025[c]	−0.3920[b]	1.2377[d]	18.28%
	Body Type 3	−0.6921[a]	0.5967[d]	0.0922[c]	35.43%
	Body Type 4	−0.3548[b]	−0.9093[a]	−0.6830[a]	20.37%

[a, b, c, d]The SNK test result.

Figure 4. Body scan images representing the four body types of large Korean females.

Table 9. The composition of the four female body types for each age group.

		Age group			
		10s	20s–30s	40s–50s	60s
Body type	Large torso and below-avg. shoulder width (Type 1)	7.35%	7.60%	29.16%	49.40%
	Wide shoulder and below-avg. lower body (Type 2)	5.71%	23.20%	23.86%	16.87%
	Small torso and large lower body (Type 3)	70.61%	56.40%	23.61%	8.43%
	Small Figure (Type 4)	16.33%	12.80%	23.37%	25.30%
	Total	100%	100%	100%	100%

a set of representative body types. The identified body types were labelled in terms of their distinct shape characteristics. The body type composition was determined for each of the four age groups considered: the 10s, 20s–30s, 40s–50s and 60s.

For large males, the factor analysis identified five factors: the 'waist and abdomen', 'leg', 'upper arm', 'torso surface' and 'biacromial breadth' factors (Table 4; Figure 1). Three factors were identified for large females: the 'torso', 'lower body' and 'biacromial breadth' factors (Table 7; Figure 3). For each sex, the corresponding factors collectively define a multi-dimensional 'shape space' in which individuals' body shapes reside: a five- and a three-dimensional space for large males and females, respectively. An individual's body shape is represented as a point in the corresponding shape space – its position corresponds to the individual's factor score vector.

The clustering analyses on the factor scores data identified four body types for each sex (Tables 5 and 8): the 'large everyway', 'small figure but above-average legs', 'large torso surface' and 'small legs and small torso surface' types for large males; and the 'large torso and below-average shoulder width', 'wide shoulder and below-average lower body', 'small torso and large lower body' and 'small figure' types for large females (Figures 2 and 4). ANOVAs and SNK tests indicated that for each sex, the identified body types significantly differ from one another in body shape characteristics (Tables 5 and 8). Overall, the results from the factor and clustering analyses suggest that for each sex, there exists significant shape variability among large individuals.

The three largeness indexes used to define large individuals, that is, the Broca index, BMI and WHR, are known as body fat measures albeit measuring body fat indirectly. Therefore, it is likely that many, if not most, of the large individuals analysed were high in body fat. For such individuals, fat deposit pattern would certainly be an important determinant of body shapes. Thus, a significant part of the observed shape variability may be attributed to the inter-individual differences in body fat distribution. Fat distribution, however, is not the sole determinant of body shapes. Muscle mass distribution can play an important role as well. The three largeness indexes do not distinguish muscle mass from fat mass. Therefore, it is reasonable to think that some of the large persons had substantial muscle mass. The inter-individual differences in muscle mass and its distribution in the body may explain a significant part of the observed shape variability. The inter-individual differences in skeletal structure is yet another source of the shape variability. The 'biacromial breadth' factors found for both sexes appear to reflect the variability in skeletal structure as they correspond to distances between two bony landmarks (the acromion processes) (Figures 1(e) and 3(c)). Internal body imaging data, such as computerised tomography (CT), dual energy X-ray absorptiometry (DEXA) or magnetic resonance imaging (MRI) measurements, would elucidate the contributions of the different sources of body shape variability; however, no such data were available in this study.

An interesting result from the factor analyses was that the shape space for large males has a higher dimensionality (five-dimensional) than that for large females (three-dimensional). In other words, large males' body shapes vary along a larger number of independent axes (factors) than large females'. The result that the two body shape spaces are spanned by different bases, in itself, is not surprising as the two sexes exhibit fundamentally different anthropometric characteristics due to the sex hormonal differences (Singh 1993). However, it is not obvious why the body shape space of large males has a higher dimensionality than that of females. In what follows, an attempt was made to provide an explanation on this between-sex difference in the dimensionality of body shape space.

Closer examinations of the stature-normalised anthropometric dimensions that belong to each of the identified factors (Figures 1 and 3) led to the following observations:

- The 'biacromial breadth' factors of large males and females seem identical in their meanings.
- The 'leg' factor of large males and the 'lower body' factor of large females appear similar to each other, although a slight difference exists – the latter relates to hip breadth as well as leg circumferences while the former, only to leg circumferences.
- For large females, various anthropometric dimensions in the torso and upper arm/shoulder areas were found to belong to a single factor (the 'torso' factor), which indicates that they are all highly correlated. On the other hand, for large males, three independent factors emerged from a similar set of anthropometric dimensions: the 'waist and abdomen', 'upper arm' and 'torso surface' factors.

Perhaps, the higher dimensionality of the large males' shape space might be in part due to the sex hormonal effects on muscle mass changes. The male sex hormone, testosterone, helps individuals gain muscle masses through physical activities (Griggs et al. 1989). An adult male body is known to produce about 10 times more testosterone than an adult female body (Dabbs and Dabbs 2000). Due to the higher testosterone level, males on average can gain muscle masses more easily than females through physical activities; put differently, it is more difficult for females to change muscle masses through physical activities. It may be that this hormonal sex difference, combined with the inter-individual variability in the amount and type of habitual physical activities, gives rise to the higher dimensionality of the large males' shape space. At this time, this is only a hypothesis that attempts to explain empirical observations.

Both the large males' and females' shape spaces seem to contain the apple and pear body shapes that are widely referred to in medical research studies on obesity and overweight. For large males, the 'waist and abdomen' and 'leg' factors can jointly represent the apple and pear body shapes and any shapes in between. For large females, the 'torso' and 'lower body' factors seem able to do so. The apple shape is associated with large visceral fat masses and high risks for largeness-associated health problems, while the pear shape is considered less harmful (Björntorp 1987; Kissebah and Krakower 1994; Lemieux and Despres 1994; Arner 1997). Regarding the associations between body shapes of large persons and health risks, the shape spaces determined in this study raise some questions: what are the health risks associated with the large persons' body shapes that are neither apple nor pear? Can the 'biacromial breadth', 'upper arm' and 'torso surface' factors be predictors of health risks, and therefore, be medically useful?

The shape spaces also appear to contain the body types frequently referred to in the clothing industry, such as rectangular, oval (apple), hourglass, triangular (pear) and inverted triangular (Simmons, Istook, and Devarajan 2004a, 2004b) – for each sex, the corresponding factors seem able to jointly represent these body types. For example, the hourglass type is typically characterised as 'equally broad on top and hips, and thin at the waist' (Simmons, Istook, and Devarajan 2004a); in terms of the three factors spanning the large females' shape space, this corresponds to the combination of large 'biacromial breadth', small 'torso' and large 'lower body'. Also, the inverted triangular and triangular (pear) types seem to roughly correspond to Body Types 2 and 3 of large females, respectively. The body types of the clothing industry are widely used among fashion designers to represent the shape variability in the general population. They are associated with different clothing style preferences, and thus, serve as an important design reference (Rasband 1994). Large individuals with different body shapes would likely vary significantly in clothing style preferences. Understanding such differences would be important for improving the design of plus-size apparels.

For each sex, this study examined the body type composition for each of the four age groups considered: the 10s, 20s–30s, 40s–50s and 60s (Tables 6 and 9). χ^2 tests for independence indicated a significant association between body type and age group for each sex. A notable observation from the body type compositions of large males (Table 6) is that the 10s group and the rest of the groups are distinct from each other: Type 2 ('small figure but above-average legs') represents 68.07% of the 10s group but less than 16% of the other groups. Type 4 ('small legs and small torso surface') represents only 16.27% of the 10s group but is the majority (42.21–50.91%) in the rest of the groups. Also, Type 3 ('large torso surface') is rare in the 10s group (2.41%) but is not so in the other groups (22.54–38.31%). These differences between the 10s group and the rest of the age groups seem to be primarily due to the fact that the 10s group included individuals who had not completed the pubertal process, while the other groups are post-pubertal. Males usually complete puberty by ages 16–18 (Lee 1980; Roenneberg et al. 2004). During the male pubertal process, the gonads start producing testosterone and it brings about a number of physical changes, including broadening of the shoulders and expansion of the rib cage. Testosterone also affects fat deposit patterns – it stimulates fat deposits in the abdominal region and inhibits fat deposits in the gluteofemoral region (Singh 1993). Thus, men lose fat from buttocks and thighs after puberty and begin depositing fat centrally (Singh 1993). The testosterone effects seem to explain the small proportions of individuals with large legs and large proportions of individuals with either large torso surfaces or small legs in the 20–30s and older groups, which sharply contrast with the body type composition of the 10s group.

The body type compositions of large females (Table 9) also exhibit some notable age-associated patterns: Type 1 ('large torso and below-average shoulder width') is rare in the 10s and 20s–30s groups representing 7.35% and 7.60%, respectively. However, its proportion increases to 29.16% for the 40s–50s group and almost half (49.40%) for the 60s. On the other hand, the proportion of Type 3 ('small torso and large lower body') decreases as age increases. Type 3 is dominant in the 10s and 20–30s groups (70.61% and 56.40%, respectively) but only accounts for 23.37% of the 40s–50s group. It becomes rare for the 60s group (8.43%). These age-related patterns are thought to be related to the female sex hormones, oestrogens. During the puberty, which typically begins at the age 10 or 11 for females, the lower half of the pelvis, and thus, hips widen due to rising levels of oestrogens. Also, the oestrogens inhibit fat deposits in the abdominal region and maximally stimulate fat deposits in the gluteofemoral region compared to any other regions of the body (Björntorp 1987; Singh 1993). When females reach menopause, which typically occurs around age 50, and the oestrogens produced by ovaries decline, fat migrates from the buttocks, hips and thighs to the abdomen area, especially in the intra-abdominal region (Shimokata et al. 1989; Ley, Lees, and Stevenson 1992; Panotopoulos et al. 1996; Toth et al. 2000).

Regarding the interpretations of the body type compositions in Tables 6 and 9, it should be noted that the age groups comparisons are cross sectional. In particular, consideration should be given to the fact that South Korea has gone through rapid industrialisation and fast economic development since the 1960s, and therefore, the age groups experienced different nutritional conditions and life styles during the developmental stage. Part of the observed between-group differences could be attributed to this.

The results from this study have multiple artefact design applications: first, for a given artefact design problem, the knowledge on the key factors of shape variability and associated anthropometric dimensions can help designers understand which dimensions of the to-be-designed artefact as well as the human body are relevant to the issue of accommodating differently shaped large individuals, and thus, correctly define the problem. Second, the knowledge and data on the representative body types of large persons, including their visual representations (Figures 2 and 4), may help designers easily recognise/identify design issues related to existing artefact designs, which may not be evident without the knowledge/data. Further, they may facilitate ideating on design solutions. Third, the body type compositions data (Tables 6 and 9) will be useful when designing artefacts targeting a particular age group within the large population.

The results from this study can also guide developing digital human models that represent the large population. A compact set of representative digital human models, known as a manikin family, is an essential element of an ergonomics computer-aided-design software program and serves as a basis for simulating man-artefact interactions and conducting ergonomics analyses in the virtual world (Chaffin 2001, 2005). Multiple past studies have developed manikin families based on the analyses of multivariate anthropometric data (Meindl, Hudson, and Zehner 1993; Kim and Whang 1997; Laing, Holland, and Niven 1999; Bittner 2000; Hsiao et al. 2005; Jung, You, and Kwon 2009). Currently, our research group is developing a manikin family of large individuals based on the data and findings from this study. They would also be useful for developing physical human models (known as test dummies) that represent large persons.

The study results may also assist researchers in designing future ergonomics and/or occupational biomechanics studies on largeness. The existing largeness studies generally did not consider body type as a factor. In fact, the absence of a relevant body type classification makes it difficult to do so. Certain research studies would likely benefit from considering body type. For example, research studies that investigate the effects of largeness on human joint ranges of motion (Park et al. 2010) or body segment parameters (Matrangola et al. 2008; Chambers et al. 2011) would do so because the differences between body types, that is, the differences in fat deposit pattern or mass distribution, would directly affect local body joint ranges of motion and body segment parameters. Also, research studies that examine the effects of largeness on body balance capabilities (Matrangola and Madigan 2011; Miller, Matrangola, and Madigan 2011) or postural stresses (Park et al. 2009) may also benefit. This is expected because different body shapes imply fundamental differences in the characteristics of the underlying biomechanical system.

For each sex, this study presented a four-cluster classification based on widely used statistical criteria (the CCC and pseudo-Hotelling T^2); however, it does not mean that they represent the best or the only possible classifications. Depending on the goal and nature of a given application, an alternative classification with a different number of body types may be more desirable. The hierarchical clustering process based on the Ward's method could aid such decision-making, as alternative body type classifications can be easily identified in the dendrogram visualisation. Any classification that results in a set of statistically and practically distinct body types may be considered as a meaningful classification.

Some limitations of this study are acknowledged here with suggestions for future research studies: first, this study examined large individuals in South Korea, and thus, the findings are limited to the large population in South Korea. While many of the current findings are expected to be generalisable, further studies need to be conducted to understand the shape variability in other large populations. The large populations of North America and Europe are currently under our investigation. Second, this study analysed only static anthropometric measurements data in studying body shapes of large individuals. Thus, it does not elucidate how different body shape determinants, that is, body fat distribution, muscle mass distribution and skeletal structure, affect large individuals' body shapes. A study that examines these shape determinants as well as static anthropometric dimensions would provide a more complete understanding of large individuals' body shapes and their formations. To do so, imaging techniques, such as CT, DEXA or MRI, will need to be employed. Finally, the investigations on the body type compositions of different age groups (Tables 6 and 9) were cross sectional. While this cross-sectional study is thought to be useful for the ergonomics design of artefacts targeting the current large population, a longitudinal study would be required to determine the aging effects on large persons' body shapes more accurately.

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Note

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