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Swedish anthropometrics for product and workplace design

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A B S T R A C T

The present study describes the anthropometrics of the Swedish workforce, aged 18–65, and compares the measurements with data collected four decades earlier. This anthropometric information is based on measurements of a total of 367 subjects, 105 males and 262 females. Of the 367 subjects, 268 responded to advertisements (Study A) and 99 were randomly selected from a community register (Study B). Subjects were scanned in four positions. Manual measuring equipment was used for hands, feet, head and stature. As differences between significant measurements in Studies A and B were negligible, the data were merged. Anthropometric descriptive statistics of women and men are presented for 43 body dimensions. Participants represent the Swedish population fairly well when compared with national statistics of stature and weight. Comparing new anthropometric data with old shows that the breadth, depth, height, and length measurements of Swedes as well as weight have increased and that Swedish anthropometric homogeneity has decreased. The results indicate that there is a need to update ergonomic recommendations and adjust products and workplaces to the new information.

1. Background

Products and workplaces are preferably designed in user-centred design processes, where ergonomic principles and anthropometrics are considered (Wichansky, 2000; Pentikis et al., 2002). Anthropometry is the branch of the human sciences dealing with measurements of the size, weight and proportions of the human body to achieve comfort, fit and usability. In an ideal design process anthropometrics are compared with relevant product and workplace measurements, for example, popliteal height with chair height (Pentikis et al., 2002). All products including clothes, consumer products as well as systems of products such as office workplaces, vehicles and assembly lines need to be adjusted to user anthropometrics to maximise usability and minimise the negative effects on the user. The fit between different products or workplaces and users is not always optimal (Wichansky, 2000; Pentikis et al., 2002). Incorrect product and workplace adjustments to anthropometric characteristics lead to discomfort, pain and disorders in the neck and shoulder (Westgaard and Aaras, 1984), arm, hand, wrist (Snook, 1978) and back (Westgaard and Aaras, 1984). Musculoskeletal disorders due to these reasons have been found in different contexts such as the office (Sundelin and Hagberg, 1989), electronic assembly line (Schuldt, 1988) as well as in a driver environment (Hedberg, 1987). To minimise poor anthropometric correspondence between product or workplace and users, designers have to use correct and updated anthropometric measurements for each target group.

Body scanning techniques have revolutionised the way of conducting anthropometric surveys and more surveys are being performed worldwide. Recently published anthropometric surveys using modern scanning, picture or traditional measuring techniques deal with such groups as Taiwanese youngsters (Wang et al., 2002), Portuguese workers (Barroso et al., 2005) and elderly Australians (Kothiyal and Tettey, 2000). This and other anthropometric information is available in printed tables (Peebles and Norris, 1998; Pheasant and Haslegrave, 2006), stand-alone databases such as *Peoplesize* (Megaw, 1996), CAESAR (Robinette et al., 2002) and *WEAR* – World Ergonomic Anthropometric Resource (Paquet et al., 2000) and/or databases integrated in ergonomics simulation and visualisation tools such as *Ramsis* (Vogt et al., 2005) and *Hadrian* (Porter et al., 2004). These databases are available for use by designers in an early design phase for information such as body segment's breadth, circumference, height, length and/or weight of the group of interest. A target group can be represented by a sample of individuals. It is common in ergonomics to use percentiles, for instance the 5th, 50th and 95th. This descriptive statistical representation strategy works fine for one-dimensional issues (e.g. to determine the appropriate roof height for a wind shelter). However, it is not suitable for multidimensional issues (Ziolek and Wawrow, 2004; Robinette and Hudson, 2006). For these problems statistical

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approaches have been proposed by Bittner (2000) and Dainoff et al. (2003). They comprise the boundary approach, which involves the selection of representative individuals on the circle's edge covering the combinations of critical anthropometric measurements. A third alternative, called the distributed cases approach, is the random selection of individuals in a data set. Choice of strategy is important in acquiring a proper representation useful for evaluation. The statistical analysis should also be based on relevant and updated anthropometric sources.

Anthropometric data are measured on humans from childhood and used as an indicator of health and nutritional status. Children's stature is measured and their bodies weighed to monitor growth; consequently, such statistics are available for many populations. Stature and weight information for other age groups is available for the populations of Sweden and other countries as large scale national health and population surveys often collect such data. Military service is compulsory for males and a possibility for females in Sweden. When enrolling, recruits' stature and weight information is collected. Such data have been useful, for instance, for comparing inhabitants in the northern, western, eastern and southern regions of Sweden and showed that Swedish people were predominantly made up of the same ethnic type (Mahalanobis, 1930). Furthermore, no anthropometric differences between social classes were found in Sweden (Lindgren, 1976). Most frequently, however, humans from higher social class are taller than those from lower social classes (Pheasant and Haslegrave, 2006). The bulk of Swedish anthropometric information concerns stature and weight only. The latest published Swedish anthropometric surveys covering the whole body were performed in the late 1960s. Ingelmark and Lewin (1968) presented anthropometric information on 104 Swedish female students and employees in the area of medicine and health care. The authors stated that their article presented the first study based on a considerable number of Swedish women. Lewin (1969) published anthropometric information on Swedish industrial workers, based on manual measurements of 164 employees, 87 males and 77 females, at SKF AB, the Swedish ball bearing company. Almost four decades have passed since the above Swedish anthropometric surveys were carried out. People's body dimensions, though, continuously change, frequently referred to as a secular trend, which mirrors the conditions in society (Pheasant and Haslegrave, 2006).

Peoples's body dimensions change with economic periods: during times of welfare anthropometric measurements increase and during economic decline or war, growth slows down or is reversed. The current trend apparent in economically developed countries is increased weight and a slowdown in stature growth (Pheasant and Haslegrave, 2006). At the same time, people are more mobile, travelling and working to a greater extent in other countries. The Swedish population of today represents an integration of many ethnic groups. Consequently, there is a need for a new Swedish anthropometric study which will set a landmark for further anthropometric predictions and provide designers with an updated source for user-centred design processes of products and workplaces.

The overall objective of this research project was to present anthropometric data for the design of products and workplaces. The aim of the present study was to describe body dimensions of the Swedish workforce, including females and males aged 18–65 as well as to compare them with body dimensions four decades earlier.

2. Methods

Subjects were scanned in Lund (Study A) and Malmö (Study B) but the procedures differed in part, as two different organisations were responsible for the studies.

2.1. Equipment and procedure

Study A. The procedure consisted of four parts. In the first, subjects were assigned a unique identification number and asked to answer a questionnaire in writing including background information such as year of birth, gender, birthplace (in or outside Nordic countries) as well as shirt, bra and trouser sizes. In the second part head, hands and feet were manually measured according to the standardised procedures described by Pheasant and Haslegrave (2006). The hands and feet were placed in a fixture, where breadth and length were relocated with a set square and read off on a rigid measuring tape. Head circumference was measured with a soft measuring tape and the length and breadth with a calliper. The accuracy when using a measuring tape is ±2 mm. Head length and breadth were measured with a calliper with an accuracy of ±3 mm. Stature and body weight were also manually measured, due to scanner and picture analysis limitations (e.g. difficulty in finding the top of the head on scanned pictures due to hair). A rigid measuring tape attached to the wall and a set square were used for gathering stature data. The weight of the person was measured by a digital measuring scale with an accuracy of 0.1 kg. In total, 13 anthropometric measurements were taken manually. All measurements together with background information were entered in a database. In the third part, the subjects were asked to undress down to their underwear and to remove glasses, watches and jewellery. Subjects with long hair were asked to make a bun. 16 markers were attached to landmarks on the subjects according to Fig. 1 to facilitate later identification in analysis software. In the fourth and final part a body scanner, VITUS/Smart 3D with software ScanWorX v2.7.2, was used. The accuracy of the scanning equipment is ±0.3%. The subjects were scanned in four positions described in ISO/DIS 20685 (2004) and illustrated in Fig. 2. After scanning, subjects dressed and were rewarded with a small gift.

Study B. The procedure consisted of four parts similar to those in Study A. In the first part, subjects were given an identification number and were asked to answer a digital questionnaire. The questionnaire gathered background information in terms of education, occupation, income, spare time interest, birth nationality and parents' birth nationality. To get an idea of their physical activity at work and in their spare time, the questionnaire also included questions from the IPAQ – International Physical Activity Questionnaire (Hallal and Victora, 2004). In the questionnaire subjects were also asked to report their stature and weight.

In the second and third parts, subjects' stature, hands, feet, head and weight were measured manually and markers were attached to the subjects, identical to Study A. The fourth and final part, scanning the subjects in four positions, was also identical to Study A

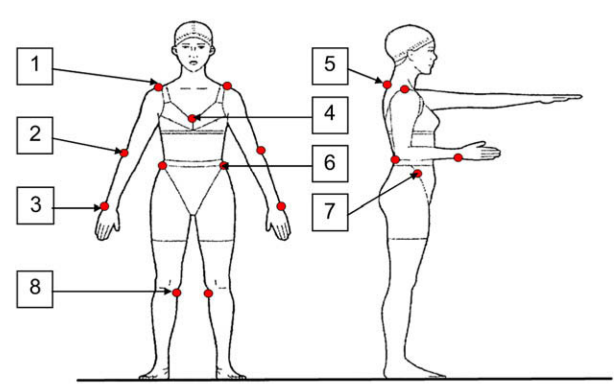

Fig. 1. Marker positions used when scanning: 1) lateral epicondylus of humerus, 2) olecranon, 3) processus styloideus ulnarae, 4) sternum between the third and fourth rib, 5) processus spinosis C7, 6) spina iliaca anterior superior, 7) trochantor major and 8) medial condylus on tibia.

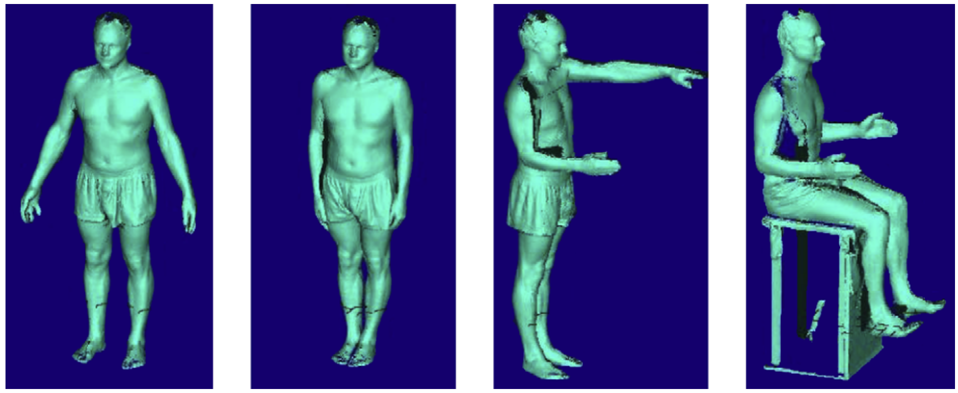

Fig. 2. Illustrations of the four body postures scanned.

except for the seating position. In Study A an adjustable seat was used to adjust the seat height so that subjects had a 90° knee angle. In Study B a high seat was used and the subjects' feet did not touch the floor. In Study B the measuring personnel, the same gender as the subject being measured, had extensive anatomic, anthropometric and ergonomic knowledge, in contrast to Study A where measuring personnel were intensively trained for the anthropometric measuring project.

2.2. Subjects in Study A

Based on available anthropometrical statistics of military recruits and Swedish adults, a desired distribution of subjects' gender, age, stature and weight was formulated. Subjects were then recruited through marketing in media and advertisement campaigns in clothing stores and workplaces close to Lund University until the desired distribution was obtained.

1682 subjects chose to participate, more females than men. Before measuring the subjects on the scanned images, a visual quality control was carried out to ensure they had an erect posture, 90° flexed elbow, horizontal arm, etc. Only subjects with four correct postures were further analysed. The quality control was performed by personnel with anatomic, anthropometric and ergonomic knowledge. After visual inspection, 268 subjects remained, 67 males and 201 females. The age distribution, birthplace, weight and stature of the female and male participants are presented in Table 1. In total 13% of the subjects were born outside the Nordic countries.

Table 1
Descriptors of female and male participants in Study A compared to those for Swedish inhabitants in general (SCB – Statistics Sweden, 2006). Measurements are given in percent except stature and weight which are given in mm and kg, respectively.

	Female		Male	
	Sweden in general	Measured ($n = 201$)	Sweden in general	Measured ($n = 67$)
Age				
18–29	23.1	38.3	23.5	50.7
30–39	21.6	29.9	21.7	26.9
40–49	21.7	12.9	21.9	17.9
50–59	21.2	12.4	20.8	3.0
60–65	12.4	6.5	12.1	1.5
Birthplace				
In Nordic countries	90.9	88.6	91.1	82.1
Outside Nordic countries	9.1	11.4	8.9	17.9
Weight (kg)	66.1	64.7	82.0	75.9
Stature (mm)	1662	1677	1800	1789

2.3. Subjects in Study B

384 persons in Malmö, Sweden, 50% females and 50% males, were randomly selected from PAR (a national person and address register: www.par.se). Gender, year of birth and postal code were the criteria used in the selection. Year of birth was used to obtain an even distribution in the age interval of 18–65 years. Postal codes were used to obtain a sample which mirrored the Swedish population, i.e. one consisting of 12% immigrants and of persons who, on average, have an annual disposable income of 170,000 SEK. These codes were selected from national statistics on number of immigrants and income together with the distance to the location of the body scanning equipment. Distance to measuring equipment was kept to a minimum to minimise subject's allocated time for participation.

An invitation letter was sent to the selected persons. The need for the new study was described together with the selection process. Persons were asked to participate and contact the research group to find a time that suited both. Subjects were rewarded with gifts for their participation (two cinema tickets or a shopping centre gift certificate of a corresponding value). A reminder was sent ten days after the first invitation letter. One month later, a second reminder was sent to non-respondents and persons who had rejected participation. In this second reminder, the reward was

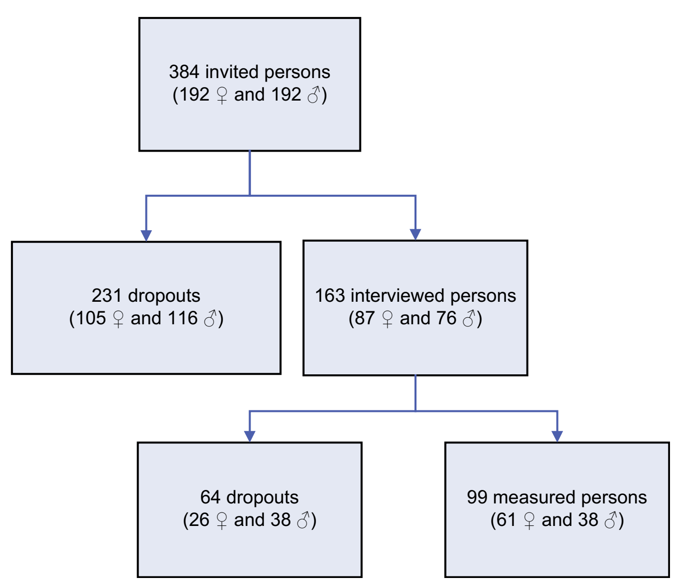

Fig. 3. Descriptions of dropouts (including the participants only interviewed), and those interviewed and measured in Study B.

Table 2
Descriptors of female and male participants in Study B compared to those for Swedish inhabitants in general (SCB – Statistics Sweden, 2006). Measurements are given in percent except weight and stature which are given in mm and kg, respectively. Weight and stature of subjects who were interviewed only are self-reported.

	Sweden in general	Female		Sweden in general	Male	
		Interviewed and measured ($n=61$)	Interviewed only ($n=26$)		Interviewed and measured ($n=38$)	Interviewed only ($n=38$)
Age						
18–29	23.1	24.6	19.2	23.5	31.6	10.5
30–39	21.6	16.4	19.2	21.7	18.4	18.4
40–49	21.7	13.1	11.6	21.9	13.2	31.6
50–59	21.2	27.9	23.1	20.8	26.3	23.7
60–65	12.4	18.0	26.9	12.1	10.5	15.8
Birthplace						
Sweden	87.5	73.8	76.9	88.4	71.0	81.6
Nordic excl. Sweden	3.4	11.5	3.9	2.7	2.6	2.6
Europe excl. Nordic	3.9	13.1	19.2	3.7	13.2	13.2
Others	5.2	1.6	0	5.2	13.2	2.6
Education						
University	36.0	72.1	65.4	29.2	55.3	68.4
Upper secondary	46.3	21.3	26.8	48.9	36.8	29.0
Primary school	16.0	3.3	3.9	20.0	7.9	2.6
Other	1.7	3.3	3.9	1.9	0	0
Weight (kg)	66.1	64.9	62.6	82.0	81.2	83.9
Stature (mm)	1662	1677	1675	1800	1806	1837

doubled to motivate the persons to participate. Those who had shown no previous interest and who had telephone numbers available in the register were contacted by phone to encourage them to participate. Those still uninterested, the dropouts, were asked to answer questions about their educational level, occupation, income, spare time interests, body stature, weight, birth country as well as their parental birth countries. All persons were not contactable. Fig. 3 describes the number of dropouts (which includes the participants interviewed only) as well as those interviewed and measured.

Of the 384 persons invited (192 females and 192 males), 163 (87 females and 76 males) agreed to answer a digital questionnaire at

Table 3
Anthropometric descriptive statistics: mean values with standard deviation for male and female participants scanned in Studies A and B. *p*-Values indicate significance of difference between studies.

		Female					Male				
		Study A ($n=201$)		Study B ($n=61$)		*p*-value	Study A ($n=67$)		Study B ($n=38$)		*p*-value
		M	SD	*M*	SD		*M*	SD	*M*	SD	
1	Stature	1677	68	1663	66	0.18	1789	62	1796	83	0.67
2	Eye height	1555	67	1546	64	0.35	1661	61	1671	80	0.54
3	Shoulder height	1360	65	1355	57	0.54	1446	58	1469	76	0.10
4	Elbow height	1053	51	1009	41	<0.005	1115	48	1084	63	0.01
5	Iliac spine height	937	52	923	49	0.06	1008	48	992	60	0.17
8	Sitting height (erect)	897	33	877	36	<0.005	946	32	940	44	0.44
9	Eye height, sitting	767	33	763	33	0.384	814	37	815	42	0.93
10	Shoulder height, sitting	575	30	574	25	0.92	604	29	614	37	0.13
12	Elbow height, sitting	238	27	236	25	0.54	240	26	240	31	0.92
13	Thigh clearance	149	14	141	15	<0.005	160	15	151	17	0.01
14	Buttock–knee length	595	34	591	27	0.33	613	28	614	38	0.91
15	Buttock–popliteal length (seat depth)	477	29	481	34	0.38	492	27	502	31	0.11
16	Knee height	525	30	511	32	<0.005	562	25	540	35	<0.005
18	Shoulder (biacromial) breadth	355	18	362	19	0.02	388	19	411	20	<0.005
19	Shoulder (bideltoid) breadth	424	23	426	22	0.73	472	25	484	28	0.05
25	Thorax depth at the nipple	253	28	191	17	<0.005	252	30	242	32	0.13
28	Abdominal depth, sitting	232	37	244	39	0.03	238	31	272	58	<0.005
29	Shoulder–elbow length	341	19	339	22	0.39	368	17	374	24	0.16
32	Head length	191	8	185	9	<0.005	201	6	197	10	0.02
33	Head breadth	147	5	148	5	0.48	153	5	155	8	0.12
34	Head circumference	555	14	557	11	0.34	580	14	583	21	0.56
35	Hand length, right	181	9	174	8	<0.005	194	9	192	10	0.22
36	Hand breadth, right	78	4	80	5	<0.005	88	5	87	6	0.63
37	Hand length, left	180	9	176	9	<0.005	194	9	194	10	0.87
38	Hand breadth, left	77	4	83	5	<0.005	86	5	87	6	0.91
39	Foot length. right	242	13	242	11	0.83	263	15	268	15	0.12
40	Foot breadth, right	92	5	92	5	0.42	101	5	102	7	0.24
41	Foot length, left	243	13	245	11	0.23	265	12	268	14	0.30
42	Foot breadth, left	91	5	92	5	0.26	99	5	102	6	0.02
43	Weight (kg)	65	11	65	9	0.80	76	11	80	17	0.16

Table 4
Descriptors of female and male participants compared to those for Swedish inhabitants in general (SCB – Statistics Sweden, 2006). Measurements are given in percent except mean stature and mean weight which are given in mm and kg, respectively.

	Female		Male	
	Sweden in general	Measured ($n = 262$)	Sweden in general	Measured ($n = 105$)
Age				
18–29	23.1	34.7	23.5	42.9
30–39	21.6	27.1	21.7	24.8
40–49	21.7	11.8	21.9	14.3
50–59	21.2	16.4	20.8	12.4
60–65	12.4	9.9	12.1	5.7
Birthplace				
Nordic	90.9	87.8	91.1	79.0
Outside Nordic	9.1	12.2	8.9	21.0
Weight (kg)	66	65	82	78
Stature (mm)	1662	1674	1800	1792

the measuring location or as a telephone interview. Of these 163, 99 persons (61 females and 38 males) agreed to be measured. Consequently, 64 persons only answered the questionnaire. Descriptors, in terms of gender, age, educational level and birthplace are presented in Table 2 for: 1) Swedish inhabitants in general, 2) persons who answered the questionnaire and were measured, and 3) persons who only answered the questionnaire. The persons who were not contactable or not willing to be measured were defined as dropouts, which amounted to 295 persons, 76.8% of those invited. 131of the dropouts were females and 154 males.

In total, 99 persons agreed to participate, 61.6% females and 38.4% males. In Table 2 the participants' distribution of age, birthplace and education are presented with corresponding figures from SCB – Statistics Sweden (2006) for Swedish females and males in general. 27.3% of the measured subjects were born outside Sweden. 64.6% had a university degree. The subjects had an average annual disposable household income of 231,600 SEK per person with a standard deviation of 128,800 SEK. Once or twice a week, 32.3% of the participants performed some kind of physically exerting activity during their spare time; 40.4% never did so. The remaining 28.3% carried out physically exerting activities more than twice a week. Over half, 56.6% of the participants, were sedentary more than 8 h a day. 28% sat between 4 and 8 h a day and 15.2% less than 4 h a day.

2.4. Treatment of data and statistical analysis

The ScanWorX software was used to measure scanned images of subjects: the garment module in Study A and the ergonomics module in Study B. In the software, anthropometric measurements according to ISO 7250 (1996) were automatically generated after identification of landmarks on the subject and reference plan in the environment such as seat surface. In Study A, 17 ergonomically relevant measurements were generated and in Study B, 30. These measurements were merged with background information and 13 measurements gathered by hand. The unique identification number for each subject in all databases enabled synchronisation in Microsoft Excel.

The statistical software SPSS 12.0 was used for analysis. An Anova test with a significance level at 0.05 was used to test gender, birth nationality and education effect on weight and stature in Study B. Descriptive statistics – minimum, 5, 50 and 95 percentile as well as maximum and standard deviations – were generated for female and male subjects, respectively. A t-test with a significance level of 0.05 was used to test anthropometric differences between studies, different participating groups and data in the reference literature.

Quality of the measurements was tested with the se and ses indices proposed by Panchon et al. (2004). The index is a comparison between a theoretically calculated upper arm length and the measured upper arm length. The theoretical upper arm length is calculated by subtracting elbow height from shoulder height in standing (se) and sitting (ses). Furthermore, the distribution of each measurement was compared to the corresponding percentile using a t-test (Lewin, 1969).

3. Results

3.1. Comparison measurements in and between studies

Table 2 presents stature and weight information from Study B. This includes: 1) Swedish females and males measured and interviewed, 2) Swedish females and males interviewed only, and 3) Swedish females and males in general (i.e. data from national health and population surveys). No significant differences in stature or body weight were found when comparing these three groups within gender with each other. Comparing 30 female anthropometric measurements from Study A with the corresponding ones from Study B showed twelve significant differences. In eight of these, measurements were larger in Study A, see Table 3. For males, seven significant measurement differences were found between studies. In three of these, measurements were larger in Study A. The differences between significant measurements in Studies A and B were less than 6%. Significantly larger measures in Study A than Study B, for both male and female, were found in elbow height, thigh clearance, knee height and head length. Significantly smaller measures in Study A than Study B, for both male and female, were found in shoulder biacromial breadth and abdominal depth (sitting). For females, larger measures in Study A than Study B were found in sitting height, thorax depth at the nipple, hand length right and hand length left. Smaller measures were found in Study A than Study B in hand breadth right and left for female and foot breadth left for male. Analysis of information from the questionnaire in Study A showed that gender, $F(76.0.1)$ $p < 0.005$, and birth nationality, $F(5.46.\ 3)$ $p = 0.01$, had a significant effect on body weight. Gender, $F(47.1.1)$ $p < 0.005$, also had a significant effect on stature. Birth nationality did not have any effect on stature; nor did educational level affect body weight or stature. Based on the information above, Studies A and B were merged into one Swedish anthropometric survey where anthropometrics was divided by gender. Table 4 presents information on all female and male participants grouped together compared to those for Swedish inhabitants in general from SCB – Statistics Sweden (2006).

3.2. Descriptive statistics of merged studies

Tables 5 and 6 present the distribution of 43 anthropometric measurements for males and females, respectively. The 50 percentile male was 1779 mm tall and the stature span was 402 mm, ranging from 1568 mm to 1970 mm (Table 5). The 50 percentile male had a body weight of 75 kg. The distribution of body weight ranged from 47 kg to 116 kg, a span of 69 kg. Combining stature and weight into body mass index (BMI), the male average was 24.1 kg/m^2, with 16.1 kg/m^2 and 36.0 kg/m^2 as low and high extremes. The 50 percentile female was 1673 mm tall (Table 6). The stature difference between the tallest female (1860 mm) and the shortest (1475 mm) was 385 mm. The 50 percentile female had a body weight of 64 kg. The heaviest weighed 130 kg and the lightest weighed 40 kg, resulting in a weight difference of 90 kg. Combining stature and weight into body mass index, the female average was 23.1 kg/m^2, with 16.4 kg/m^2 and 45.8 kg/m^2 as low and high extremes.

Table 5
Anthropometric descriptive statistics: range and percentile values with standard deviation for male participants ($n = 105$). Weight is given in kg, other measurements in mm.

		Min	5	50	95	Max	*M*	SD
1	Stature	1568	1669	1779	1902	1970	1792	70
2	Eye height	1430	1562	1657	1778	1863	1665	68
3	Shoulder height	1258	1333	1459	1548	1632	1454	66
4	Elbow height	896	1020	1108	1181	1275	1104	56
5	Iliac spine height	837	920	999	1086	1166	1002	53
6	Crotch height[a]	628	693	810	899	938	803	56
7	Tibia height[a]	340	391	452	511	540	452	34
8	Sitting height (erect)	841	883	946	1006	1029	944	36
9	Eye height, sitting	711	757	816	874	982	814	39
10	Shoulder height, sitting	536	557	607	668	708	608	33
11	Cervical height, sitting[a]	590	592	678	737	743	675	37
12	Elbow height, sitting	166	195	238	292	300	240	28
13	Thigh clearance	119	129	158	184	191	157	16
14	Buttock–knee length	509	565	613	667	683	613	32
15	Buttock–popliteal length (seat depth)	406	451	493	545	567	496	29
16	Knee height	427	505	556	603	646	554	31
17	Lower leg length (popliteal height)[a]	415	437	491	534	571	486	32
18	Shoulder (biacromial) breadth	343	362	395	436	458	396	23
19	Shoulder (bideltoid) breadth	420	437	478	520	542	476	27
20	Elbow-to-elbow breadth[a]	400	423	535	628	660	536	59
21	Chest breadth, standing[a]	283	295	345	415	416	347	34
22	Hip breadth, sitting[a]	325	326	387	445	451	391	35
23	Hip breadth, standing[a]	304	309	362	403	410	363	28
24	Chest depth, standing[a]	193	194	243	295	312	242	32
25	Thorax depth at the nipple	193	198	246	294	398	248	31
26	Body depth, standing[a]	165	186	241	343	359	251	45
27	Buttock–abdomen depth, sitting[a]	153	171	259	362	406	262	62
28	Abdominal depth, sitting	182	204	237	351	427	250	46
29	Shoulder–elbow length	324	336	370	404	436	370	20
30	Forearm–fingertip length[a]	394	422	487	524	540	484	27
31	Elbow–wrist length[a]	220	239	286	317	320	284	20
32	Head length	172	185	200	210	220	200	8
33	Head breadth	140	144	155	165	170	154	7
34	Head circumference	515	551	581	605	620	581	16
35	Hand length, right	168	178	193	210	216	193	9
36	Hand breadth, right	75	80	87	98	106	87	5
37	Hand length, left	170	178	194	212	218	194	9
38	Hand breadth, left	75	80	85	96	106	86	5
39	Foot length, right	194	245	266	286	306	265	15
40	Foot breadth, right	82	93	101	112	121	101	6
41	Foot length, left	229	248	266	289	308	266	13
42	Foot breadth, left	85	90	100	111	117	100	6
43	Weight (kg)	47	57	75	103	116	78	13

[a] Based on 38 male subjects participating in Study B.

3.3. *Quality index*

The se and ses indices proposed by Panchon et al. (2004) were calculated for each subject. The mean quality se index for standing anthropometric measurements was calculated to 5.4% (SD 7.7) for males and 7.0% (SD 7.3) for females. The corresponding sitting ses index for sitting anthropometrics was calculated to 1.1% (SD 2.5) for males and 0.7% (SD 2.2) for females. Using information from Table 5 in the overall quality index calculation for males resulted in se = 5.1% and ses = 0.3%. The corresponding indices for females from Table 6 were se = 8.2% and ses = 0.6%.

4. Discussion

The participants in this study represent the Swedish population fairly well. When compared to national statistics on body stature and weight as well as with stature and weight for interviewed non-measured persons, no significant differences were found. The female representation, 71.4% of the participants, and the male representation, 28.6% of the participants, are distorted when compared to the national distribution of 50.4% females and 49.6% males. The larger proportion of females participating in the study may be explained by their greater interest in body appearance. Furthermore, students and white-collar workers with higher education were over-represented as well as persons in the age categories 18–29 and 30–39 years of age. One possible reason for this may be the location of the scanner: at a university in Lund (Study A) and outside of the centre of town in Malmö (Study B). Another plausible explanation was the amount of spare time available and the ability to get time off from work. People between 30 and 49 years of age may be busy raising children and with their careers, and thus may not prioritise participation. Furthermore, blue-collar workers tend to have less flexibility in their working hours compared to white-collar workers. The total participation rate of 26% was low compared to other similar studies. In health studies performed in Sweden, a participation rate of about 60% is common (Bjork et al., 2006). However, participating in an anthropometric study may be less attractive as subjects have to expose their almost nude bodies in front of strangers. The low number of participants and high number of university educated persons may explain why level of education did not have any effect on anthropometric measurements, a finding which is in agreement with Lindgren (1976) who did not find any differences between social classes in Sweden.

The measuring equipment, body scanner, calliper and body weight scale have high precision. The highest sources of errors were introduced in the body posture of the subjects and landmark identification in the analysing software. These factors were also

Table 6
Anthropometric descriptive statistics: range and percentile values with standard deviation for female participants ($n = 262$). Weight is given in kg, other measurements in mm.

		Min	5	50	95	Max	*M*	SD
1	Stature	1475	1562	1673	1789	1860	1674	68
2	Eye height	1367	1446	1553	1668	1744	1553	66
3	Shoulder height	1188	1252	1357	1468	1569	1359	63
4	Elbow height	881	957	1044	1130	1202	1042	52
5	Iliac spine height	774	843	934	1018	1105	933	52
6	Crotch height[a]	658	696	776	837	887	772	43
7	Tibia height[a]	350	359	406	451	480	407	25
8	Sitting height (erect)	773	832	892	949	993	892	35
9	Eye height, sitting	646	710	762	820	867	766	33
10	Shoulder height, sitting	491	521	577	624	643	575	29
11	Cervical height, sitting[a]	577	585	632	673	711	634	27
12	Elbow height, sitting	170	192	238	285	311	238	27
13	Thigh clearance	112	126	145	173	202	147	15
14	Buttock–knee length	511	539	596	644	719	594	32
15	Buttock–popliteal length (seat depth)	296	431	477	522	572	478	30
16	Knee height	450	468	521	568	711	522	31
17	Lower leg length (popliteal height)[a]	385	397	444	500	524	447	28
18	Shoulder (biacromial) breadth	306	327	356	388	410	357	19
19	Shoulder (bideltoid) breadth	368	390	425	467	517	425	23
20	Elbow-to-elbow breadth[a]	350	381	444	538	570	450	47
21	Chest breadth, standing[a]	225	256	304	342	364	303	24
22	Hip breadth, sitting[a]	358	367	416	463	492	414	30
23	Hip breadth, standing[a]	320	333	372	413	425	370	24
24	Chest depth, standing[a]	158	162	190	220	232	191	17
25	Thorax depth at the nipple	158	176	241	295	380	238	37
26	Body depth, standing[a]	171	183	223	280	290	226	25
27	Buttock–abdomen depth, sitting[a]	193	206	253	345	367	258	39
28	Abdominal depth, sitting	163	191	227	317	432	235	38
29	Shoulder–elbow length	289	304	341	376	412	341	20
30	Forearm–fingertip length[a]	365	392	436	479	497	437	26
31	Elbow–wrist length[a]	200	215	252	284	300	251	21
32	Head length	140	178	190	200	208	189	8
33	Head breadth	130	140	146	155	161	147	5
34	Head circumference	505	535	555	578	598	556	14
35	Hand length, right	155	165	179	194	216	179	9
36	Hand breadth, right	66	71	78	86	94	78	4
37	Hand length, left	155	165	179	195	210	179	9
38	Hand breadth, left	68	70	78	87	97	78	5
39	Foot length, right	202	223	243	263	288	242	12
40	Foot breadth, right	78	84	91	101	112	92	5
41	Foot length, left	201	224	243	264	284	243	12
42	Foot breadth, left	78	83	90	100	109	91	5
43	Weight (kg)	40	50	64	80	130	65	11

[a] Based on 61 female subjects participating in Study B.

identified by Kouchi and Mochimaru (2006) as causing measurement errors. In Study A, a large amount of scans was rejected due to poor subject posture. However, the majority of subjects were rejected due to missing postures (ergonomic anthropometric measurements were introduced in the garment study). In Study B the subjects' posture was carefully checked with markers for foot position, for instance, and a quality check of scanned posture was always carried out before continuing to the next posture. Quality measurements were thus obtained in this study, which is confirmed by three of four acceptable se and ses indices. The fourth index was just outside the range of ±7% which Panchon et al. (2004) set as acceptable. Factors such as system hardware and software, operator skill and procedure protocol were deemed to have had a minor effect in this study. This was due to the hardware and software being established on the market, to an experimental protocol that was defined in detail and to participating personnel experienced in dealing with people, locating landmarks and handling computer programs.

The 43 anthropometric measurements presented are a complement to stature and weight information gathered by the Swedish Armed Forces and Statistics Sweden and are also an update to Lewin's (1969) detailed anthropometric study. The anthropometric data collected agreed with weight and stature information from Statistical Sweden (2006) and differed from anthropometric data presented in Lewin (1969). Studying Table 7, it can be observed that 48 of 60 measurements were significantly different: 23 male and 25 female measurements. Of these 48 measurements, six had decreased (all for female); the remaining 42 had increased. Stature was one of these measurements. It has increased 0.9 mm/year for females and 1.4 mm/year for males. Numbers that are in agreement with general secular trend growth rate figures (Pheasant and Haslegrave, 2006) and growth rate for Italians (Arcaleni, 2006). Weight had also increased. Female weight had increase by 9.8% between 1969 and 2006. During the same period, female stature increased by 2.0%. Comparing these length and weight figures it is evident that Swedes have followed global trends with increased BMI over the four decades (e.g. Matton et al., 2007). The same pattern is seen in examining the relationship between length/ height measurements and weight/ breadth/depth measurements. Two of the twelve non-significant measurements were related to weight, breadth and depth. If the Swedes had grown equally in length and height as in weight, breadth and depth, four or five measurements should have been non-significant. Now it seems that Swedes have grown more in breath and depth compared to length and height. However, the increasing BMI trend seems to have slowed down or reversed in the last decade (Sjoberg et al., 2008).

Table 7
Comparison of female and male 50 percentile measurements from present study's 367 subjects with corresponding data from Lewin's (1969) 164 subjects. Negative % change indicates a decrease in the present study compared to Lewin's (1969). N.a. = not applicable: measurement not available or not reasonable in source.

		Female					Male				
		2007		1969		*p*-value	2007		1969		*p*-value
		Mean	SD	Median	% Change		Mean	SD	Median	% Change	
1	Stature	1674	68	1640	2.0	<0.005	1792	70	1740	3.0	<0.005
2	Eye height	1553	66	1535	1.1	<0.005	1665	68	1630	2.1	<0.005
3	Shoulder height	1359	63	1355	0.3	0.33	1454	66	1445	0.6	0.16
4	Elbow height	1042	52	1025	1.7	<0.005	1104	56	1100	0.3	0.49
8	Sitting height (erect)	892	35	860	3.7	<0.005	944	36	900	4.9	<0.005
9	Eye height, sitting	766	33	755	1.4	<0.005	814	39	785	3.8	<0.005
10	Shoulder height, sitting	575	29	575	−0.1	0.81	608	33	600	1.3	0.02
12	Elbow height, sitting	238	27	215	10.5	<0.005	240	28	225	6.6	<0.005
13	Thigh clearance	147	15	155	−5.2	<0.005	157	16	152	3.3	<0.005
14	Buttock–knee length	594	32	585	1.5	<0.005	613	32	595	3.1	<0.005
15	Buttock–popliteal length (seat depth)	478	30	485	−1.5	<0.005	496	29	480	3.3	<0.005
16	Knee height	522	31	500	4.3	<0.005	554	31	530	4.6	<0.005
17	Lower leg length (popliteal height)[a]	447	28	400	11.8	<0.005	486	32	430	13.0	<0.005
18	Shoulder (biacromial) breadth	357	19	350	1.9	<0.005	396	23	400	−1.0	0.08
19	Shoulder (bideltoid) breadth	425	23	390	8.9	<0.005	476	27	465	2.5	<0.005
22	Hip breadth, sitting[a]	414	30	365	13.4	0.042	391	35	360	8.3	<0.005
25	Thorax depth at the nipple	238	37	241	−1.2	0.21	248	31	220	12.9	<0.005
28	Abdominal depth, sitting	235	38	245	−4.0	<0.005	250	46	240	4.3	0.02
29	Shoulder–elbow length	341	20	335	1.7	<0.005	370	20	355	4.4	<0.005
30	Forearm–fingertip length[a]	437	26	n.a	n.a.	n.a	484	27	475	1.9	0.41
32	Head length	189	8	180	5.2	<0.005	200	8	195	2.4	<0.005
33	Head breadth	147	5	145	1.7	<0.005	154	7	155	−0.7	0.08
35	Hand length, right	179	9	180	−0.4	0.21	193	9	190	1.8	<0.005
36	Hand breadth, right	78	4	75	4.6	<0.005	87	5	85	2.9	<0.005
37	Hand length, left	179	9	180	−0.4	0.22	194	9	190	2.2	<0.005
38	Hand breadth, left	78	5	75	4.5	<0.005	86	5	85	1.8	0.01
39	Foot length, right	242	12	245	−1.1	<0.005	265	15	265	−0.1	0.89
40	Foot breadth, right	92	5	95	−3.5	<0.005	101	6	95	6.5	<0.005
41	Foot length, left	243	12	245	−0.8	0.01	266	13	265	0.5	0.30
42	Foot breadth, left	91	5	95	−4.3	<0.005	100	6	95	5.4	<0.005
43	Weight (kg)	65	11	59	9.8	<0.005	78	13	n.a.	n.a.	n.a.

[a] Based on 61 female and 38 male subjects participating in Study B.

Factors other than secular trends may also explain the differences found between the present study and Lewin's (1969). It is established that geographical location and social class have an effect on anthropometrics (Pheasant and Haslegrave, 2006). The majority of participants in this study were white-collar workers and Lewin (1969) measured blue-collar workers; however, educational or occupation effects were not found in Study B. Another explanation for the differences between the two studies may be related to the geographic origin of the subjects. The present study includes Swedes from the southern region compared to the Lewins's study which included subjects from the western region, about 300 km north of the southern cities of Lund and Malmö. However, studies from 1930 showed that Swedish people were predominantly made up of the same ethnic type. Furthermore, in the present study, the proportion of subjects born outside Nordic country was higher than in Sweden in general. Lewin (1969) did not report nationality background information on his subjects. However, during the late 1960s, working immigrants from other Scandinavian countries and southeast Europe were common, which may also have been reflected in Lewin's test group.

Studying Table 8, it was observed that 39 of 60 standard deviations had increased compared to Lewin (1969), i.e. 18 female and 21 male measurements. These differences indicated that Swedish anthropometric homogeneity has decreased and that the differences between the largest and smallest as well as heaviest and lightest persons have increased. These anthropometric changes make the user-centred design process even more challenging for designers.

The anthropometric data presented in Tables 5 and 6 are useful information for designing products and workplaces for Swedish females and males. However, the minimum and maximum percentiles presented in the tables are suitable for one-dimensional design problems, such as defining a doorway height (Dainoff et al., 2003) and not suitable for multidimensional issues (Ziolek and Wawrow, 2004; Robinette and Hudson, 2006). For these types of problems, such as designing a vehicle cockpit, other statistical approaches have been proposed (Zehner et al., 1993; Bittner, 2000). To facilitate such statistical analysis, body dimension data sets are handed out on request. The data set can be imported in statistical tools for applying own analysis methods or integrated in digital human modelling software where multidimensional design tools are available. With raw data in their hands product and workplace designers can use the information after their interest; e.g. study body dimensions of specific age intervals.

5. Conclusion

The body dimensions of Swedish inhabitants are different than they were four decades ago. With the present data, products and workplaces with one key anthropometric variable can be designed according to body measurements of Swedish males and females of 2006. The information can be used by designers in a user-centred design process to achieve human friendly products and workplaces with none or limited negative effects on human health. For products and workplaces with two or more key anthropometric variables, Swedish female and male

Table 8
Comparison between female and male standard deviation measurements from present study with corresponding data from Lewin (1969). Negative % change indicates a decrease in the present study compared to Lewin's (1969). N.a. = not applicable: measurement not available or not reasonable in source.

	Measurement	Female			Male		
		1969	2006	Difference (%)	1969	2006	Difference (%)
1	Stature	62	68	9.7	68	70	2.9
2	Eye height	62	66	6.5	68	68	0.0
3	Shoulder height	60	63	5.0	62	66	6.5
4	Elbow height	73	52	−28.8	49	56	14.3
8	Sitting height (erect)	33	35	6.1	43	36	−16.3
9	Eye height, sitting	30	33	10.0	42	39	−7.1
10	Shoulder height, sitting	30	29	−3.3	34	33	−2.9
12	Elbow height, sitting	31	27	−12.9	31	28	−9.7
13	Thigh clearance	16	15	−6.3	18	16	−11.1
14	Buttock–knee length	35	32	−8.6	30	32	6.7
15	Buttock–popliteal length (seat depth)	33	30	−9.1	30	29	−3.3
16	Knee height	28	31	10.7	30	31	3.3
17	Lower leg length (popliteal height)[a]	29	28	−3.4	27	32	18.5
18	Shoulder (biacromial) length	15	19	26.7	20	23	15.0
19	Shoulder (bideltoid) breadth	20	23	15.0	27	27	0.0
22	Hip breadth, sitting[a]	31	30	−3.2	29	35	20.7
25	Thorax depth at the nipple	35	37	5.7	27	31	14.8
28	Abdominal depth, sitting	40	38	−5.0	31	46	48.4
29	Shoulder–elbow length	17	20	17.6	20	20	0.0
30	Forearm–fingertip length[a]	n.a	26	n.a.	20	27	35.0
32	Head length	7	8	14.3	7	8	14.3
33	Head breadth	6	5	−16.7	6	7	16.7
35	Hand length, right	10	9	−10.0	10	9	−10.0
36	Hand breadth, right	4	4	0.0	5	5	0.0
37	Hand length, left	10	9	−10.0	10	9	−10.0
38	Hand breadth, left	4	5	25.0	5	5	0.0
39	Foot length, right	11	12	9.1	14	15	7.1
40	Foot breadth, right	4	5	25.0	6	6	0.0
41	Foot length, left	11	12	9.1	14	13	−7.1
42	Foot breadth, left	4	5	25.0	6	6	0.0
43	Weight (kg)	7	11	57.1	n.a.	13	n.a.

[a] Based on 61 female and 38 male subjects participating in Study B.

anthropometrics are made available on request. Statistical methods, boundary and random representation approaches are preferably applied to these data for proper user representation in a user-centred design process.

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