Design for Plus Size People

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Abstract. Obesity is a growing issue in western societies with consequences for the field of human centered design. Most anthropometric data sources assume the data follow the Gaussian distribution, with population data symmetrically distributed above and below the mean value. This assumption is often true in length measurements like body heights, but may not be true for measurements more sensitive to body mass, like body weight, hip width, elbow-to-elbow width, and body depth. While length measurements have remained relatively stable over time in western societies, mass related measurements are increasing.

The authors have experience in providing data via an interactive website DINED, which seeks to make anthropometry accessible without requiring expert knowledge about anatomy and statistics. Currently all DINED dimensions are assumed Gaussian, including those related to body mass. This might not work when designing for plus size people. Future additions in DINED will be about design for obesity and about how to implement 3D scanning into the design process in order to redress these defects.

Keywords: Anthropometrics · Ergonomics education · Product design Plus-size

1 Introduction

Obesity is a growing issue in western societies. According to the World Health Organization obesity has tripled from 1975–2016 worldwide. At the moment about 2 billion people have a body mass index (BMI) of more than 25 (overweight) and 650 million are even over 30 (obese) [1]. For the first time in history obesity has outnumbered underweight [2]. At lot of health issues are connected with a high BMI and there is a tendency to focus mainly on this aspect of plus sized people. Although prevention programs on healthy living, with enough exercise and healthy foods, are put into effort to tame the obesity-epidemic, fact is that there actually are vast amounts of people overweight. And overweight people tend to be larger people, not in height, but in width. From a product designer's point of view this presents new challenges. Especially when following the inclusive design ideology 'not to exclude people by design', which means in this case; taking care that the largest people are able to use products comfortably. But how large are the largest? Anthropometrics are needed so

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products and services can be designed that fit, or physically accommodate, users [3]. Designers need to be aware that not only the one-dimensional aspect of body circumference is affected. Increasing body mass also affects movement of the body like forward bending, field of view downwards, and hence leads to usability problems with many products, like toilets [4], surgical tables, chairs, wheelchairs, and public transport. However, data from overweight or obese people are rare in public databases. The group in itself is not easy to investigate. Being overweight makes travelling to a research site a challenge. In addition, experience teaches that when the purpose of measuring is not made absolutely clear or doesn't relate to an actual design problem, subjects are prone to feel embarrassed by the act of measuring. Some [5] have therefore chosen the method of self-reporting to tackle this problem, although this method clearly has its drawbacks in terms of reliability.

In this paper, we will explore the current methods available when designing for plus sized people.

2 DINED as a Tool for Designers and Researchers

2.1 Ergonomics and Anthropometry in Education

User-centered design has been taught at the faculty of Industrial Design Engineering (IDE) since its start in 1969. Ergonomics is one of the 4 pillars of IDE from the start, next to Aesthetics, Marketing and Engineering. Currently the scope is towards consumer products, services and social designs. Courses at IDE are aimed at giving insight in the optimization of the human-product interaction from the viewpoint of the consumer (ergonomics) and from the viewpoint of the producer (marketing).

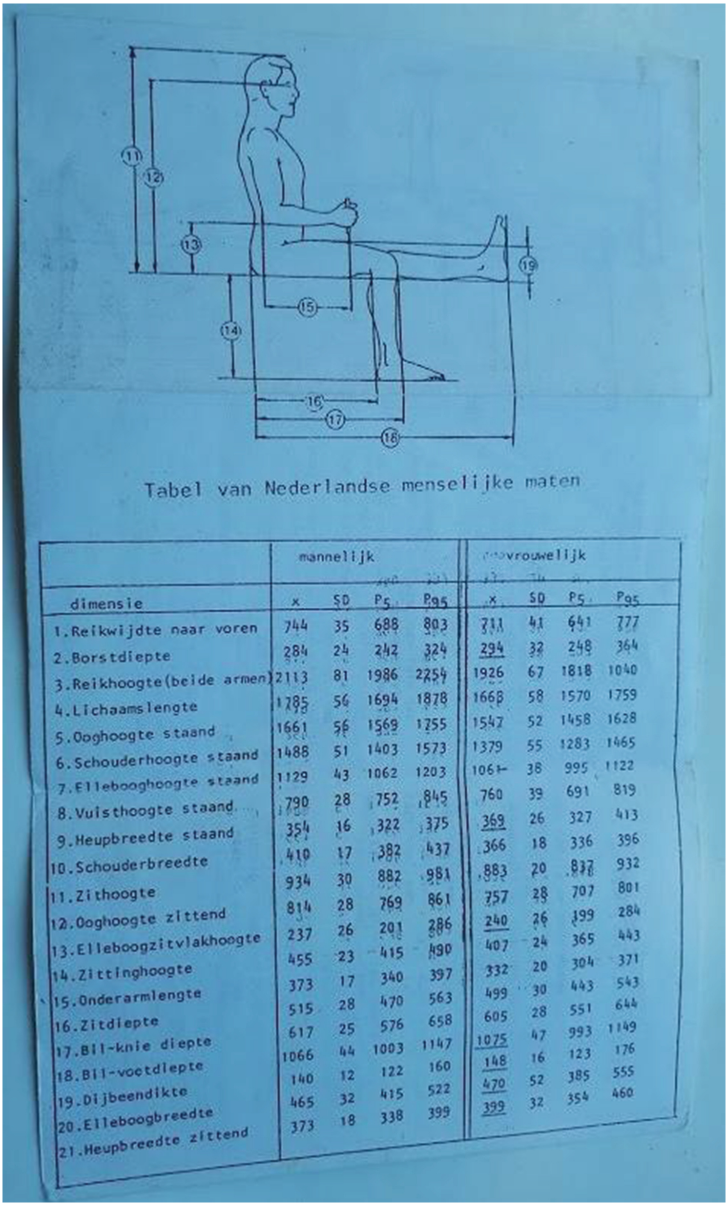
One of the main topics is observational research. Students are taught to study the behavior of people (consumers) using products and services in order to find potential user problems, which can lead to clues for product innovation. One of the outcomes for example could be that the product and user do not fit 'physically'. Here anthropometrics come onto stage.

The best way to teach about anthropometry is to let students experience the impact of anthropometrics themselves. A design-assignment e.g. could be: 'Design a minimum shower cabin that fits all students but makes it possible to use the shower in a comfortable way'. In this way students have to think about relevant body dimensions, experience for themselves through repeated measurements what it takes to measure accurately and finally experience for themselves that nobody is average: not one body will score the 'P50' average on all body dimensions.

2.2 History of DINED.nl

To support the anthropometry and ergonomics education, and to explain related statistics and anatomy, a tool called DINED was gradually developed (www.dined.nl). Now DINED has become an anthropometric information system including data from several populations around the world and tools to make design decisions more easily.

It all started around 1980 as a table on 1 A4 cardboard showing the P5-P50-P95 percentiles of body dimensions frequently used in product design (see Fig. 1).



Tabel van Nederlandse menselijke maten

	mannelijk				vrouwelijk			
dimensie	x	SD	P5	P95	x	SD	P5	P95
1. Reikwijdte naar voren	744	35	688	803	711	41	641	777
2. Borstdiepte	284	24	242	324	294	32	248	364
3. Reikhoogte (beide armen)	2113	81	1986	2254	1926	67	1818	1040
4. Lichaamslengte	1785	56	1694	1878	1668	58	1570	1759
5. Ooghoogte staand	1661	56	1569	1755	1547	52	1458	1628
6. Schouderhoogte staand	1488	51	1403	1573	1379	55	1283	1465
7. Elleboohoogte staand	1129	43	1062	1203	1061	38	995	1122
8. Vuisthoogte staand	790	28	752	845	760	39	691	819
9. Heupbreedte staand	354	16	322	375	369	26	327	413
10. Schouderbreedte	410	17	382	437	366	18	336	396
11. Zithoogte	934	30	882	981	883	20	837	932
12. Ooghoogte zittend	814	28	769	861	757	28	707	801
13. Elleboogzitvlakhoogte	237	26	201	286	240	26	199	284
14. Zittinghoogte	455	23	415	490	407	24	365	443
15. Onderarmlengte	373	17	340	397	332	20	304	371
16. Zitdiepte	515	28	470	563	499	30	443	543
17. Bil-knie diepte	617	25	576	658	605	28	551	644
18. Bil-voetdiepte	1066	44	1003	1147	1075	47	993	1149
19. Dijbeendikte	140	12	122	160	148	16	123	176
20. Elleboogbreedte	465	32	415	522	470	52	385	555
21. Heupbreedte zittend	373	18	338	399	399	32	354	460

Fig. 1. DINED-table 1980

It consisted of an estimation of Dutch adults based on German DIN33402; the German dataset was adjusted according to predictions for the Dutch population based on the Dutch Growth Diagrams 1980, which resulted in 3,5% higher values for the Dutch male and 2% for the Dutch female, respectively. These data were later coupled with data collected from the Dutch population (amongst others students and elderly people). New possibilities of computer graphics led to an interactive DINED website with more visual tools for designers, thus making anthropometry accessible without requiring expert knowledge about anatomy and statistics [6].

In Table 1 an overview is given on the current collection of searchable anthropometric data made available via DINED. Preparations are currently going on to develop DINED-3D. These data will become available as statistical shape models.

Table 1. DINED-datasets in 2018

1D and 2D data	Size dataset	Variables	Age
Dutch students 1986	n = 354	v = 50	
Dutch students 2014	n = 400	v = 40	
Dutch elderly GDVV 1983	n = 822	v = 30	
Dutch elderly GERON 1998	n = 600		Age 50+
Dutch adults GERON 1998	n = 150		Age 20–30
Dutch children KIMA 1993	n = 2400		Age 0–12
Chilean children 2012	n = 3046		Age 6–18
Chilean adults 2016	n = 2946		Age 18–99

3 Current Usage of DINED

According to Google Analytics each year about 50k users use the DINED.nl website to find anthropometric data. Since a few years past, users need to set up a (free) user account, which enables one to see the professional status and background of DINED users. From being originally aimed at TU Delft students, the tool is now used by educational institutions all of the world, many companies involved in product development and even medical institutions. It would be interesting to analyze to what purpose the various offered tools are used, to improve the tool in general and to extend the platform, though this is yet a plan for the future. Current tools available at DINED are:

- Percentiles: Calculating percentiles assuming normal distribution (Fig. 2)
- Reach Envelopes: Developed especially to show large differences related to age (Fig. 3)
- Profiler: to show nobody is average (Fig. 4)
- Ellipse: to show correlation between 2 variables (Fig. 5)
- Other sources: a library of digital sources in anthropometry
- Raw data: excel tables with measured data.

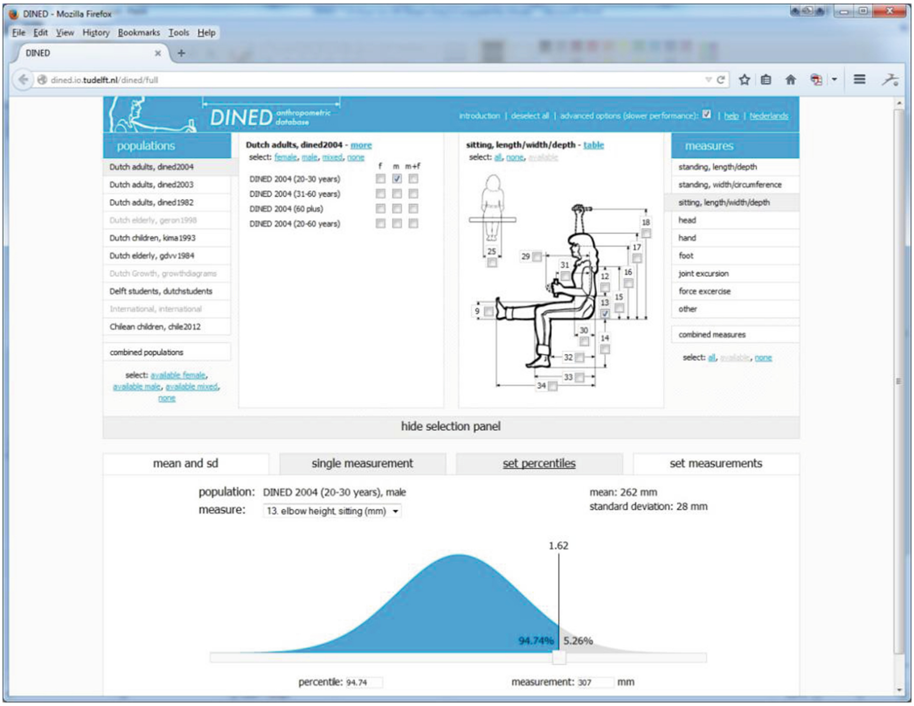


Fig. 2. Calculating percentiles assuming normal distribution using DINED percentiles

3.1 Percentiles

In this tool, several populations and body dimensions can be chosen. Thereafter the designer can choose how much percentage will be excluded from the design. The data is based on real measurements or on estimated data [3, 6–8].

3.2 Reach Envelope

This is an interactive tool that shows the designer immediately which region it is comfortable (green) or out-of-reach (red). The data is based on real measurements of 750 elderly that draw lines of comfort on a large white board [9].

3.3 Profiler

This is an interactive tool that allows you to enter a number of measurements of one's own and to compare them with one of the populations inside DINED. The outcome is a profile of percentiles of each body dimensions and will show in most cases that your dimensions are not average! A useful eye-opener for designers that follow the ego-design approach.

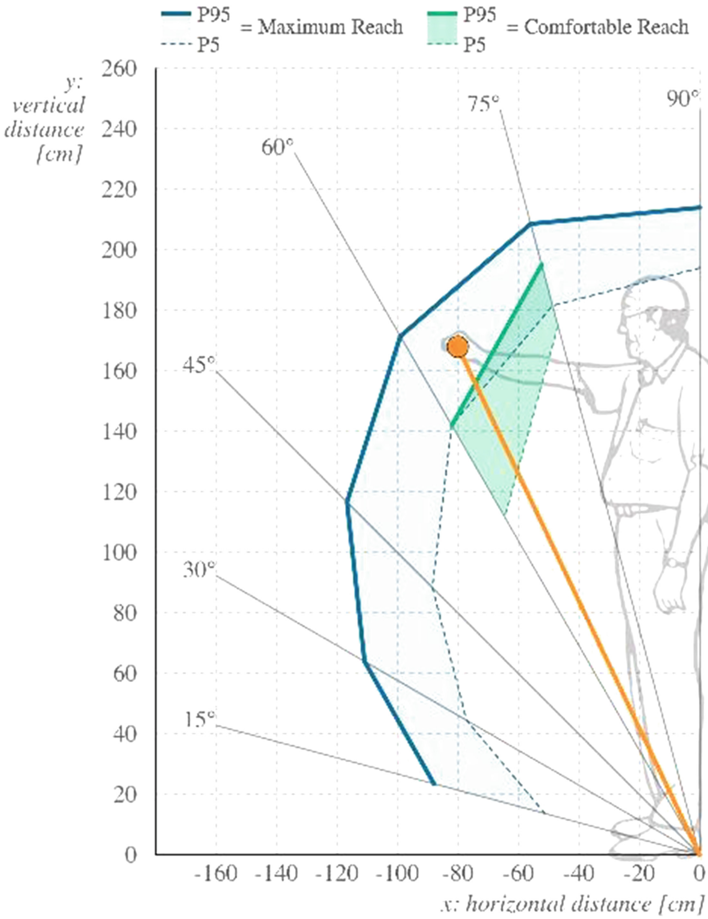


Fig. 3. DINED reach envelopes, developed especially to show large differences related to age (Color figure online)

3.4 Ellipse

This is an interactive tool that allows the designer to show the correlation between the raw data of 2 variables. If no raw data are available an ellipse can also be drawn if mean and SD values of both dimensions and the correlation coefficient, R, between them are known. The resulting ellipse, including scatterplot of the data, gives insight in the bi-variate distribution and it allows the drawing of 'rectangles' representing a size of a product like, for instance, the different sizes in a sizing system.

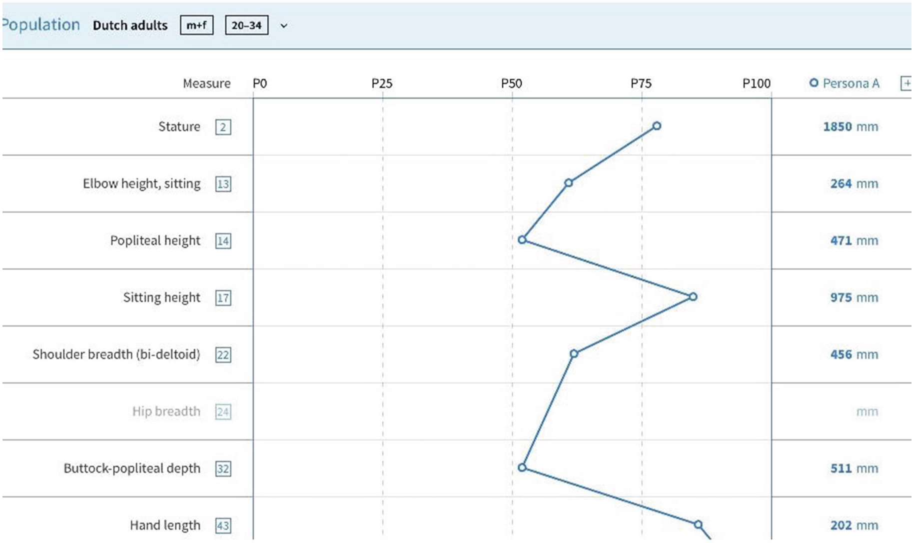


Fig. 4. DINED profiler shows nobody is average…

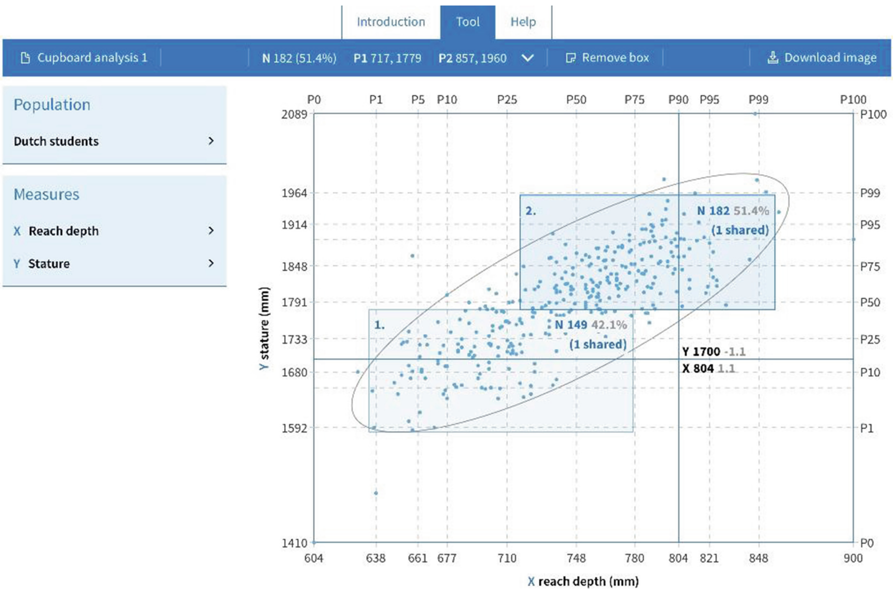


Fig. 5. DINED Ellipse showing correlation between two variables (stature and reach depth). Rectangles showing two sizing options and corresponding inclusion percentages (rectangles 1 and 2)

4 Future Additions to DINED

Several future additions to the DINED website are currently planned:

- Publishing and visualization of own anthropometric datasets
- Knowledge base for using 3D-scans in design
- Experience data of 4D anthropometry, involving the 'moving' human body.

4.1 Publish Your Own Data

Adding to the existing databases would be the possibility to use DINED as a platform to publish your own data. After verification of the quality of the real measured data, the population (sample) you measured data will be displayed with means, sd and percentiles if the data is (normal) Gaussian distributed.

4.2 Knowledge Base 3D-Anthropometry

This addition will include our knowledge, tools and experience about how to use 3D scans for designers [10]. One tool is able to integrate a scatterplot form Ellipse with 3D-scans from a person that will pop-up after a mouse-click on a dot in the scatterplot. Caesar data are available for TU Delft Campus use only. The first dataset that will become available are the 3D-scans from the project 'Ventilation mask' [11, 12].

4.3 Experience 4D-Anthropometry

In our Bodylab we are able to capture 4D data from humans in motion. After some experiments we learned we have to develop extra digital space and software to be able to manipulate these 4D data. Illustrative: a single experiment involving capturing motions of the shoulder joint took up nearly 0,5 terabyte in raw data. Sharing these and other experiences might help other researchers and developers.

5 Design for Plus-Size People

One group of people that has been growing in number over the last decades and has not been taken into consideration by all of the before mentioned anthropometric design tools, offered to designers to 'make products that fit all human beings'; people that have an above average weight. The absolute maxima to date are a man by the name John Brower Minoch (1941–1983) and a woman called Carol Yager (1960–1993) that weight at least 635 kg and 720 kg respectively [13]. Though design goals will not accommodate for the extreme, there is still lack of data on much larger group of people that are overweight (Fig. 6).

Fig. 6. John Brower Minoch in 1983, height 180 cm, weight 635 kg [22]

5.1 Own Data

A first start to fill the knowledge gap about anthropometric dimensions of 'Plus-size' people was made in measuring 21 'seriously overweight' people in 2003 and later in 2010 another 3 people in 2010. The results are shown in Table 2.

5.2 Other Methods to Estimate Sizes of Plus Size People

From the Gaussian distribution we know each percentile can be estimated or calculated by z * SD when z is a fixed number for each percentile P. P5 = mean − 1.65 * SD and P1 = 2.33 * SD. The current DINED table values are all more or less based on the Gaussian symmetric distribution. Real measurements of a group of people will mostly be close to the Normal or Gaussian distribution because there are as many small people as there are tall people. So they average and we see an symmetric Gaussian distribution. But when considering body weight or other body dimension that include body fat, this symmetry will disappear and the distribution will be skewed to the right because we have more and more plus size people in western societies and less lean people. To get a representative model either the dataset has to be extended with data from plus-size people (see Table 2). A valid estimation of the actual size distribution needs a larger sample of a few hundred test persons though. Finding these test persons proves to be difficult; obese people usually are limited in movement and endurance and/or don't like to be subjected to measurement.

Table 2. Plus-size anthropometrics, measured in Lunteren by Molenbroek on Annual Meeting Dutch Obesitas Society 2003

nr	m/f	Body weight kg	Height mm	Dist floor-fist sitting mm	Buttock-popliteal lgth mm	Popliteal hght mm	Abdominal dpth mm	Reach dpth forward mm	Thigh clearance mm	Elbow to elbown mm	Hip width mm	Waist circ mm
1	f	129	1755	226	535	489	426	774	176	660	494	1240
2	f	138	1667	327	510	428	428	723	221	654	538	1290
3	f	134	1672	315	521	431	504	715	173	669	545	1490
4	f	143	1611	246	498	418	509	649	210	686	560	1360
5	f	99	1640	90	510	425	365	688	170	583	505	1175
6	f	111	1738	225	549	399	325	747	220	559	530	980
7	f	96	1850	0	550	494	316	784	173	537	463	1030
8	f	143	1675	234	558	456	438	780	242	693	572	1260
9	f	126	1860	40	584	500	383	850	200	570	420	1170
10	f	96	1767	89	541	480	320	798	160	587	451	1010
11	f	106	1678	278	523	503	398	765	180	590	473	1080
12	f	99	1610	20	510	368	361	694	175	567	460	1100
13	f	112	1698	70	527	440	353	690	207	576	535	1060
14	f	115	1661	330	525	467	430	716	176	661	546	1140
15	f	144	1810	413	577	533	433	772	213	636	573	1200
16	f	185	1708	370	523	462	570	750	172	722	632	1730
17	f	117	1745	378	538	485	410	740	154	610	470	1290
18	m	163	1672	215	488	462	655	766	165	712	590	1680
19	m	127	1938	455	535	532	368	839	177	620	472	1230
20	m	175	1880	385	590	512	632	920	143	747	547	1850
21	m	186	1815	310	535	507	580	813	190	785	566	1750
22*	f	137	1716	–	540	429	457	744	196	630	537	157

(*continued*)

Table 2. *(continued)*

nr	m/f	Body weight kg	Height mm	Dist floor-fist sitting mm	Buttock-popliteal lgth mm	Popliteal hght mm	Abdominal dpth mm	Reach dpth forward mm	Thigh clearance mm	Elbow to elbown mm	Hip width mm	Waist circ mm
23*	f	135	1633	–	530	422	495	726	182	647	559	157
24*	m	205	1856	–	57	485	647	917	124	760	606	192
sum		3220	41655	5016	12354	11127	10803	18360	4399	15461	12644	27621
mean		134	1736	209	515	464	450	765	183	644	527	1151

*Nr 22–24 were measured in juli 2010, while testing an surgery table for Plus size people

5.3 Self-reporting

This was described by [5]. Chosen method to collect data was by self-reporting and additionally 101 people were asked to be measured by a partner and fill in a standard form. This method was verified with a small sample (n = 10) that was actually measured by tape and scale.

5.4 Estimating SDX

Because it is not easy to get obese people to your laboratory to be measured, it makes sense to make some estimations. First it would be good to know what is the range of the body weight of a living human being. The maximum can be found in the Guiness Book of Record (625 kg) and the weight of one of the smallest human with a stature of 58 cm should be around 5 kg [8]. This means the body weight has a very skewed distribution to design for.

A very rough estimation can be done as follows; a normal distribution is taken but the right part is enlarged by increasing the SD a factor 2 times SD (to reach a P99 = 145 kg) is taken or 3 times SD (to reach P99 = 175 kg) and with 4 times SD we get P99 about 200 kg when the mean value = 83 kg and SD = 13 kg (DINED 20–60).

5.5 Multivariate Techniques with Sample of Intended Users

As mentioned earlier, many anthropometric data sources assume that all the measurement data have a Gaussian (Normal) distribution and are symmetrically distributed. If this is so, then the 5th and 95th percentile values of each measurement would be equidistant from the mean value. It has been shown [14], at least for the data presented in ISO 7250-2 [15], that these percentile values are not equidistant from the mean value.

Similarly, many of these data sources, such as ISO 7250-2, present their data exclusively in the form of tables of percentile values. Combining these percentile values in a design is problematic. For example, one might want to design a chair seat with dimensions of depth, width and height above the floor that accommodates 90% of the intended users. If the 90th percentile values of each of these dimensions are combined, the result is unlikely to accommodate exactly 90% of the intended users. While techniques to combine two or more percentile values exist that can be used in situations when only percentile values are available [16, 17] to the designer, there are other multivariate techniques available if a representative sample of data of the intended users is available.

Recently a user-friendly multivariate tool has been developed for use in the ANSI/HFES 100 standard [18–20]. The tool does not require assumption of normally distributed data, it simply counts the number of individuals in the sample whose measurements are concurrently within the specified ranges for all variables of interest. It is presented as an Excel spreadsheet, a widely used and familiar format.

To use the tool, a designer enters a measurement value or range of values for each of the variables of interest. The tool then determines the overall proportion of individuals in the sample who are within the specified range of measurements for all the specified variables. An individual is counted as accommodated only if his or her measurements are within the specified range for each and every variable of interest. For example, if there were three variables of interest, an individual is counted as accommodated only if his or her measurements are concurrently within the specified range for all of the three variables of interest.

Clearly it is necessary to make the sample as representative as possible of the intended user population. In the case of the ANSI/HFES 100 tool, that was accomplished by statistically weighting the CAESAR anthropometric dataset for US civilians [21] to match the current height and mass of US civilians [19].

A similar strategy is proposed to integrate plus-sized individuals into an anthropometric sample representative of individuals in the Netherlands and to incorporate that data into the DINED tool.

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