3D Anthropometric Data Set of the Head and Face of Children Aged 0.5-7 Years for Design Applications

Lyè GOTO*, Johan F.M. MOLENBROEK, Richard H.M. GOOSSENS
Industrial Design Engineering, Delft University of Technology, Delft, The Netherlands

http://dx.doi.org/10.15221/13.157

Abstract

In product design, human body measurements are essential when it comes to products that need to fit the contour of the human body in order to be effective. When designing these products, designers must integrate anthropometric dimensions in their design process to optimize the usability and functioning of the product. In spite of the wide variety of available anthropometric tools, designers most commonly use traditional (1D) anthropometric information when designing and evaluating products. This does not always offer the detailed information of the human body shape required to develop a product with an optimal fit. This is especially the case for medical products such as respirators and orthesis, but also in consumer products, such as helmets and protective glasses.

3D anthropometry however, creates a significant opportunity for designers by offering detailed information regarding the shape of the human body. Advances in 3D imaging technologies have reinforced these possibilities in the field of anthropometry. With the use of these technologies, it is possible to capture a complete 3D image of the whole body in a matter of seconds, making the measurement process less invasive and therefor more suitable for populations that are difficult to measure with traditional means like children, elderly and physically impaired persons.

The objective of this study is to map the variation of children's heads and faces and to define a new way to present this 3D anthropometric data so that it is tailored for use in design. For the first stage of this study, an anthropometric survey was conducted, whereby the heads and faces of children between the ages of 0.5 to 7 years old were analysed. Around 300 boys and girls were measured combining traditional anthropometric measurements with measurements derived from 3D images. All subjects were photographed using a digital three-dimensional photogrammetry system (3dMD Face imaging system). This paper presents the preliminary 3D data set of the heads and faces of children aged 0.5-7 years for design applications and shows the summary statistics for some of the traditional anthropometric measurements.

Keywords: 3D Anthropometry, Children, Head and Face, Design

1. Introduction

In spite of the wide variety of available anthropometric tools, designers most commonly use traditional (1D) anthropometric information when designing and evaluating products [1]. 3D anthropometric data however, offers a significant opportunity when it comes to designing products whereby detailed information of human body shape is needed. This is especially the case for medical products such as respirators and orthesis, but also in consumer products such as, helmets and protective glasses. 3D anthropometry offers good opportunities for designers by offering detailed information of the shape of the human body.

3D imaging technologies are increasingly being used in anthropometric surveys around the world [2][3][4]. There are many advantages in using 3D imaging in anthropometric surveys. In traditional anthropometry the measuring process is often time consuming. When considering that large scale anthropometric surveys can include an average of 100 traditional measurements, the subject is asked to remain still for quite some time. With the use of 3D technology it is possible to capture a complete 3D image of the whole body in a matter of seconds, making the whole process less invasive and more suitable for people who are unable to remain in the same posture for a long period of time. Anthropometric measurements are derived from the 3D data after 3D image collection and this results in a higher and more efficient throughput during the survey. The types of measurements, information on geometry and other variables which are extracted from the stored 3D image file are limitless and

* l.goto@tudelft.nl; +31 15 278 2879; www.io.tudelft.nl

can be recalled when necessary. This brings us to another important advantage of 3D anthropometric data; where traditional anthropometric data offers information about 1D body dimensions like arm length and head circumference, 3D anthropometric data has the potential to also provide information about the shape, volume and geometry of the body. Also, 3D anthropometric data can be converted to different formats, thus making it possible to import a 3D scan into CAD (Computer Aided Design) programmes. As a result designers can easily integrate 3D anthropometric information into their design process.

A number of studies have mapped the variation of children's heads and faces [5][6][7]. L.G. Farkas carried out an elaborate growth study of the heads and faces of both children and adults. However, to date, the authors have not been able to find 3D anthropometric studies of children, which evaluate the form and shape variation of the head and face that also take into account the growth. This information is of particular importance when designing protective gear and medical devices that require an accurate fit, such as ventilation masks. Therefor the objective of this study is two-fold:

1. To map the anthropometric variance of children's heads and faces.
2. To develop an anthropometric database of heads and faces of children aged 0.5-7 years for design applications.

The study will provide preliminary data for the development of a methodology for using 3D data in sizing and designing products whereby fit is important.

2. Materials and Methods

2.1. Subjects

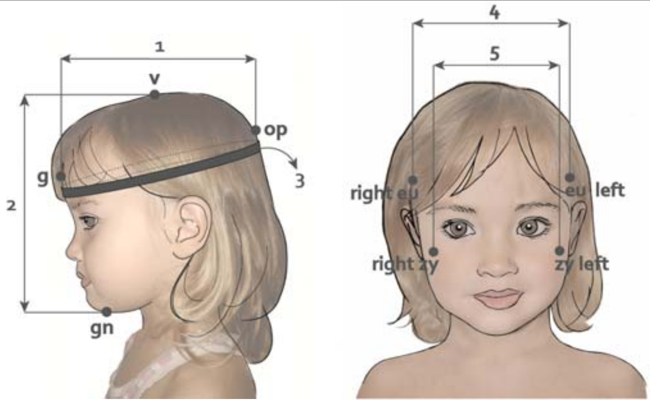
The subjects were sampled by age and gender, and included Dutch children aged 0.5 – 7 years old. 30 subjects per age group per gender will be surveyed. Besides the two gender strata, the age stratification is as indicated in table 1. The minimum number of subjects required for this survey was calculated according to the guidelines provided by the International Organization for Standardization, ISO 15535 [8].

Table 1. Age stratification. N (realised) represents the number of subjects surveyed up to now and N (intended) represents the number of subjects that is intended to be surveyed.

Age Group	Individual Age (Years)	Gender	N (Realised)	N (Intended)
1	0.50-1.49	Male	19	30
		Female	10	30
2	1.50-2.49	Male	18	30
		Female	8	30
3	2.50-3.49	Male	20	30
		Female	14	30
4	3.50-4.49	Male	19	30
		Female	13	30
5	4.50-5.49	Male	40	30
		Female	21	30
6	5.50-6.49	Male	24	30
		Female	23	30
7	6.50-7.49	Male	20	30
		Female	19	30
		Total:	268	420

2.2. Anthropometric Measurements

The study design consisted of traditional anthropometric measurements and anthropometric measurements obtained through digital three-dimensional photogrammetry. Photogrammetry was used because of its accuracy and capturing speed [9]. In addition to the stature and weight, 5 traditional head and face measurements were taken (figure 2). These direct measurements are used to calculate anthropometric indices and facilitate when sorting, comparing and analysing data. But more importantly they serve as a check of the accuracy of the imaging system and the 3D image extracted values. The measurements were also used to calculate the correlation between the traditional measurements and the 3D image derived measurements.



Dimension	description
1	Length of Head (gonion-op)
2	Craniofacial Height (v-gn)
3	Head circumference
4	Width of Head (eurion right – eurion left)
5	Width of the Face (zygion left – zygion right)

Fig. 1. 5 traditional measurements served as a check of the accuracy of the 3D imaging system.

2.3. Data collection

2.3.1. Equipment

The 3dMD Face system (figure 2) was used in order to obtain the 3D images of the subjects. The 3dMD imaging system is based on a combination of stereo photogrammetry and structured light. The two pods that are mounted on the system each consist of 3 digital cameras and a projector. During each acquisition 6 pictures are taken simultaneously within 1.5 milliseconds. These images are then automatically combined into a 3D image. The system's three flashes ensures sufficient lighting of the subject. The imaging set-up is as presented in figure 3.

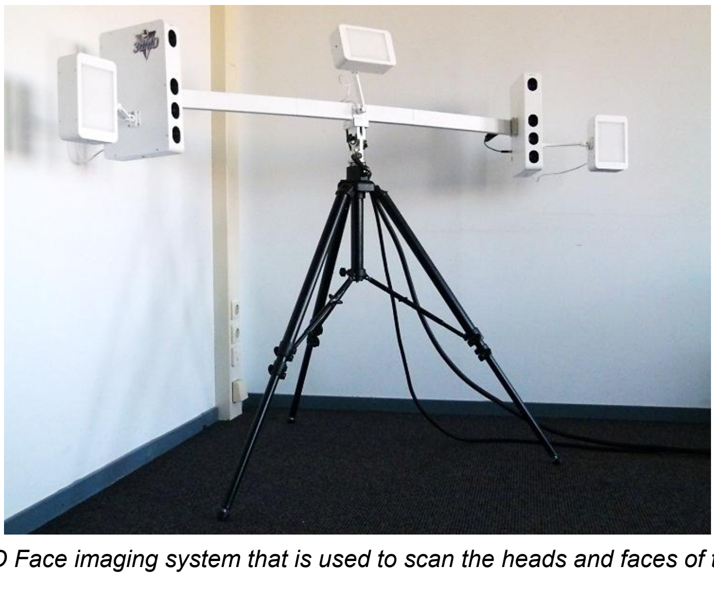


Fig. 2. 3dMD Face imaging system that is used to scan the heads and faces of the subjects.

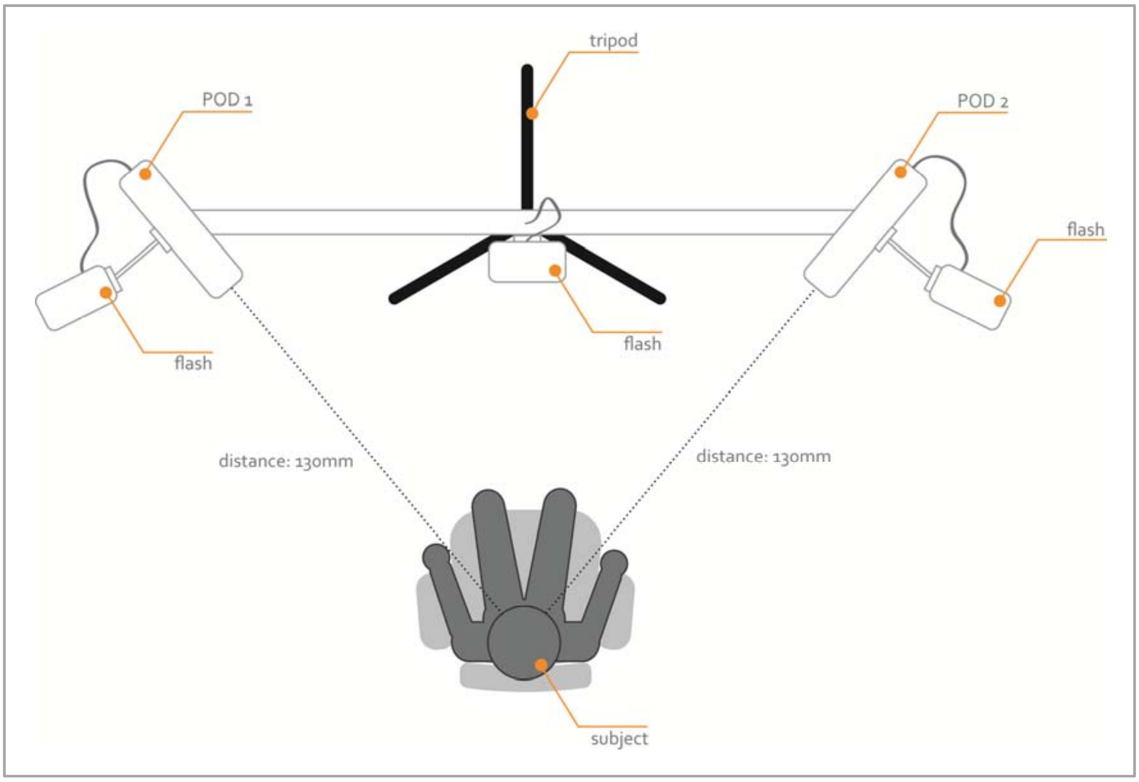


Fig. 3. Floor footprint for the imaging set-up.

2.3.2. Recruitment

Potential subjects were recruited through schools and day-care centres. In the case that schools were willing to cooperate, an information sheet was sent to the parents of the children providing them with information about the purpose of the research and the protocol of the survey. Parents could indicate whether they wanted to cooperate and give permission for their child or children to participate in the survey by signing a consent form and filling in a brief demographic questionnaire. Recruitment at the day-care centres took place on site by approaching the parents personally. Ethical approval for the survey was gained from the Human Research Ethics Committee of the Delft University of Technology.

2.3.3. Measuring and image capture

After an introduction of the study and a short explanation of the protocol the anthropometric data form was filled in and a reference number was assigned to the subject. For each child the type of clothing was identified and coded on the data sheet (nude=0, underwear=1, light clothing=2, other clothing=3). Traditional anthropometric measurements were recorded starting with the weight and stature. Children less than 24 months old were weighed using a baby scale, children older than 24 months were weighed with a standing scale. Children less than 24 months old who were not able to stand up by themselves were measured lying down (recumbent length) with a horizontal length scale whilst older children were measured with a stadiometer. Next, the head circumference was measured with a measuring tape and head and facial dimensions were recorded with a speading caliper and a sliding caliper. Lastly the 3D images were obtained. A total of 4 images of the subject were taken from the front, 45° to the left, 45° to the right and the back, respectively in order to get a complete image of the head and face of the child (figure 4). Before photographing each subject was provided with a nylon wig cap to capture the shape of the head and to avoid noise or holes in the 3D data caused by hair.

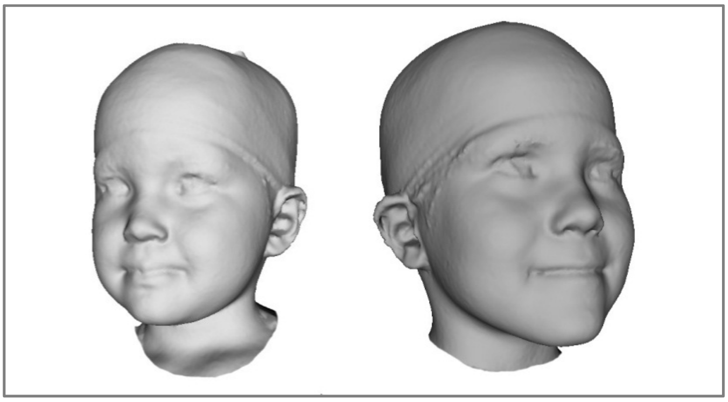


Fig. 4. Example of a 3D image of a 3 and a 5 year old girl. Both images are examples of images taken from the front.

2.3.4. Data analysis

For age group 1 the statistical data of traditional measurements were analysed. Gender specific means and standard deviations were calculated using SPSS software. In addition, for each dimension the maximum and minimum values were determined. Finally, the accuracy of the 3D imaging system was tested by comparing the traditional measurements with scan derived measurements. Two head measurements of age group 1 were chosen, one including hair and one without hair. The dimensions were then measured directly and collected from the 3D image using the 3dMD Vultus software. The maximum allowable error between extracted value and traditionally measured value for head dimensions were 1 mm for dimensions without hair and 2 mm for dimensions with hair [10]. The mean difference between the traditional measurements and the image derived measurements were calculated. Also 3D image derived measurements were compared with the anthropometric study of North American Caucasians aged from 1 to 18 years conducted by L.G. Farkas [5]. The surface based tragion-subnasale arc (left and right) (figure 5) of one year olds was extracted from the 3D images. With a t-test the significance of the differences between the two datasets were examined.

3. Results

3.1. Descriptive statistics

Results of the traditional anthropometric measurements are presented in table 2 for age group 1. The mean, standard deviation, minimum and maximum dimensions are given. N varies per measurement for the reason that for some subjects it was not possible to take any direct measurements because they were either scared or emotional. This happened mostly within age group 1 and 2. Capturing a 3D image however, was in most cases still possible.

Table 2. Summary statistics (Mean, Standard deviation, minimum and maximum) by gender for age group 1.

	Male					Female				
Dimension	N	Mean (mm)	SD (mm)	Min (mm)	Max (mm)	N	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Stature	19	786.4	50.5	656	845	10	758.9	56	678	840
Body weight *(kg)*	19	10.7	1.28	7.4	12.8	10	9.3	1.32	7.0	11.3
Head circumference	19	471.6	17.9	440	505	10	448,5	9.9	430	467
Width of Head	15	130.8	9.8	122	148	8	122.5	4.8	118	129
Width of the Face	16	103.4	7.8	91	108	8	98.3	4.1	92	103
Length of Head	14	156.9	7.0	145	168	5	154.3	8.9	145	168
Craniofacial Height	12	162.8	13.9	143	198	6	165.4	9.8	148	172

3.2. Traditional Measurements vs. 3D image derived measurements

The traditionally measured dimensions that were derived directly from the 3D images were compared to provide an indication of the accuracy of the imaging system. Two head dimensions of age group 1, width of the head and width of the face, respectively, were measured traditionally and extracted from the 3D image. The resulting dimensions were compared by calculating the mean, mean differences and the significance of the mean difference compared to the allowable error. The results are shown in table 3.

Table 3. Traditional measurements compared with 3D image derived measurements. The maximum allowable error between extracted value and traditionally measured value for width of head is 2 mm and for the width of face it is 1 mm.

		Male (N=15)	Female (N=8)
Dimension		Mean	Mean
Width of Head	Traditional (mm)	129.6	122.5
(eu-eu)	Scan derived (mm)	131.3	123.9
	Difference (mm)	2.3	1.4
	Allowable error, ISO 20685 (mm)	2	2
Width of Face	Traditional	102.1	98.3
(zy-zy)	Scan derived	99.0	93.6
	Difference (mm)	3.1	4.7
	Allowable error, ISO 20685 (mm)	1	1

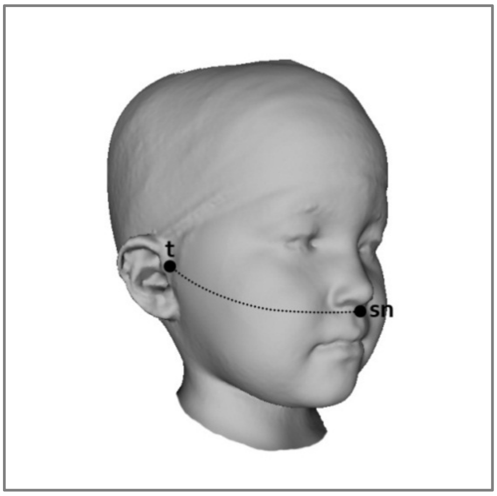


Fig. 5. Tragion - subnasale arc, right side.

3.2. 3D image derived measurements compared with existing anthropometric data

A comparison in mean and standard deviation between 3D image derived measurements of the tragion-subnasale arc (figure 5) of age group 1 and the same measurements of 1 year olds collected by L.G. Farkas are presented in table 2. The tragion-subnasale arc (left and right) of the 3D data set was found to be significantly larger than the dimensions of the Farkas dataset in male as well as in females.

Table 2. Comparison of the tragion – subnasale arc (Maxillary Half-arc) (left and right) of 1 year olds, 3D dataset compared with the dataset of L.G. Farkas.

Tragion – subnasale arc	*3D data set (N=18)*			*Farkas (N=17)*			*3D data set vs. Farkas*			
	M_{3D}	*SD_{3D}*		*M_F*	*SD_F*		*M_{3D}-M_F*	*M_{3D}/M_F*	*SD_{3D}/SD_F*	*T*
Male, right side	*110.2*	*4.4*		*113.2*	*4.2*		*-3.0*	*0.97*	*1.05*	*2.1**
Male, left side	*108.7*	*5.1*		*112.8*	*4.7*		*-4.1*	*0.96*	*1.09*	*2.5**
Tragion – subnasale arc	*3D data set (N=11)*			*Farkas (N=15)*			*3D data set vs. Farkas*			
	M_{3D}	*SD_{3D}*		*M_F*	*SD_F*		*M_{3D}-M_F*	*M_{3D}/M_F*	*SD_{3D}/SD_F*	*T*
Female, right side	*107.4*	*4.9*		*110.6*	*4.3*		*-3.2*	*0.97*	*1.14*	*1.8***
Female, left side	*105.7*	*3.1*		*110.9*	*4.0*		*-5.2*	*0.95*	*0.78*	*3.5****

*significant at 1%
**Significant at 5%
***Significant at 0.1%

4. Discussion

The present study shows the development of a 3D anthropometric data set of children based on an anthropometric survey that was conducted amongst Dutch children. The results of this preliminary analysis shows that there is a difference between the traditional measurements and the measurements extracted from the 3D images. However this difference does not indicate which of the measurements are more accurate nor does it give a definite answer to the question which of the measurements represent the population better. The differences between the scan derived measurements and the traditional measurements of the width of the face for male and female both exceeded the allowable error whereas the measurements for the width of the face seemed to be more accurate. This could be explained by the fact that the zygion landmarks are difficult to locate. One has to palpate the bony structure underneath the skin. This is not possible when landmarking a 3D image. Another explanation is that when the dimension is measured directly, one can easily impress the skin with the measuring device. A 3D image derived measurement however is always based on the actual dimensions of the face and there is no risk of compressing the soft tissue which could otherwise result in an inaccurate measurement. For the surface based measurements that were compared with an existing dataset significant difference were found. The measurements extracted from the 3D images were significantly smaller than the measurements of Farkas. Demographic factors could therefor have been an important factor. The 3D dataset is based on a Dutch population whereas Farkas' study was based on a North American population. Another factor that could result in this difference is that by extracting a surface based dimension from the 3D image the contour of the surface is followed and the shortest distance between the landmarks is automatically selected. The traditional measuring protocol for this specific dimension could differ, giving different results for the same measurement. Finally, even though at first glance both populations consisted of one year old children, this remains a rather broad definition given that the head of a child grows considerably during the first couple of years [6]. It is therefor possible that Farkas' population could have consisted of a larger number of older one year olds than the 3D dataset.

Integration of 3D anthropometric data of children's head shape in the design process should facilitate in creating a better fit. Because of its acquisition speed, photogrammetry makes it possible to scan babies and young children in a matter of seconds. At present, this group of children cannot easily be measured in the traditional way due to the fact that they are not able to sit still for long periods of time. In addition, to extract the measurements from the 3D image, markers need to be placed on the body to get an accurate result because some landmarks need palpation of the body structure that lies underneath the skin. However, when working with specific target groups such as children, this is not always feasible. When considering its application in design, this dataset gives a good indication of the variation within the population.

The potential of this dataset and its application in design lies in the fact that the 3D images collected in this study not only provide statistical information of the traditional anthropometric measurements, it also provides information about the shape. For designers who need to develop products that need to fit the human body, the shape variation offers more useful information then traditional 1D anthropometric dimensions since two points in the human body are rarely connected by a straight line. By simulating product fit or evaluating their product in a virtual environment, using these 3D images, designers are able to gain a better insight into proportions and filter out problems at an early stage in the design process. As a result, designers can improve the quality of the product design, the efficiency of the development process, all within a shorter time span.

However, there are some drawbacks when applying 3D anthropometric data in the design process. As a result of the complexity and denseness of the data the required computational load is high, making it difficult to sort and analyse [11,12,13] Unprocessed 3D scans need to be analysed, processed, converted and tailored to its design application. A number of studies have focussed on analysing and presenting 3D anthropometric data for specific purposes [3,14,15,16] However little research has been done on how 3D anthropometric data is applied in the design process nor into the needs of the designers themselves [17].

5. Conclusion

This paper presents the first results of a new 3D anthropometric data set for the heads and faces of children aged 0.5 to 7 years. The main conclusions are:

- Traditional measurements and 3D image extracted measurements differed but further research is required in order to determine whether traditional or 3D measurements are more accurate.
- 3D imaging offers a fast and efficient way to collect 3D anthropometric data when dealing with young children.
- 3D anthropometric data has the potential to offer designers valuable information regarding the form and shape of the human body which they can utilize during the design process to create optimally fitting products. However, to achieve this further research is required regarding the type of anthropometric information designers need and how to integrate this information in the design process.

This anthropometric data will form the bases for the development of a valuable 3D anthropometric database that will complement the various traditional anthropometric information of children that is currently available. The aim of this study, of which this paper presents the first step, is to analyse this data set from a designers point of view and tailor it to its application in design. It will serve as a valuable resource for designers that develop face and head wear for children such as helmets, ventilation masks and spectacles.

References

[1] Molenbroek JFM, Bruin R De. Enhancing the use of anthropometric data. Hum. Factors Des. Safety, Manag., 2005, p. 289 – 297.
[2] Robinette KM, Daanen HAM, Paquet E. The CAESAR project: a 3-D surface anthropometry survey. Second Int. Conf. 3-D Digit. Imaging Model., 1999, p. 380 – 386.
[3] Zhuang Z, Bradtmiller B. Head-and-face anthropometric survey of U.S. respirator users. J Occup Environ Hyg 2005;2:567–76.
[4] Ball R, Molenbroek JFM. Measuring Chinese Heads and Faces. Proc. 9th Int. Congr. Physiol. Anthropol. , Hum. Divers. Des. life, 1988, p. 150–5.
[5] Farkas LG. Anthropometry of the head and face. New York: Raven Press; 1994.
[6] Steenbekkers LPA. Child development, design implications and accident prevention. 1993.
[7] Schneider LW, Lehman RJ, Pflug MA, Owings CL. Size and shape of the head and neck from birth to four years. Final Rep to Consum Prod Saf Comm 1986.
[8] European Committee for Standardisation (ISO). General requirements for establishing anthropometric databases (ISO 15535) 2007.
[9] Wong J, Oh A, Ohta E, Hunt A. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. Palate-Craniofacial 2008.

[10] European Committee for Standardisation (ISO). 3-D scanning methodologies for internationally compatible anthropometric databases (ISO 20685) 2010.
[11] Luximon Y. BRJL. The 3D Chinese head and face modeling. CAD Comput Aided Des 2012;44:40–7.
[12] Niu J.a Li Z. XS. Block Division for 3D Head Shape Clustering. Lect Notes Comput Sci (including Subser Lect Notes Artif Intell Lect Notes Bioinformatics) 2009;5620 LNCS:64–71.
[13] Godil A. Advanced Human Body and Head Shape 2007:92–100.
[14] Robinette KM. Fit testing as a helmet development tool. Proc. Hum. Factors Ergon. Soc., vol. 1, 1993, p. 69–73.
[15] Mochimaru M. KMDM. Analysis of 3-D human foot forms using the Free Form Deformation method and its application in grading shoe lasts. Ergonomics 2000;43:1301–13.
[16] Kouchi M, Mochimaru M. Analysis of 3D face forms for proper sizing and CAD of spectacle frames. Ergonomics 2004;47:1499–516.
[17] Sims RE, Marshall R, Gyi DE, Summerskill SJ, Case K. Collection of anthropometry from older and physically impaired persons: Traditional methods versus TC2 3-D body scanner. Int J Ind Ergon 2012;42:65–72.