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Traditional and 3D scan extracted measurements of the heads and faces of Dutch children

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ABSTRACT

3D anthropometry has created a significant opportunity for designers to improve fit by offering detailed information regarding the shape of the human body. Various researchers have shown the benefit of using 3D anthropometric data in the development or evaluation of head related products for adults. However, detailed 3D anthropometric data of children heads and faces is still lacking. This paper presents up to date descriptive statistics of detailed measurements made of heads and faces of Dutch children. For the purpose of developing ergonomic head and face wear for children, an anthropometric survey was conducted, whereby children aged 6 months to 7 years were measured, utilising both traditional anthropometric measurement techniques and 3D image derived measurements. The traditional measurements were compared with the most recent dataset of Dutch children and, on a more detailed level, with a dataset of North American children.

1. Introduction

Anthropometry plays an important role in product design. Designers utilise anthropometric information during the product development process to optimise the usability and fit of the product. The required type of anthropometric information highly depends on the product that needs to be developed. Currently, traditional anthropometric data is being used extensively in product development but it lacks the level of detail that is essential in products that need to closely fit the human body.

3D anthropometry has created a significant opportunity for designers to improve fit by offering detailed information regarding the shape of the human body. Advances in 3D imaging technologies have resulted in new developments and applications in the field of anthropometry. Collecting 3D body scan data is thus increasingly being incorporated in anthropometric surveys (HQL, 1997; Robinette et al., 2002; Zhuang et al., 2010a,b; Ball, 2011; Ballester et al., 2015). The use of 3D scanning technologies facilitates the collection of measurements and shape information, and because of their high capturing speed, it makes the whole process less time consuming. Moreover, 3D scanners offer the opportunity to gather anthropometric data in a less invasive way and is therefore more suitable for elderly, physically impaired persons and children (Kau et al., 2004; Conkle et al., 2019).

3D anthropometric information can be especially important for the development of head- and face-related products, such as oxygen masks, helmets and goggles (Wuhrer et al., 2012; Luximon et al., 2016). These products need to fit well, to ensure functionality, safety and comfort. Various researchers have shown the benefit of using 3D anthropometric data in the development or evaluation of head related products (Liu et al., 2008; Alemany et al., 2012; Schreinemakers et al., 2013; Ellena et al., 2016; Stavrakos and Ahmed-Kristensen 2016; Lacko et al., 2017; Verwulgen et al., 2018; Skals et al., 2016). In medical products, a proper fit can have an immediate impact on the health of the patient. For instance, in a ventilation mask, an improper fit could result in eye infections, pressure sores and, for young children, it may even affect the growth of the face (Fauroux et al., 2005; Norregaard, 2002).

Currently, there is no suitable full face ventilation mask (covering the nose and mouth) available for young children (younger than 6 years old) who suffer from, for example, muscular diseases, obstructive sleep apnea syndrome or who have a cranial facial disorder. Most of the existing paediatric masks are nasal masks which cover only the nose. However, nasal ventilation is not always effective. For example, with children who sleep with their mouth open (Amin et al., 2016). Because of this deficiency, some hospitals have chosen to make their own custom-made masks (Fauroux et al., 2005; Mellies et al., 2003; Norregaard, 2002) or modify nasal masks for adults in order to use it as a full face mask for children (Samuels and Boit, 2007; Simonds et al., 2000). However, this is only an intermediate solution. In order to

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improve the comfort of the patient and the functionality a ventilation mask, designed specifically for children is required.

Anthropometric data of the head and face is necessary in order to develop a ventilation mask for young children. Most traditional anthropometric surveys of children include only a select number of head dimensions such as head circumference, head length and head breadth (Steenbekkers, 1993; Fryar et al., 2012). Growth studies typically only include head circumference (Schönbeck and van Buuren, 2010; WHO Multicentre Growth Reference Study Group, 2009). Only a select number of studies provide anthropometric data of children specifically for product design and safety (Steenbekkers and Molenbroek, 1990; Steenbekkers, 1993) and only two of these studies include the more detailed dimensions of the head and face (Schneider et al., 1986; Snyder et al., 1977). Other studies that provide detailed data of head and face related dimensions are often from the medical field, e.g. orthodontics or plastic surgery (Farkas, 1994; Bugaighis et al., 2013; Tutkuviene et al., 2015; Meyer-Marcotty et al., 2014). Medical studies are a potential source of information but not fine-tuned to design and often focus on specific (facial) areas. Nevertheless, there is no detailed anthropometric information currently available of heads and faces of Dutch children. Moreover, there are no 3D anthropometric studies of young children, which evaluate the form and shape variation of the head and face. This is especially important in the development of a mask that has to follow the contours of the face in order to achieve a good fit.

The aim of the present study was to provide data for detailed head and face dimensions of Dutch children employing 3D scanning techniques. In this study, 303 Dutch children aged 6 months to 7 years were measured for the purpose of designing head and face wear for children and as a first step in the development of a methodology for using 3D data in the sizing and design of a ventilation mask for children (Goto et al., 2013). The measurements of this dataset were analysed and compared with the most recent dataset of Dutch children (Steenbekkers, 1993) to identify anthropometric differences or trends. Steenbekkers measured 2421 Dutch children aged 0–12 years to obtain data of physical and psychomotor characteristics for the development of safer daily-life products for children. The survey included five head dimensions (breadth, height, length, circumference and chin to crown length). However, because of the lack of data regarding the more detailed facial dimensions in this study and since there is no reference data of the more detailed facial measurements of Dutch children, detailed measurements of current dataset were compared to that of North American children (Farkas, 1994). Farkas measured the heads and faces of around 1590 North American Caucasian children aged 1–18 years as part of research in craniofacial anthropometry with applications in medicine and genetics and this dataset is still, up until now one of the most extensive normative databases of the head and face available.

2. Methods

2.1. Participants and recruitment

The participants were Dutch children aged 6 months to 7 years old of mixed ethnicity. In this sample 17.8% (N = 54) were of non-native Dutch origin. A child was considered to be of non-native Dutch origin when the country of origin of either one or both parents was not the Netherlands. They were sampled by age and gender. A total of 302 children (128 females 174 males) were recruited. The age of each child was calculated by determining the difference between the date of measurement and the date of birth. It was then rounded to the nearest decimal and categorised in age groups (e.g., children aged 3.00–3.99 were categorised as 3 year olds). The total numbers of children per age and gender are presented in Table 1.

Potential participants were recruited through primary schools and health centres in the Delft, Rijswijk and Leidschendam-Voorburg municipalities in the Province of South-Holland and through the Delft University of Technology. When schools were willing to cooperate, an information package 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(ren) to participate in the survey by signing a consent form and filling in a brief demographic questionnaire. Recruitment at the health centres took place on site by approaching the parents personally. University staff was contacted through newsletters. Ethical approval for the survey was gained from the Human Research Ethics Committee of the Delft University of Technology.

Table 1
Sample size by age and gender, including age range, average age and standard deviation (SD).

Age group	Age range	Average age and SD	Gender	N
0	0.5–0.9	0.8 ± 0.2	Male	10
			Female	7
1	1.0–1.9	1.4 ± 0.2	Male	21
			Female	8
2	2.0–2.9	2.5 ± 0.3	Male	12
			Female	11
3	3.0–3.9	3.3 ± 0.2	Male	17
			Female	15
4	4.0–4.9	4.6 ± 0.2	Male	39
			Female	15
5	5.0–5.9	5.5 ± 0.3	Male	34
			Female	30
6	6.0–6.9	6.48 ± 0.3	Male	32
			Female	34
7	7.0–7.9	7.2 ± 0.2	Male	9
			Female	8
			Total	302

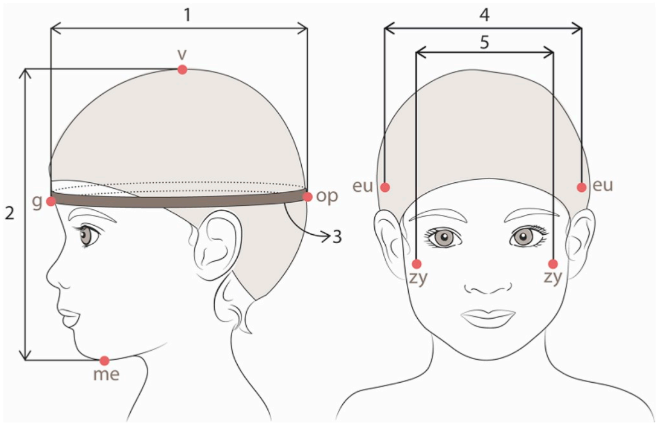
2.2. Data collection

In the survey a combination of traditional anthropometric measurement techniques as well as 3D image derived measurements were used.

2.2.1. Measuring and image capture

After explaining the purpose of the study and the protocol, the anthropometric data form was filled out and a reference number was assigned to the participant. Traditional anthropometric measurements were then recorded. These included 5 head and face measurements (Fig. 1) and stature and weight. 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, while older children were measured with a stadiometer. The head circumference was measured with a measuring tape and head and facial dimensions were recorded with an anthropometer and a spreading calliper. These head measurements were measured traditionally because they are more difficult to extract from 3D images since the landmarks rely primarily on palpation and not only on visual inspection.

Lastly, the 3D images were obtained using the 3dMD Face system (3dMD Ltd., London, UK). 3D photogrammetry was used because of its accuracy (geometric accuracy of 0.2 root mean square) and high capturing speed (1.5 ms) (Wong et al., 2008; Lübbers et al., 2010). The imaging set-up was as presented in Figs. 2 and 3. Before photographing, each participant 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. A total of 4 images of the participant were taken from the front, 45° to the left, 45° to the right and from the back. The child was positioned on a highchair that was mounted on a plateau on wheels (Fig. 3) in order to be able to rotate the child in the respective angels.



Dimension	Description
1	Head length (g-op)
2	Head height (v-me)
3	Head circumference
4	Head breadth (eu - eu)
5	Face width (zy - zy)

Fig. 1. Traditional measurements (eu: eurion, g: glabella, me: menton, op: opisthocranion, v: vertex, and zy: zygion).

2.2.2. Data process and alignment

The four 3D images that were captured were combined in Artec Studio 9 software (Artec group, Luxembourg) to obtain a complete 3D image of the participant (Fig. 4). Subsequently, remaining holes in the image were repaired in Geomagic Studio 2013 software (3D Systems, Rock Hill, SC, USA). The 3D images and landmark coordinates are not directly comparable, as the position of each participant and the orientation of the head relative to the 3D imaging system varied. All images were aligned with MATLAB™ 2015a software (The MathWorks, Inc., Natick, MA, USA) according to the Frankfort horizontal plane and the sellion landmark. The Frankfort plane, which is a commonly used anthropometric reference plane, runs through the right infraorbitale and the left and right tragion landmarks (Martin and Knussmann, 1988). The sellion landmark was set as the origin point (0, 0, 0) and subsequently, the 3D image of the face was rotated around the x, y, and z axes until a line through the landmarks was parallel to either the x, y or z axis. For example, the face was rotated around the y-axis until the line passing through the left and right infra-orbitale landmarks was parallel to the z axis. In this way, all the 3D faces were aligned so when they are superimposed they are all oriented according to the same coordinate system.

Fig. 3. 3D imaging setup with a 3-year-old girl (left) and with a 1-year-old girl sitting on the highchair mounted on the wheeled plateau (right).

2.2.3. Landmarking and measurement extraction

The 3D images were manually landmarked using 3dMDvultus 2.1 software (3dMD Ltd., London, UK). A total of 15 landmarks were selected in order to obtain information of the facial area relevant to the design of ventilation mask. The landmarks included in this study could be located on the 3D image without the use of palpation and were based on identifiable facial features (Fig. 5). Landmark descriptions were defined based on previous research (Martin and Knussmann, 1988; Zhuang et al., 2010a,b; Facebase, 2013). The landmarks included in this study were; glabella, sellion, endocanthion (left/right), nasal root point (left/right), pronasale, alare (left/right), subnasale, cheilion

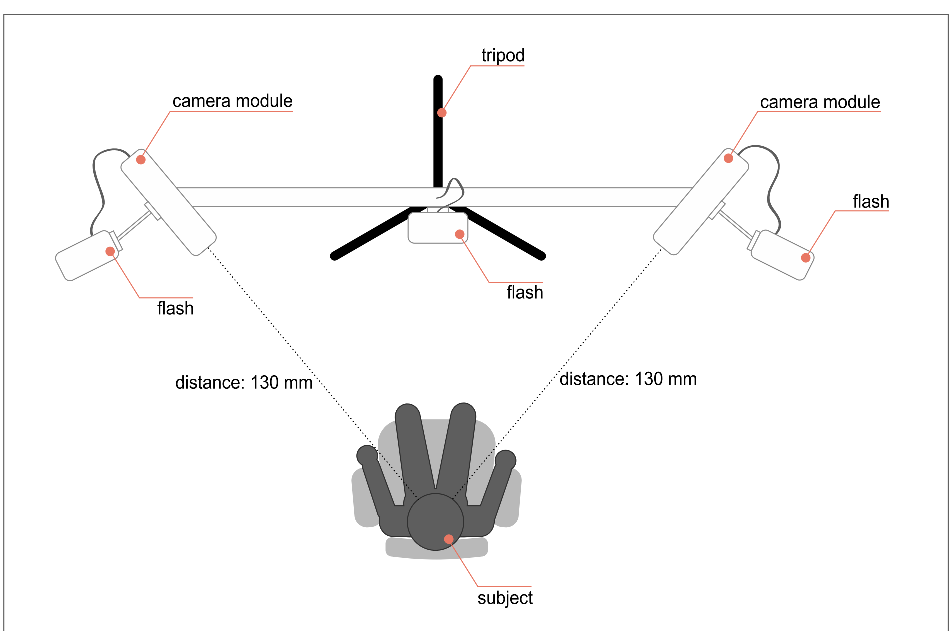


Fig. 2. Floor footprint of the imaging system.

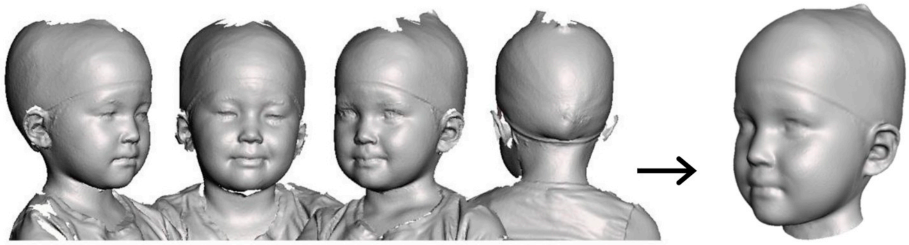


Fig. 4. Four images were combined into a complete 3D image of the head (From left to right; image 45° from the right, from the front, 45° from the left, the back and the merged complete 3D head).

(left/right), sublabiale, pogonion and menton. Facial measurements were extracted from the 3D images by calculating the Euclidian distances between these landmarks with a programme developed in MATLAB™ (Fig. 6).

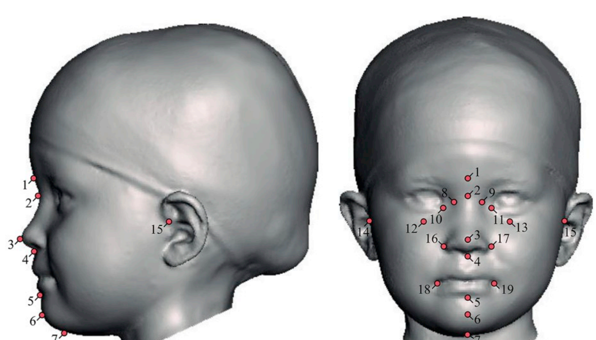
2.2.4. Reliability of the measurements

Measuring the participants and landmarking the 3D images was all done by one investigator (first author). The reliability of the consistency of both measuring methods was also evaluated. The reliability of the traditional head measurements was tested by measuring the same single participant five times with an interval of at least 24 h to reduce memory bias. The magnitude of the intra-observer variation in standard variation was equal or less than 2 mm for four out of five dimensions. This is within the allowable error as defined by Gordon et al. (2014). One dimension showed greater differences than the allowable error (2.45 mm), namely the length of the head; hair volume might have influenced these measurements.

In order to test the reliability of the 3D image extracted measurements, a 3D scanned head of one and the same participant was landmarked by the investigator on five separate occasions with at least 24 h in between. The Euclidean distance between two landmark pairs was calculated in order to extract the face measurements. The intra-observer variation in standard deviation were all less than 1 mm. Also, the coefficient of variation (CV) was calculated for each dimension which resulted in scores less then 1% for 4 dimensions and less then 3% for the remaining 4. This translates to a very good (CV = 1%–3.9%) to excellent (CV = 1% or less) precision as stated by Weinberg et al. (2004).

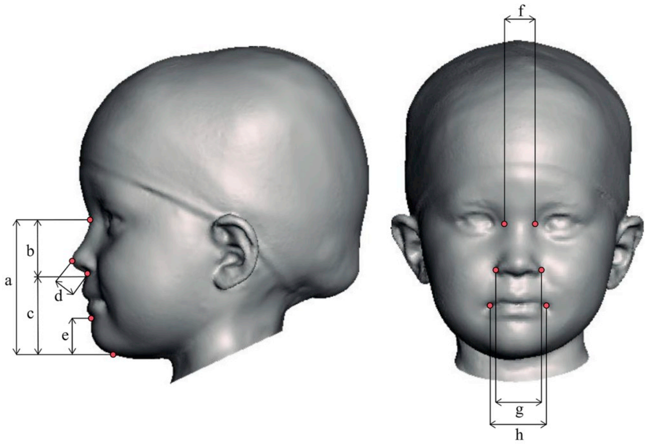
2.3. Data analysis and comparison

The data was analysed using descriptive statistics and scatter plots. Two-dimensional scatterplots were generated by pairing age with all dimensions, outliers were checked for data entry errors or incorrect landmarking and corrected or eliminated if necessary. The number of



No.	Landmark	Definition
1	Glabella (g)	The most prominent point in the median sagittal plane between the eyebrow ridges.
2	Sellion (s)	The deepest point of the nasalfrontal angle.
3	Pronasale (prn)	The most protrusive point on the nasal tip in the midline of the face.
4	Subnasale (sn)	The junction the lower border of the nasal septum, the partition that divides the nostrils, and the cutaneous portion of the upper lip in the midline.
5	Sublabiale (sl)	The deepest point of the labiomental groove at the midline.
6	Pogonion (pg)	The most anterior point in the middle of the soft tissue chin.
7	Menton (me)	The lowest point in the midline on the lower border of the chin.
8/9	Nasal root point (nrp) (right/left)	The point on the side of the nasal root halfway between endocanthion and the midline of the nasal bridge.
10/11	Endocanthion (en) (right/left)	Bilateral landmark located at the inner corner of the eye where the upper and lower eyelids meet.
12/13	Infraorbitale (or) (right/left)	Lowest point on the inferior margin of the left and right orbit, directly inferior to the pupil.
14/15	Tragion (t) (right/left)	Bilateral landmark located at the most anterior point of the small notch just above the tragus where the cartilage meets the face.
16/17	Alare (al) (right/left)	Bilateral landmark defined by the most lateral point on the nasal ala.
18/19	Cheilion (ch) (right/left)	The outer corner of the mouth where the outer edges of the upper and lower vermilions meet.

Fig. 5. Landmark locations and definitions.



	Description
a	Face height (s-me)
b	Nose length (s-sn)
c	Lower face height (sn-me)
d	Nasal tip protrusion (sn-prn)
e	Chin height (sl-me)
f	Nasal root breadth(nrp-nrp)
g	Nose width (al-al)
h	Mouth width (ch-ch)

Fig. 6. 3D image extracted measurements.

participants (N) varies per dimension because specific measurements of some children were eliminated because of an unwanted facial expression that influenced the measurement (e.g. smiling, open mouth). But also, because for some participants it was not possible to take any (N = 10) or some direct measurements because they were either too scared or emotional. This happened mostly within age group 1 to 3, when measuring head dimensions with the anthropometer. For instance, in age group 1, head height is missing for all except one female participant. Capturing a 3D image however, was in all cases possible. A statistical analysis of traditional measurements and scan-derived measurements was conducted for all age groups using SPSS Statistics 22 software (IBM, New York, NY, USA). Mean values and standard deviations of all measurements were calculated for each gender and age group. In addition, for each dimension the maximum and minimum values were determined. Also, summary statistics of the gender combined data are calculated. Gender combined data can often be more useful for design applications (Bradtmiller, 1996). Additionally, the mean values (M_G) of the traditional measurements of the current dataset were compared with the mean values (M_S) of Dutch children of Steenbekkers' dataset. Steenbekkers' dataset consisted of five head dimensions (breadth, height, length, circumference and chin to crown length) of which the latter was not was not included in this study. Furthermore, these dimensions, including the more detailed facial measurements of current dataset, were also compared with mean values (M_F) of the facial measurements of North American children collected by Farkas. A *t*-test ($\alpha = 0.05$) was conducted to determine the significance of the differences between each mean value of each dimension of this dataset and that of Steenbekkers' and Farkas' dataset. The dimensions that were included in all three datasets were head circumference, head breadth, head height and head length.

3. Results

3.1. Descriptive statistics

The results of the traditional anthropometric measurements and 3D scan extracted measurements are presented in Table 2. The mean and standard deviation for each dimension are presented for each age group and gender. The summery statistics of the gender combined data can be found in Appendix 1 and charts showing the mean value and standard deviation of a selection of measurements per age group are presented in Appendix 2.

3.2. Comparison of this dataset with Steenbekkers' dataset

A selection of traditional measurements of this dataset was compared to the corresponding dimensions of Steenbekkers' dataset by calculating the difference between the mean values ($M_G - M_S$). The number of participants included in Steenbekkers' study, mean and standard deviation are presented per age group for each dimension in Table 3. Of the total of 88 comparisons between mean values, 44 (50%) cases showed significant differences (21 among male versus 23 among female). In 57 (65%) comparisons (28 male and 29 female), significant and non-significant, the values of current dataset were smaller than Steenbekkers' dataset.

The differences were distributed throughout all age groups and different dimensions. Just a couple of significant differences between the datasets were found for weight and stature. Only one significant difference was observed for weight and stature for the male participants. For the females, one value showed a significant difference for weight and two for stature. Significant differences were found in all age groups except two for head circumference, for both male and female. In all instances, current dataset showed smaller values (M_G - $M_S = -15.4 \sim -7.0$ mm) than Steenbekkers' dataset. Head length was found to be significantly different for males in all age groups and for female all except one (M_G - $M_S = -12.6 \sim -3.7$ mm). For head height, only significant differences were observed for female (M_G - $M_S = -9.5$–2.5 mm) and not for male whereas for head breadth, more differences (all except one) were observed in the male population (M_G - M_S = 3.8–9.5 mm). The only dimension for which current dataset showed bigger values than Steenbekkers' dataset throughout almost all age groups for both male and female (all except age group 4), was head breadth.

3.3. Comparison of this dataset with Farkas' dataset

The head dimensions and the more detailed facial dimensions, were compared with the corresponding dimensions of Farkas' dataset. In Table 4, the number of participants included in Farkas' study, mean and standard deviation are presented per age group for each dimension. Out of the total of 160 comparisons between mean values, 73 (46%) cases showed significant differences (38 among male and 35 among female). In 85 (53%) cases (44 male and 41 female), significant and non-significant, the values of current dataset were smaller than Farkas' dataset. A comparison of the mean values (M_G - M_F) for head breadth indicated that the children in this dataset have significantly broader heads in comparison with Farkas' dataset. Face width (M_G - $M_F = -6.2 \sim -2.9$ mm for age groups 5, 6 and 7 and M_G - M_F = 5.6–7.2 mm for age groups 1,2 and 3), nose length (M_G - $M_F = -1.6 \sim -4.2$ mm) and nasal tip protrusion (M_G - M_F = 1.1–2.4 mm) for the male participants were significantly different for most of the age groups. A few significant differences were found for head height and head length. For head height, one significant difference was found in one age group for male and in two age groups for female. A significant difference was observed for head length in only one of the age groups for both male and female.

4. Discussion

This paper presents the descriptive statistics of traditional and 3D scan extracted measurements of children's heads and faces based on an anthropometric survey conducted amongst Dutch children. The survey took place in the Province of South-Holland which represents only a part of the Dutch population of 0.5 to 7-year-old children. Although there are no studies to determine how representative these children are

Table 2
Summary statistics of face and head measurements (Mean and Standard Deviation) of Dutch children of six months to seven years of age. Traditional measurements and *3D image derived measurements(mm).

Age	Stature						Weight (kg)						Head Circumference					
	Male			*Female*			*Male*			*Female*			*Male*			*Female*		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
0	10	736.0	47.9	7	721.6	26.6	10	8.8	1.1	7	8.8	0.9	10	458.2	13.2	7	446.7	12.4
1	21	827.2	43.0	7	805.4	51.9	21	11.2	1.2	7	10.1	1.8	20	478.7	12.4	7	459.7	17.0
2	12	942.0	66.6	11	934.5	86.8	12	14.0	1.8	11	13.5	2.1	11	492.6	12.1	11	483.4	8.8
3	17	1005.3	35.2	15	1002.2	47.2	17	15.7	1.1	15	15.3	2.1	17	506.9	13.1	15	498.8	26.6
4	39	1088.6	43.6	15	1108.6	30.8	39	19.0	2.4	15	18.7	2.5	39	511.0	13.5	15	502.2	9.7
5	34	1160.3	59.1	30	1147.2	50.6	34	21.3	3.1	30	20.5	2.1	34	513.7	11.6	30	507.1	15.6
6	32	1218.8	57.2	34	1216.9	44.0	32	22.9	2.8	34	22.6	2.6	32	517.6	14.9	34	508.8	15.9
7	9	1260.3	50.9	8	1240.1	43.7	9	24.8	2.5	8	24.3	2.4	9	517.6	15.7	8	511.5	11.7

Age	Head Breadth						Head Height						Head Length					
	Male			*Female*			*Male*			*Female*			*Male*			*Female*		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
0	8	124.9	5.6	7	123.1	4.8	8	155.8	9.7	5	162.0	9.9	8	152.4	8.8	5	150.6	6.9
1	18	133.2	8.2	2	123.5	7.8	15	168.5	7.8	–	–	–	17	162.7	7.8	3	163.3	9.9
2	11	138.0	6.6	11	133.4	7.2	11	175.3	15.0	11	174.5	11.1	11	164.4	12.0	11	166.6	9.2
3	17	139.9	4.8	15	135.3	7.0	17	185.1	12.5	15	177.7	11.9	17	173.6	6.2	15	170.4	9.1
4	39	141.8	5.2	15	135.6	4.7	39	189.6	10.0	15	183.9	9.4	39	176.1	7.1	15	175.3	5.4
5	34	143.4	5.9	30	139.9	7.3	34	194.4	9.4	30	187.0	7.9	34	179.4	6.6	30	176.1	6.8
6	32	145.5	6.3	34	142.6	8.0	32	195.7	10.0	34	192.0	10.5	32	180.3	7.7	34	175.5	7.8
7	9	148.2	8.4	8	142.5	3.9	9	199.6	8.6	8	186.5	4.8	9	179.7	7.6	8	177.4	7.5

Age	Face Width						*Face Height						*Lower Face Height					
	Male			*Female*			*Male*			*Female*			*Male*			*Female*		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
0	8	100.4	6.2	7	98.7	3.6	10	75.0	3.6	7	74.2	4.6	10	47.3	3.0	7	46.7	3.6
1	19	103.9	7.3	2	96.0	5.7	21	80.7	4.1	8	78.2	3.7	21	51.0	2.9	8	49.9	3.2
2	11	104.5	4.4	11	102.8	6.7	12	84.8	3.2	11	82.5	4.2	12	53.2	1.9	11	51.6	3.0
3	17	108.4	4.4	15	104.6	4.4	17	88.4	3.3	15	87.3	4.0	17	55.1	2.7	15	54.1	3.7
4	39	108.8	6.0	15	106.2	3.4	39	93.2	4.2	15	92.4	3.3	39	57.8	3.7	15	56.0	3.3
5	34	108.9	5.4	30	108.2	6.2	34	96.0	5.0	30	93.7	4.3	34	58.7	3.7	30	57.8	3.7
6	32	110.5	7.0	34	110.9	6.8	32	97.4	4.4	34	95.1	4.2	32	59.0	3.9	34	58.0	2.8
7	9	109.8	8.5	8	112.4	4.4	9	99.5	3.1	8	96.0	6.1	9	60.9	2.1	8	57.0	4.3

Age	*Height of Chin						*Nasal Root Breadth						*Nose Length					
	Male			*Female*			*Male*			*Female*			*Male*			*Female*		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
0	10	16.8	2.1	7	18.1	2.1	10	19.7	1.5	7	19.0	1.2	10	27.7	2.0	7	27.5	1.8
1	21	20.0	2.8	8	19.6	1.8	21	20.1	2.0	8	17.5	1.8	21	29.7	1.8	8	28.3	1.4
2	12	21.3	1.7	11	21.9	2.9	12	19.7	2.0	11	19.8	2.0	12	31.5	2.5	11	30.9	3.0
3	17	24.4	3.2	15	24.0	2.8	17	21.0	1.1	15	20.4	1.5	17	33.3	2.0	15	33.2	2.5
4	39	25.3	3.0	15	23.9	2.1	39	21.4	2.0	15	21.2	1.3	39	35.3	2.1	15	36.3	1.9
5	34	25.4	2.4	30	25.1	2.5	34	21.2	1.4	30	21.0	2.0	34	37.3	2.3	30	35.8	2.2
6	32	26.2	2.8	34	26.1	2.3	32	21.5	2.0	34	21.4	1.7	32	38.4	2.5	34	37.2	2.6
7	9	26.8	2.3	8	24.8	2.7	9	21.6	2.8	8	21.8	1.1	9	38.6	1.9	8	38.9	3.4

Age	*Nasal Tip Protrusion						*Nose width						*Mouth width					
	Male			Female			Male			Female			Male			Female		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
0	10	11.5	1.0	7	11.4	1.0	10	25.6	1.6	7	24.8	0.7	9	34.4	3.8	7	30.5	2.5
1	21	11.8	0.9	8	11.4	1.0	21	26.5	1.8	8	25.4	1.2	20	34.2	2.9	8	34.1	1.3
2	12	12.4	1.5	11	12.5	1.7	12	27.4	2.2	11	26.4	1.6	11	35.7	2.0	11	35.4	2.6
3	17	13.4	1.3	15	13.1	1.5	17	28.4	2.1	15	27.4	2.3	17	37.6	2.8	15	35.6	2.8
4	39	14.1	1.2	15	14.6	1.0	39	28.4	1.7	15	27.3	1.1	39	37.8	2.7	15	36.3	3.0

(*continued on next page*)

Table 2 (*continued*)

Age	Stature						Weight (kg)						Head Circumference					
	Male			*Female*			*Male*			*Female*			*Male*			*Female*		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
5	34	15.0	1.2	30	14.4	1.1	34	28.7	1.6	30	27.9	1.3	34	39.3	3.5	30	37.9	3.3
6	32	15.5	1.4	34	15.0	1.1	32	29.4	1.4	34	28.5	1.7	32	39.9	2.9	34	39.6	3.3
7	9	15.0	0.9	8	15.8	1.6	9	29.4	1.6	8	29.5	1.2	9	40.6	3.4	8	41.4	3.7

for the entire population of 0.5 to 7-year-old Dutch children when it comes to head and facial measurements, research conducted by Steenbekkers (1993) found that when measuring children in all Provinces of the Netherlands, there were no significant differences for head circumference, despite differences for stature, weight and popliteal height based on geographical region/location. The question is whether this is also the case for other head dimensions and the more detailed facial measurements and if these differences would influence design decisions.

When comparing this dataset to that of Steenbekkers', with regard to traditional measurements, a number of significant differences were found. These differences could be observed throughout different age groups, for different measurements and for both male and female. However, considerably less significant differences were found for

Table 3
Summary statistics of L.P.A. Steenbekkers (1993) and a comparison between mean values (M_G-M_S) (mm). Mean values of this dataset (M_G) are all based on traditional measurements.

Age**	Weight (kg)								Stature							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S
6.0–11.9 mo.	35	8.9	0.9	−0.1	30	8.6	1.1	0.2	35	728.0	35.6	8.0	30	715.4	37.0	6.2
12.0–17.9 mo.	17	10.8	1.0	0.3	28	9.6	1.3	0.0	17	787.1	36.2	31.3*	28	772.6	43.0	20.4
2	81	14.5	1.9	−0.5	92	14.1	1.6	−0.6	81	939.0	45.0	3.0	92	929.0	46.0	5.5
3	97	17.0	2.0	−1.3*	86	16.0	1.8	−0.7	97	1021.0	44.0	−15.7	86	1004.0	45.0	−1.8
4	85	18.6	2.0	0.4	79	18.4	2.1	0.3	85	1085.0	47.0	3.0	79	1082.0	40.0	26.6*
5	86	21.6	2.8	−0.3	94	21.0	3.0	−0.5	86	1170.0	48.0	−9.7	94	1159.0	49.0	−11.8
6	98	23.5	2.5	−0.6	92	23.6	2.6	−1.0	98	1225.0	47.0	−6.2	92	1227.0	49.0	−10.1
7	106	26.4	3.6	−1.6	93	26.9	4.3	−2.6*	106	1287.0	53.0	−26.7	93	1286.0	57.0	−45.9*

Age	Head Circumference								Head Breadth							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S
6.0–11.9 mo.	35	455.7	11.4	2.5	30	450.5	13.7	−3.8	35	118.0	4.7	6.9*	30	116.6	5.8	6.5*
12.0–17.9 mo.	17	480.5	13.9	−0.9	28	466.1	13.1	−12.3*	17	123.9	4.8	9.5*	28	121.3	5.8	2.2
2	81	508.0	13.0	−15.4*	92	493.0	15.0	−9.6*	81	134.0	4.0	4.0	92	130.0	5.0	3.4
3	97	515.0	14.0	−8.1*	86	504.0	15.0	−5.2	97	136.0	5.0	3.9*	86	133.0	5.0	2.3
4	85	518.0	12.0	−7.0*	79	510.0	13.0	−7.8*	85	138.0	5.0	3.8*	79	136.0	4.0	−0.4
5	86	524.0	13.0	−10.3*	94	516.0	14.0	−8.9*	86	139.0	5.0	4.4*	94	137.0	5.0	2.9*
6	98	529.0	14.0	−11.4*	92	522.0	13.0	−13.2*	98	141.0	5.0	4.5*	92	138.0	4.0	4.6*
7	106	531.0	12.0	−13.4*	93	524.0	14.0	−12.5*	106	142.0	5.0	6.2*	93	140.0	5.0	2.5

Age	Head Height***								Head Length***							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S	N	Mean	SD	M_G-M_S
2	81	176.0	11.0	−0.7	92	172	12.0	2.5	81	177.0	6.0	−12.6*	92	172.0	7.0	−5.4
3	97	185.0	11.0	0.1	86	178	11.0	−0.3	97	180.0	7.0	−6.4*	86	176.0	7.0	−5.6*
4	85	190.0	11.0	−0.4	79	186	11.0	−2.1	85	182.0	7.0	−5.9*	79	179.0	6.0	−3.7*
5	86	198.0	11.0	−3.6	94	193	10.0	−6.0*	86	185.0	7.0	−5.6*	94	182.0	6.0	−5.9*
6	98	199.0	11.0	−3.3	92	193	10.0	−1.0	98	185.0	7.0	−4.7*	92	184.0	6.0	−8.5*
7	106	204.0	11.0	−4.4	93	196	10.0	−9.5*	106	187.0	6.0	−7.3*	93	184.0	6.0	−6.6*

*Significantly different; $p < 0.05$.
**Steenbekkers categorised age group 0 and 1 per three months. In order to compare the datasets, the mean and standard deviation were calculated per six months and *N* was adjusted accordingly.
***Steenbekkers did not include age group 0 and 1 for the dimensions Head Height and Head Length.

Table 4
Summary statistics of Farkas (1994) and a comparison between mean values (M_G-M_F) (mm).). Mean values of this dataset are based on traditional measurements (M_G) and 3D scan derived measurements (M_G*).

Age	Head Circumference								Head Breadth							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F
6–12 mo.	20	452.6	14.1	5.6	8	451.6	16.3	−4.9	20	97.8	5.2	27.1*	8	94.6	4.6	28.5*
1	18	490.9	11.1	−12.2*	28	475.5	16.8	−15.8*	18	96.7	3.3	36.5*	27	95.6	4.3	27.9*
2	31	500.8	14.5	−8.2	30	490.7	10.5	−7.3*	31	98.9	4.9	39.1*	32	97.9	3	35.5*
3	30	508.8	12.9	−1.9	30	502.2	12.8	−3.4	30	101.4	5	38.5*	30	101.2	4.2	34.1*
4	30	518.4	14.7	−7.4*	30	508.9	10.3	−6.7*	30	110.2	5.4	31.6*	30	106.8	4.6	28.8*
5	30	520.0	11.9	−6.3*	30	516.7	9.4	−9.6*	30	111.8	5.1	31.6*	30	109.4	3.6	30.5*
6	50	518.6	14.3	−1.0	49	507.4	12.1	1.4	50	114.9	5.3	30.6*	50	113.4	5.1	29.2*
7	50	521.2	14.2	−3.6	50	515.4	14.4	−3.9	50	116.0	5.8	32.2*	50	115.8	4.6	26.7*

Age	Head Height								Head Length							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F
6–12 mo.	–	–	–	–	–	–	–	–	20	151.9	5.3	0.5	8	158.3	3.9	−7.7*
1	17	177.5	7.1	−9.0*	28	173.8	6.2	–	18	166.7	6.2	−4.0	28	162.0	7.9	1.3
2	31	182.5	8.6	−7.2	32	179.3	6.5	−4.8	30	170.5	12.4	−6.1	32	168.6	5.7	−2.0
3	30	187.4	7.1	−2.3	30	181.6	7.0	−3.9	30	177.5	6.7	−3.9	30	173.7	6.3	−3.3
4	30	193.0	7.1	−3.4	30	188.1	5.9	−4.2	30	181.5	6.2	−5.4*	30	175.2	5.2	0.1
5	30	193.0	6.1	1.4	30	190.9	6.6	−3.9*	30	180.5	6.2	−1.1	30	178.8	5.2	−2.7
6	50	198.2	9.9	−2.5	50	194.0	9.8	−2.0	50	183.2	7.6	−2.9	50	177.7	5.8	−2.2
7	50	201.1	10.7	−1.5	50	199.0	9.4	−12.5*	50	184.0	7.7	−4.3	50	180.8	6.4	−3.4

Age	Face Width								Face Height							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F
6–12 mo.	20	97.8	5.2	2.6	8	94.6	4.6	4.1	20	70.5	4.8	4.5*	8	68.0	4.4	6.2*
1	18	96.7	3.3	7.2*	27	95.6	4.3	0.4	18	80.6	4.8	0.1	19	72.7	4.9	5.5*
2	31	98.9	4.9	5.6*	32	97.9	3.0	4.9*	31	87.5	3.5	−2.7*	31	77.2	3.9	5.3*
3	30	101.4	5.0	7.0*	30	101.2	4.2	3.4*	30	88.5	3.5	−0.1	30	83.8	2.4	3.5*
4	30	110.2	5.4	−1.4	30	106.8	4.6	−0.6	30	96.4	4.3	−3.2*	30	86.9	3.6	5.5*
5	30	111.8	5.1	−2.9*	30	109.4	3.6	−1.2	30	96.7	3.5	−0.7	30	92.6	4.6	1.1
6	50	114.9	5.3	−4.4*	50	113.4	5.1	−2.5	50	98.5	5	−1.1	50	96.5	4.4	−1.4
7	50	116.0	5.8	−6.2*	50	115.8	4.6	−3.4*	50	99.5	5	0	50	95.7	3.7	0.3

Age	Nose Length								Nasal Tip Protrusion							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F
6–12 mo.	20	27.0	1.7	0.7	8	26.9	1.6	0.6	20	9.1	1.2	2.4*	8	9.7	0.8	1.7*
1	18	30.9	1.9	−1.2	20	29.2	2.6	−0.9	18	10.1	1.5	1.7*	20	10.2	1.4	1.2*
2	31	33.7	2.7	−2.2*	31	32.6	2.6	−1.7	31	11.3	1.5	1.1*	31	11.5	1.4	1.0
3	30	35.3	2.6	−2.0*	30	34.6	2.3	−1.4	30	12.1	1.4	1.3*	30	12.4	1.8	0.7
4	30	39.5	1.9	−4.2*	30	37.8	1.9	−1.5*	30	13.0	1.1	1.1*	30	12.3	1.1	2.3*
5	30	38.9	2.7	−1.6*	30	39.3	2.1	−3.5*	30	13.3	0.8	1.7*	30	13.1	1.2	1.3*
6	50	40.1	2.6	−1.7*	50	39.3	2.7	−2.1*	50	15.1	1.5	0.4	50	14.8	1.2	0.2
7	50	41.4	1.9	−2.8*	50	40.7	2.7	−1.8	50	15.3	1.3	−0.3	50	15.5	1.1	0.3

Age	Nose Width								Mouth width							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F	N	Mean	SD	M_G*-M_F
6–12 mo.	20	26.5	1.4	−0.9	8	1.5	25.4	−0.6	20	33.1	2.2	1.3	8	1.6	33.0	−2.5*
1	18	26.5	1.5	0	21	1.4	25.9	−0.5	18	34.8	2.6	−0.6	28	2.5	33.3	0.8
2	31	25.6	1.4	1.8*	31	1.2	26.1	0.3	31	35.2	2.6	0.5	31	1.8	35.0	0.4
3	30	26.1	1.5	2.3*	30	1.1	25.9	1.5*	30	36.7	2.4	0.9	30	2.5	36.3	−0.7
4	30	28.4	1.7	0	30	1.3	27.8	−0.5	30	38.9	2.5	−1.1	30	2.2	37.9	−1.6

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Table 4 (*continued*)

Age	Head Circumference								Head Breadth							
	Male				*Female*				*Male*				*Female*			
	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F	N	Mean	SD	M_G-M_F
5	30	28.9	1.5	−0.2	30	1.5	28.5	−0.6	30	40.7	2.4	−1.4	30	2.7	39.5	−1.6*
6	50	28.6	1.6	0.8*	50	1.3	27.8	0.7*	50	41.7	2.8	−1.8*	50	2.9	41.2	−1.6*
7	50	28.8	1.9	0.6	50	1.7	28.6	0.9	50	42.7	2.7	−2.1	50	2.2	42.4	−1.0

weight as well as for stature. Besides the traditionally measured head dimensions, the scan extracted, more detailed facial measurements were compared with Farkas' dataset. Significant differences were found for various dimensions throughout different age groups, for both male and female. Overall, the results of both comparisons showed no clear trend.

When comparing the mean values of the dimensions that were included in all three dataset (head circumference, head breadth, head height and head length) the difference is generally smaller between Steenbekkers' and Farkas' datasets than compared to values of this dataset. This is true for all except head breadth, for which the current dataset is closer to Steenbekkers' dataset for both male and female in all age groups. These observed differences between the datasets could be potentially explained by a number of factors, including age composition, ethnicity, secular growth changes and measuring protocols.

Firstly, the age composition within each age category could differ for each dataset which could influence the results. The dimensions of the face experience the most growth of the entire head, with rapid growth phases occurring mostly between the ages of 6 months and 4 years (Farkas et al., 1992; Burdi et al., 1969). As a result, having more children with an age between 12 and 18 months in age group 1 (that runs from 12 months to 24 months), for example, could result in smaller average values. Comparing these measurements with the same age group of a different dataset with a different composition would thus result in larger differences between the mean values. For future studies, it could therefore be important to mention the average age of the age group.

Moreover, in product design, it may be more appropriate to concentrate on other variables, rather than age (Lueder and Berg Rice, 2008; Steenbekkers, 1993), especially given that adjacent age groups often show great overlap for a variety of dimensions. In product sizing, often a number of easy to measure dimensions is used to group individuals of the target population. These so-called key dimensions are often also predictive of other dimensions. A number of studies have identified key dimensions related to mask design for adults (Oestenstad and Perkins, 1992; Zhuang et al., 2005; Lee et al., 2018). For children, Amirav et al. (2013) suggest that width of the mouth and sellion-promentale length are relevant dimensions for the sizing of aerosol masks. And interestingly, Ramirez et al. (2012) assign ventilation masks to young patients not only based on age but primarily on weight. Weight is a common way to define product sizes for children as for instance in car seats and diapers. Determining the key dimensions, investigating the variability of these dimensions and how to translate these into product sizes for face mask design will be subject of further study.

Secondly, the current dataset consists of different ethnicities and ethnicity is known to influence growth (Churchill et al., 1978; Farkas et al., 2005). Indeed, the anthropometric dimensions of children with native Dutch parents tend to be larger than the dimensions of children whose parents are not native Dutch, implying a difference in growth (Steenbekkers, 1993). For this sample, 18% (55 out of 302 children) were considered of non-native Dutch origin of which 39 had one parent that was native Dutch. The country of origin of one or both parents varied considerably (30 different countries). Steenbekkers' data was based on a Dutch population including children of non-Dutch origin (4%) and Farkas' study was conducted amongst the North American population and was exclusively Caucasian. A comparison between the datasets however, did not show any trend that could be explained by differences in the composition of the datasets in terms of ethnicity. Moreover, analysing the effect of ethnicity on the variance of the dimensions in this dataset would have been complex because of the sample size and the diverse composition of the group that was considered non-Dutch. However, ethnicity and ethnic composition of a country is important and due to globalization, interpreting anthropometric data becomes more complex. For example, the distribution of Dutch and non-Dutch citizens in the Netherlands was 22.6% on January 1st' 2017 (Statistics Netherlands (CBS), 2017).

Thirdly, given that Steenbekkers' survey was conducted in/before 1993 and Farkas' study was conducted around 1992 it is likely that secular growth changes have taken place in the last 20 years. Recent studies have shown an increase in Dutch children that are overweight (Schönbeck et al., 2011) but they have stopped growing taller ever since 1997 (Schönbeck et al., 2013). Even though the comparison between the datasets did not directly show these trends, these growth shifts could also affect the more detailed dimensions of, for example, the face.

Differences between datasets could also be caused by differences in measuring protocols. For instance, Steenbekkers measured head height, length and breadth with an automated anthropometer whereas in this study we used an anthropometer for height and length and for head breadth we used a spreading calliper as according to Kolar and Salter (1997). The measuring protocol for Farkas' study is unknown given that the study only shows the landmarks that define the dimensions. It is therefore not possible to come to a valid comparison between the results.

Finally, scan derived measurements from the current dataset were compared with traditional measurements of Farkas' dataset. When a dimension is measured directly, one has to palpate the bony structure underneath the skin and one can easily impress the skin with the measuring device which could influence the measurement. Although a 3D image derived measurement is always based on the actual dimensions of the face, landmarking is sometimes more challenging because of the difficulty of recognizing the difference between soft and hard tissue without palpation. Previous studies have shown the accuracy and reliability of using 3D images of the 3dMD face system (Wong et al., 2008; Hong et al., 2017; Lübbers et al., 2010) and other 3D imaging systems in anthropometry (Lee et al., 2017; Weinberg et al., 2004; Fourie et al., 2011) by comparing traditional measurements with scan extracted measurements. However, the identified differences between the two approaches still do not indicate which of the measurements are more accurate and it does not deliver a verdict on which of the measurements represent the population better.

A clear advantage of including 3D imaging in an anthropometric survey is that it facilitates the collection of data of young children for whom a direct anthropometric examination is often too intense for they cannot sit still for long periods of time (Farkas, 1996). Ball et al. (2011) scanned 400 children for the Size China survey but the rejection rate under the age of five was close to 100% because of the slow capturing speed of the scanner they used at the time. During the current survey, we observed that taking traditional, direct measurements was in some cases not possible (especially in the younger age categories 0–3 years) whereas taking a 3D image of children, who initially refused to cooperate during the direct measurements, was still possible mainly because of the fast capturing speed. And even though some challenges still remain (Sims et al., 2012), this 3D scanning technology seems to be promising also for collecting data of physical impaired persons or elderly. Furthermore, the added value of this dataset lies in the fact that beside the statistical information of facial measurements of children, the collection of 3D images provides richer, more detailed information. In addition, the 3D dataset can be accessed whenever needed and relevant, new information can be extracted depending on the application without re-inviting participants. But most importantly the data also provides valuable information about the shape of the face (Goto et al., 2015; Zhuang et al., 2013) for product designers. But, before it can be integrated into the design process, the data first needs to be processed, analysed and tailored to a certain design application such that this shape information can be presented to and utilized by designers.

5. Conclusion

This paper presented up to date descriptive statistics of detailed measurements made of heads and faces of Dutch children. But also, a 3D dataset which can be referenced in the future for different purposes and to study face and head shapes of children. Collecting anthropometric data of very young children is time consuming when done by hand. This study shows that 3D photogrammetry offers an efficient way to scan babies and young children and facilitates this process because of its quick acquisition speed. This anthropometric dataset is an addition to the traditional anthropometric information of Dutch children that currently is available and the first study providing information that is richer and more up to date.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ergon.2019.102828.

Appendix

Appendix 1. Summary statistics of face and head measurements (Mean and Standard Deviation) of Dutch children (gender combined). Traditional measurements and 3D image derived measurements* (mm).

Age	Stature										Weight									
	Male + Female										*Male + Female*									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	17	730.1	40.1	655.0	655.8	720.0	735.0	760.0	780.0	800.0	17	8.8	1.0	6.6	6.9	8.5	9.1	9.6	10.0	10.3
1	28	821.8	45.4	720.0	766.8	799.3	818.0	840.0	876.5	976.0	28	10.9	1.4	8.0	8.8	10.1	11.0	11.6	13.1	13.2
2	23	938.4	75.1	810.0	842.0	893.0	932.0	967.0	1057.2	1154.0	23	13.8	1.9	11.3	11.4	12.1	13.6	14.7	17.3	18.5
3	32	1003.8	40.6	894.0	944.2	980.0	1009.5	1038.0	1058.5	1080.0	32	15.5	1.6	11.0	13.4	14.3	15.5	16.7	18.0	19.1
4	54	1094.2	41.2	1015.0	1034.0	1061.0	1093.0	1127.0	1162.4	1185.0	54	18.9	2.4	12.0	15.1	17.5	19.0	20.5	22.6	23.5
5	64	1154.2	55.3	1020.0	1066.1	1124.8	1153.5	1188.5	1246.4	1292.0	64	20.9	2.7	16.0	17.1	19.0	20.5	23.0	25.9	29.5
6	66	1217.8	50.4	1108.0	1139.5	1177.5	1214.0	1254.0	1296.8	1331.0	66	22.7	2.7	17.5	18.6	21.0	22.3	25.0	26.8	31.0
7	17	1250.8	47.3	1185.0	1189.0	1211.0	1255.0	1269.0	1338.0	1338.0	17	24.6	2.4	21.0	21.0	23.0	24.5	26.0	27.8	29.0

Age	**Head Circumference**										**Head Height**									
	Male + Female										*Male + Female*									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	17	453.5	13.8	430.0	434.8	440.0	454.0	467.0	472.4	474.0	13	158.2	9.9	143.0	145.4	150.0	156.0	168.0	170.8	172.0
1	27	473.7	15.9	448.0	450.0	463.0	475.0	481.0	501.5	505.0	16	168.8	7.6	157.0	158.5	164.5	168.5	172.0	179.5	187.0
2	22	488.0	11.3	467.0	472.1	483.0	490.0	493.0	499.9	518.0	22	174.9	12.9	137.0	161.0	170.3	176.0	183.3	192.0	195.0
3	32	503.1	20.6	468.0	475.1	488.8	498.5	514.5	542.3	550.0	32	181.6	12.6	150.0	168.1	173.0	179.5	188.3	203.9	209.0
4	54	508.5	13.1	479.0	490.0	500.0	507.5	517.5	531.4	540.0	54	188.0	10.1	165.0	175.0	183.0	187.0	192.8	208.4	221.0
5	64	510.6	13.9	475.0	490.0	502.8	510.5	520.0	531.0	553.0	64	190.9	9.4	166.0	177.2	184.8	192.0	196.0	206.9	216.0
6	66	513.1	15.9	467.0	487.8	501.5	515.5	522.8	539.5	543.0	66	193.8	10.4	170.0	179.0	187.0	193.0	200.0	207.8	230.0
7	17	514.7	13.9	493.0	496.2	500.0	517.0	525.0	533.4	535.0	17	193.4	9.6	177.0	181.8	187.0	191.0	202.0	207.6	210.0

Age	**Head Breadth**										**Head Length**									
	Male + Female										*Male + Female*									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	15	124.1	5.1	115.0	117.1	120.0	125.0	127.5	130.9	133.0	13	151.7	7.9	136.0	141.4	147.0	152.0	158.0	162.4	163.0
1	20	132.3	8.5	118.0	121.8	128.8	131.5	135.0	151.2	154.0	20	162.8	7.8	147.0	151.8	156.8	161.5	168.5	172.3	177.0
2	22	135.7	7.1	122.0	124.3	131.3	134.5	141.0	147.9	150.0	22	165.5	10.5	132.0	150.3	163.3	168.0	172.8	177.0	179.0
3	32	137.8	6.3	124.0	126.6	134.3	139.5	143.0	144.0	148.0	32	172.1	7.7	160.0	161.7	167.8	170.0	176.0	183.3	197.0
4	54	140.1	5.8	130.0	132.0	135.3	140.0	144.5	149.4	152.0	54	175.9	6.6	162.0	166.0	171.0	176.0	179.0	187.4	192.0
5	64	141.8	6.8	131.0	132.3	136.0	142.0	146.0	153.7	163.0	64	177.8	6.8	159.0	167.3	174.8	177.0	182.0	188.9	194.0
6	66	144.0	7.3	130.0	134.0	138.5	143.5	148.8	156.0	163.0	66	177.8	8.1	155.0	165.3	173.0	178.0	183.0	190.8	194.0
7	17	145.5	7.1	135.0	137.4	142.0	144.0	149.0	154.2	167.0	17	178.6	7.4	167.0	168.6	172.0	179.0	183.0	190.4	192.0

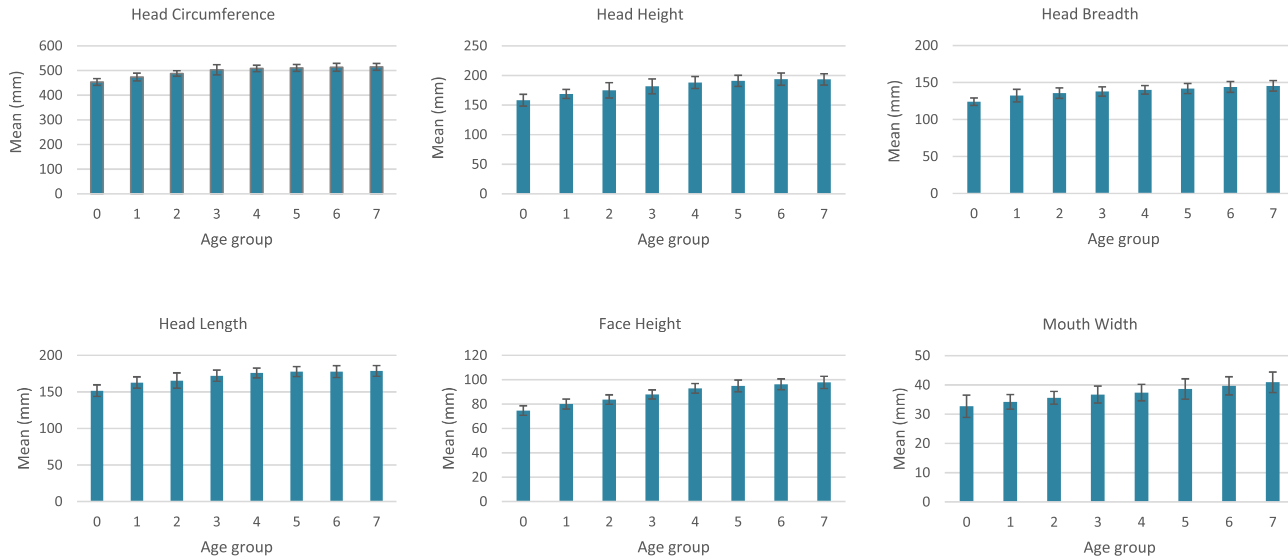
Age	**Face Width**										**Face Height***									
	Male + Female										*Male + Female*									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	15	99.6	5.0	93.0	93.7	96.5	98.0	103.0	107.1	112.0	17	74.7	3.9	66.8	69.3	71.8	74.3	77.5	80.6	81.3
1	21	103.1	7.4	90.0	91.0	100.0	102.0	107.0	116.0	116.0	29	80.0	4.1	72.4	74.2	76.8	80.0	83.3	86.1	87.9
2	22	103.7	5.6	91.0	93.2	100.3	104.0	107.0	111.9	113.0	23	83.7	3.9	76.5	78.7	80.6	83.4	86.6	90.6	90.8
3	32	106.6	4.7	98.0	98.6	103.0	107.0	110.0	113.0	116.0	32	87.9	3.7	79.8	83.8	85.4	87.4	89.5	94.0	95.0
4	54	108.1	5.5	100.0	101.0	103.3	107.0	111.0	118.7	123.0	54	92.9	4.0	83.9	87.6	90.4	92.9	95.3	99.9	104.5
5	64	108.6	5.8	100.0	101.0	104.0	108.0	112.0	120.6	123.0	64	94.9	4.8	84.2	87.7	91.4	94.4	98.6	102.3	104.9
6	66	110.7	6.9	99.0	100.3	106.0	111.0	114.0	123.0	129.0	66	96.2	4.4	85.9	88.7	93.4	95.9	99.4	102.8	106.6
7	17	111.0	6.8	99.0	102.2	108.0	110.0	114.0	121.2	126.0	17	97.8	5.0	84.2	90.5	95.5	98.0	100.8	104.5	105.6

Age	Lower Face Height* Male + Female										Height of Chin* Male + Female									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	17	47.0	3.2	39.8	42.1	45.0	48.1	49.5	50.4	51.7	17	17.4	2.1	13.6	14.3	15.8	17.5	18.3	20.9	21.2
1	29	50.7	3.0	45.3	46.1	48.1	50.5	52.7	56.0	56.8	29	19.9	2.6	15.4	16.0	18.3	19.5	21.2	24.6	25.4
2	23	52.4	2.6	47.2	48.4	50.1	53.0	54.1	55.8	56.4	23	21.6	2.3	16.9	17.8	20.3	22.0	22.7	24.8	26.1
3	32	54.6	3.2	46.8	49.0	52.9	54.5	56.5	58.8	61.3	32	24.0	2.9	19.4	20.3	21.8	23.9	25.4	27.9	33.0
4	54	57.3	3.7	48.9	51.9	55.2	57.3	59.0	63.1	67.8	54	24.9	2.8	19.3	20.6	22.8	24.7	26.7	29.3	32.0
5	64	58.3	3.7	50.3	52.4	55.8	57.8	61.1	63.9	67.7	64	25.3	2.4	20.6	21.5	23.4	25.5	26.9	29.1	32.0
6	66	58.5	3.4	51.6	53.4	55.7	58.1	61.1	63.5	66.9	66	26.2	2.5	20.5	21.6	24.7	26.4	27.6	30.0	33.7
7	17	59.1	3.8	49.5	52.8	57.6	60.4	61.3	63.1	65.1	17	25.8	2.6	20.7	22.3	24.0	25.9	27.6	29.1	31.7

Age	Nasal Root Breadth* Male + Female										Nose Length* Male + Female									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	17	19.4	1.4	17.8	17.8	18.6	19.2	20.1	21.2	23.4	17	27.6	1.9	24.8	25.4	26.7	27.2	28.4	30.9	31.5
1	29	19.4	2.2	14.4	15.6	18.6	19.1	21.3	22.4	23.4	29	29.3	1.8	25.9	26.2	28.2	29.4	30.4	32.0	33.5
2	23	19.7	2.0	14.8	15.7	18.8	20.0	21.2	21.8	23.0	23	31.2	2.7	25.9	26.6	30.2	31.1	32.9	34.9	36.4
3	32	20.7	1.3	17.0	18.6	19.8	21.1	21.9	22.2	22.8	32	33.2	2.2	28.5	30.0	31.5	33.4	34.7	36.6	38.0
4	54	21.3	1.8	17.4	18.6	20.1	21.1	22.5	24.6	26.0	54	35.6	2.1	31.4	32.3	34.0	35.9	36.7	38.7	40.4
5	64	21.1	1.7	16.9	17.8	20.3	21.1	22.4	23.3	24.5	64	36.6	2.3	31.8	33.4	34.9	36.4	38.0	40.6	42.7
6	66	21.4	1.9	17.0	18.9	20.1	21.3	22.7	24.4	26.8	66	37.8	2.6	31.1	33.0	35.9	37.8	39.7	41.6	43.0
7	17	21.7	2.1	16.6	19.4	20.7	21.5	22.4	25.1	26.2	17	38.8	2.6	34.7	35.7	36.4	38.7	40.4	43.0	44.5

Age	Nasal Tip Protrusion* Male + Female										Nose width* Male + Female									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**	**N**	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	17	11.5	1.0	9.6	9.9	10.9	11.6	12.1	12.8	13.0	17	25.3	1.4	23.3	23.8	24.2	25.2	25.9	27.4	28.5
1	29	11.6	0.9	10.4	10.5	10.8	11.4	12.4	13.0	13.5	29	26.2	1.7	23.6	24.0	24.9	26.1	26.7	29.6	30.1
2	23	12.5	1.6	9.8	10.4	11.0	12.4	13.7	14.7	15.4	23	26.9	1.9	24.3	24.5	25.6	26.8	27.4	30.0	32.4
3	32	13.2	1.4	10.4	11.4	12.2	13.3	14.1	15.5	15.9	32	27.9	2.2	24.3	25.5	26.4	27.8	28.6	32.2	34.7
4	54	14.2	1.2	11.0	12.3	13.5	14.0	15.2	16.1	16.4	54	28.1	1.6	25.1	25.8	26.6	27.9	29.2	31.1	31.5
5	64	14.7	1.2	12.0	12.9	13.9	14.6	15.6	16.5	18.1	64	28.3	1.5	24.6	26.1	27.3	28.2	29.1	30.9	32.5
6	66	15.2	1.3	12.6	13.2	14.3	15.4	15.9	17.2	19.0	66	28.9	1.6	25.7	26.1	27.9	28.9	30.1	31.1	32.3
7	17	15.4	1.3	13.5	14.0	14.5	15.3	16.0	17.5	18.9	17	29.5	1.4	27.1	27.4	28.6	29.3	30.6	31.1	32.5

Age	Mouth width* Male + Female									
	N	**Mean**	**SD**	**Min**	**5th**	**25th**	**50th**	**75th**	**95th**	**Max**
0	16	32.7	3.8	26.8	27.8	29.7	33.1	35.4	38.0	38.8
1	28	34.2	2.5	30.1	30.8	32.0	34.1	35.6	37.8	40.1
2	22	35.6	2.2	29.7	32.9	34.3	35.7	37.0	39.1	39.4
3	32	36.7	2.9	31.6	32.6	34.2	36.2	39.1	41.1	42.1
4	54	37.4	2.8	32.7	33.6	35.2	37.2	39.2	41.9	44.7
5	64	38.6	3.5	29.9	33.0	36.6	38.7	41.8	43.8	44.0
6	66	39.7	3.1	32.2	34.7	37.5	39.5	41.9	44.9	45.9
7	17	40.9	3.5	33.1	36.2	38.2	41.4	43.0	45.1	47.3



Appendix 2. Bar charts showing mean values (mm) and standard deviations per age group for head circumference, head height, head breadth, head length, face width, face height and mouth width.

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