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Published in:
Procedia Engineering

DOI (link to publication from Publisher):
10.1016/j.proeng.2015.07.182

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Perret-Ellena, T., Skals, S. L., Subic, A., Mustafa , H., & Pang, T. Y. (2015). 3D anthropometric investigation of head and face characteristics of Australian cyclists. *Procedia Engineering*, *112*, 98-103. https://doi.org/10.1016/j.proeng.2015.07.182

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 112 (2015) 98 – 103

Procedia Engineering

www.elsevier.com/locate/procedia

7th Asia-Pacific Congress on Sports Technology, APCST 2015

3D Anthropometric investigation of Head and Face characteristics of Australian Cyclists

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Abstract

Design specialists have acknowledged the need for more accurate measurements of human anthropometry through the use of 3D data, especially for the design of head and facial equipment. However, 3D anthropometric surveys of the human head are sparse in the literature and practically non-existent for Australia. Research published to date has not proposed concrete methods that can accurately address the hair thickness responsible for inaccurate representation of the head's shape. This study used a state-of-the-art handheld white light scanner to digitize 3D anthropometric data of 222 participants in the Melbourne Metropolitan Area. The participants volunteered for the study consisted of 46 females and 176 males (age: 34.6 ± 12.5). The participants' head scans were aligned to a standard axis system, whereby a Hair Thickness Offset (HTO) method was introduced to more accurately describe the true shape of the head. It is envisaged that the database constructed through this research can be used as a reference for the design and testing of helmets in Australia.

Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Anthropometric survey; 3D scanning; helmet; head dimensions

1. Introduction

Recently, a study commissioned by Safe Work Australia [1] investigated the use of anthropometric data in the design of wearable products for the Australian market. The two primary objectives were to identify the anthropometric data currently used, and to assess whether this data actually reflected the shape diversity of the country's current population. Results of the study indicated that when designing a product, most Australian's designers and engineers still use traditional 1D anthropometric databases [2-6] as their primary source of references.

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Peer-review under responsibility of the the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
doi:10.1016/j.proeng.2015.07.182

Although these databases are well-documented, they are out-dated, and none of them were sourced in Australia. Most studies were either based in the U.S. or the U.K. and were conducted on their military workforces. Therefore, there is no evidence that these data can accurately represent the contemporary population of Australia where more than one quarter of the inhabitants have arrived as migrants and almost one-eighth have Asian ancestry [7]. Furthermore, previous studies have established that Asian head shapes are significantly different compared to Caucasians' [8, 9]; insights that are not incorporated in the anthropometric data currently applied. In conclusion, Safe Work Australia recommended the development of a national database of anthropometric data aimed at improving fit of wearable products for the Australian population.

Additionally, product design specialists have acknowledged the need for more adequate measurements of human anthropometry through the use of 3D scanning techniques [1]. Compared with traditional 1D anthropometric measures, which only capture numerical values of single parameters (e.g. head circumference and length); 3D data provide information on the contours and shapes of the subject. For example, Robinette et al. [10] have emphasized the need for applying 3D anthropometry when designing head and facial equipment, such as helmets, goggles and respirator masks, as these objects cannot stretch like garments and other similar products.

In the late 1990s, advancements in scanning technology and computational software have created new opportunities in the field of anthropometry. Extensive 3D anthropometric studies have been undertaken worldwide, such as the *CAESAR* [11], *SizeChina* [12] and *NIOSH* [13] surveys. The CAESAR project began in 1997 where researchers collected 1D and 3D data on 2,400 North American and 2,000 European civilians. The researchers applied the first ever built 3D full body scanner, which had low accuracy and resolution that limiting its application to head and face studies. In 2006, Ball et al. started the SizeChina project to capture the 3D digital shape of the Chinese head. The heads of 1,600 participants were digitized using an advanced 3D scanner capable of capturing geometrically complex body parts at high resolution. Finally, Zhuang et al. used similar techniques to capture the facial shape variability of U.S. respiratory users in the NIOSH survey. To our knowledge, such surveys do not exist for the Australian population.

One of the main limitations when applying 3D scans for headgear design is the presence of the subjects' hair in the scanned data, which compromise the exact geometric and shape characterisation of the skull. Individual hairstyle, hair length and thickness limit the use of standard methods to deal with this problem. Most researchers have used wig caps on the head to hide and compress the hair over the skull. However, long or bulky hairstyles still produce significant bumps and irregularities on the head's surface. In particular, the back of the head is commonly associated with large surface deformations due to this issue. The design of headgear founded on these 3D scan data might be skewed if the hair thickness under the wig caps' compression is not properly accounted for.

This research aims to achieve the following: (i) construct a 3D head scan database of Australian cyclists for headgear design; (ii) develop a method for alignment of all scans to a common standard axis system; and (iii) introduce a new method to account for the hair's thickness on scanned data.

2. Materials and Methods

2.1. Sampling Plan

The sample size was determined according to the procedures outlined in the *ISO 15535: General requirements for establishing anthropometric databases* [14]. The standard estimates the sample size based on the true population 5th and 95th percentiles of a parameter with 95% confidence, and a percentage of relative accuracy:

$$n = (1.96 * CV/a)^2 * 1.534^2 \quad (1)$$

$$CV = 100 * SD/\bar{x} \quad (2)$$

$$a = 100 * \bar{x}/precision\ level \quad (3)$$

where CV is the coefficient of variation and is the ratio between the Standard Deviation (SD) and the mean of a population ($\bar{x}$) (multiplied by 100), a is the percentage of relative accuracy desired, and n is the estimated sample size. In this study, the calculations were based on the head circumference dimension. This dimension, along with head breadth and head length, is the most common dimension used in helmet design. Furthermore, head circumference is associated with the largest variability of these three dimensions and, therefore, would provide a worst case sample size (n increases when SD increases). The *ISO 7250-1: Basic human body measurements for technological design* [15] defines the head circumference as the maximum horizontal circumference above the glabella, crossing the rearmost point of the skull (occipital bone). However, these landmarks are usually not aligned horizontally. Furthermore, the standard does not indicate whether the hair should be compressed under the tape measure. In view of the above, a measurement precision level of 3.5 mm was deemed adequate for this study. Replacing Eqs. (2) and (3) in (1) gave a sample size estimator that relies only on the precision level and the SD of the dimension in question:

$$n = (1.96 * SD/precision\ level)^2 * 1.534^2 \qquad (4)$$

The expected SD was predicted to be around 17 mm, corresponding to a sample size estimate of 214 participants. A combination of anthropometric surveys of the European and U.S. populations was used to determine the expected SD for the head circumference [9, 16-19].

Fig. 1. Typical Post-Processed 3D Head Scan.

2.2. Participants and Locations

The survey took place at multiple sites around the metropolitan area of Melbourne, Australia and spanned over a 9-month period throughout 2014 (April to December). The study was approved by RMIT University Human Research Ethics Committee. Interview venues included five local bicycle shops and a university research laboratory. Recreational and commuter cyclists were recruited through advertisement (e.g. online forums, Melbourne bicycle and triathlon clubs) or directly at the survey site. Cyclists had to be of 18 years of age or above. All participants volunteered for the study and provided written informed consent. Participant information was obtained through a questionnaire, including gender, age, ethnicity, mass and height.

2.3. 3D-Scanning

The anthropometric survey was implemented using an advanced portable white light scanner; the Artec Eva™ 3D. On average, a full head scan was completed in 40 seconds (Fig. 1). Participants were asked to wear a wig cap, to look at a fixed point in front of them, and to maintain a neutral facial expression during the scan. The posture position and scanning techniques were in accordance with the requirements of *ISO 20685:2010(E) 3D scanning methodologies for internationally compatible anthropometric databases* [20]. In-depth description of the scanning procedures and post-processing techniques used during the study were presented in [21].

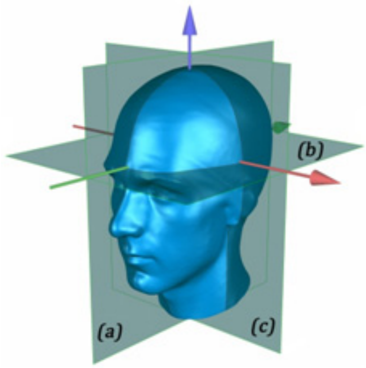

Fig. 2. Head scan alignment. (a) Sagittal Arc Plane. (b) Head Circumference Plane. (c) Bitragion Coronal Plane.

2.4. Head Scan Alignment

An alignment procedure was developed to obtain comparable positions and orientations of head meshes. It was based on the creation of a generic axis system for each individual scan. The procedure begins with the creation of three planes associated with key dimensions of the head; i.e. the Head Circumference, Sagittal Arc and Bitragion Coronal Arc (Fig. 2). Firstly, the plane spanning the Sagittal Arc (SA plane) was created as symmetrical with respect to the head (Fig. 2.(a)). Secondly, the plane spanning the Head Circumference (HC plane) was established (Fig. 2.(b)). This was enabled by using the outer corners of the eye sockets to make the plane approximately horizontal and subsequently moving the plane to a position spanning the area slightly above the glabella and near the top of the occipital bone. The plane was adjusted visually in order to obtain the position of the head circumference. Thirdly, the plane spanning the Bitragion Coronal Arc (BCA plane) was created as perpendicular to the two existing planes, positioned according to the Tragions (Fig. 2.(c)). An orthogonal axis system was created using the position of the three planes, which was subsequently aligned to a standard axis system incorporated in the software.

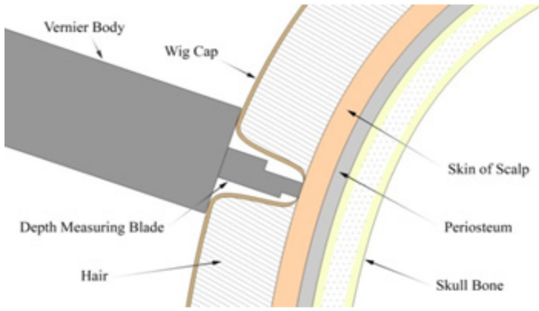

Fig. 3. Hair Thickness Offset detection – Vernier caliper method.

2.5. Head Thickness Offset (HTO)

In order to evaluate the exact head shape of the participants, the hair thickness under the wig cap compression was measured and considered during the processing stage. First, The Hair Thickness Offset (HTO) value was detected through either the computational method [21], or manually using a Vernier calliper. In the computational method, the HTO was determined as the maximum negative deviation from the alignment of the participant's head scan and a bicycle helmet scan. The caliper measurement was performed with the depth measuring blade of the apparatus (Fig. 3) pointed at three locations around the head, i.e. the top, back and side. The bottom edge of the Vernier Body was kept adjacent to the top of the wig cap (Fig. 3) during the measurement. Cross-checked comparisons between the two proposed methods were performed for ten participants, displaying similar HTO values (up to 1 mm differences).

Subsequently, a manual offset was performed on the head scan. Fig. 4 shows the five-step procedures for a male and female participant with a 3.1 mm and 6.2 mm HTO respectively. The procedures are described as follows:
(1) the region on the head covered by the hair is defined, starting from the forehead hairline (detectable in the scan), spanning over the ears and through the neckline.
(2) the selected set of polygons is lowered by the HTO value. Additional triangles are created in a narrow surrounding band to keep the overall surface intact.
(3) the polygons around the narrow band are selected
(4) the polygons around the narrow band are deleted.
(5) the surface reconstruction is performed to create a smooth transition between the offset region and the surrounding mesh.

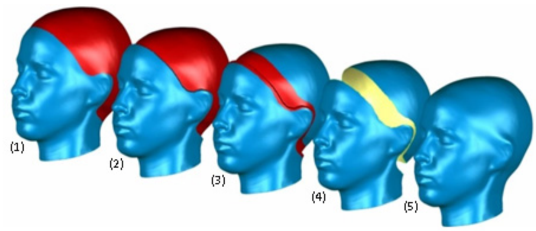

Fig. 4. Manual offset procedure for a female with 6.2 mm HTO.

3. Results

A total of 222 cyclists were recruited for the 3D anthropometric survey, slightly more than the target sample size of 214. Table 1 provides a summary of the demographic characteristics of the participants.

Fig. 5 displays the head shape differences for two participants before and after the HTO process. The transparent contours in blue inside the "zoom in" areas represent the scanned head shape, while the solid blue contours represent the true head shape of the participants after the HTO method has been applied.

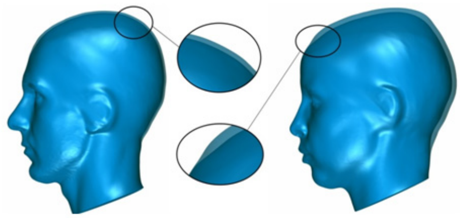

Fig. 5. Cross-section showing the head scans of two participants before and after the Hair Thickness Offset.

4. Discussion and Conclusion

The main objective of this research was to develop a database of 3D head shapes for the Australian population that could be used for the design of various head and facial equipment. A total of 222 Australian residents volunteered for the survey in 2014, covering a wide range of the population, aged from 18 to 80+, of both genders.

As the aim of the study did not involve the comparison of standard head dimensions between particular population groups, no distinctions were made with respect to gender, age or ethnic background. A simple random sampling plan was applied. The sample size was measured in accordance with *ISO 15535: General requirements for establishing anthropometric databases* [14] and adapted to meet the design specifications of 3D anthropometric data, as previously described in the SizeChina and NIOSH projects [13, 22]. The head circumference dimension was used for the estimation. Since no formal anthropometric study of the Australian population has been published previously, we used a combination of anthropometric surveys of the European and U.S. populations to determine the expected SD for the head circumference. Although the high proportion of Asian descendants in Australia could have slightly biased our sample estimate calculation [7].

A handheld 3D scanner was used to digitize the participants' heads. The resulting scans were then post-processed, using the computational techniques described in [21], and aligned to a common axis system defined using three planes spanning the Sagittal Arc, Head Circumference and the Bitragion Coronal Arc.

The present study developed a method to accurately describe the head's shape of 3D scanned data by applying a Hair Thickness Offset (HTO) to the triangle mesh within the region of the hairline. Unlike current databases that might overestimate the size of the head due to the hair thickness, especially for females, the final head scans presented in this survey are believed to represent more accurately the head shape of each participant. Further works are needed to validate this claim by comparing true head scans (e.g. CT scans) with the head meshes of participants before and after the HTO process.

The database of 3D head shapes can be used for the design and testing of various head and facial products for the Australian market.

Table 1. Characteristics of the Participants

	Male					Female					Total
Ethnic Group	AU	EU	Asian	Other	Total	AU	EU	Asian	Other	Total	
Number	88	46	28	14	176	28	8	8	2	46	222
Proportion (%)	40	21	12.6	6.3	79.3	13	4	3.6	0.9	20.7	100
HTO (mm)					3.6±1.7					5.8±1.9	4.1±1.9

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