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3D digital headform models of Australian cyclists

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ABSTRACT

Traditional 1D anthropometric data have been the primary source of information used by ergonomists for the dimensioning of head and facial gear. Although these data are simple to use and understand, they only provide univariate measures of key dimensions. 3D anthropometric data, however, describe the complete shape characteristics of the head surface, but are complicated to interpret due to the abundance of information they contain. Consequently, current headform standards based on 1D measurements may not adequately represent the actual head shape variations of the intended user groups. The purpose of this study was to introduce a set of new digital headform models representative of the adult cyclists' community in Australia. Four models were generated based on an Australian 3D anthropometric database of head shapes and a modified hierarchical clustering algorithm. Considerable shape differences were identified between our models and the current headforms from the Australian standard. We conclude that the design of head and facial gear based on current standards might not be favorable for optimal fitting results.

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1. Introduction

For decades traditional 1D anthropometric measurements have been used as the primary source of information for a multitude of applications and disciplines, as for instance, the study of human physical variation, epidemiology, forensics and ergonomics. The extensive use of these data for product design rests upon their capability to simply and inexpensively provide comprehensive information about the size dispersion of specific body dimensions. Compared to 3D anthropometry, however, 1D measurements do not capture shape attributes, which are essential in the design of close-fitting head and facial equipment, such as respirator masks, glasses and helmets.

In 2009, Safe Work Australia (Veitch, 2009) conducted a study on the use of anthropometric data for the design of wearable clothing and accessories amongst Australian ergonomists. The aim was to identify what types of anthropometric information are being used nowadays, and to evaluate the accuracy of these data for describing the body shapes of the country's current population. The results of the study indicated that most ergonomists still use 1D anthropometric databases (Diffrient, 1974; Tilley and Dreyfuss, 2001; Woodson and Tillman, 1992; Pheasant, 1986; Snook, 1978) as their primary source of references. When 3D data are used, most rely on generic digital models such as mannequins and headforms (Australian/New Zealand Standard, 2009; ASTM International, 2015; BS, 2006) to create their design. Although these models are provided in 3D, they are the result of a mix of science (1D anthropometric measurements) and artistry (sculpture makers) (Meunier et al., 2009), resulting in inaccurate representations of the human body shape.

While these two sources of anthropometric data are well-documented, they are outdated, and have yet to be developed based on data from the Australian population. Most of the 1D anthropometric studies cited were either based in the U.S. or the U.K., and were conducted on military personnel. For example, Standards Australia developed the *AS/NZS 2512.1:2009 Methods of testing protective helmets Part 1: Definitions and headforms* (Australian/New Zealand Standard, 2009) based on the ISO/DIS 6220:1983 draft (Australian/New Zealand Standard, 1998), which was itself founded on the first set of test headforms manufactured by the UK Transport Road Research Laboratory in the 1950s (British Standards Institution, 2006; Zhuang et al., 2010). Consequently, there is no evidence that these data can accurately represent the

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population of Australia today, where more than one-quarter of the inhabitants are migrants and almost one-eighth have Asian ancestry (Australian Bureau of Statistics (2011)). For instance, researchers demonstrated that the head shapes of Asians are significantly different from those of Caucasians, including wider, rounder sides and a flatter back (Ball et al., 2010). Such differences should be accounted for when designing head and facial gear for the Australian market.

In addition, product design specialists interviewed during the Safe Work Australia investigation acknowledged the need for more adequate measurements of the human body shape through the use of 3D scanning techniques. The demand for accurate 3D anthropometric data is not new, as Robinette and co-authors (Robinette and Whitestone, 1994) already stressed the need for applying 3D anthropometry to improve design of user-centered products in 1994.

In conclusion, Safe Work Australia suggested the development of a national database of anthropometric data aimed at improving fit of wearable products for the Australian population. Furthermore, these data should focus on more accurate representations of the size and shape of the human body parts considered and, therefore, recommendations were made to increase the use of 3D data in future studies.

2. Previous work and contributions

In the late 1990s, advancements in scanning technology and computational software created new opportunities in the field of anthropometry. Extensive 3D anthropometric studies have been undertaken worldwide, such as the *CAESAR* (Robinette et al., 2002), *SizeChina* (Ball and Molenbroek, 2008), and *NIOSH* (Zhuang and Bradtmiller, 2005) surveys. The CAESAR project began in 1997 where researchers collected 1D and 3D data on 2400 North American and 2000 European civilians. The researchers used the first ever built 3D full-body scanner. However, the low accuracy and resolution of the apparatus limited its application, in particular for the study of the head and face. In 2006, Ball et al. initiated the SizeChina project in order to capture the 3D digital head shapes of the Chinese population. The heads of 1600 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 on 1013 U.S. respiratory users in the NIOSH survey.

As a result of these surveys, the researchers were able to develop new generic models, such as headforms and mannequins, for the population studied. For example, in (Zhuang et al., 2010) investigators created five facial headforms of the current U.S. workforce using the 3D scanned data and principal component analysis. Similar studies were reported for the Chinese population in (Yu et al., 2012) and (Luximon et al., 2012). To our knowledge, such studies do not exist for the population of Australia.

The results presented in this study provide valuable information about the head shape diversity amongst Australians. More specifically, we focus on the head shape variation of Australian adult cyclists. It is envisaged that the presented results can be used to design better-fitting bicycle helmets in Australia.

In this paper, we present four new digital headform models based on a medium-sized 3D anthropometric database of the head, established in (Perret-Ellena et al., 2015), and a new head scan sizing method, employing an innovative clustering algorithm. The new algorithm is presented in detail in (Ellena et al., 2016a). We compare the shape of these new headforms with the current Australian standard models. Finally, recommendations are made, where the need to revise existing standards is highlighted.

3. Materials and methods

3.1. Participants and data collection

Two hundred participants from the 2014 *3D Anthropometric Database of Australian Cyclists* (Perret-Ellena et al., 2015) were randomly selected to be included in the analysis. A detailed description of the data collection and digitisation processes were presented in (Ellena et al., 2016b). The Hair Thickness Offset (HTO) method was applied to the head scanned data, as described in (Perret-Ellena et al., 2015) (Fig. 1).

3.2. Clustering procedures

The 3D-HEAD-CLUSTERING algorithm (Ellena et al., 2016a) was applied on the selected sample. Using point set registration (Allen et al., 2003; Amberg et al., 2007) and rigid transformation methods (Besl and McKay, 1992), we first normalised the individuals' head scans to enable shape comparison on a point-by-point basis. The methods consist of warping the same uniform polygon mesh, called the template, over the raw 3D data, ensuring similar positions between the individuals for all points defining the head shape. Only the points of the polygon mesh that should be under helmet protection were selected for the clustering process (Fig. 2) (see (Ellena et al., 2016b) for more details). We named these specific vertices the Head Covering Points (HCP). The proposed method (Ellena et al., 2016a) was based on a modified hierarchical algorithm, where the clusters were created one after another in the classification process. At each algorithm iteration, an optimal cluster was selected among multiple possibilities through the use of four internal quality criteria (intra-cluster similarity). As demonstrated in (Ellena et al., 2016a), the clustering results of this new routine permitted the creation of fewer clusters, while still categorizing a higher ratio of individuals, compared to other conventional clustering methods.

4. Results

4.1. Grouping

The 3D-HEAD-CLUSTERING algorithm was solved using a distance stopping criterion of 20 mm, meaning that the maximum distance between any two participants in a cluster at any specific

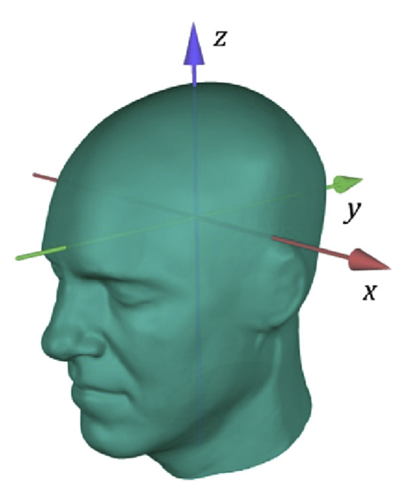

Fig. 1. Typical 3D head scan from the 3D anthropometric database of Australian cyclists.

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