Generation of a Midsize-Male Headform by Statistical Analysis of Shape Data

Final Report

UMTRI-2013-39

by

Matthew P. Reed
University of Michigan Transportation Research Institute

Brian D. Corner
US Army Natick Soldier Research, Development, and Engineering Center

October 2013

UNCLASSIFIED: Distribution Statement A. Approved for Public Release

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Generation of a Midsize-Male Headform by Statistical Analysis of Shape Data

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Reed, Matthew P., and Corner, Brian D.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Michigan
Transportation Research Institute

US Army Natick Soldier Research,
Development, and Engineering Center

8. PERFORMING ORGANIZATION REPORT

UMTRI-2013-39

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Tank Automotive Research,
Development, and Engineering Center

Warren, MI 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S NUMBER(S)
Issued Upon Submission

12. DISTRIBUTION / AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Human surrogates for safety applications, such as crash dummies, are often constructed to represent the mean or average of individuals within a population. Generating accurate mean headforms is particularly challenging, even with three-dimensional (3D) surface measurement technology, because hair limits the ability to accurately represent the shape of the head. This report presents a new midsize-male headform generated using statistical analysis of head dimensions and landmark data, combined with a reference shape obtained by averaging the head shapes of two men close in size to the target stature and body weight. The locations of 26 head and face landmarks from 1747 men were extracted from the 1988 U.S. Army Anthropometric Survey (ANSUR) and registered using a Procrustes superimposition. A linear regression predicted landmark locations as a function of stature and body mass index, using target values of 1755 mm and 27.3 kg/m^2. To construct a reference head shape, two bald men whose head and face dimensions were within 2% of the target mean values were extracted from a large database of head scans. The scans were visually aligned using landmark locations, then resampled cylindrically and averaged. The reference head shape was then morphed to match the target landmark locations using a radial-basis-function (RBF) morphing method with a multiquadric kernel. A second morphing step was performed to match the desired head length, head breadth, and the distance from the tragion landmarks to the top of the head. In contrast with headforms obtained solely by averaging individuals close to the desired body size, the current headform is generated from a statistical model that represents a large range of head size and shape, and hence a broad set of statistically consistent headforms can be generated programmatically without additional analysis. Approved for public release.

15. SUBJECT TERMS
Anthropometry, Head Form, Statistical Shape Analysis, Safety

16. SECURITY CLASSIFICATION OF: UNCLAS			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON M.P. Reed
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLAS	UNCLAS	UNCLAS			(734)936-1111

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

ACKNOWLEDGMENTS

This work was supported by the Automotive Research Center, a U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles led by the University of Michigan. The opinions expressed here are those of the authors alone and do not reflect the views of the U.S. Army. The authors thank Dr. Peng Li (Anthropology Team, US Army Natick RDEC) for his help with head curvature extraction and summarization. Approved for unlimited public release.

CONTENTS

EXECUTIVE SUMMARY

Human surrogates for safety applications, such as crash dummies, are often constructed to represent the mean or average of individuals within a population. Generating accurate mean headforms is particularly challenging, even with three-dimensional (3D) surface measurement technology, because hair limits the ability to accurately represent the shape of the head. We present a new midsize-male headform generated using statistical analysis of head dimensions and landmark data, combined with a reference shape obtained by averaging the head shapes of two men close in size to the target stature and body weight. The locations of 26 head and face landmarks from 1747 men were extracted from the 1988 U.S. Army Anthropometric Survey (ANSUR) and registered using a Procrustes superimposition. A linear regression predicted landmark locations as a function of stature and body mass index, using target values of 1755 mm and 27.3 kg/m^2. To construct a reference head shape, two bald men whose head and face dimensions were within 2% of the target mean values were extracted from a large database of head scans. The scans were visually aligned using landmark locations, then resampled cylindrically and averaged. The reference head shape was then morphed to match the target landmark locations using a radial-basis-function (RBF) morphing method with a multiquadric kernel. A second morphing step was performed to match the desired head length, head breadth, and the distance from the tragion landmarks to the top of the head. In contrast with headforms obtained solely by averaging individuals close to the desired body size, the current headform is generated from a statistical model that represents a large range of head size and shape, and hence a broad set of statistically consistent headforms can be generated programmatically without additional analysis.

INTRODUCTION

Creating an accurate three-dimensional (3D) head model has typically combined standard 1D anthropometry with considerable artistry (Powell 1943, Brues 1945). One way to improve headform accuracy and fidelity is to replace artistic interpretation with population-level surface geometry. An early adaptation of 3D data was made in the early 1970s during the development of the Personnel Armor System for Ground Troops (PASGT) helmet. There, cranial surface contours were defined using a head-borne device shown in Figure 1 (Claus et al 1974). The probes on this device overcome the problem of characterizing the shape of the head under the hair. Once the population-level data were obtained (N=106), a statistical model was created for each of the four PASGT helmet sizes and a sculptor modeled the face.

A variety of statistical techniques have been used to create headforms from traditional anthropometry, 3D landmark locations, and 3D surface measurements. A common technique is to run a multivariable statistical analysis and select representative forms (Bittner et al., 1996; Meindl et al, 1993; Munier et al., 2000; Plaga et al, 2005).

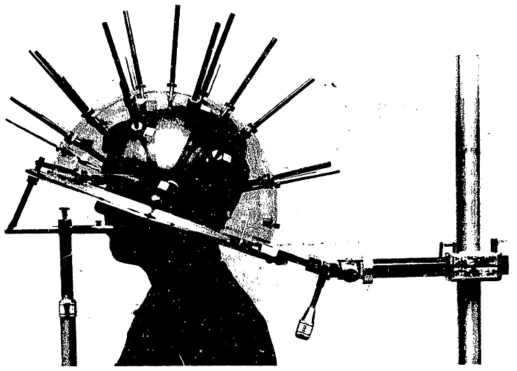

Figure 1. Three-dimensional headform models were created for the PASGT helmet using data gathered with this device.

Many other headforms have been constructed for various purposes. Reddi et al. (1994) used data from ANSUR to create small, medium, and large male headforms for the Army to be used for testing retention and fit of helmets. Because no 3D head or face data were available at the time, the headform surfaces were generated by artistic interpolation between landmark locations with reference to target standard anthropometric dimensions. Figure 2 shows the Reddi et al. midsize headform.

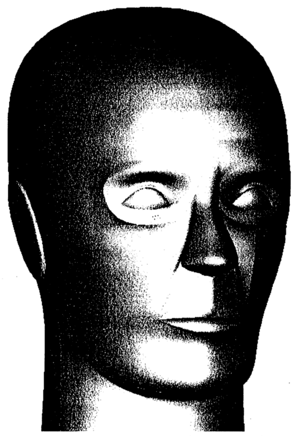

Figure 2. Midsize male headform from Reddi et al. (1994).

A recent midsize-male headform was developed for the assessment of protective eyewear. The FOCUS headform (Kennedy et al. 2006) was based on an earlier US Army headform, but with more accurate and detailed eye and face geometry.

Ball et al. (2010) conducted a combined study of U.S. and Chinese head shapes, using a merged dataset from SizeChina and the U.S. portion of the CAESAR study. A template mesh was fit to each head and a statistical analysis of the vertex locations was conducted. Although head shapes intended for specific applications were not generated, the underlying model is capable of producing a wide range of shapes. Importantly, neither the SizeChina nor CAESAR datasets includes large numbers of bald heads, so the analysis includes hair effects.

The representative form approach works relatively well, particularly when based on well-sampled large-scale data sets with complementary 1D and 3D included. The next advance is the establishment of a parametric model that may be altered to represent any form directly. In this paper we describe the creation of a mid-size male headform as part of a larger project to develop a new anthropomorphic test device (ATD) for the US Army.

METHODS

Reference Headform

An existing US Army headform with associated landmarks was selected as a starting template. This headform was created by cylindrical averaging of scan data from two bald men near mean values for stature and body weight. The reference headform was symmetrical about the midsagittal plane.

The headform was aligned to a head coordinate system with origin at mid-tragion, where the X axis was parallel to the Frankfort Horizontal (FH), Y axis was set to the bitragion line, and the Z axis was perpendicular to FH.

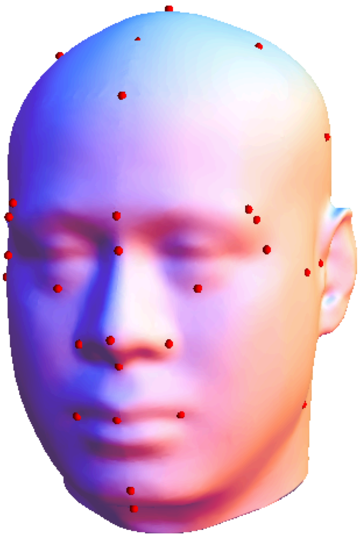

Figure 3. Reference headform with landmarks.

Head and Face Landmark Analysis

Head and face landmarks were obtained for the male Soldiers in the ANSUR 1988 working database (Annis and Gordon, 1988; Gordon et al, 1989). Of the 1774 subjects, 27 with one or more missing landmarks were deleted. Stature and body mass index (BMI) were also obtained from the ANSUR working database.

To improve the correspondence with the ANSUR position relative to adjacent face landmarks, right and left ectoorbitale landmarks of the template head were lowered by 12 mm. Crinion was added to the template model using the ANSUR relationship with glabella.

The landmarks were registered using a Procrustes alignment with scale restored (Bookstein 1991, Dryden and Marcus, 1993). Landmark locations were then predicted from stature and BMI using linear regression. Target dimensions were stature=1755 mm and BMI=27.3 (body mass=84 kg). The resulting predicted landmark locations were all within a millimeter of the overall mean from ANSUR.

Morphing the Reference Headform

A landmark-based radial-basis function technique (RBF) was used to morph from the reference to the target (ANSUR) using a multiquadric kernel with radius=10 mm (Li et al. 2011). For the first iteration, frontotemporale and zygofrontale landmarks were omitted as their position was inconsistent between ANSUR and the template headform. The landmarks were later added back into the model.

New target landmarks euryon (left and right) and opisthocranion were generated using the desired target values for head length, breadth, and head height (tragion to vertex) based on ANSUR mean (197, 152, and 131 mm, respectively).

Sagittal Profile Data

A convenience sample (N=83) of male bald-head 3D surface scans (Cyberware PX) was compiled from data available in the US Army Natick 3D lab database (Paquette et al, 2009; Gordon et al. 2013). Scans were preprocessed with an initial cleaning, including removal of stray vertices and non-manifold mesh points. If the scan had a movement artifact, the scan was corrected using in-house software developed to remove the offset. Pre-marked landmarks were located on each scan. These included tragion (right and left), orbitale (right and left), glabella, and cervicale. In-house visualization and data extraction software, NatickMeasure, was used to locate and record landmark locations. Scans were aligned to FH.

Unwanted points were trimmed from the scans makes it easier to generate a cross-section containing only vertices from glabella to cervicale. The trimming plane was established by translating and rotating a coronal plane around the Y axis to a line defined by glabella and cervicale. Vertices anterior and inferior to the plane were trimmed away as shown in Figure 4. Once trimmed, a midline vertical cross-section slice of the scan from glabella to cervicale was obtained (Figure 5).

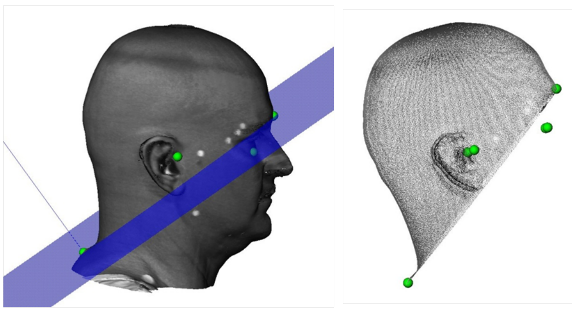

Figure 4. Example bald head scan with clipping plane located at glabella and cervicale, and clipped mesh.

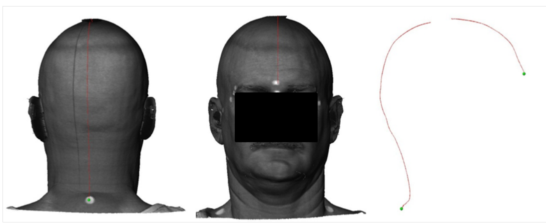

Figure 5. Example bald head scan showing glabella-cervicale sagittal cross-section in posterior, anterior and lateral views. A spline was used to close the gap at the top.

A spline through the resultant vertices was generated to fill any gaps and to produce a smooth curve of 150 points from glabella to cervicale. The cross-section curves were aligned to the same anatomical coordinate system based on FH and a summary curve was calculated by averaging X, Y, and Z coordinate values.

Final Morph

The mean profile was scaled linearly in the anteroposterior direction to achieve the target head length (197 mm), and adjusted vertically to obtain the target height above tragion (131 mm). Ten new evenly distributed target landmarks were generated on the scaled sagittal profile. Corresponding landmarks were located at the closest point on the reference headform. Left and right euryon landmark locations were defined with the target head breadth (152 mm). Finally, a new RBF morph was done with the additional target points.

RESULTS

The completed head form is shown in Figures 6 and 7. The landmark locations are listed in Table 1.

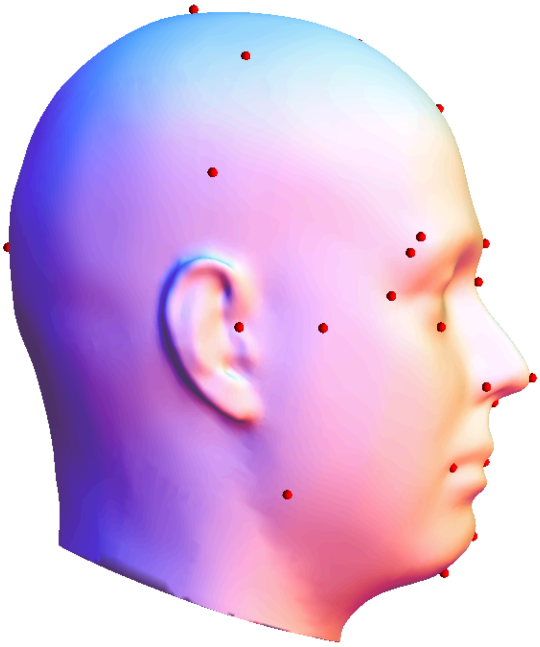

Figure 6. Final headform with landmarks (side view).

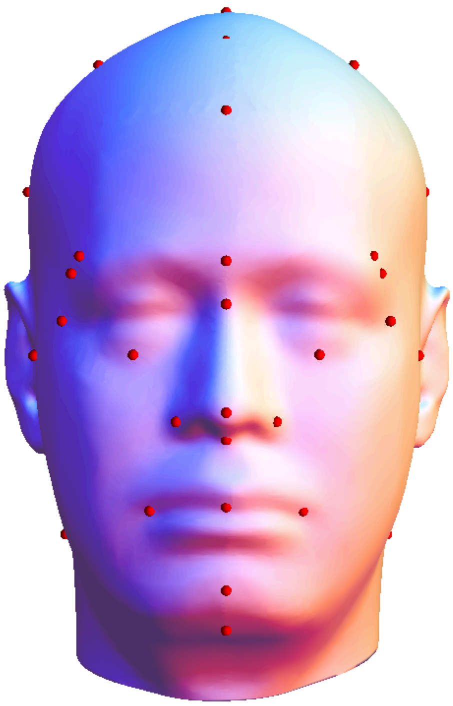

Figure 7. Final headform with landmarks (front view)

Table 1
Landmark Locations†

X	Y	Z	Name
102	18	-25	Alare, Left
87	28	-58	Cheilion, Left
83	0	90	Crionion
62	61	13	Ectoorbitale, Left
-11	76	62	Eurion, Left
74	56	34	Frontotemporale, Left
102	0	35	Glabella
19	61	-68	Gonion, Left
83	35	0	Infraorbitale, Left
85	0	-102	Menton
-96	0	33	Opisthocranion
97	0	-87	Promenton
121	0	-21	Pronasale
99	0	19	Sellion
102	0	-56	Stomion
105	0	-31	Subnasale
0	73	0	Tragion, Left
-5	0	131	Vertex
34	73	0	Zygion, Left
69	58	28	Zygofrontale, Left

†mm with respect to FH coordinate system. Origin is mid-tragion, X axis positive forward, Y to the left

DISCUSSION

The methods used in this work are a hybrid of earlier approaches. Some 1D data were used directly (head length and breadth, vertex height above tragion), and 3D landmark data were used for the face and front of the head. The face landmark locations are based on a large sample of over 1700 men. The head profile is based on an average of 83 bald men, but the face detail is substantially influenced by the features of the reference headform, which is based on only two men.

One of the significant challenges in creating an "average" head shape from 3D measurements is the correspondence problem. Data from multiple subjects can be aligned in many ways, including using an anatomically defined coordinate system (as in the current work), a Procrustes-type least-squares alignment based on many landmarks, or a global algorithm using all surface points. The aligned heads can be resampled in a spherical or cylindrical coordinate system, providing a uniform set of data that can then be averaged (or processed in many other ways). However, this method will always yield an average with smoother features than is typical for an individual subject, because of differences in the feature alignments.

A template fitting approach using landmarks can overcome some of this smoothing by fitting features from a reference shape into the corresponding features of each scan. The RBF morphing procedure used in the current work is one way to align a template to features, but additional processing is needed to move the template mesh into the target surface. Many methods have been used for this process (see Allen et al. 2004, for example).

In the current work, minimal smoothing occurred due to the small number of subjects used to create the reference template, but this means that the shapes of the features (for example, the nose or lips) cannot be considered to be representative, although the locations of these features are.

Although the sagittal profile was derived from 83 men, the coronal profile was based on morphing of the reference headform, and hence is not as representative. Future headform development should be based on the largest possible sample of bald-head men, although one consideration not addressed in the current work is whether bald men have different head shapes than those with hair.

The analysis method in the current work is capable of generating many alternative headforms, not only an average. For example, the mean head shape for men taller or shorter than the mean can be generated. Importantly, the statistical model captures the residual variance in head landmark locations that is not attributable to overall body dimensions (stature and BMI). Future research on the sizing of head-borne equipment and protective gear could take advantage of this concise representation of head variability to generate a large range of synthetic headforms for virtual fit testing.

REFERENCES

Annis JF and Gordon CC (1988) *The Development and Validation of an Automated Headboard Device for Measurement of Three-Dimensional Coordinates of the Head and Face*. NATICK/TR-88/048. U.S. Army Natick Soldier Research, Development, and Engineering Center, Natick, MA.

Ball, R., Shu, C., Xi, P., Rioux, M., Luximon, Y., Molenbroek, J. (2010). A comparison between Chinese and Caucasian head shapes. *Applied Ergonomics*, 41:832-839.

Bittner AC, Wherry RJ, and Glenn FA (1986) *CADRE: A Family of Manikins for Workstation Design*. Technical Report 2100.07B, Man-Machine Integration Division, Naval Air Development Center, Warminster, PA.

Bookstein FL (1991) *Morphometric Tools for Landmark Data*. Cambridge University Press:New York.

Brues A (1945) *Study of Anthropometric Data*. MIT-MR No. 166. Chemical Warfare Service Development Laboratory, Massachusetts Institute of Technology, Cambridge, MA.

Claus WD, McManus LR, and Durand PF (1974) *Development of Headforms for Sizing Infantry Helmets*. 75-23-CEMEL, US Army Natick Laboratories, Natick, MA.

Dryden IL and Mardia KV (1998) *Statistical Shape Analysis*. Wiley:New York.

Gordon CC, Churchill T, Clauser CE, Bradtmiller B, McConville JT, Tebbetts I, and Walker RA (1989) *1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*. NATICK/TR-89/044. U.S. Army Natick Soldier Research, Development, and Engineering Center, Natick, MA.

Gordon CC, Blackwell CL, Bradtmiller B, Parham JL, Hotzman J, Paquette SP, Corner BD, and Hodge BM (2013) *2010 Anthropometric Survey of Marine Corps Personnel: Methods and Summary Statistics.* NATICK/TR-13/018. U.S. Army Natick Soldier Research, Development, and Engineering Center, Natick, MA.

Goulet DV and Sacco WJ (1972) *Algorithms for Sizing Helmets*. Memorandum Report No. 2185, Ballistics Research Laboratories, Aberdeen Proving Ground, MD.

Kennedy, E., Duma, S., Depinet, P., Morgan, C., Beebe, M., Roller, R., Crowley, J., and Brozoski, F. (2006). *Design of an Advanced Headform for the Prediction of Eye and Facial Injuries.* Technical Report ADA481591, DTIC.

Li, Z., Hu, J., Reed, M.P., Rupp, J.D., Hoff, C.N., Zhang, J., and Cheng, B. (2011). Development, validation, and application of a parametric pediatric head finite-element model for impact simulations. *Annals of Biomedical Engineering*, 39(12):2984-2997. 10.1007/s10439-011-0409

Meindl RS, Hudson JA, and Zehner GF (1993) *A Multivariate Anthropometric Method for Crew Station Design*. AL-TR-1993-0054. Air Force Materiel Command, Wright-Patterson AFB, OH.

Meunier P, Tack D, Ricci A, Angel H, and Bossi L (2000) Helmet accommodation analysis using 3D laser scanning. *Applied Ergonomics, 31*, 361-369.

Paquette SP, Gordon CC, and Bradtmiller B (2009) *ANSUR II Pilot Study: Methods and Summary Statistics*. NATICK/TR-09/014. U.S. Army Natick Soldier Research, Development, and Engineering Center, Natick, MA.

Plaga JA, Albery C, Boehmer M, Goodyear C, and Thomas G (2005) *Design and Development of Anthropometrically Correct Head Forms for Joint Strike Fighter Ejection Seat Testing.* AFRL-HE-WP-TR-2005-0044, Wright-Patterson AFB, OH.

Powell H (1943) Typical American flyer. *Popular Mechanics*, *142*(3):96-101.

Reddi, M., DeCleene, D.F., Oslon, M.B., Bowman, B.M., and Hartmann, B.T. (1994). *Development of Anthropometric Analogous Headforms.* Technical Report DAMD17-94-C-4065. DTIC.