Analysis of Human Head Shapes in the United States

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Abstract : The ability to customize garments for fit in the apparel industry is directly tied to the availability of comprehensive and accurate sets of anthropometrical data for each consumer. The data for apparel sizing systems is available from three major standard/ research organizations: ASTM (American Society for Testing and Materials), ISO (International Standard Organization), and NCHS (National Center for Health Statistics). However, these standards ignore various head shapes and are outdated for the development future head products. This creates a data gap an ever changing multi-cultural society such as the United Sates. Although major government and industry safety organizations recognize the importance of safety for head products, few studies were found to support their reasoning. The purpose of this study is to provide accurate head dimension data for developing safety head products by analyzing various head shapes in the United Sates which includes various ethnic backgrounds. This study was carried out on 105 males in the United States. Factor analysis, cluster analysis, Moreover, Duncan analysis were all used for analyzing various head shapes.

Key Words : head shapes, American men, types of head

I. Introduction

Various industries utilize human anthropometrical data such as the apparel industry, automobile industry, ergonomics, and public health. In the apparel industry, the ability to customize garments for fit is directly tied to the availability of a comprehensive and accurate sets of anthropometrical data for each consumer. Data for apparel sizing systems is available from three major standard/research organizations: ASTM (American Society for Testing and Materials), ISO (International Standard Organization), and NCHS (National Center for Health Statistics). However, these standards have a lack of consensus and acceptance of standard measurements by the apparel industry since the data is too old to be applicable for the current apparel market (Hwang & Istook, 2001). Understanding this need, national size surveys have been conducted in South Korea, Europe, and the United States.

In South Korea, The ATS (Agency for Technology and Standards) has anthropometrical data from surveys taken every 4 to 6 years. More recently, Size Korea (2003) for South Korea was conducted for two years to collect data for developing industrial products such as apparel, home furnishings, houses, and automobiles. In the Size Korea survey, 21,295 Koreans were measured. Age groups ranged from infant to over 90 years of age. Whole body scanners with measurement extraction software were used for measuring 119 body dimensions. In addition, 35 various poses were tested to investigate body movement ranges.

On the other side of the world, in 1998, the Civilian

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American and European Surface Anthropometry Resource program (CAESAR) at Wright-Patterson Air Force Base initiated the largest anthropometric survey performed in over 30 years (Brunsman *et al*.,1997; CAESAR, 1999; Workman & Lentz, 2000). Later, Size UK (2002) for the British population and Size USA (2003) for the United States population were conducted in each nation, using advanced measurement technology known as the 3D body scanner, which is a device that scans the whole body and provides consistent and accurate measurement data in a few second.

In the United States, understanding various body dimensions is very important for developing apparel products. This is because the U.S. immigrant population grew rapidly during the 1990s with growth rates especially high across a wide band of states in the Southeast, Midwest, and Rocky Mountain regions (Urban Institute Immigration Studies Program, 2002). The Size USA (2003) was a successful national sizing survey, providing the most current accurate population data. However, head dimension data was omitted in the Size USA national sizing survey because the measuring technology being used was unable to provide head dimension data.

Head dimension data is directly related to head protection and safety since the data is used to further develop head products such as helmets and hardhats, that are important for protecting the wearer in hazardous environments military operations, professional sports, or motorized vehicles. A good fit and comfort design is essential for developing helmets (Robinette & Whitestone, 1992). A good fit requires an accurate measurement of head shapes in 3 dimensions. Using body scan technology, head geometry can be captured in a few second.

Lee, *et al*. (2003) and Ashdown, *et al*. (2005) evaluated images of hats worn by female golfers to assess their effectiveness for UV radiation, using a TechMath body scanner. The resulting scanned files were transferred to Innovmetric's Poyworks software for analysis. The methodology allowed effective visualization and image analysis for developing sun protection hat design.

A method of scanning the body in a 3-D forms for assisting in the early stages of helmet design was devised in the early 1990s (Robinette & Whitestone, 1992). Further, fitting to maximize the performance of helmet mounted display systems has been studied in the CARD (Computerized Anthropometric Research & Design Laboratory) in the Warfighter Interface Division located at Wright-Patterson Air Force Base (Whitestone & Robinette, 2002). In the study, to identify fit problems such as asymmetry, designers needed fit test results that included both fit quantification information and the 3-D spatial location of the head with respect to the helmet in sufficient detail to visualize the relationship between the two. The ability to measure the 3-D geometry permits accurate identification and correction of fit problems. However, the study was limited to personnel in the U.S. Air Force.

Lee (2004) analyzed the head shapes of 214 male students for varying headgears in South Korea. The study uses statistic analysis methods: factor analysis, cluster analysis, and Duncan Test with 15 variables. A 3D Head scanner was used for image analysis in the study. In the study (Lee, 2004), 4 clusters represented characteristics of men's head types. Type 1 had a larger head thickness, Type 2 had a smaller thickness and smaller width, Type 4 had a generally larger head. In the distribution of the four clusters, Type 1 was distributed 34 %. Type 4 was distributed 23%. According to the results, Type 1 of the more thick and narrow head was dominant among head types of men. The methods in the previous study (Lee, 2004) were successfully used for analyzing various head shapes in South Korea.

Although the importance of helmet, safety is an accepted norm, few studies were found. Understanding the importance of head safety products and considering the diversified ethnicities in the United Sates, it was necessary to investigate the problem of fit by collecting and analyzing human head dimension data from a cross-cultural section of the population. Therefore, the purpose of this study is to provide accurate head dimension data for developing safety head products by analyzing various head shapes in the United Sates.

II. Method

1. Subjects

Men from the state of Texas were measured. Ages ranged from 18-55. Caucasian, African-American, Hispanics/Mexican and Asians were included in the study. <Table 1> shows the subjects' ages, and 41.9% of the subjects were from the 26-35 age groups while the 45-55 age groups accounted for 2.9%. It should be noted that 71.4 % of the subjects were in the 18-35 age groups.

<Table 2> shows the frequency of the subjects' ethnicity. The majority were Caucasian and African American (82.8%), with the remainder being Hispanic (12.4%), Mexican, and Asian(4.8%). This indicates that diverse ethnicities exist in the United States. It is important to better understand the diversity since it differs from Korea that is homogeneous.

<Table 1> Frequency of Age

Age	Count	%
18-25	31	29.5
26-35	44	41.9
36-45	27	25.7
45-55	3	2.9
Total	105	100

<Table 2> Frequency of Ethnicity

Ethnicity	Count	%
Caucasian	69	65.7
African American	16	15.2
Hispanic	13	12.4
Caucasian & African American	2	1.9
Mexican	3	2.9
Asian	2	1.9
Total	105	100

2. Measurement

In this study, four landmarks were used: Gallabella, Menton, Tragion, and Zygion. Martin Measurement Instrument's spreading caliper and a measuring tape were used to size head dimensions. Acrylic panel (size in cm: 40(height)×24 (width)×0.1 (depth)) was used for top of the head measurements. In this study, measurement methods were based on Lee's head study method (2004) and a measurer's handbook (Clauser, *et al*., 1988) that was used for a U.S. Army anthropometric survey.

The head shapes were analyzed in the following categories: girth, length, width, and height. Nine items were measured and two calculated ratios were used. <Figure 1> shows the measurement locations and <Table 3> shows the list of head dimensions and measurement methods.

III. Results and Discussion

1. Basic statistics of head part

Body measurement data is useful for the industry to develop comfortable and protective products. The head is a very important body part in that it shells the brain that controls human body functions and needs to be protected in hazardous environments such as sports and industrial work places.

Understanding the importance of head protection and the need for reliable and accurate measurement data for head products, basic statistics were used for a fundamental analysis of the humans head dimensions. <Table 4> shows the statistic results from the American's head shape analysis in 11 dimensions with each value of mean, standard deviation, minimum, and maximum. According to the results in <Table 4>, the average value of menton-top of head was 24.1cm.

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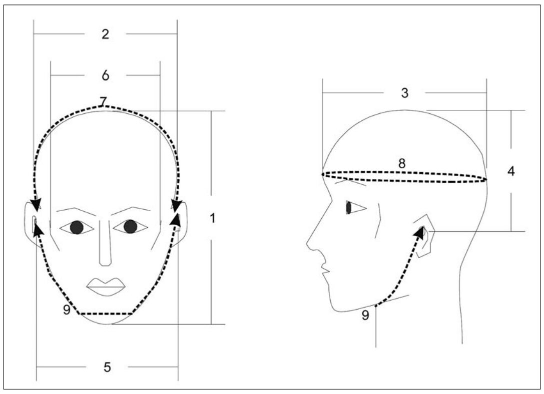
<Table 3> The List of Head Dimensions and Measurement Methods

No.	Dimensions	Measurement methods
1	Menton-top of head	The vertical distance between the menton landmark at the bottom of the chin and the horizontal plane tangent to the top of the head is measured.
2	Head breadth	The maximum horizontal breadth of the head above the attachment of the ears is measured with a spreading caliper.
3	Head thickness	The distance from the glabella landmark between the grow ridges to the posterior point on the back of the head is measured with a spreading caliper.
4	Tragion-top of head	The vertical distance between the tragion landmark on the cartilaginous flap in front of the ear hole and the horizontal plane tangent to the top of the head is measured.
5	Bitragion breadth	The straight line distance between the right and left tragion landmark on the cartilaginous flaps in front of each ear hole is measured.
6	Bizygomatic breadth	The maximum horizontal breadth of the face (between the zygomatic arches) is measured with a spreading caliper.
7	Bitragion Coronal Arc	The surface distance between the right and left tragion landmarks across the top of the head is measured with a tape.
8	Head circumference	The maximum circumference of the head above the attachment of the ears to the head is measured with a tape passing just above the ridges of the eyebrows and around the back of the head.
9	Bitragion submandibular arc	The surface distance between the right and left tragion landmarks across the submandibular landmark at the juncture of the jaw and the neck is measured with a tape.
10	Head breadth & thickness Ratio	Head breadth/ Head length × 100
11	Menton top of head & bizygomatic breadth Ratio	Menton-top of head/ Bizygomatic breadth × 100

*Landmarks: Gallabella/ Menton/ Tragion/ Zygion
**Equipments: 1. Spreading caliper 2. Measurement tape



<Figure 1> Head Dimensions

<Table 4> Basic Statistics

Scale: cm, kg

No	Dimensions	Mean	St. Dv	Min.	Max.
1	Height	176.2	9.7	152.4	198.1
2	Weight	80.6	15.0	54.4	136.1
3	Menton-top of head	24.1	2.5	19	29.1
4	Head breadth	14.5	1.3	10.2	17.4
5	Head thickness	19.4	2.5	13.8	23.9
6	Tragion-top of head	14.2	1.5	11	16.9
7	Bitragion breadth	13.2	1.7	9.4	16.8
8	Bizygomatic breadth	13.9	1.2	11.1	16.8
9	Bitragion Coronal Arc	38.0	2.3	34	43.5
10	Head circumference	57.4	2.1	53.4	61.6
11	Bitragion submandibular arc	29.9	2.9	25	35.8
12	Head breadth & thickness Ratio	76.4	13.4	48.5	110
13	Menton top of head & bizygomatic breadth Ratio	174.5	22.3	129.2	231.5

<Table 5> Factor Analysis

Head dimensions	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Bitragion breadth	**.882**	.012	-.023	.009	.672
Bizygomatic breadth	**.798**	-.069	-.008	-.149	.706
Head breadth	**.794**	-.099	.007	.257	.837
Tragion-top of head	**.611**	.396	.099	-.121	.554
Head thickness	-.021	**.904**	.017	.135	.779
Bitragion Coronal Arc	-.201	.206	**.767**	-.192	.664
Menton-top of head	.278	-.195	**.695**	.274	.708
Head circumference	-.040	.119	.007	**.913**	.849
EIGENVALUE(Varience)	2.538	1.084	1.082	1.065	
% of Varience	31.727	13.552	13.522	13.318	
Cumulative %	31.727	45.279	58.801	72.119	

2. Factor analysis for grouping of head characteristics

Factor analysis was performed by means of eight variables. The variables were selected through a variable screening process. The Bitragion submandibular arc was a very low value in the communality of Factor analysis so it was ruled out in using with the eight variables. In the results, as shown in <Table 5>, four factors were found: Factor 1(width factor) was explained with Bitragion breadth, Bizygomatic breadth, Head breadth, Tragion-top of head. Factor 2 (depth factor) was explained with Head thickness. Factor 3 (length factor) was explained with Bitragion Coronal Arc, Menton-top of head. Factor 4 (girth factor) was explained with head circumference. The cumulative percentage of four factors was 72.1%, which shows considerably strong factors.

3. Grouping of head types using cluster analysis

American's head shapes were analyzed with the cluster analysis method that categorizes main characteristics of various head shapes. According to the cluster analysis in this study, four head shapes were categorized. <Table 6> shows the frequency of head types. As shown in <Table 6>, the average head type was Type 1 (30.5%) while Type 2 possessed a frequency of 15.2%.

<Table 6> Frequency of Head Types

Types	Frequency	%
1	32	30.5
2	16	15.2
3	29	27.6
4	28	26.7
Total	105	100.0

<Table 7> shows the characteristics of head types by factor categories. As shown in <Table 7>, four head types are categorized: Type 1 had a large value of the width factor and a small value of the length factor. This indicates that Type 1 shows a large head type, showing wide breadth and girth. Type 2 contained the largest value of the length factor and a small value of the girth factor. This

<Table 7> Characteristic of Head Types by Factor Categories

Factors \ Types	Type 1	Type 2	Type 3	Type 4	F value
Factor 1 (width factor)	1.099	-.247	-.476	-.621	40.823***
Factor 2 (depth factor)	-.204	-.492	.534	-.039	5.036**
Factor 3 (length factor)	-.289	1.542	-.591	.061	32.375***
Factor 4 (girth factor)	.225	-.785	-.706	.923	30.902***

**: p<.01, ***: p<.001

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<Table 8> Result of Duncan Test

Dimensions	Type 1		Type 2		Type 3		Type 4		F Value	Duncan Test
	Mean	St. Dv	Mean	St. Dv	Mean	St. Dv	Mean	St. Dv		
Height	176.3	9.2	174.6	11.6	175.0	9.7	178.1	9.2	0.6	Type2 = Type 3 = Type 1 = Type 4
Weight	80.8	15.1	78.4	15.9	79.0	14.9	83.4	14.7	0.6	Type2 = Type 3 = Type 1 = Type 4
Menton-top of head	24.7	3.0	26.0	1.9	22.1	1.6	24.6	1.6	13.7***	Type3< Type 4 = Type 1< Type 2
Head breadth	15.5	0.7	14.1	1.4	13.7	1.3	14.2	1.1	14.2***	Type 3 = Type 2 = Type 4<Type 1
Head thickness	18.9	3.0	18.1	3.0	20.5	2.0	19.7	1.7	4.0*	Type 2 = Type 1≦Type 4≦Type 3
Tragion-top of head	15.0	1.2	13.9	1.5	14.2	1.4	13.6	1.5	5.9**	Type 4 = Type 2 = Type 3< Type 1
Bitragion breadth	15.0	0.9	12.8	1.5	12.5	1.4	12.1	1.4	30.8***	Type 4 = Type 2 = Type 3< Type 1
Bizygomatic breadth	15.1	0.6	14.0	1.0	13.4	1.2	13.1	0.7	30.5***	Type 4 = Type 2 = Type 3< Type 1
Bitragion Coronal Arc	36.8	1.8	41.2	1.8	37.6	1.9	37.8	1.5	23.0***	Type 1 = Type 3 = Type 4< Type 2
Head circumference	57.9	1.7	56.0	2.1	56.1	1.9	59.1	1.3	19.3***	Type 2 = Type 3< Type 1< Type 4
Bitragion submandibular arc	30.4	2.9	31.1	3.4	29.7	2.9	28.8	2.4	2.7	Type 4 = Type 3 = Type 1 = Type 2
Head breadth & thickness Ratio	85.2	13.6	79.6	14.5	67.7	9.3	73.6	9.5	12.4***	Type 3≦Type 4≦Type 2≦Type 1
Menton top of head & bizygomatic breadth Ratio	163.0	18.2	187.4	23.0	166.0	20.4	189.0	15.9	13.6***	Type 1 = Type 3< Type 2 = Type 4

*: p<.05, **: p<.01, ***: p<.001

indicates that Type 2 represents a long head type, showing long length. Type 3 had the largest value of the depth factor among all types and a smaller value of the length factor than other types. This indicates that Type 3 indicates a small head, being deep in depth but very narrow in width. Type 4 had large value of the girth factor and small value of the width factor. This indicates that Type 4 is a narrow head type, showing very narrow width but large girth. In addition, as shown in <Table 7>, each factor shows significant differences among head types.

4. Characteristics of four head types

According to head type analysis using the Duncan Test <Table 8>, four head types had the following characteristics. In Menton-top of head, Type 2 was the longest one, while Type 3 was the shortest one among the types. This indicates that Type 2 has characteristics of the long head. In Head breadth, Type 1 shows a large value that provides evidence of big head type characteristics. In addition, Type 1 shows large values in Bitragion breadth, Bizygomatic breadth.

In Bitragion Coronal Arc, Type 2 shows the largest value that supports evidence of long head type's characteristics. The characteristics of head shapes were successfully explained with the ratio of head breadth to thickness. Type 1 shows wider head breadth to thickness, while Type 3 (small head type) represents a smaller ratio.

IV. Conclusion

This study investigated various head shapes in the United Sates where various ethnic backgrounds exist. 105 American men's head shapes were analyzed in this study and the following factors and characteristics were found: In the basic statistics, American men have long Menton-top heads but narrow head breadth. According to factor analysis, four factors were defined. as Factor 1(width factor), Factor 2 (depth factor), Factor 3 (length factor), and Factor 4 (girth factor). Each factor was significantly related to head shape type (Type 1 through Type 4). Type 1 (large head type) has the widest breadth and girth among all types. Type 2 (long head type) has the smallest girth, the second widest breadth, and longer length. Type 3 (small head type) has large head girth but narrow depth. Type 4 (narrow head type) has narrow depth like Type 3, but it is distinguished in that Type 3 has significantly smaller head sizes than Type 4. Types 3 and 4 were commonly found in this study, showing

54.3% of the 105 American men studied had narrow faces and large head circumferences.

This study's results can be useful for international standardizing organizations to develop sizing systems for export/import safety helmet products. This study has a limitation due to it being conducted in only one state. Results in this study should not be applied to all other potential different head shapes and types in the United States. Therefore, further study should be conducted nationwide, and it will be necessary to compare head measurement data among different countries. In addition, it is recommended that a database system containing all international body measurement data be developed since many countries are developing international products based upon their own body measurement data.

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