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Development of prototype hat patterns for elderly women based on three-dimensional modeling

Jungil Jun[1], Youngshil Ryoo[2], Kuengmi Choi[3] and Sunmi Park[4*]

*Correspondence: sunmipark@kku.ac.k
[4] Associate Professor, Department of Fashion Design, Konkuk University, 322 Danwol-dong, Chungju-si 27478, Republic of Korea
Full list of author information is available at the end of the article

Abstract

Population aging is a global phenomenon, and the elderly population has a higher economic capability today than that in the past. Thus, this population is considered to be a growing consumer group that enjoys both consumer and leisure life. In this study, we developed prototype hat patterns for elderly women that can be used for developing close-fitting hats, helmets, masks, and smart headwear. Three-dimensional (3D) head scan data of elderly women were employed herein, and the data were classified into three groups with common head size and head shape. The target group was selected from a high-frequency group among the classified groups, and a standard head form representing the target group was developed using averaging and wire frame generation techniques. Four hat types were considered, design baselines were developed for each type, and prototype patterns were designed for each hat type using a flattening technique. The suitability of the developed prototype hat patterns was subsequently verified. Our results showed that all four prototype patterns had errors less than 5 mm^2 (1.40%). The hat patterning method proposed in this study is expected to improve the wearing comfort of high-value-added products designed for the elderly.

Keywords: Digital fashion, Standard head form, Hat prototype pattern, Active seniors, Wearable technology, Aging, 3D scanning

Introduction

The number and proportion of elderly people are increasing as the life expectancy of humans increases owing to advanced medical technologies and improved quality of life across the globe. According to the world population trend data published by the United Nation, the global population of people over 60 years of age increased from approximately 200 million in 1950 to 350 million in 1975, and it is expected to reach 2 billion in 2050 (Scherbov et al., 2018; United Nations, 2017). In this paper, we define active seniors as middle-class retirees, who are financially stable and socially and economically active; and those with a high purchasing power who actively invest in their health, leisure, culture, looks, and self-development (Neugarten, 1982). The concept of "active seniors" and age standards vary depending on political, economic, social, and cultural circumstances.

However, the consensus among researchers (Kim & Kim, 2018; Song, 2011) is that among the elderly in their 50 s and 60 s, active seniors are young in their minds, engage in various activities designed for the young population, and are active consumers based on their stable financial status.

Active seniors have a high purchasing power. Thus, they have attracted attention from various areas and are emerging as a new consumer group (Hazel & Gwendolyn, 1994; Penick & Fallshore, 2005; Salusso et al., 2006; Thomas & Peters, 2009). In the US and Japan, active seniors have already become mainstream consumer groups since the early 2000s (Sim, 2013). In line with this new trend, businesses are taking steps to transform the main consumer market for products and services to be oriented toward active seniors (Baek & Seo, 2018; Kim & Uh, 2019). According to the investment firm Merrill Lynch, annual worldwide consumer spending by adults aged 60 is projected to increase by more than double—from $7 trillion in 2017 to $15 trillion in 2020 (Nahal & Ma, 2014). The McKinsey Global Institute predicted that with the increase in the elderly population with purchasing power, the size of the market of the elderly friendly industry will rapidly increase worldwide. This is expected to have a positive impact on the vitalization of the overall economy (Dobbs et al., 2016). The apparel industry has also attracted interest in active seniors who differentiate themselves from the existing Silver Generation. In particular, elderly women are more interested in fashion and related trends, and they are more active consumers than their male counterparts. Numerous studies have been conducted on elderly women as one of the main active consumer groups (Chae, 2020; Kim, 2015; Kim & Lee, 2008). To maintain a young psychological age, senior women of the New Silver Generation exhibit active spending habits in terms of health, esthetics, and fashion. In line with these findings, the State of the Future report by the United Nations expects that the apparel industry will be more oriented toward the Silver Generation and female customers by the year 2040 (Bae, 2016; Park et al., 2014).

With the recent commercialization of three-dimensional (3D) whole-body scanners, 3D human body scan data are being utilized in various high-technology industries, including the apparel, automobile, medicine, animation, and artifact restoration industries (Brown et al., 2009; Haleem & Javaid, 2019; Istook, 2008; Molenbroeka & Gotoa, 2015; Treleaven & Wells, 2007). This technology provides various forms of digitalized information by acquiring 3D geometry information of human body parts, as well as by enabling database construction and reuse of the same data. Therefore, in the apparel industry, a wide range of research has been performed using 3D body scanning technology—from product design and production to service and marketing (Greder et al., 2020). Further, this technology has been employed in the apparel industry to develop anthropometric measurement and sizing systems, as well as for the development of representative body types and 3D virtual fitting systems (Ashdown & Loker, 2010; Baytar & Ashdown, 2015; Griffey & Ashdown, 2006; Pei et al., 2019; Song & Ashdown, 2015). It has also been used to develop undergarments (including brassieres and corsets) as well as sportswear (including golf wear and cycle wear) that better fit the human body (Han & Yi, 2019; Jeong & Hong, 2010; Kim & Hong, 2012; Pei et al., 2020). Thus, in the apparel industry, 3D scanning technology is regarded as indispensable for the future development of the industry; therefore, research utilizing 3D scan data is being actively pursued (Azouz et al., 2006; Connell et al., 2006; Istook & Hwang, 2001; Liu et al., 2017).

The shape of the skull, which determines the shape of the head, varies with age and gender; it also varies depending on race and ethnicity, as well as over generations (Ahn & Suh, 2004; Ball et al., 2010; Du et al., 2008; Lee et al., 2019; Yoon & Jung, 2002). In addition, the head shape changes according to changes in diet and lifestyle. Because individual differences in the skull shape are greater than those in any other parts of the body, continuous research on the head shape is required to develop a close-fitting head product with a good fit (Kim, 2019a, 2019b; Koh et al., 2001). Wearable healthcare products such as wristbands, watches, glasses, helmets, and hats are particularly useful for the elderly because of their ability to continuously monitor individual health status in a non-intrusive manner (Lee & Lee, 2011; Park et al., 2014; Sul, 2016). In this regard, wearable healthcare clothing accessories such as hats that predict stroke have recently been developed for the elderly with an ever-increasing interest in health (Angelini et al., 2013; Ariyatum et al., 2005; Lattanzio et al., 2014; Sul, 2016). Such clothing products serve the dual function of providing both comfort and protection to maintain, promote, or restore the health of the human body and add convenience to daily life. To design or manufacture such healthcare clothing products, it is essential to obtain three-dimensional (3D) information regarding the body shapes of consumers (Koo et al., 2017; Lee & Jeong, 2016; Park et al., 2014). The head is a suitable target for wearable healthcare devices such as hats and helmets. However, human heads of the same size may have different geometries (e.g., protruding and flat types). Therefore, such products must be developed based on accurate measurements so that they are comfortable to wear for long periods of time yet fit the head tightly. Otherwise, users may experience stuffiness or headaches, which may force them to their abandon the item over time. Thus, it is necessary to identify the geometrical characteristics of the head, classify head types, and develop hat patterns for each type to produce hats with a close fit. It follows from the above discussion that it is essential to obtain the 3D body shape data of consumers for the designing and manufacturing of healthcare clothing products with good ergonomics (Koo et al., 2017; Lee & Jeong, 2016; Park et al., 2014).

In this regard, previous studies on 3D head scan data have compared images of 3D heads between different races (Ball, 2009; Ball et al., 2010), developed representative head shapes (Ball, 2009; Lee et al., 2018; Luximon et al., 2012; Oh, 1998; Zhuang et al., 2010), and developed products related to headwear or face wear (Ahn & Suh, 2004; Kim & Ahn, 2010; Kim & Kim, 2010; Lee, 2013; Meunier et al., 2000; Yang et al., 2009). In addition, various studies have been conducted to categorize head shapes using 3D body measurements and identify the geometry for each categorized type (Ahn & Suh, 2004; Choi et al., 2009, 2010; Kim et al., 2006; Kim, 2019a, 2019b; Lim, 2004). However, most of these previous studies did not sufficiently analyze the characteristics of head shapes in elderly women.

This study presents standard head forms and prototype hat patterns for elderly women that can be used for various purposes. Different head geometries were classified into several groups with common characteristics by using the 3D head scan data of elderly women, and a standard head form was developed by identifying the characteristics of each group. The standard head form can be used to design close-fitting hats and to develop wearable smart clothing, including wearable healthcare products. Furthermore, design baselines were developed for each hat type. Ergonomic product designs created based on 3D modeling are expected to be used as the basic data for developing smart healthcare clothing products for active seniors. Furthermore, sustainability is a trend that has attracted the attention of the apparel industry in recent times as consumers are increasingly interested in production processes that use minimal resources when producing apparel. Therefore, research focused on on-demand and made-to-measure (MTM) clothing is being actively conducted (Gam et al., 2009; Jiang et al., 2018; Shen, 2014). The standard head form and design baseline by type of hats developed in this study are expected to be utilized as basic data for on-demand and MTM clothing production.

Methods

This study used 3D head scan data from the 6th Size Korea Project conducted by the Korean Agency for Technology and Standards (Korean Agency for Technology & Standards, 2012). The analysis was conducted on 201 elderly women aged between 60 and 69 years. This age group was selected because an examination of previous studies on body shape changes in elderly women showed that distinct physical changes appeared in the late 50 s (Choi, 1997; Choi et al., 2009; Kim, 2010, 2019a, b; Kim et al., 2006). In addition, Kim (2019a, 2019b) analyzed the head shape of adult women (20 s or older) using 3D scan data from the 6th Size Korea Project and reported that women in their 50 s and 60 s showed distinct differences in terms of changes in head shapes and characteristics.

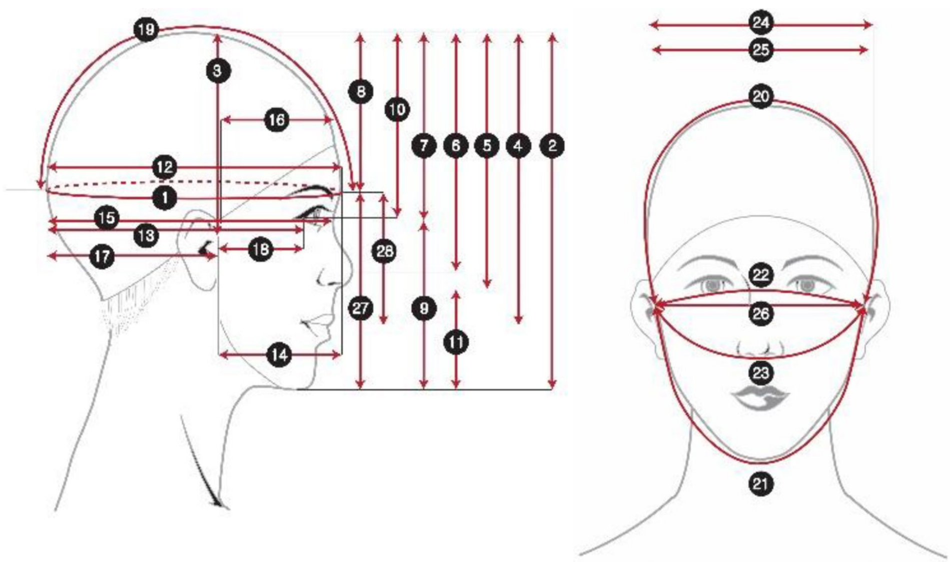
The 3D whole-body scanner used in the 6th Size Korea Project (Hamamatsu BL Scanning System, Japan) was a non-contact type whole-body scanner that extracted 3D surface data using an infrared LED source. A circular landmark with a diameter of 10 mm was attached to the body of the participants before scanning to help identify the reference point more accurately and quickly when extracting size dimensions from the head measurement program. The scan data included noise and unscanned areas during the scanning process, which were processed after the scan through a series of surface reconstruction procedures, including cleaning and filling holes, by using Rapidform XOR3.

Among the 45 body measurements extracted from the 3D head scan data of elderly women, 28 measurements related to the development of hat patterns were selected for this study based on a literature review (International Organization for Standardization, 2017a, 2017b; Lee, 2013). These are listed in Table 1. IBM SPSS 15.0 was used for the data analysis. Rapidform XOR3 and AutoCAD 2017 were used for the 3D scan data analysis.

This study was conducted in four steps, as listed in Fig. 1. In step 1, the major characteristics of the head geometries of elderly women were identified and classified into different head types. To this end, head geometry components were analyzed using 28 3D head dimensions of 201 elderly women, and head types were classified. In step 2, a standard head model representing elderly women was designed. A high-frequency group was selected among the head types classified in step 1, and the standard head model representing this group was developed. In step 3, close-fitting hat patterns that can be developed into various designs were designed. Design baselines based on the hat types were created on the standard head model developed in step 2, and the prototype patterns were developed by converting 3D surfaces into 2D patterns. In step

Table 1 3D head measurement dimensions

No	Measurement dimension	No	Measurement dimension
1	Head circumference	15	Sellion to wall
2	Head height	16	Otobasion superius to sellion
3	Right tragion to vertex height	17	Occiput to right tragion distance
4	Stomion to vertex height	18	Ectocanthus to tragion
5	Subnasale to vertex height	19	Sagittal arc
6	Pronasale to top of head	20	Bitragion arc
7	Sellion to vertex height	21	Bitragion-menton arc
8	Glabella to vertex height	22	Bitragion-sellion arc
9	Morphologic face height	23	Bitragion-subnasale arc
10	Right ectocanthus to top of head	24	Head breadth
11	Menton-subnasale length	25	Inter-otobasion superius breadth
12	Sagittal arc of head	26	Bitragion breadth
13	Occiput to right ectocan-thion distance	27	Menton to glabella
14	Tragion to glabella	28	Glabella to stomion



4, the suitability of the developed prototype patterns was verified by comparing the areas of the 3D standard head model with those of the 2D patterns.

Results

3D head type classification for elderly women

Classification of head size types using absolute values

Factor analysis was conducted using 28 items to identify the major head geometry components. A principal component model was used for the factor analysis. To clarify the nature of the factors, an orthogonal rotation method (varimax method) was

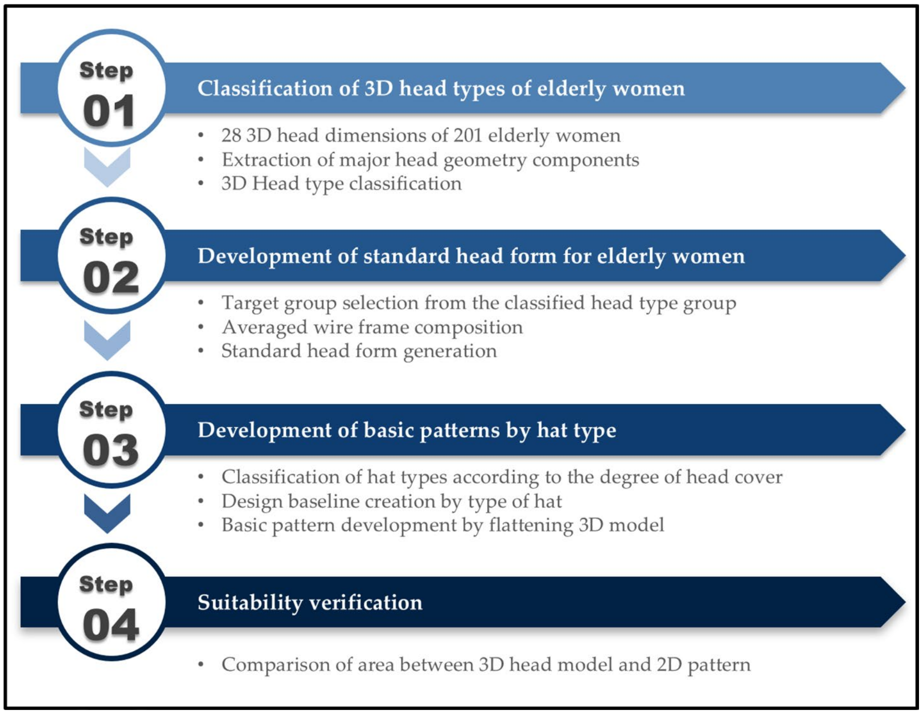


Fig. 1 Research process flow chart

Table 2 Factor analysis results using absolute values

Item	Factor 1	Factor 2	Factor 3	Factor 4	Explanation
Sellion to vertex height	*.960*	−.012	.181	.127	Length of the upper head
Glabella to vertex height	*.947*	−.122	.108	.113	
Right ectocanthus to top of head	*.943*	.076	.110	.129	
Menton to glabella	−.064	*.953*	.064	.208	Face length
Morphologic face height	−.203	*.876*	−.049	.188	
Glabella to stomion	.208	*.864*	.156	.090	
Ectocanthus to tragion	.052	.097	*.939*	.139	Face thickness
Tragion to glabella	.290	.035	*.897*	.119	
Sagittal arc of head	.122	.192	.177	*.895*	Head size
Head circumference	.191	.222	.093	*.892*	
Total	2.935	2.541	1.814	1.763	–
% of variance	29.354	25.405	18.137	17.627	
Cumulative %	29.354	54.760	72.897	90.524	

Italic values indicate high loading values

used. Four factors were extracted, and their cumulative contribution rate was found to be 90.524% (see Table 2).

As can be observed from the table, Factor 1 comprises three items: sellion to vertex height, glabella to vertex height, and right ectocanthus to the top of the head. These are associated with the vertical length of the head that excludes the face from the entire head height; they can thus be interpreted as factors representing the "length of the upper head." Similarly, the items related to Factor 2 (comprising menton to glabella,

Table 3 Results of analysis of variance by factor score of absolute values (unit: mm)

Dimension		Total (n = 201)		Type 1 (n = 74)		Type 2 (n = 76)		Type 3 (n = 51)		*f*-value
		M	SD	M	SD	M	SD	M	SD	
Length of the upper head	Sellion to vertex height	113	9.42	*116* A	9.79	113 AB	8.92	110 B	8.49	7.111**
	Glabella to vertex height	90	8.62	*93* A	8.77	89 B	7.49	85 C	7.99	13.954***
	Right ectocanthus to top of head	115	8.51	*117* A	9.34	114 B	7.73	112 B	7.50	5.911**
Face length	Menton to glabella	135	6.69	132 B	4.64	133 B	5.19	*143* A	4.77	88.434***
	Morphologic face height	112	6.19	109 B	4.23	110 B	4.81	*119* A	5.22	73.109***
	Glabella to stomion	95	5.25	94 B	4.37	94 B	4.77	*100* A	3.83	43.283***
Face thickness	Ectocanthus to tragion	69	5.59	66 C	4.53	*72* A	4.13	68 B	6.04	35.230***
	Tragion to glabella	86	7.58	83 B	6.94	*90* A	6.26	84 B	7.27	26.044***
Head size	Sagittal arc of head	186	6.86	181 B	5.19	*189* A	6.00	187 A	6.59	37.375***
	Head circumference	564	14.35	556 B	13.08	*570* A	13.01	568 A	12.72	23.517***

Letters represent Duncan grouping (A > B > C)

Italic values indicate items that best represent each type of characteristic

M mean, *SD* standard deviation

*** $p < .001$, ** $p < .01$

Table 4 Characteristics by head type by cluster classification of absolute values

Head type	Classification	Characteristic
Type 1 (n = 74, 36.8%)	Small head with long upper head type	Head type with the longest length of the upper head For face length and face thickness, normal Head type with the smallest head size
Type 2 (n = 76, 37.8%)	Protruded face and large head type	For length of the upper head and face length, normal Head type with the largest face thickness and head size
Type 3 (n = 51, 25.4%)	Head type with a long face	For length of the upper head, face thickness, and head size, normal Head type with the longest face length

morphologic face height, and glabella to stomion) are associated with the vertical lengths of the eyes, nose, and mouth and can thus be interpreted as factors representing the "face length"; those related to Factor 3 (comprising ectocanthus to tragion and tragion to glabella) are associated with the thickness of the face and can be interpreted as factors representing "face thickness"; and those related to Factor 4 (comprising sagittal arc of head and head circumference) are associated with thickness and circumference of the head and can be interpreted as factors representing the "head size."

To classify the head shape of elderly women, cluster analysis was performed using the factor scores obtained from the factor analysis. Cluster analysis classified the head shape into three different clusters. To examine the characteristics of each type, analysis of variance was performed on the factor scores for each type. The results of analysis of variance confirmed significant differences between clusters for all factors (Table 3).

Based on these results, the characteristics of each cluster type can be summarized as follows (see Table 4). For type 1, the length of the upper head was the longest, whereas the face length and thickness were found to be average. The head size was the smallest, thereby showing the characteristic of a "small head with long upper head." For type 2, the length of the upper head and the face length were close to the average, but the face thickness and the head size were the largest, thereby exhibiting the characteristic of a "protruded face and large head." For type 3, the face length was the largest, and the overall head height was also found to be the largest, thereby showing the characteristic of a "head with a long face."

Classification of head shape types using index values

The human body exhibits various characteristics and shapes depending on the size of the skeleton, the level of muscle development, the thickness and location of the subcutaneous layer, and posture. The outline of the body can be described in terms of size and shape. Because items related to body size and obesity account for a large part of the absolute values obtained by anthropometric measurements, it is highly likely that the body shape is classified based on the size of the body (Choi, 1997; Kim & Choi, 2009). In this study, to minimize the influence of size and extract characteristics of the head shape,

Table 5 Factor analysis results using index values

Item	Factor 1	Factor 2	Factor 3	Factor 4	Explanation
Right tragion to vertex height/HH	*.872*	.213	−.114	−.067	Head size Ratio
Bitragion arc/HH	*.848*	.080	.075	.104	
Sagittal arc/HH	*.790*	−.076	.280	−.023	
Sagittal arc of head/HH	*.705*	.262	.282	.242	
Sellion to vertex height/HH	−.130	−*.929*	−.167	.060	Face length Ratio
Menton to glabella/HH	.100	*.911*	.197	.047	
Glabella to stomion/HH	.110	*.858*	.121	−.053	
Bitragion-menton arc/HH	.012	.220	*.909*	.250	Face width Ratio
Bitragion-subnasale arc/HH	.149	.166	*.850*	.376	
Bitragion breadth/HH	.237	.173	*.840*	−.063	
Tragion to glabella/HH	.033	−.144	.085	*.929*	Face thickness Ratio
Ectocanthus to tragion/HH	.092	.066	.256	*.905*	
Total	2.727	2.686	2.587	1.974	
% of variance	22.726	22.386	21.557	16.452	
Cumulative %	22.726	45.112	66.668	83.121	

Italic values indicate high loading values

HH head height

factor analysis was performed using the index values obtained by dividing each measurement item by the vertical length of the head. As a result of factor analysis, four factors were extracted, and their cumulative contribution percentage was 83.121% (Table 5).

Factor 1 is related to the size of the head, such as the width, thickness, height, and length of the head, and represents the "head size ratio." Similarly, Factor 2 is related to the position and length of the mouth and eyes and represents the "face length ratio"; Factor 3 is related to the width of the face and represents the "face width ratio"; and Factor 4 is related to the thickness of the face and represents the "face thickness ratio." As a result of analyzing the data using the index value, we found that the "face width ratio" is a new factor that was not extracted using the absolute values, and that factors reflecting the head shape rather than the size were extracted.

Cluster analysis results using the factor scores derived from the factor analysis classified the head shape into three clusters. Analysis of variance confirmed that clusters for all factors significantly differed; the mean of the index values between cluster types was compared. The results are summarized in Table 6.

As a result of analyzing the type of head using the index values, the head shape was classified into three types as follows: "A slim head type with a long ratio of the upper part of the sellion," "A long head type with a short ratio of the upper part of the sellion," and "A wide head type with normal face length ratio." The characteristics of each cluster are listed in Table 7.

After analyzing the distribution of head types classified using absolute values and head types classified using index values, groups that fell under "Small head with long upper head type" and "A slim head type with a long ratio of the upper part of the sellion" were identified as groups with high frequency; 23.4% of the total was analyzed to fall under these types (Table 8).

Table 6 Results of analysis of variance by factor score of index values (unit: mm)

Dimension		Total (n = 201)		Type 1 (n = 102)		Type 2 (n = 51)		Type 3 (n = 48)		*f*-value
		M	SD	M	SD	M	SD	M	SD	
Head size ratio	Right tragion to vertex height/HH	.611	.033	.594 C	.027	*.637* A	.028	.620 B	.032	42.715***
	Bitragion Arc/HH	1.638	.062	1.604 B	.048	*1.674* A	.052	*1.674* A	.057	47.441***
	Sagital Arc/HH	1.290	.055	1.260 C	.037	*1.330* A	.058	1.310 B	.048	45.681***
	Sagittal arc of head/HH	.826	.037	.806 B	.028	.844 A	.037	*.850* A	.030	44.986***
Face length ratio	Sellion to vertex height/HH	.502	.027	*.512* A	.026	.486 C	.023	.500 B	.027	17.625***
	Menton to glabella/HH	.602	.027	.593 B	.026	*.614* A	.025	.610 A	.027	14.415***
	Glabella to stomion/HH	.178	.019	.173 B	.017	*.188* A	.019	.179 B	.019	12.745***
Face width ratio	Bitragion-menton arc/HH	1.392	.073	1.364 C	.062	1.395 B	.067	*1.447* A	.069	26.344***
	Bitragion-subnasale arc/HH	1.248	.064	1.220 C	.052	1.251 B	.055	*1.305* A	.058	41.048***
	Bitragion breadth/HH	.673	.038	.654 B	.027	*.694* A	.038	.690 A	.035	35.470***
Face thickness ratio	Tragion to glabella/HH	.382	.032	.377 B	.023	.355 C	.021	*.419* A	.022	109.457***
	Ectocanthus to tragion/HH	.306	.025	.300 B	.020	.292 C	.020	*.335* A	.018	74.254***

Italic values indicate items that best represent each type of characteristic

Letters represent Duncan grouping (A > B > C)

M mean, *SD* standard deviation, *HH* head height

*** $p < .001$

Development of standard head form for elderly women

Target group selection for the development of a standard head form

Based on these results, five representative subjects from the high-frequency group ("small head with long upper head type" and "a slim head type with a long ratio of the upper part of the sellion") were selected as the analysis targets for modeling the standard head form ("target group").

Averaged wire frame composition

Extraction of head geometry characteristic cross-sections From the 3D head scan data of the target group, five characteristic cross-sections were extracted, including the midsagittal plane, head circumference plane, tragion vertical plane, tragion horizontal plane, and neck circumference plane. Table 9 describes these characteristic cross-sections.

Creation of head geometry average cross-sections Based on the characteristic cross sections extracted from the target group, average cross-sections were created by measuring

Table 7 Characteristics by head type by cluster classification of index values

Head type	Classification	Characteristic
Type 1 (n = 102, 50.7%)	A slim head type with a long ratio of the upper part of the sellion	Compared with the head height, the length ratio above the sellion is longer and the proportion of the face length is thinner and smaller
Type 2 (n = 51, 25.4%)	A long head type with a short ratio of the upper part of the sellion	Compared with the head height, the length ratio above the sellion is shorter and the proportion of the face length is longer, a flat-headed figure
Type 3 (n = 48, 23.9%)	A wide head type with normal face length ratio	A head shape with a normal face length ratio and a wide face

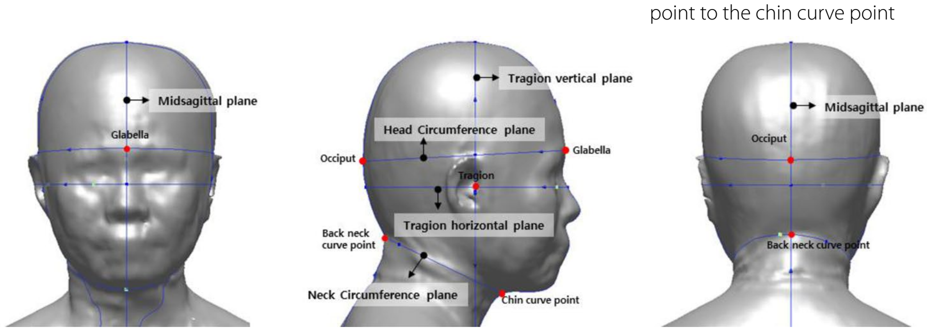
Table 8 Head type distribution in elderly women (unit:N, %)

		Classification of head shape types using index values			Total
		A slim head type with a long ratio of the upper part of the sellion	**A long head type with a short ratio of the upper part of the sellion**	**A wide head type with normal face length ratio**	
Classification of head size types using absolute values	Small head with long upper head type	*47 (23.4%)*	22 (10.9%)	5 (2.5%)	74 (36.8%)
	Protruded face and large head type	25 (12.4%)	12 (6.0%)	39 (19.4%)	76 (37.8%)
	Head type with a long face	30 (14.9%)	17 (8.5%)	4 (2.0%)	51 (25.4%)
Total		102 (50.7%)	51 (25.4%)	48 (23.9%)	201 (100.0%)

Italic values indicate group with high frequency

Table 9 Reference planes of the head selected for 3D modeling

No	Reference plane	Definition
1	Midsagittal plane	Vertical plane through the glabella
2	Head circumference plane	Cross plane through the glabella and occiput
3	Tragion vertical plane	Vertical plane through the tragion
4	Tragion horizontal plane	Horizontal plane at the tragion level
5	Neck circumference plane	Cross plane from the back-neck curve point to the chin curve point



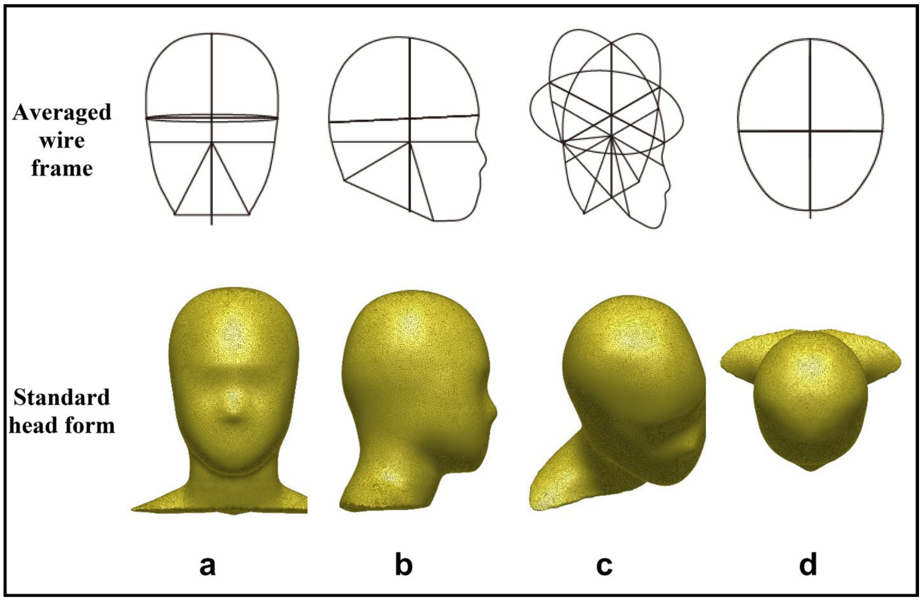


Fig. 2 Results of averaged wire frame generation and standard head form. **a** Front view; **b** right view; **c** SE Isometric view; **d** top view

Table 10 Error verification of standard head form and averaged wire frame (unit: mm)

Measurement dimension	Averaged wire frame (A)	Standard head form (B)	Difference (B–A)
Head circumference	547	547	0
Flatness (head breadth/head length)	0.85	0.85	0
Sagittal arc of head/head height	313	312	− 1
Tragion to top of head/head height	0.59	0.59	0
Sellion to top of head/head height	0.51	0.51	0
Bitragion-menton arc/head height	1.36	1.35	− 0.01
Tragion to glabella/head height	0.38	0.39	0.01

the length from the center of the cross-section at intervals of 1° by using the averaging technique suggested by Park et al. (2011).

Wire frame generation The averaged wire frame of a target group was generated by taking horizontal cross-sections and vertical section curves from the 3D head scan dataset. Based on the completed average cross-sections, a wire frame was assembled (see Fig. 2).

Modeling of standard head form

To model the standard head form, surface modeling was performed by reflecting the curvature of the wire frame. Figure 2 shows the standard head form developed in this study for elderly women. The standard head form is a 3D geometrical model that includes the average dimensions of the high-frequency group, and also the geometrical characteristics of the head. Therefore, it is possible to design hats that provide an ergonomic fit across various age groups of the elderly women.

Table 11 Classification of hat types according to degree of head cover

Classification	Definition
Type 1 (crown type)	A type that protects the upper head based on the head circumference line
Type 2 (hood type)	A type that protects the upper head based on the line connecting the glabella and inion
Type 3 (helmet type)	A type that protects the ear areas and the upper head based on the line connecting the glabella, gonial angle, and inion
Type 4 (pullover type)	A type that protects the entire head except the eye areas

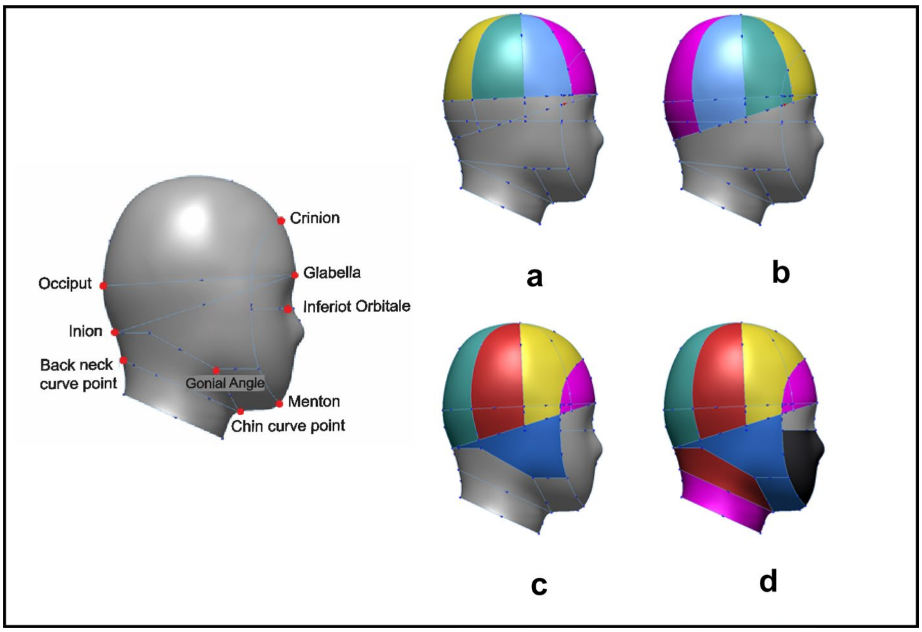


Fig. 3 Results of design baseline creation by hat type. **a** Crown type; **b** hood type; **c** helmet type; **d** pullover type

When dimensional errors between the standard head form and the averaged wire frame were verified, all items were found to be included within an error range of ± 1 mm according to ISO 20685-1 (International Organization for Standardization, 2018). This verification process confirmed that the developed standard head form is a model that represents the high-frequency group (see Table 10).

Development of prototype patterns by hat type

Creation of design baselines

Four hat types were considered to develop various hat designs. Table 11 lists the hat types classified according to the degree of head cover. Figure 3 shows the design baselines of each hat type created based on the standard head form.

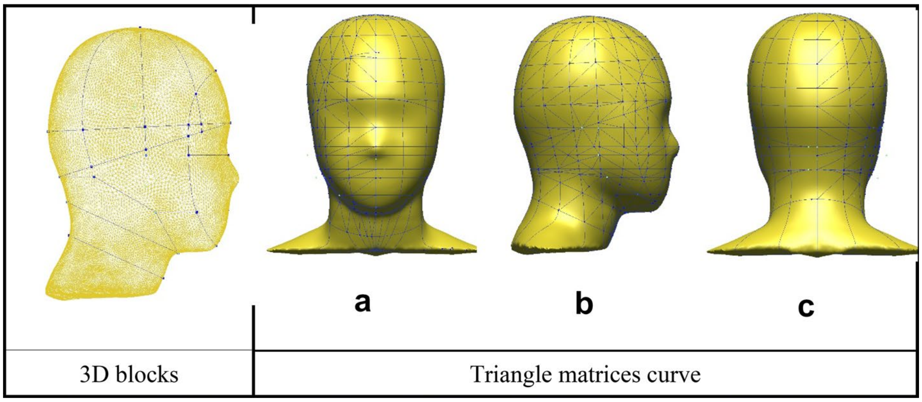


Fig. 4 3D block and triangular curved mesh creation for pattern development. **a** Front view; **b** right view; **c** back view

Creation of matrices for pattern development

3D blocks were set by referring to the design baselines of each hat type. To flatten the 3D blocks into 2D patterns, triangular curved meshes were created for each block (see Fig. 4).

Development of 3D prototype hat patterns

Prototype patterns for each hat type were developed by converting the triangular curved meshes created on the standard head form into 2D patterns based on the flattening technique (see Table 12) suggested by Park et al. (2011).

Suitability verification

To verify the suitability of the developed prototype hat patterns, the areas of the 3D models were compared with those of the corresponding 2D patterns. When their areas were measured and compared for each hat type, it was found that the area of the 2D pattern was 3.76 mm^2 (1.40%) smaller than that of the 3D model for the crown type, 4.57 mm^2 (1.39%) smaller for the hood type, 4.61 mm^2 (1.21%) smaller for the helmet type, and 3.10 mm^2 (0.54%) smaller for the pullover type.

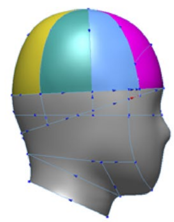
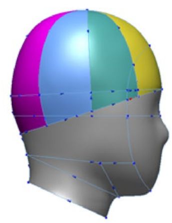
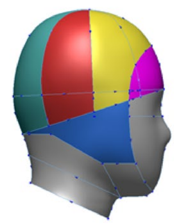
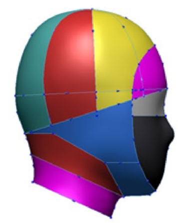
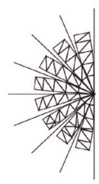
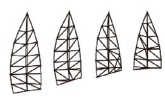
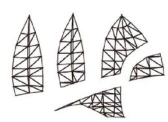
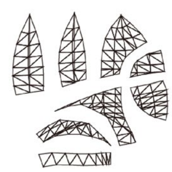
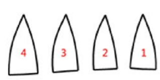
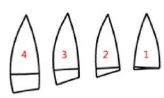
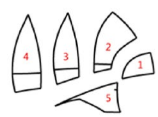
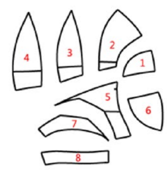
Choi et al. (2006) suggested that when the 3D human body scan data are developed in a 2D plane pattern, both accuracy and efficiency can be simultaneously satisfied if the ratio of the difference in areas between the 3D shape and the corresponding 2D plane piece is less than 2.22%.

Because the error between the 2D pattern and the 3D model was less than 5 mm^2 (1.40%) for all hat types, it was confirmed that the developed 2D patterns reflected the corresponding 3D models (see Table 13).

Discussion

To develop a clothing product with high consumer satisfaction, the structure, function, and geometry of the human body must be properly identified, and its size or geometry must be quantified and incorporated in the pattern design (Kim & Ahn, 2010; Kim & Choi, 2009; Kim & Kim, 2010). In this study, by using 3D scan data, the structure of

Table 12 Results of prototype pattern development by hat type

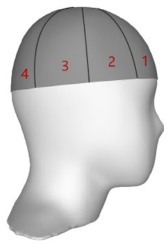
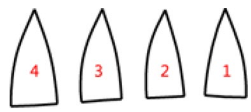
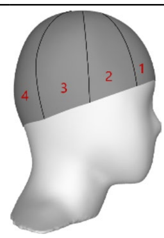
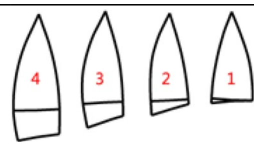
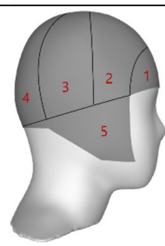
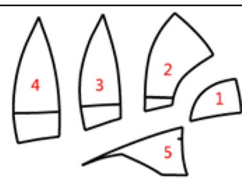
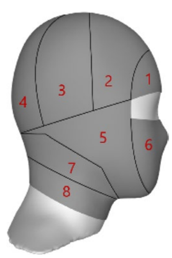
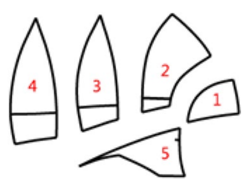
Classification	Crown type	Hood type	Helmet type	Pullover type
3D blocks				
3D patterns				
2D patterns				

the head and its 3D shape were characterized, and this information was converted into numerical data through 3D design technology to design a prototype hat pattern. Using the results obtained in this study, we confirmed that the use of 3D scan data and 3D design technology enables the design of close-fitting hats with a high level of fit in terms of shape. The developed ergonomic hat pattern design technology presented herein is expected to improve the wearing comfort of high-value-added products designed for active seniors.

Previous studies that developed a hat prototype pattern using a 3D head model are outlined as follows. Oh (1998) developed a model of an average head for women in their 20 s, and by using this head model, three types of hat patterns were developed: toque, beret, and conical hat. However, because only the head circumference dimension was used when developing the head model, the characteristics of the head shape were overlooked in the design. Because the difference in individual body shape increases with increasing age for elderly women, to improve the overall fit, it is necessary to classify the body shape by analyzing the factors representing shape as well as the factors related to size (Kim & Choi, 2009). In this study, we classified the head shape of elderly women by a size factor using the absolute and index values.

Kim and Ahn (2010) reported that 3D anthropometric measurements capture various forms of information that are difficult to collect using the conventional method; thus, with the use of 3D scan data, hat patterns can be designed with more ease and accuracy. In addition, to develop a cap with good comfort of fit, the following six points were proposed as the main reference points for hat pattern production: crinion, forehead midpoint, glabella, superior auricle, occiput, and inion. In this study, in addition to the reference points presented by Kim and Ahn (2010), the inferior orbitale, menton, chin

Table 13 Verification of the developed prototype hat patterns (unit: mm^2, %)

Type of hat	Area measurement			Area		
	3D model	2D prototype pattern	No	3D model (A)	2D pattern (B)	B–A
Crown type			1	62.73	61.09	−1.64
			2	59.17	58.96	−0.21
			3	67.71	66.66	−1.05
			4	77.78	76.92	−0.86
			Sum	267.39	263.63	−3.76 (−1.40%)
Hood type			1	64.87	63.85	−1.02
			2	68.26	67.43	−0.83
			3	86.33	85.43	−0.90
			4	110.02	108.21	−1.82
			Sum	329.49	324.92	−4.57 (−1.39%)
Helmet type			1	37.26	36.33	−0.93
			2	94.14	93.93	−0.21
			3	86.33	85.43	−0.90
			4	110.02	108.21	−1.82
			5	53.41	52.66	−0.75
			Sum	381.17	376.56	−4.61 (−1.21%)
Pullover type			1	37.26	36.33	−0.93
			2	94.14	93.93	−0.21
			3	86.33	85.43	−0.90
			4	110.02	108.21	−1.82
			5	81.87	81.52	−0.34
			6	61.65	61.41	−0.24
			7	47.66	48.40	0.74
			8	50.53	51.12	0.59
			Sum	569.46	566.36	−3.10 (−0.54%)

curve point, gonial angle, and back neck curve point were used as reference points for hat pattern design. This is because the hat developed in this study was designed with more emphasis on the functionality of protecting the head rather than fashion.

Kim and Kim (2010) reported that to make a hat with good fit for the head, wearing comfort, and good visual looks, the design must be based on the accurate calculation of the size and shape of the head. To this end, the use of 3D head scan data was found to be effective. They compared the wearing state of a hat fabricated using the traditional method and a hat fabricated using 3D data and reported that hats made using 3D data showed higher wearing comfort than those made using the existing method. They designed a pattern divided into six pieces to produce a crown-shaped hat and reported that increasing the number of pieces of a pattern provides a better fit of the head shape. In this study, a crown-shaped hat pattern using four pieces was designed. While the number of pattern pieces was fewer compared with that used by Kim and Kim (2010), the result confirmed that the fit of shape was maintained. Moreover, the use of fewer pieces is more suitable from the point of view of production efficiency.

Ahn (2004) reported that most hat makers use only one dimension of the head circumference when designing hat patterns and, for other dimensions, they adjust the dimensions arbitrarily according to the design. This is because the sizing systems for hats are not as detailed as that for apparels (Lee & Do, 2003; Lim, 2004). For example, the sizing system for hats (Korean Industrial Standards 2019: KS K 0059) specified in the Korean Industrial Standard includes a size standard for headwear with 1 cm intervals based on the head circumference only. Even in the international standard (ISO), only the size labeling method is used for headwear (International Organization for Standardization, 1977: ISO 4417); moreover, for general hats other than protective gear, the sizing systems are not separately specified. Ahn (2004) reported that owing to the diversified demands of modern-day consumers, hat makers require scientific hat pattern design technology, and that they are particularly interested in the standard head models of consumers. In this study, a standard head model was developed and a hat design method incorporating the characteristics of the standard head model was proposed. Thus, it is expected that the findings of this study will provide the data necessary for hat makers that produce close-fitting headwear.

The combination of digital technology and fashion has enabled the commercialization of virtual shopping and virtual fitting services (Bae, 2016; Park et al., 2014). The 3D head model and digitalized hat pattern developed in this study are expected to provide the basic data necessary for virtual shopping and virtual fitting services. By using the standard head model and pattern developed by this study, it is possible to virtually check the products in a state closely resembling the real product without going through the actual production process, thereby reducing the production costs for hat makers.

Conclusion

Because active seniors are considerably interested in health and outside activities, such as trips, sports, and leisure, related services and products are being actively launched. Among them, there is a growing demand for close-fitting hats that can protect the heads of elderly people and wearable smart headwear. For the design and production of such products, it is important to obtain accurate head geometry information for elderly people. In this study, we developed prototype hat patterns for elderly women that can be used for various purposes in an aging society.

Because this study was conducted on elderly women in South Korea, careful consideration is required in the interpretation and application of the results obtained in this study. If further research can be conducted on a larger number of samples for target groups with various classifications, it will contribute to improving the fit of headwear products with close fit to the head and also provide basic data to related industries requiring head-related information such as medicine, beauty, and marketing.

Despite remarkable advancements in 3D scanning technology, there are still challenges to be tackled. One of them is processing areas where holes are made because they cannot be scanned, such as areas between fingers, armpits, groin areas, and the crown of the head. In addition, problems such as measurement errors caused by the volume of the hair when scanning the head area should be addressed. If unresolved, owing to the volume of the hair, the 3D measurement value can become larger than the manual measurement value. In future studies, further investigation is required on how factors related to the volume of hair affect the design of hats.

Abbreviations
ISO: International Organization for Standardization; 3D: Three-dimensional; 2D: Two-dimensional; MTM: Made-to-measure.

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Authors' contributions
KC designed of the work and interpreted the data. JJ, YR and SP obtained and analyzed the data and have drafted the work. All authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Instructor, Department of Fashion Design, Dong-Seoul University, 76, Bokjeong-ro, Sujeong-gu, Seongnam-si, Gyeonggi-do 13117, Republic of Korea. [2]Instructor, Department of Fashion Design, Dong-Seoul University, 76, Bokjeong-ro, Sujeong-gu, Seongnam-si, Gyeonggi-do 13117, Republic of Korea. [3]Professor, Department of Fashion Design, Dong-Seoul University, 76, Bokjeong-ro, Sujeong-gu, Seongnam-si, Gyeonggi-do 13117, Republic of Korea. [4]Associate Professor, Department of Fashion Design, Konkuk University, 322 Danwol-dong, Chungju-si 27478, Republic of Korea.

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