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Skincare Device Product Design Based on Factor Analysis of Korean Anthropometric Data

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Abstract: The "beauty device" market, which enables simple skincare for those with busy lives, is growing steadily as an increasing number of people are trying to take care of their skin at home to save time and money. As opposed to dermatologists and esthetics centers, which require regular visits, the fact that their skin can be easily managed in leisure hours at home attracts consumers who value convenience. Thus, various beauty-care devices that use light-emitting diodes (LEDs) have been launched. However, in the case of skincare devices using LEDs, pressure is expected to be applied to one's face. Therefore, there is a need to develop a design based on ergonomic measurements that can distribute the pressure evenly on the skin. This study analyzed data to create a design for certain skincare devices that can be worn as glasses, using a three-dimensional human-measurement database of South Korean women between 30 and 49 y, as they are the major consumers of such devices. Additionally, a product design was proposed after a review of preference surveys from consumer focus group interviews and through an analysis of the direction of the light beams from the source using three-dimensional scanning data.

Keywords: skincare device; product design; ergonomic design

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1. Introduction

According to an analysis of the global home-use beauty devices market conducted by an international research firm, Prescient & Strategic Intelligence, in 2021, it was forecast that the market would grow from $9,571.6 million in 2020 to $89,535.1 million by 2030, for a compound annual growth rate of 25.5%. As people's incomes increase and women's socioeconomic participation grows, the demand for home beauty devices is rapidly increasing worldwide [1]. Factors such as an elevated awareness of appearance, heightened perception of beauty devices, the prevalence of skin diseases, and the surging elderly population have also increased the market demand. Furthermore, with the outbreak of the COVID-19 pandemic and its prolonged presence, the market for these products is booming as an increasing number of consumers prefer the easy and convenient management of their skin through home beauty devices instead of visiting skincare centers or dermatologists. Owing to these changes, the types of beauty products that were once limited to light-emitting diode (LED) masks and cleansing devices have gradually diversified, and customized beauty devices are creating an oversupply in the market. By virtue of this trend, companies such as LG Electronics, Cellreturn, Cuckoo Homesys, and Kyowon Wells have begun to infiltrate the LED mask market [2–4]. However, no sizable difference can be found in the patterns of wear and usage. According to the results of consumer focus group interviews

(FGIs) conducted to analyze LED-mask usage behavior and needs, strong demand was observed for products that could be easily stored and that could allow the pursuit of everyday activities, such as cleaning and watching TV, during consumers' skincare routines. [5].

Several previous studies investigated consumers' usage behavior and satisfaction levels using skincare devices; however, these studies had limitations in that recently emerging personal beauty devices were not considered. Further, it is difficult to find studies in which precise head data were utilized in the analysis of ergonomic LED-mask product design. Human-measurement data of men aged between 20 and 39 y were utilized in the study "Spectacle Frame Size System Development for Smart Glass Design" [6], but it is difficult to apply these outcomes to women, who are the primary users of skincare devices.

In this study, an LED mask in the form of smart glasses was formulated as a design concept to meet consumers' needs. Considering the morphological characteristics of these products, this study applied the size components of eyeglass frames to the product design. For this purpose, the human body dimensions of women aged between 30 and 49 y were statistically analyzed to design the glasses frames.

Furthermore, this study conducted simulations based on 3D facial scan data to enable the efficient application of each beaming angle of LED light sources. The draft design was modified to reflect consumer surveys to obtain the final product design.

Research Background

A consumer analysis comprising focus group interviews conducted by the authors identified that a product concept that enables simple daily activities, such as watching television while wearing an LED mask, was adequately persuasive. To design such eyeglass-type wearable products, research was conducted on the size of the glasses frames. Choi [6] proposed a glasses-frame size system for men using the width between the eyebrow ridge and tragus, the width between the earlobes, and the width between the inner corners of the eyes. As data regarding a male human body were utilized for this design, it is feasible to design products suitable for men from the perspectives of design and size; however, it must be noted that these data are not suitable for designing similar products for women, the primary users of LED masks [6,7].

2. Materials and Methods

2.1. Research Targets

To develop an LED-mask design, the 3D head measurement data of adult women between 30 and 49 y collected by the sixth "Size Korea" project [8,9] were used for analysis (399 women in total). Size Korea provides 45 items related to head measurements. Among these items, eight items relevant to glasses or smart glasses, and highly relevant when designing foldable LED masks, were selected as analysis targets, as shown in Figure 1. The definitions of the items are given in Table 1 [8].

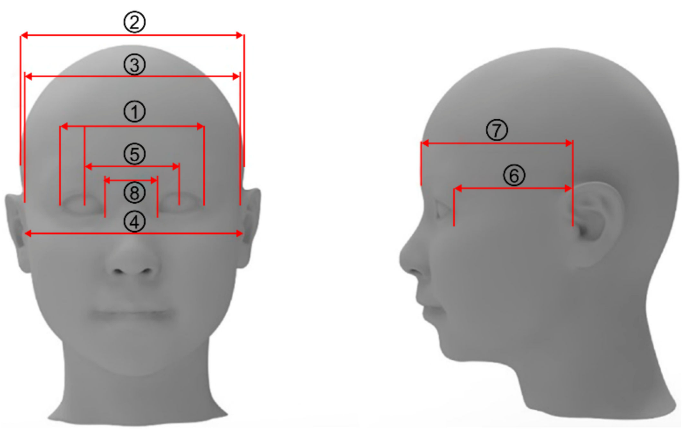


Figure 1. 3D head measurement items.

Table 1. Definitions of representative items from Figure 1.

No.	Item	Definition
1	Width between lateral canthi	Horizontal distance between outer canthi
2	Head width	Horizontal distance between the dots next to the head
3	Width between earlobes	Horizontal distance between the root points on both ear lobes
4	Width between tragi	Horizontal distance between the two tragi
5	Width between pupils	Horizontal distance between the pupil centers
6	Width between lateral canthus and tragus	Horizontal distance from outer canthus point to tragus point
7	Width between eyebrow ridge and tragus	Horizontal distance from the middle of forehead to the tragus point
8	Width between medial canthi	Horizontal distance between inner corner of the eyes

2.2. Data Analysis

Factor analysis was conducted to summarize human body dimensions related to the frame design of the eyeglass-type wearable LED mask. The factor analysis was used to analyze the principal components; three factors were selected, and the component matrix was orthogonally rotated using the varimax method. Among them, the representative items for size—width between earflaps, width between eyebrow ridge and tragus, and width between medial canthi—most closely related to mask designs were selected, and a size section was formulated using the mean and standard deviation, after which the most frequent proportions were extracted through cross-analysis and used for the design [9,10]. SPSS 26.0 software was used for data analysis.

3. Results

3.1. Extraction of Representative Dimension Items for Frame Size Development

The elements that form the frame of the glasses-type LED masks were identified to be frame length, bridge width (distance between lenses), and temple length of the glasses frame, with reference to the smart glasses design guidelines by the Korean Agency for Technology and Standards (KATS) [8]. Women aged 30 to 49 y were selected as the primary target customers, and representative dimension items were extracted through an analysis of factors obtained from the data of Size Korea to summarize the human body-dimension items corresponding to the design elements of each frame.

According to Choi [6], the width between earlobes, between eyebrow ridge and tragus, and between the inner corners of the eyes should be used to design glasses frames. In Tang et al. [11], eye width was used in the design of the front and bridge of the glasses frames.

In this study, the width of the earlobes, which determines the total width of the frame, was considered the front factor; the width between the eyebrow ridge and tragus, which determines the size of the temple length, was considered to be the temple measurement; and the width between medial canthi was considered the bridge factor. The eyehole of the mask was considered to be the representative dimension item (see Table 2).

Table 2. Results of factor analysis of the human body measurement items related to the glass frame.

Factor	Measurement Item	Component 1	Component 2	Component 3	Eigenvalue	Explanatory Power (%)
Front	Width between lateral canthi	0.797	−0.064	0.325	3.257	40.707
	Head width	−0.351	0.255	0.593		
	Width between earlobes	0.912	−0.036	0.784		
	Width between tragi	0.352	0.147	0.799		
	Width between pupils	0.474	0.038	0.195		
Temple	Width between lateral canthus and tragus	−0.012	0.934	0.113	1.835	22.939
	Width between eyebrow ridge and tragus	0.182	0.954	0.116		
Bridge	Width between medial canthi	−0.037	0.245	0.734	1.130	14.122

Extraction Method: PCA (Principal components analysis) with varimax rotation

3.2. Setting the Size of Sections

The size of sections was calculated using the average and standard deviation of the width between earlobes, between eyebrow ridge and tragus, and between medial canthi, which were selected as representative dimensions. The center section size was calculated using average ± standard deviation (SD), and the other section sizes were calculated using twice the standard deviation intervals from the center. The width between the medial canthi was denoted as EC, between eyebrow ridge and tragus as EE, and between earlobes as EW. Please see Tables 3 and 4 for the calculation of the sizes.

Table 3. Average and standard deviation of representative dimension items (mm).

	Average	Standard Deviation	Min. Value	Max. Value	N
EW	157.2231	7.82458	137.00	182.00	399
EE	88.5188	7.80922	61.00	127.00	399
EC	31.4311	3.41290	23.00	40.00	399

EW: Width between earlobes, EE: Width between eyebrow ridge and tragus, EC: Width between the medial canthi.

Table 4. Size of sections based on representative dimensions (mm).

	EE			EW			EC	
	72.9	<80.7		142	<149.38		24.6	<28
80.7≤	88.5	<96.3	149.38≤	157.2	<165.02	28≤	31.4	<34.8
96.3≤	104.1	<111.9	165.02≤	172.8	<180.66	34.8≤	38.2	<41.6
111.9≤	119.7		180.66≤	188		41.6≤	45	

EW: Width between earlobes, EE: Width between eyebrow ridge and tragus, EC: Width between the medial canthi.

3.3. Derivation of High-Frequency Proportion Range According to Cross-Analysis

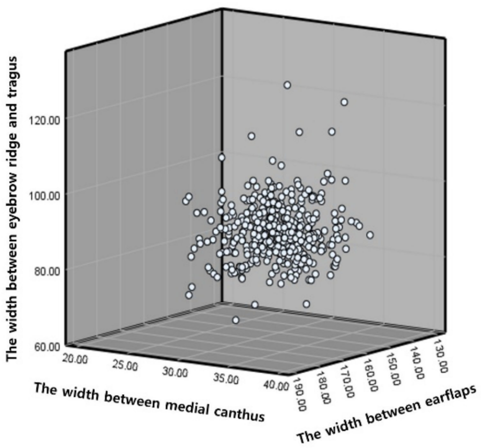
A cross-analysis was conducted by dividing the size section of each dimension. In accordance with previous studies conducted by KATS [9] and Choi [5], six-size sections, distributed as more than 5% of the total 399 subjects, were selected as high-frequency proportion sections (see Table 5 below) [11,12].

Table 5. Cross-analysis results of the representative dimensions of sections (%).

EC	EE	EW				Total
		142	157.2	172.8	188	
24.6	72.90	0.26	3.12	0.26	-	3.64
	88.50	4.42	8.83	1.30	-	14.55
	104.10	-	0.52	0.25	-	0.77
31.4	72.90	2.08	4.42	1.30	-	7.79
	88.50	9.61	30.13	6.49	-	46.23
	104.10	1.04	6.23	1.30	-	8.57
	119.70	-	-	0.26	-	0.26
38.2	72.90	0.26	0.52	-	-	0.78
	88.50	0.26	9.61	4.42	0.26	14.55
	104.10	0.25	1.30	0.78	-	2.33
	119.70	-	-	0.52	-	0.52
Total		18.18	64.68	16.88	0.26	100.00

EW: Width between earlobes, EE: Width between eyebrow ridge and tragus, EC: Width between the medial canthi.

The proportion coverage of the six size-sections selected through the cross-analysis reached 70.9%. High-frequency proportions were derived as 31.4 mm between medial canthi, 157.2 mm between earlobes, and 88.5 mm between eyebrow ridge and tragus (Figure 2). The reference dimensions for designing LED-mask products were hence calculated using the extracted human head dimensions. Based on the calculated size, the first product design concept was developed as seen in Figure 3.



High frequency section (mm)	Frequency(%)
24.6 – 88.5 – 157.2	8.83
31.4 – 88.5 – 142	9.61
31.4 – 88.5 – 157.2	30.13
31.4 – 88.5 – 172.8	6.49
31.4 – 104.1 – 157.2	6.23
38.2 – 88.5 – 157.2	9.61
Total	70.9

Size range: EC-EE-EW

Figure 2. Distribution of sizes with high frequencies.

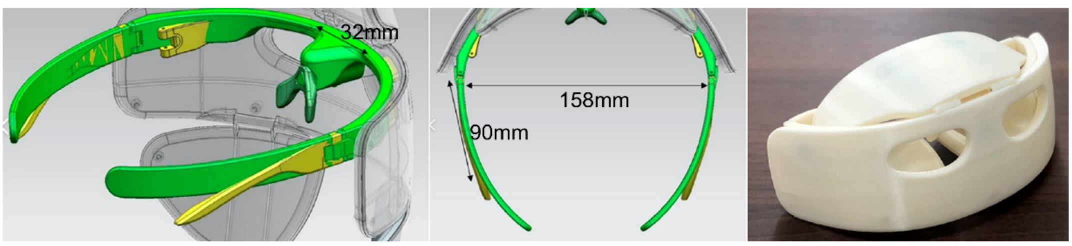


Figure 3. First LED-mask design concept.

3.4. 2D and 3D Positioning of the Main Stimulation Points of LED Light Sources

In addition to designing the appearance of the product using human body dimensions, a study was conducted on the main wrinkles of the face to define the arrangement of LED light sources used to irradiate the face. The positions of the muscles that permit facial expressions based upon face wrinkle location, face muscle anatomy data, and so forth, were marked on 2D faces, as shown in Figure 4 [13–16].

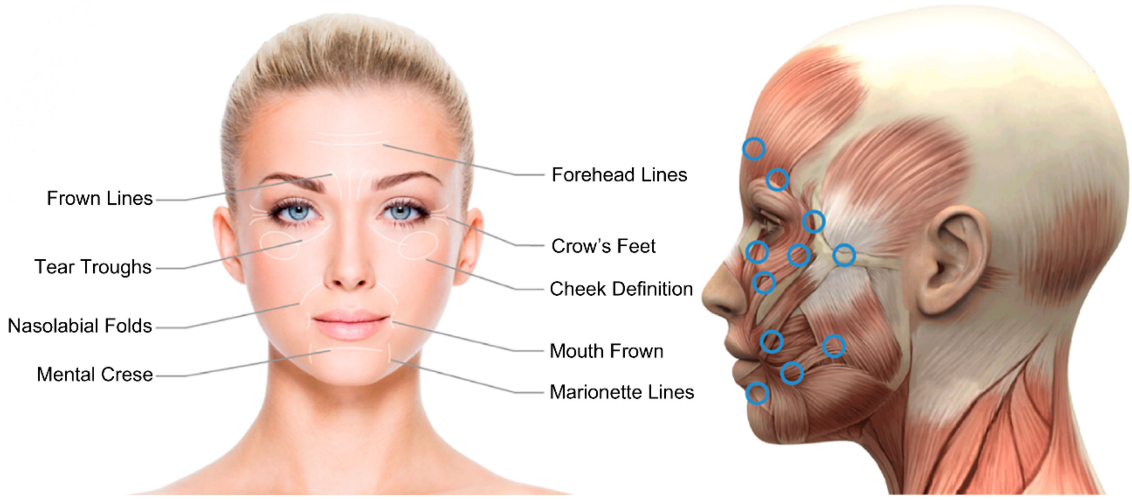


Figure 4. Skin stimulation point positioning (source: https://skincaredenver.com/ (accessed on 25 May 2021)) [17].

Based on the range assumed by the authors to be sufficient to irradiate the face, grouping was performed on a total of 24 areas of the face, with two sections of the forehead, six sections of the cheeks (the area from the chin to the crown of the head in vertical view and from the nose to the ear in horizontal view), and four sections of the jaw for each side of the face (Figure 4). The light sources were placed to cover the main location with a minimum number of LEDs by designating the appropriate beaming range. It was anticipated that cost reduction and skincare effects would be maximized only when the LED light sources were centered around the main facial stimulation points (as seen in Figures 5 and 6) [9,18–20].

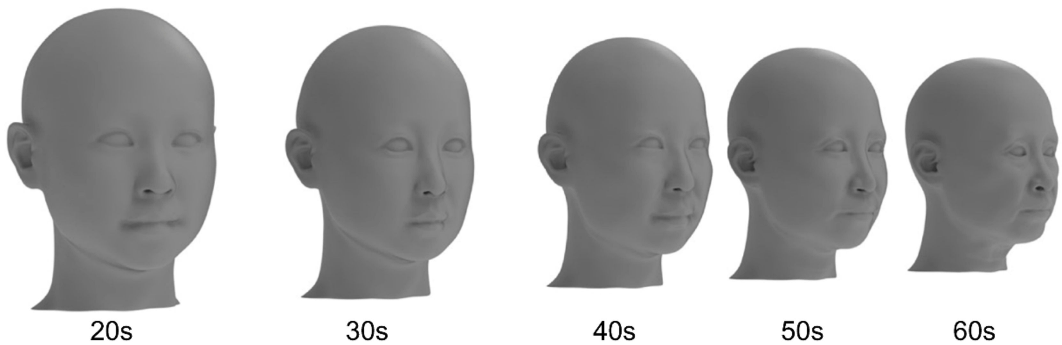


Figure 5. Women's head 3D data by age group.

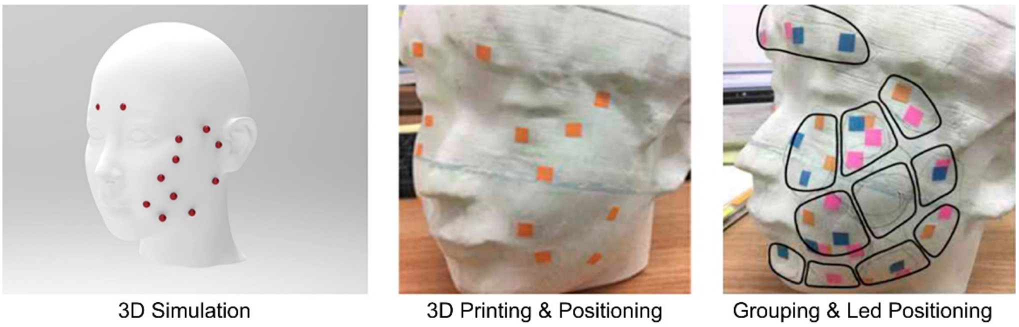


Figure 6. LED lighting module positioning.

LED modules were positioned as shown in Figure 7, based on actual 3D scan data using Korean women's standard 3D head data [9], a 3D scanner (3D Systems, SENSE), and 3D design simulations using 3D design tools. Each module output was set as wide as possible to ensure that light irradiation was evenly distributed over the entire face [19].

Figure 7. LED positioning-based LED mask basic design.

To reduce the discomfort caused by moisture generated by the nose and mouth, which was found to have occurred during the use of existing products, this product was designed to increase the sense of openness around the nose and the mouth (Figure 8) [21]. A design concept for easy storage was applied through manufacturing the forehead and cheek portions in a structure that could be folded inward. After protecting the eyes by ensuring that the LED light source would not be directed to them, the consumer response was investigated; a barrier film was also applied inside.

Figure 8. Second LED-mask design concept.

3.5. Consumer Focus Group Interviews

A consumer FGI survey was conducted in collaboration with Embrain, a market research company, for the mask products designed based on prototype design data [5,22]. The FGI was conducted according to prepared guidelines, considering the proportion of working women and full-time homemakers aged 25 to 54 y (32 people in total) and living in Seoul and the surrounding metropolitan areas, who were interested in skincare. Working women and fulltime homemakers in a ratio of 1:1 were surveyed regarding using and purchasing LED masks. Age was also considered in the group classification. The mask design of the second concept had the advantage of allowing consumers to perform simple daily chores during their skin care routine by adding a barrier against the LED light; however, it was found to be burdensome because it was reminiscent of sports goggles or smart glasses, rather than a skincare device. In addition, the inability to apply skincare on the nasal portion raised the issue of coverage (Figure 9).

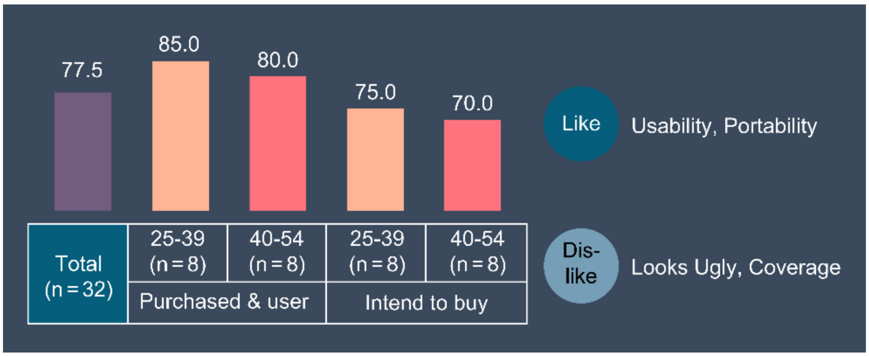


Figure 9. Consumer evaluation of a foldable LED-mask concept.

For storage convenience, a folding design was adopted, but consumer preference was judged to be lower for such a complex structure. Accordingly, the eye-care device was designed as a module that could be easily attached by magnet and used concurrently with the facial care module. Additionally, the design was revised for nose care (see Figure 10).

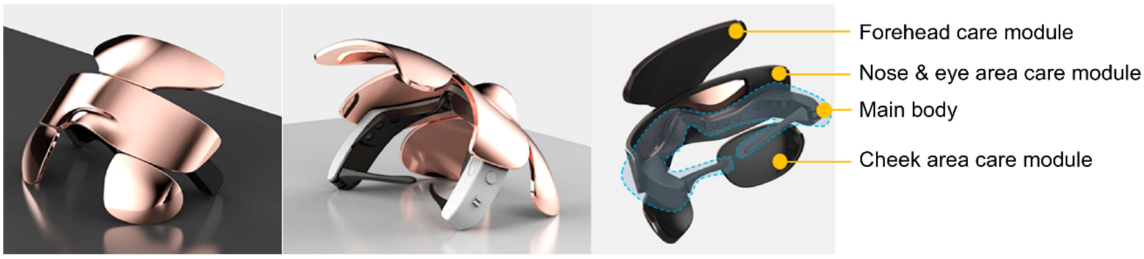


Figure 10. Final design concept.

4. Conclusions

To derive human body dimensions related to the design of a glasses-based LED mask, a total of three factors were extracted based on factor analysis and existing studies. Among the human-measurement data, three factors were selected as representative measurements, namely, the width between the inner corners of the eyes, the width between the earlobes, and the horizontal distance between the eye and ear. Three measurement sizes were categorized using means and standard deviations, and through crosstabulation of these size distributions, six size categories with a frequency of 5% or greater in the sample were derived. These sizes covered 70.9% of the population, with the representative sizes being 31.4 mm between medial canthi, 88.5 mm between eyebrow ridge and tragus, and 157.2 mm between earlobes. These human body-dimension data were used in the design of glasses-type wearable LED-mask products. In addition, the efficient placement of LED light sources was simulated and applied to the design using 3D scan data, and the design refinement process was conducted using FGI.

As the human body-dimension data used in this study were based upon the head measurements of South Korean adult women, it is anticipated that more diverse human-measurement data are needed for product development in the global market. Furthermore, consumer surveys from diverse cultures and geographic regions must be conducted to enhance product competitiveness in the global market.

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