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DESIGNING THE SHAPE OF A NOSE CLIP FOR A HALF-FACE MASK USING 3D ANTHROPOMETRIC FACE ANALYSIS

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This study designed the shape of a nose clip for a half-face mask by considering 3D facial contours. 3D facial scan data for 60 participants (mean age = 23.8 ± 2.0 years old) were collected. Three facial shapes were identified in a cluster analysis based on the facial dimensions: small (3.3%), medium (88.3%), and large (8.3%). The medium group, with the largest accommodation, was selected as the shape of the nose clip. Next, a virtual fitting test for a digital prototype with the nose clip shape was conducted to evaluate to the match with participants' facial contours. Lastly, a half-face mask with the novel nose clip was compared to a half-face mask without the nose clip in terms of subjective satisfaction and humidity level caused by air leaking. The half-face mask with the nose clip achieved better performance for both subjective satisfaction (4.9 out of 7) and humidity level (9.4%).

Keywords: Half-Face Mask, Nose Clip, Anthropometric Facial Analysis, Fit and Comfort, Mass Customization

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1. INTRODUCTION

The fit and comfort of a face mask have been considered to be critical factors in the design of the mask (Lee *et al.*, 2018; Cai *et al.*, 2016; Chu *et al.*, 2015; Lei *et al.*, 2014) since individual facial shapes and sizes vary (Zhuang *et al.*, 2010; Yokota *et al.*, 2005; Kim *et al.*, 2003). People wear masks to cover or protect their noses and mouths from dust, contaminants, pathogenic bacteria, or cold weather. However, a mask that does not fit properly may degrade the user experience (Tjolleng *et al.*, 2020; Han and Kim, 2014; Lee *et al.*, 2013; Dai *et al.*, 2011). For instance, masks that fit too tightly may induce excessive pressure on the nose, chin, or around the lips, which detracts from the user experience; in contrast, masks that fit loosely could cause air leakage, which sometimes interferes with bespectacled users' vision due to foggy glasses. For these reasons, designing a well-fitted mask is warranted for improving usability and user experience.

Existing studies have developed sizing systems or new designs for multiple-size products (e.g., clothes, helmets) using face anthropometric data measured by three-dimensional (3D) scanning technology (Purnomo and Kurnia, 2021; Tjolleng and Jung, 2020; Fu and Luximon, 2019). 3D anthropometric face analyses have often been conducted to improve the sizing system of a mask. Han and Kim (2014) designed a half-face mask using 10 facial dimensions, including face length and lip length, from 3D anthropometric face data. They reported that their new mask showed better performance than an existing mask on the market of quantitative fit tests (QNFT). Next, Chu *et al.* (2015) proposed a new design for a respiratory mask with 3D anthropometric face data, and the mask obtained a higher geometric similarity to users' faces compared to masks on

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the market. Lastly, Lee *et al.* (2018) introduced a new design for an oxygen mask for Air Force pilots based on their 3D anthropometric face data. They reported that its user discomfort levels, facial contact pressures, and slip distance on the face were improved by 33%-56%, 11%-33%, and 24%, respectively, compared with the existing oxygen masks being supplied in the Air Force.

Although the studies above have proposed mask designs, a nose clip for a half-face mask needs to be developed using 3D anthropometric face data. A half-face mask is cost-effective in protecting respiratory systems at a reasonable price. However, it has a usability problem that causes eyeglasses to fog due to breath escaping between the nose area and mask. A nose clip softly pinching the nose can efficiently resolve this usability issue. To design the nose clip, 3D anthropometric data of the face and nose should be considered to provide a proper fit for the face shape. However, few previous studies have designed nose clips using 3D anthropometry.

The present study aims to develop a novel nose clip of a protective half-face mask for young people (design target population) by considering 3D facial anthropometry. Two research hypotheses were tested: (1) the nose clip can significantly affect the humidity level in the air leaked from the top portion of the mask; (2) the nose clip can significantly affect user satisfaction. Sixty participants in their 20s were recruited considering of the design target population, and their face shapes were scanned in 3D. Facial dimensions for determining the shape and size of the nose clip were selected and quantified in terms of heights (nose height, eye center height, and outer eye height) and widths (nose width, eye center width, and outer eye width). A virtual fitting test was performed, and the digital prototype of the nose clip was validated in fitting to the participants' facial 3D scans. Lastly, a usability test was conducted to evaluate the half-face masks with/without the nose clip in terms of user satisfaction and breath-leaking.

2. MEASUREMENT OF 3D FACIAL SHAPES

2.1 Method and Materials

2.1.1 Participants

A total of 60 college students (30 males and 30 females) were recruited to scan facial shapes in 3D; the sample sizes were determined by considering three head dimensions (head length, width, and circumference) for each gender, based on Equation 1 (the sample size formula [ISO, 2006; Lee *et al.*, 2013]) with a confidence level (1-α) of 95% and precision level (k) of 3%. Their average age was 24 years old (SD = 1.95, range = 20 ~ 28 years old). In addition, the average ages for male and female participants were 24 years old (SD = 1.4, range = 21 ~ 28) and 22 years old (SD = 2.0, range = 20 ~ 28), respectively. All participants were given a description of the study objective and procedure, and they agreed to join in the experiments with an informed consent form. They were compensated for participation in the present study.

$$n = (1.96 \times \frac{CV}{k})^2 \times 1.534^2 , \tag{1}$$

where
CV = coefficient of variation,
k = precision level.

2.1.2 Equipment

A structured, light-based Artec Eva 3D scanner (Model EV.30.88255035, Artec 3D Co., Luxembourg) was employed to capture the 3D facial shapes of the participants. A desktop computer (Model 32MB25HM, LG Inc., South Korea) was connected to the scanner by a USB cable to obtain the scanning results. Artec 3D Studio 12 scanning software (Artec 3D Co.) was used to process and analyze the scanned facial data.

2.1.3 Measurement Procedure

The overall process consisting of two phases (face-scanning phase (section 2.1.3) and face shape analysis phase (section 2.1.4)) to define the representative contact lines for the nose clip using 3D facial shapes was illustrated in a flowchart as shown in Figure 1. Three-dimensional scanning of the face-scanning phase was conducted according to the following three steps. In the first step, the study objective and scanning procedure were explained to the participants, and their informed consent was obtained. In the second step, each participant was instructed on how to wear a given half-face mask (disposable nonwoven mask) properly, and three contact points between the face and the top portion of the mask were manually selected as landmarks with circular stickers (diameter = 5 mm), as shown in Figure 2. The points selected were points of contact between the face and mask, specifically (1) the points vertically aligned with the lateral ends of the eyes and (2) making contact with the mid-nasal point. In the third step, 3D scanning was conducted. The participants were instructed to sit on chairs and allowed to adjust their seat heights (range = 40.2 ~ 50.5 cm). They were asked to naturally stay in a static posture as possible as they can during the face-scanning process (approximately 30 ~ 45 seconds; Figure 3) to reduce unnecessary movements and spasms (Artec 3D, 2022; Yang *et al.*, 2020; Lee *et al.*, 2013). If there were significant distortions (e.g., irregularity of scanned surface and distorted shape of circular stickers attached to the face) due to unnecessary movements and spasms, the scanning process was repeated. The face scanning was done at a distance of 40 ~ 100 cm from the participant's face and was conducted both with and without the given mask. The 3D scanned facial data were automatically stored for further processing.

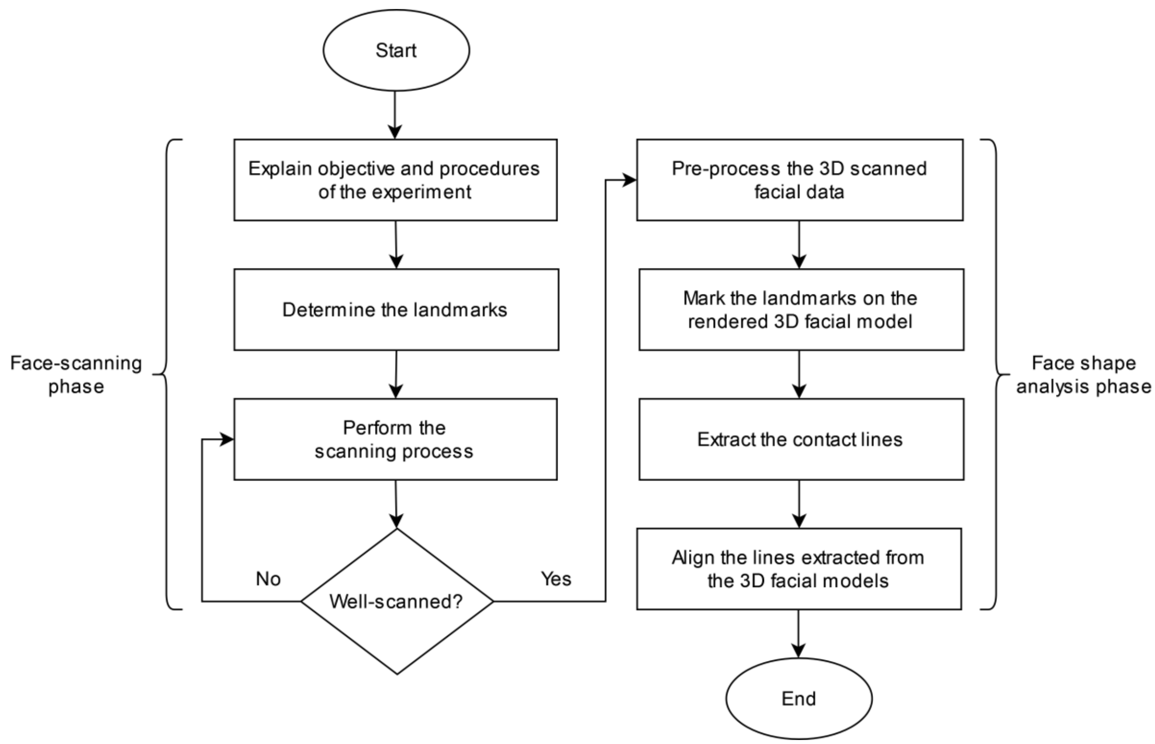

Figure 1. A flowchart of the 3D scanning and analysis process to determine the contact line for the nose clip

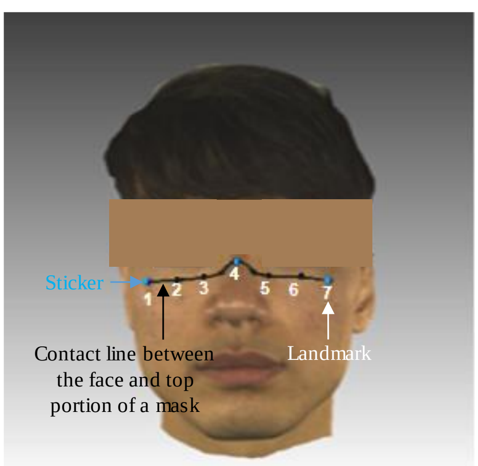

Figure 2. Illustration of the markers (sky blue), contact line (black), and landmarks (white) on the face

Figure 3. Illustration of the 3D scanning process for a participant

2.1.4 Analysis Method

The 3D-scanned facial data of all the participants were analyzed in four steps in order to configure the contact lines between the faces and the top portion of the masks. In the first step, the 3D scanned facial data without a mask were individually imported to the Artec 3D Studio 12 space and were reconstructed with merging, editing, refinement, hole-filling, and smoothing functions, and their reconstructed 3D facial models were completed using the method addressed in the previous study (Lee *et al.*, 2013). In the second step, the three landmarks (point numbers 1, 4, and 7) were marked over the three stickers on the rendered 3D facial models, as shown in Figure 2. In the third step, the contact lines between the faces and the top portion of the masks (from the 3D scanned face data with masks) were extracted on the three landmarks and four points, including eye centers and dorsal bases (points numbered 2 and 6, and points numbered 3 and 5, respectively, in Figure 2) were manually added on the extracted line for defining facial dimensions and contouring the shapes of the top portion of the masks. In the last step, all the lines extracted from the 3D facial models were aligned using a custom script coded in Matlab (MathWorks, Inc., Natick, MA, USA) before computing their descriptive statistics. The mid-nasal points (point number 4) were translated to the origin of a coordinate system, as illustrated in Figure 4. In addition, the lines were rotated to minimize the mean squared errors of their end points using Equation 2. In the second step, the aligned lines were represented quantitatively in terms of vertical and horizontal distances. The vertical distances were described with three height dimensions: (1) nose height = vertical distance between points number 4 and 3 (or 5); (2) eye center height = vertical distance from points number 4 to 2 (or 6); and (3) outer eye height = vertical distance from points number 2 to 1 (or 7). In addition, horizontal distances were addressed with three width dimensions: (1) nose width = horizontal distance between the dorsal bases (points number 3 and 5); (2) eye center width = horizontal distance between the eye center levels (points number 2 and 6); and (3) outer eye width = horizontal distance between the lateral ends of the eyes (points number 1 and 7). Table 1 summarizes the descriptive statistics of the height and width dimensions of the face shape considered in this study.

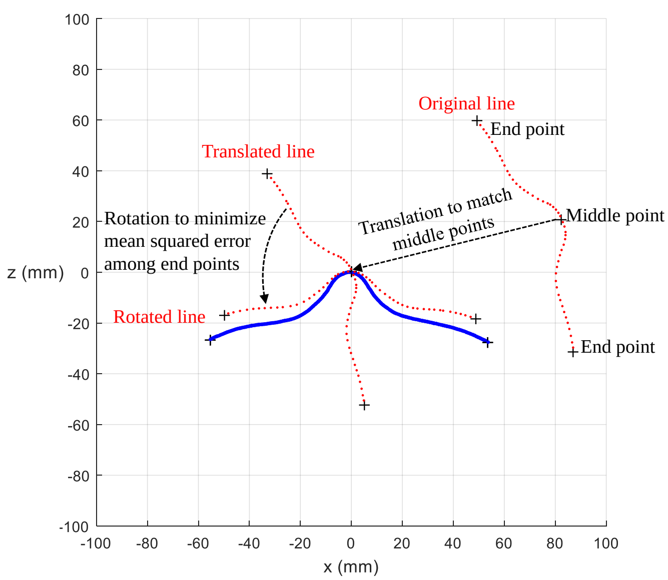

Figure 4. Contact line alignment process

$$\min_{xyz} \sum_{i=2}^{n} \sum_{j=1}^{2} (p_{ij} R_{xyz} - p_{1j})^2, \quad (2)$$

where n = total number of participants,
i = participant number,
j = end point number of a line (1: left end point, 2: right end point),
p_{ij} = coordinate of end point j of line i,
R_{xyz} = rotation matrix with x, y, and z rotation angles.

Table 1. Descriptive statistics of the anthropometric dimensions of face shape (n = 60, unit: mm)

Anthropometric dimensions		Male (n = 30)				Female (n = 30)			
		Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Height	**Nose**	10.5	2.8	3.8	16.1	9.3	2.5	3.9	15.1
	Eye center	18.3	2.8	13.0	24.4	15.5	2.8	10.9	24.4
	Outer eye	23.2	3.7	15.4	30.7	19.9	3.4	13.9	29.1
Width	**Nose**	26.0	4.8	15.0	36.2	26.0	4.1	16.7	34.7
	Eye center	72.0	3.5	64.9	78.4	69.8	4.7	57.0	77.8
	Outer eye	106.1	4.8	95.5	120.1	103.0	6.3	84.7	114.0

2.2 Determination of Representative Contact Lines

A representative contact line between the faces and masks was determined by hierarchical clustering analysis. The hierarchical clustering analysis, which employed the Euclidean distance as a similarity measure, was conducted in Minitab 17.0 (Minitab Inc., U.S.) to categorize the contact lines into multiple-sized groups. The dendrogram resulting from the clustering analysis (Figure 5) determined three groups: (1) small (green), (2) medium (blue), and (3) large (red), as illustrated in Figure 6. The accommodations for the small, medium, and large size groups were 3.3% (frequency = 2 people out of the 60 participants), 88.3% (53 people), and 8.3% (5 people), respectively. The descriptive statistics for the three multiple-sized groups are summarized in Table 2. In addition, we also provided the three multiple-sized groups across gender, as listed in Table 3.

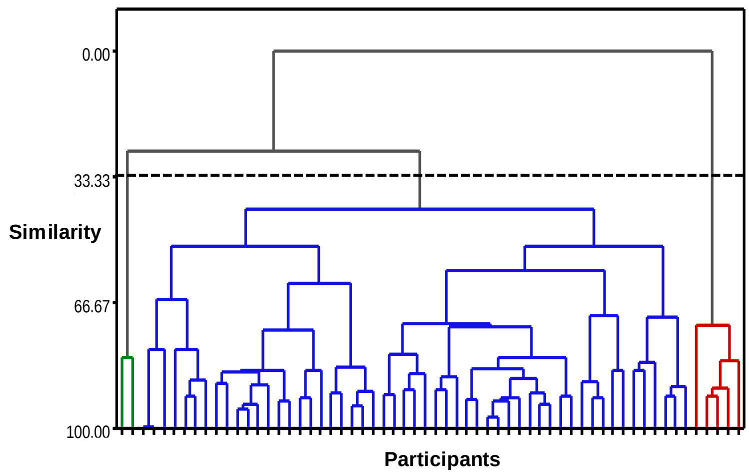

Figure 5. Three size clusters of contact lines resulted from hierarchical clustering analysis

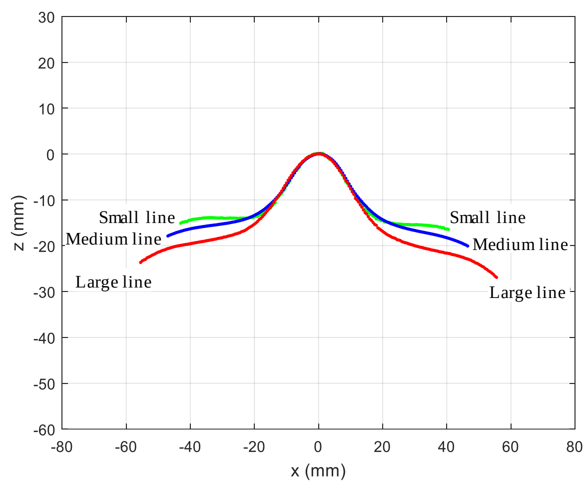

Figure 6. Three size clusters of contact lines between the faces and masks

Table 2. Descriptive statistics of three representative contact lines resulted from hierarchical clustering analysis[a] (n = 60, unit: mm)

Anthropometric dimensions		**Small** (n = 2)	**Medium** (n = 53)	**Large** (n = 5)
Height	**Nose**	9.8 (0.8)	9.6 (2.7)	12.8 (1.3)
	Eye center	14.7 (1.7)	16.6 (3.1)	20.4 (2.0)
	Outer eye	16.6 (1.1)	21.3 (3.7)	26.5 (2.7)
Width	**Nose**	24.8 (0.0)	25.6 (4.3)	30.9 (3.4)
	Eye center	59.0 (2.9)	70.8 (3.3)	77.1 (1.8)
	Outer eye	88.0 (4.7)	104.2 (4.1)	114.5 (3.2)

[a] The values are in mm, and standard deviations are presented in parentheses.

Table 3. Descriptive statistics of three representative contact lines resulted from hierarchical clustering analysis across gender (n = 60, unit: mm)

Anthropometric dimensions		**Male** (n = 30)			**Female** (n = 30)		
		Small (n = 0)	**Medium** (n = 26)	**Large** (n = 4)	**Small** (n = 2)	**Medium** (n = 27)	**Large** (n = 1)
Height	**Nose**	-	10.1 (2.8)	12.7 (1.5)	9.8 (0.8)	9.2 (2.5)	13.2
	Eye center		17.9 (2.8)	20.8 (2.0)	14.7 (1.6)	15.4 (2.8)	18.8
	Outer eye		22.7 (3.5)	26.8 (2.9)	16.6 (1.1)	19.9 (3.4)	25.1
Width	**Nose**		25.4 (4.6)	30.5 (3.7)	24.8 (0.0)	25.8 (4.1)	32.8
	Eye center		71.2 (3.1)	77.0 (1.3)	59.0 (2.9)	70.4 (3.6)	77.8
	Outer eye		104.7 (3.5)	114.7 (3.7)	88.0 (4.7)	103.7 (4.6)	114.0

3. ERGONOMIC DESIGN OF A NOSE CLIP

3.1 Design for Prototyping

The contact line of the medium-sized group with the largest accommodation (88.3%) was selected for final prototyping since this study intends to provide a nose clip for a one-size-fits-all half-face mask. The digital prototyping for a nose clip was conducted in two steps. In the first step, the overall shape and size of the nose clip were determined based on the contact line of the medium-sized group, as shown in Figure 7; exceptionally, the overall length and width were separately adjusted at 80 mm and 15 mm, respectively, in order for the nose clip to attach to the top of the mask. In addition, an empty space (2 mm) was established between the outer and inner frames of the nose clip for easy attachment to a half-face mask. In the second step, the digital prototype of the nose clip was rendered with SolidWorks (SolidWorks Corp., U.S.).

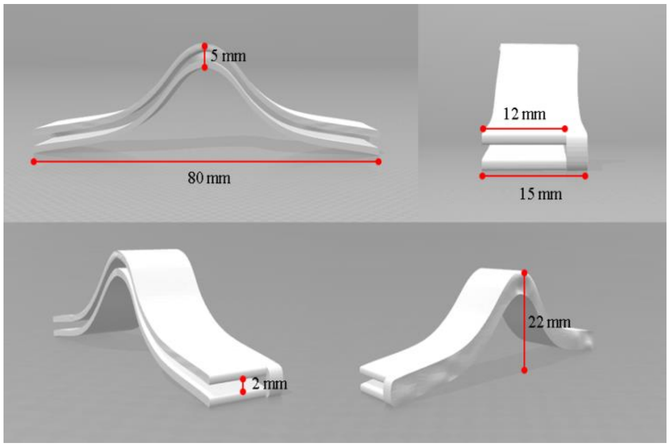

Figure 7. Digital prototyping of a novel nose clip

3.2 Virtual Fitting Test

The digital prototype of the novel nose clip was evaluated to determine how well it fits to the 3D virtual face models rendered in the 3D scanning and post-process phases before physical prototyping. The intensity of the contact pressure between the nose clip and 3D virtual faces, plus the size of the area affected by the contact pressure, were employed as measures to evaluate the fitting performance. Testing was conducted in the following five steps. First, three representative face models corresponding to small, medium, and large clusters were randomly selected from the 3D virtual face models. Second, the digital prototype of the nose clip and the representative face models were imported to Artec 3D Studio 12. Third, the digital prototype was attached to the face models, referring to the representative contact line between the masks and faces that were extracted in Section 2.2. Fourth, the virtual fitting test was conducted with a surface-distance maps tool provided by Artec 3D Studio 12. Finally, the fitting performance was evaluated, and the results were presented as two colors (green = good fitting with approximate zero distance [range = 0.0 mm ~ 0.5 mm]; red = poor fitting [out of the good fitting range]). For example, the green color indicates that the novel nose clip fits the virtual face models well, whereas red indicates an unacceptable fit.

Figure 8. Virtual fitting for three representative face models corresponding to small, medium, and large clusters (green color = good fitting with around zero distance (range = 0.0 mm ~ 0.5 mm), red color = poor fitting (out of good fitting range))

The result of the virtual fitting test showed that the rendered digital prototype, based on the contact line of the medium cluster, was relatively well-fit to the representative face model. Overall, green and light green were widely distributed on the contact area between the nose clip and face model, as illustrated in Figure 8. As expected, however, results featuring insufficient fits were observed with the representative face models that were selected from the small and large clusters. Green and light green were rarely observed in the contact areas between the nose clips and faces. In summary, since the present study pursued the one-size-fits-all nose clip and the medium cluster accommodated approximately 90% of the participants, the digital prototype, based on the contact line of the medium cluster, was confirmed as the final design for its physical prototyping.

4. USABILITY EVALUATION OF THE PHYSICAL PROTOTYPE

4.1 Methods and Materials

4.1.1 Participants

Forty college students were recruited to validate the physical prototype of the novel nose clip in terms of subjective satisfaction scores. The participants consisted of 20 males and 20 females, and their average age was 22.7 years old (SD = 1.93, range = 19~26 years). The participants were healthy and had not reported any discomfort or medical issue on the day of the experiment. In addition, twenty out of forty participants (male: 10, female: 10) were participated to evaluate the physical prototype of the novel nose clip in terms of humidity performance. Their age and range were 21.9 years (SD = 1.87) and 19~26 years, respectively. They agreed with an informed consent form, and their participation was compensated.

4.1.2 Prototype

The physical prototype of the novel nose clip was manufactured from polylactic acid (PLA) with a 3D printer (Model: 3Dison Pro AEP, ROKIT, South Korea), as designed in Section 3.1. Figure 9 shows the physical prototype of the nose clip proposed in this study. The prototype was attached to the top rim of a half-face mask, as shown in Figure 10. The prototype was placed onto the outer surface of the mask to reduce discomfort caused by its rough surface.

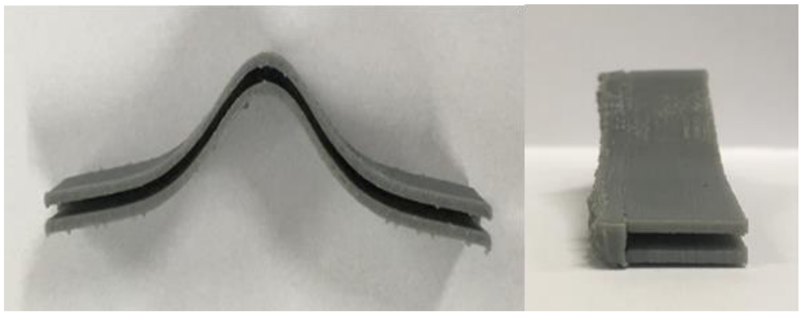

Figure 9. Illustration of the physical prototype of the novel nose clip printed using the 3D printer

Figure 10. Humidity measurement wearing a half-face mask with the novel nose clip

4.1.3 Equipment

The Smart Temp Checker (Technonia Inc., China) was used for measuring the humidity level in the air leaked from a mask. The Smart Temp Checker was plugged into the headphone jack of a smartphone, and humidity was measured approximately 1 cm away from the top rim of the mask, as shown in Figure 10. Humidity data was obtained and displayed by the application software provided by Technonia Inc.

4.1.4 Experimental Design

A one-factor within-subject design was employed for testing. One independent variable was the presence of the nose clip in a given half-face mask (two levels): (1) the mask with the proposed nose clip and (2) the mask without the proposed nose clip. In addition, there are two dependent variables: (1) a difference between the humidity levels in the leaked air before and after wearing the masks (i.e., humidity increment) and (2) subjective satisfaction scores.

The participants were asked to sit comfortably in a chair. Two half-face masks, with and without the novel nose clip, were prepared as aforementioned, and the participants were asked to close their eyes to prevent them from recognizing the type of mask. The participants were instructed to wear masks for two minutes each. The humidity levels (unit: %) were separately measured for about 3 seconds before and after wearing the masks (in the middle of the task). The average values of the humidity increments (%) from before and after wear were computed for the corresponding masks, respectively. In addition, subjective satisfaction was asked of the participants with a 7-point Likert scale (1: very dissatisfied, 4: neutral, and 7: very satisfied). The order of the tasks was fully counterbalanced across the participants to minimize the learning effect. Also, the temperature and humidity of the experimental chamber during the experiments were maintained at approximately 28.3ºC (SD: 1.6) and 41.8% (3.1), respectively. After testing, a short debriefing session was conducted for each participant to (1) explain humidity levels measured for the two masks that might be informative to the participants and (2) ask the participant's subjective opinions regarding the two masks.

4.1.5 Statistical Analysis

A one-factor within-subject analysis of variance (ANOVA) was conducted using Minitab v17.0 (Minitab Inc.) at $\alpha = 0.05$. Statistical differences between the half-face masks with and without the novel nose clip were tested in two dependent variables: subjective satisfaction and humidity level.

4.2 Results

The presence of the nose clip in the half-face masks showed a significant effect on the humidity increments (%) before and after wearing the masks ($F[1, 19] = 64.39$, $p < 0.001$). The humidity increment of the half-face mask with the nose clip (mean ± SD: 9.4 ± 1.5%) was substantially lower than that of the mask without the nose clip (22.0 ± 2.0%), as shown in Figure 11.

The presence of the nose clip in the half-face masks showed a significant effect on subjective satisfaction ($F[1, 39] = 4.22$, $p = 0.047$). The subjective satisfaction score of the half-face mask with the nose clip (4.9 ± 0.2 pt.) was significantly higher than that of the half-face mask without the nose clip (4.4 ± 0.2 pt.), as shown in Figure 12. The participants were slightly more satisfied with wearing the mask with the nose clip than with wearing the mask without the nose clip. Note that they expressed neutrality while wearing the mask without the nose clip.

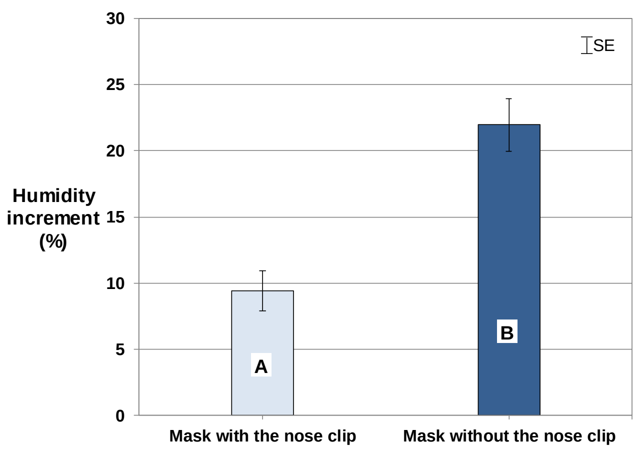

Figure 11. Humidity increment of half-face masks with and without the nose clip

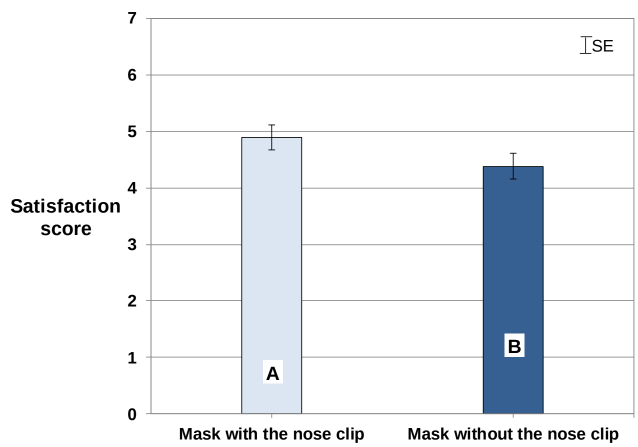

Figure 12. Subjective satisfaction scores of half-face masks with and without the nose clip

The usability test in terms of humidity increment of the half-mask with and without the nose clip is summarized in Table 4. In addition, Figure 13 shows the usability test results in subjective satisfaction for the half-mask with and without the nose clip.

Table 4. The percent of humidity increment for the half-masks with and without the nose clip ($n = 20$)

No.	Humidity increment (%)	
	Mask with the nose clip	Mask without the nose clip
1	8.6	21.5
2	8.6	38.4
3	10.1	20.4
4	9.2	27.0
5	7.7	18.4

No.	Humidity increment (%)	
	Mask with the nose clip	Mask without the nose clip
6	9.9	37.8
7	7.1	14.1
8	20.6	28.5
9	5.4	18.7
10	5.4	19.8
11	1.3	15.9
12	5.4	8.7
13	2.7	20.6
14	6.1	17.9
15	4.7	10.5
16	3.6	14.4
17	6.5	15.2
18	24.2	31.9
19	23.1	38.0
20	18.6	21.7

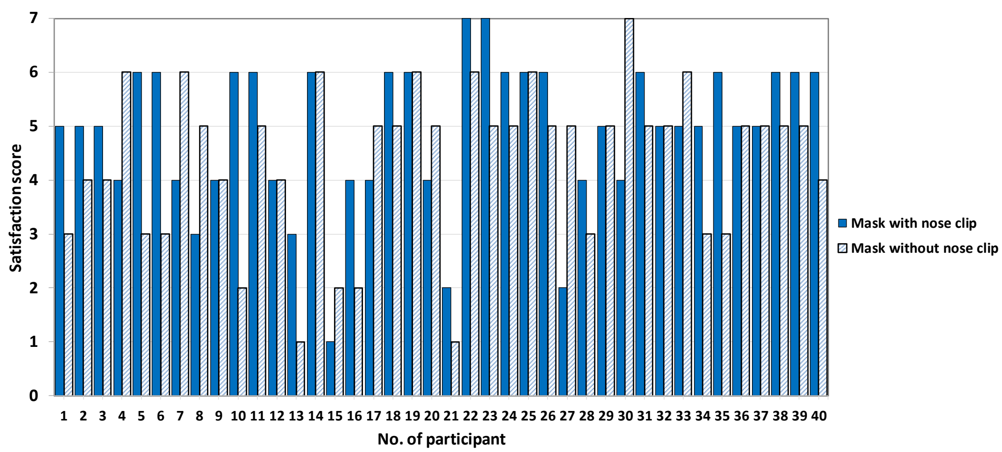

Figure 13. Subjective satisfaction scores for the half-face masks with and without the nose clip (n = 40)

5. DISCUSSION

The present study investigated the effects of a novel nose clip that was designed using 3D facial anthropometric data. To apply actual face shapes to the design of the nose clip, a representative contact line between the face and the top portion of a half-face mask was contoured with the 3D facial anthropometric data of 60 participants, and it was registered in the design process of the novel nose clip. In addition, the size of the nose clip for a one-size-fits-all mask was determined by hierarchical clustering analysis, and its accommodation was improved by up to about 90%. Consequently, the half-face mask with the novel nose clip showed significantly better performance in the virtual fitting and usability tests conducted in the present study. In particular, while wearing the mask with the nose clip, the humidity decreased, and user satisfaction increased compared to wearing the mask without the nose clip.

The design of the novel nose clip was based on the medium-sized group identified in the hierarchical clustering analysis because the medium group showed the largest accommodation (approximately 90%) in the clustering analysis. As expected, the virtual fitting testing showed that its digital prototype was well-fit with the representative face randomly selected from the medium-sized group, but a relatively poor fit was found between the digital prototype and representative faces from the small and large-sized groups. This was because the medium-sized group could not accommodate people with extreme sizes despite its large accommodation. Previous studies advised that one-size-fits-all or design-for-the-average concepts are efficient and competitive design strategies, but simultaneously, they can result in poor fitting problems, which may lead to discomfort or dissatisfaction (Lee *et al.*, 2013; Zhuang *et al.*, 2010; Kim *et al.*, 2003). Although the novel nose clip proposed in the present study did not have significant issues in terms of accommodation or fitting, a new design strategy (e.g., multiple sizes or mass customization) is worth developing for further improvement.

The experimental results revealed that wearing the mask with the nose clip emitted less humidity than wearing the mask without the nose clip; the humidity increment, leaked from the top portion of masks, decreased (about 12.6%) when wearing the mask with the nose clip. This finding can be interpreted in two ways. First, this phenomenon could indicate that the half-face mask with the nose clip was well-fit with the faces of the participants. This is because the low humidity indicates that there is a small gap between the mask and the face, which could be interpreted as the mask fitting onto the face. This result is consistent with the mechanisms addressed by previous researchers who revealed the relationships between the fit of masks and humidity leakage (Lee *et al.*, 2013 and 2018; Oestenstad & Bartolucci, 2010; Han *et al.*, 2004). Second, we can conclude that the novel nose clip blocked humidity from leaking out from the mask because the analysis of the humidity increment showed that wearing the mask with the nose clip reduced humidity leakage by as much as about 43%, as compared to wearing the mask without the nose clip. It is understood that the humidity leaked from the mask could adversely affect user satisfaction and user discomfort since it is likely to obstruct vision in the form of fog or water particles (especially for spectacle users) (Lee *et al.*, 2018; Chu *et al.*, 2015). That is to say, the nose clip proposed in this study blocked humid air, which could be leaked from the top portion of the mask, and also positively affected the user experience.

The half-face mask with the nose clip showed a higher subjective satisfaction rating than that without the nose clip. About 65% of the participants rated their satisfaction scores more than 4 (neutral) for the half-face mask with the nose clip. Although the subjective scores showed a significant difference in the presence of the nose clip, the difference (approximately 0.5 points) was small between the two conditions. The reason for this result is unclear, but we estimate that this would be associated by changing the material of the prototype. Prototypes manufactured with a 3D printer commonly have rough surfaces and (sometimes) are heavy in weight due to the inherent properties of the materials (Han & Kim, 2014). The PLA used for 3D printing in the present study is considered one such material. Naturally, negative opinions could follow, which would be likely to adversely affect user experience, as shown in the present study. This assumption is also supported by the debriefing session, where similar opinions on the material of the prototype were expressed by some participants.

Future studies are warranted for further investigation of the findings obtained in this study. First, the findings from the present study need to be validated with larger samples for diverse ethnicities, age groups, and gender. Extended research for diverse populations could be helpful for better reaffirmation of the present study. Second, design approaches for multiple sizes or mass customization (Liang, 2013) of the nose clip would be worth exploring to accommodate more users with different face sizes. Although the present study showed high accommodation (approximately 90%) despite the one-size-fits-all design, we believe there is still room to improve the accommodation using appropriate sizing. Third, the effects of temperature and humidity level of the environment also need to be considered in the future since the current study is limited in comprehensively investigating those aspects. Lastly, lightweight or soft material is recommended for physical prototyping. As mentioned above, the rough surface or heavy weight of the prototype could adversely affect user comfort and user satisfaction. A lightweight or soft material for physical prototyping could help alleviate these issues and allow participants to focus only on evaluating the fit.

6. CONCLUSION

The present study designed a novel nose clip for a one-size-fits-all half-face mask design. The 3D facial anthropometric data of 60 participants were measured, and they were defined in terms of vertical and horizontal distances (e.g., nose height, nose width, eye center height, and eye center width). Hierarchical clustering analyses with the 3D facial anthropometric data determined three size groups (small, medium, and large), and the digital prototype of the novel nose clip for the one-size-fits-all design was developed based on the 3D facial anthropometric data corresponding to the medium-sized group with the largest accommodation (approximately 90%). A virtual fitting test was conducted with the digital prototype, and it confirmed that the digital prototype fit the representative face model that was selected from the medium cluster. Lastly, a physical prototype of the novel nose clip was manufactured, and the prototype was tested in terms of humidity (in the air leaked from masks) and subjective user satisfaction. Results indicated that the half-face mask with the novel nose clip performed better in terms of humidity levels and user satisfaction than the mask without the nose clip.

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