ANALYSIS OF THE FACIAL ANTHROPOMETRIC DATA OF KOREAN PILOTS FOR OXYGEN MASK DESIGN

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The present study measured Korean pilots' facial dimensions to design a pilot oxygen mask which would fit Korean pilots, and compared Korean pilots' facial dimensions to Korean male civilians and US male pilots' facial characteristics. The present study selected the 22 facial anthropometric dimensions related to oxygen mask design by referring to previous studies. The facial dimensions of 366 Korean male and female pilots (including 52 female cadets of the Korean Air Force Academy) were measured using Martin's anthropometer and 3D scanner. Korean male pilots' faces were significantly larger (mean difference = 1.3 ~ 27.0 mm) and less variable (ratio in SD = 0.29 ~ 0.85) than Korean male civilians' faces (α = 0.05), which indicates that facial anthropometric data derived from Korean pilots should be used to design the oxygen mask for Korean pilots. In terms of criteria of the oxygen mask sizing system which is currently based upon the US Air Force anthropometric data (face length and lip width), Korean male pilots were significantly longer on face length (mean difference = 4.7 mm) and narrower on lip width (mean difference = -2.4 mm) than US male pilots (α = 0.05), which indicates that the oxygen mask sizing system as well as the oxygen mask shape should be changed for Korean pilots. Additionally, Korean male pilots have wider nasal roots (mean difference = 5.2 mm) than US male pilots, which indicates that the shape of nose of the current oxygen mask should be widened. Lastly, Korean female pilots' facial dimensions were significantly smaller (mean difference = 0.6 ~ 26.1 mm) than Korean male pilots (α = 0.05), which indicates that Korean female pilots' facial characteristics need to be considered in the design of oxygen masks which fit Korean pilots.

INTRODUCTION

The required pilot oxygen mask (model name: MBU-20/P) used by Korean fighter pilots was designed based on US Air Force facial anthropometric data, and it causes excessive pressure or oxygen leakage at the nasal area of some Korean pilots. The pilot oxygen mask is a half-face type mask covering the nasal area and mouth which stably supplies oxygen to a pilot at high altitude (Alexander et al., 1979). MBU-20/P (Gentex Corporation, USA) was initially designed based on US Air Force anthropometric survey data (Churchill et al., 1977), and then its size and shape were modified based on 3D facial scans data of 30 male and 30 female pilots (Gross et al., 1997). The questionnaire about the usability of pilots' equipment which was conducted by the Republic of Korea Air Force in 2006 reported that MBU-20/P causes excessive pressure or oxygen leakage at the nasal area of Korean pilots.

The mask is designed based on facial anthropometric data, but there is a lack of understanding of Korean pilots' distinguishing facial characteristics. Previous researchers (Han et al., 2004; Gross et al., 1997; Hack & McConville, 1978; Young, 1966) designed half-face masks based on the facial dimensions such as face length, lower face length, face width, nose length, nose width, nose protrusion, lip width, and bitragion-subnasale arc. Hack & McConville (1978) and Young (1966) suggested using a nasal dimensions (e.g., nasal root breadth, maximum nasal bridge breadth, nasal bridge-menton length, nasal bridge-chin length) to design the shape of the nose part of the half-face mask. In terms of Korean anthropometric data, the previous studies (e.g., Korean Agency for Technology and Standards, 2004; Han et al., 2004; and so on) measured Korean civilians' face. However, these previous studies didn't measure Korean pilots' faces, and Jeon (2011) raised the point that the body size of Korean military pilots (specifically helicopter pilots) is different than Korean civilians. Moreover, the data from Korean civilians lack facial dimensions (e.g., nasal root breadth, nasal bridge breadth, nasal bridge-menton length) which are necessary to design a pilot oxygen mask. Therefore, in order to design an oxygen mask specifically for Korean pilots, a facial anthropometry survey focused on Korean pilots rather than civilians is required.

The present study measured and analyzed facial dimensions of Korean pilots to design a pilot oxygen mask which would fit Korean pilots' faces precisely. Facial dimensions related to oxygen mask design were selected by reviewing previous research. Korean pilots' facial dimensions were extracted through 3D face scanning and were compared to Korean male civilians and US male pilots to determine differences between Korean and US pilots.

METHODS

Measurement Dimensions

The 22 facial dimensions related to oxygen mask design were selected by literature review and expert discussion. The 109 facial and head measurement dimensions (length: 53, width: 18, thickness: 24, circumference: 14) were comprehensively gathered by referring to 15 previous studies (Ahn & Shu, 2004; Clauser et al., 1988; Enciso et al., 2003; Hack & McConville, 1978; Han et al., 2004; Hughes & Lomaev, 1972; Kim, 2004, 2005; Kim et al., 2004; Korean Agency for Technology and Standards, 2004; Oestenstad et al., 1990; Oh & Park, 2010; Yokota, 2005; Zhuang et al., 2010a, 2010b). The 22 facial dimensions (length: 11, width: 7, circumference: 4) which are related to half-mask design were selected among 109 dimensions by discussion (see the Figure 1).

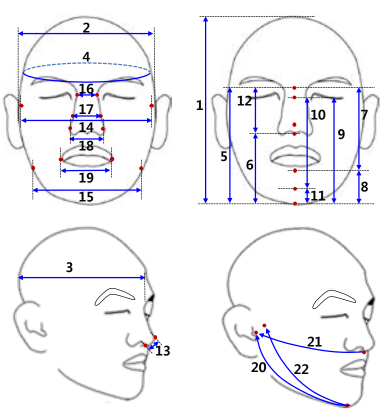

Figure 1. The 22 facial dimensions for oxygen mask design

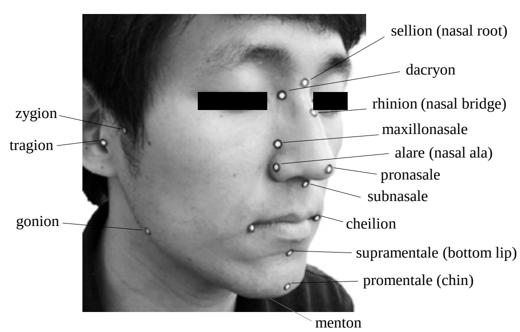

Figure 2. The 21 facial landmarks for facial measurement

Participants

The present study measured 336 Korean pilots which was a greater number than the minimum sample size (n = 158) calculated by statistical analysis. The minimum sample size for facial measurement was calculated by Formula 1 ~ 3 (Montgomery & Runger, 2003) using statistical data (mean, standard deviation) of Korean male civilians (Korean Agency for Technology and Standards, 2004). Korean civilians' data provides the 4 facial dimensions (face length, nasal bridge-chin length, nose width, and lip width) which were evaluated as highly important to the design of the oxygen mask by this study. By considering an acceptable sampling error (2 mm) of the 4 important facial dimensions and measurable number of Korean pilots, the present study determined 158 pilots for the minimum sample size at k = 2%. For practical use (e.g., mask design and evaluation using 3D face data), the present study tried to measure as many Korean pilots as possible, and 336 pilots (278 male pilots, 6 female pilots, 52 female Air Force Academy cadets) were measured.

$$n = \left(z_{\alpha/2} \times \frac{s}{k \times \bar{x}}\right)^2 \qquad \text{(Formula 1)}$$

where: n = sample size,
z = standard normal score,
α = significant level,
s = sample standard deviation,
k = precision level,
$\bar{x}$ = sample mean

$$\bar{X} = \frac{(\bar{X}_1 \times n_1) + (\bar{X}_2 \times n_2)}{n_1 + n_2} \qquad \text{(Formula 2)}$$

where: $\bar{X}$ = sample mean of a composite population,
$\bar{X}_i$ = sample mean of population i,
n_i = sample size of population i

$$s = \sqrt{\frac{n_1 \times \bar{X}_1^2 + (n_1 - 1) \times s_1^2 + n_2 \times \bar{X}_2^2 + (n_2 - 1) \times s_2^2 - (n_1 + n_2) \times \bar{X}^2}{n_1 + n_2 - 1}}$$

$$\cong \sqrt{p_1 \times \left(\bar{X}_1^2 + s_1^2\right) + p_2 \times \left(\bar{X}_2^2 + s_2^2\right) - \bar{X}^2} \qquad \text{(Formula 3)}$$

where: s = sample standard deviation of a composite population,
$\bar{X}$ = sample mean of composite population,
$\bar{X}_i$ = sample mean of population i,
s_i = sample standard deviation of population i,
n_i = sample size of population i,
p_i = proportion of population i

Measurement protocol

The present study measured Korean pilots' facial dimensions using Martin's anthropometer and 3D scanner. Facial measurement was conducted through a five-step process composed of (1) introduction to the experiment and signing an informed consent form, (2) marking facial landmarks, (3) measurement using Martin's anthropometer, (4) 3D face scanning, and (5) compensation. First of all, the purpose and process of facial measurement were explained to participants. The 21 sticker-type facial landmarks (see the Figure 2) were marked on the pilot's face. The 4 head dimensions (head height, head breadth, head length, and head circumference) were measured by Martin's anthropometer (spreading caliper and measuring tape). Both the pilot's face and facial landmarks were captured in 3D by a Rexcan 560 3D scanner (Solutionix Co., South Korea) and ezScan software (Solutionix Co., South Korea) to measure the remaining 18 facial dimensions. The 3D facial images were scanned from the five different viewpoints (left 60°, left 30°, 0°, right 30°, right 60°; see the Figure 3).

Figure 3. Initially 3D scanned images (left) and the post-processed image (right)

The 3D face scan data were processed (image merging, data editing, and landmark redefining) using ezScan software and the 18 facial dimensions were automatically measured by a facial measurement system which was developed in the present study. The five 3D scanned images were merged into a single 3D digital face (see the Figure 3). The 3D face was edited (e.g., hole-filling, smoothing, abnormal surface cleaning), and landmarks which weren't saved during 3D scanning and editing were manually redefined. The 18 facial dimensions (length: Euclidian distance between two landmarks, circumference: minimum convex hull distance of 3D face data between three landmarks) were automatically measured by the facial measurement system developed in this study using MATLAB^{TM} (The MathWorks, Inc., USA).

Anthropometric Data Analysis

The facial characteristics of Korean male pilots were determined by comparison to Korean male civilians, US male pilots, and Korean female pilots. Among the 22 facial dimensions, 9 dimensions of the Korean civilians and 13 dimensions of the US Air Force data were comparable (see the Table 1). The 22 dimensions were analyzed by a paired *t*-test and *F*-test in term of mean difference (MD) and ratio in standard deviation (RSD).

RESULTS

Korean Male Pilots vs. Korean Male Civilians

The 7 facial dimensions of Korean male pilots were greater (mean difference = 1.3 ~ 27.0 mm) than Korean male civilians on average (except head circumference and nose width), while the variability of the facial dimensions of Korean male pilots was less (ratio in SD = 0.29 ~ 0.85) than Korean male civilians on all 9 dimensions (see the Table 1 and Figure 4).

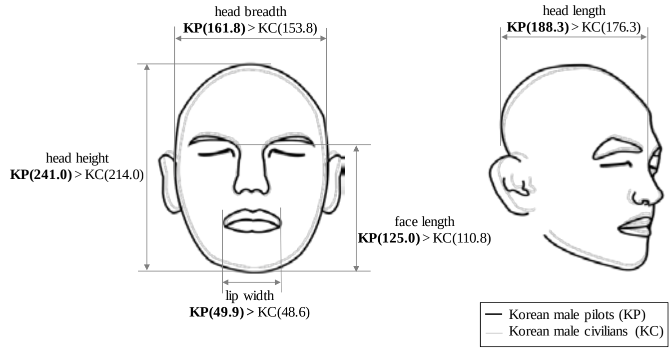

Figure 4. Average differences between Korean male pilots and Korean male civilians

In general, Korean male pilots' heads were bigger than those of Korean male civilians on average in 5 dimensions (head height, head breadth, head length, face length, lower face length). The exception was head circumference (mean difference of head circumference = -7.0 mm). Korean male pilots' noses were more protruded (mean difference of nose protrusion = 6.1 mm), but narrower (mean difference of nose width = -1.1 mm) than those of Korean male civilians. Mean differences were significant by paired *t*-test on all 9 facial dimensions ($\alpha = .05$). On the other hand, the variability of Korean male pilots' facial dimensions was significantly less (ratio in SD = 0.29 ~ 0.85) than the variability of Korean male civilians' facial dimensions by *F*-test on all 9 dimensions ($\alpha = .05$).

Korean Male Pilots vs. US Male Pilots

In general, the length and width dimensions (except maximum

Table 1. Comparison between anthropometric survey data

No.	Anthropometric dimension	Korean male pilot (n = 278)		Korean male civilians (n = 803)		US male pilots (n = 2420)		Korean female pilots (n = 58)		Korean male pilots vs. Korean male civilians			Korean male pilots vs. US male pilots			Korean male pilots vs. Korean female pilots		
		mean	SD	mean	SD	Mean	SD	mean	SD	MD	RM	RSD	MD	RM	RSD	MD	RM	RSD
1	head height	241.0	8.2	214.0	28.6	227.7	10.2	228.2	9.2	27.0**	1.13	0.29**	13.3**	1.06	0.81**	12.8**	1.06	0.90
2	head breadth	161.8	6.4	153.8	18.0			157.1	5.0	8.0**	1.05	0.35**				4.7**	1.03	1.28*
3	head length	188.3	6.5	176.3	20.5	198.7	6.7	181.1	5.7	12.0**	1.07	0.32**	-10.4**	0.95	0.97**	7.2**	1.04	1.14
4	head circumference	566.0	13.4	573.0	16.4			557.0	11.7	-7.0**	0.99	0.82**				9.0**	1.02	1.14
5	face length	125.0	5.2	110.8	14.4	120.3	6.1	116.1	4.6	14.2**	1.13	0.36**	4.7**	1.04	0.85	8.8**	1.08	1.14
6	lower face length	70.0	4.2	63.3	8.3	69.0	5.3	65.0	3.5	6.7**	1.11	0.50**	1.0**	1.01	0.79**	5.0**	1.08	1.18
7	sellion-bottom lip length	98.3	4.6					91.3	4.0							7.0**	1.08	1.18
8	bottom lip-menton length	26.7	2.9					24.9	3.0							1.8**	1.07	0.96
9	nasal bridge-menton length	110.4	4.8					102.9	4.4							7.4**	1.07	1.10
10	nasal bridge-chin length	97.2	4.7					88.8	3.7							8.4**	1.09	1.28*
11	chin-menton length	13.1	2.4					14.1	2.6							-1.0**	0.93	0.93
12	nose length	55.0	3.1			51.3	3.7	51.1	3.0				3.7**	1.07	0.83**	3.8**	1.07	1.03
13	nose protrusion	18.5	1.9	12.4	2.3			17.9	1.8	6.1**	1.49	0.85**				0.6*	1.03	1.06
14	face width	156.4	5.2			142.3	5.2	147.0	6.0				14.1**	1.10	1.00	9.4**	1.06	0.88
15	chin width	132.0	8.1			117.3	6.9	123.3	4.6				14.7**	1.13	1.18**	8.7*	1.07	1.78
16	nasal root breadth	20.6	2.5			15.4	2.1	17.2	2.2				5.2**	1.34	1.19**	3.4**	1.20	1.13**
17	maximum nasal bridge breadth	31.3	2.4			34.7†	3.2†	27.0	1.9				-3.4**	0.90	0.75**	4.3**	1.16	1.28*
18	nose width	38.1	2.5	39.2	3.4	35.0	2.9	35.0	2.0	-1.1**	0.97	0.74**	3.1**	1.09	0.86**	3.2**	1.09	1.26
19	lip width	49.9	3.4	48.6	5.2	52.3	3.7	45.4	3.2	1.3**	1.03	0.67**	-2.4**	0.95	0.94	4.5**	1.10	1.07
20	bitragion-menton arc	318.2	13.0			327.0	12.4	292.1	12.1				-8.8**	0.97	1.05	26.1**	1.09	1.08
21	bitragion-subnasale arc	285.8	11.1			293.0	10.2	269.8	12.4				-7.2**	0.98	1.09*	16.0**	1.06	0.90
22	bizygomatic-menton arc	309.1	11.3					284.6	12.1							24.5**	1.09	0.93

SD: standard deviation, MD: mean difference, RM: ratio in mean, RSD: ration in standard deviation

† Los Alamos Scientific Laboratory (LASL) survey data (Hack et al., 1978)

* $p < .05$; ** $p < .01$ (MD: results of paired *t*-test, RSD: results of *F*-test)

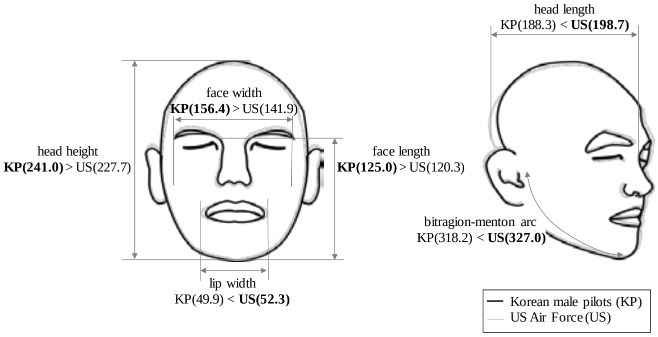

Figure 5. Average differences between Korean male pilots and US male pilots

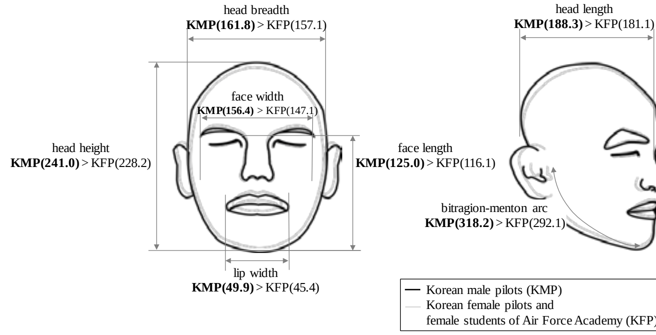

Figure 6. Average differences between Korean male pilots and Korean female pilots

nasal bridge breadth and lip width) of Korean male pilots were greater (mean difference = 1.0 ~ 14.7 mm) on average; while the variability of the length dimensions of Korean male pilots was less (ratio in SD = 0.79 ~ 0.97) than US male pilots (see the Table 1 and Figure 5). In particular, Korean male pilots' faces were relatively longer (mean difference of face length = 4.7 mm) and wider (mean difference of face width = 14.1 mm) than those of US male pilots on average. However, maximum nasal bridge breadth (mean difference = 3.4 mm) and lip width (mean difference = 2.4 mm) of Korean male pilots were narrower than US male pilots on average. Mean differences were significant by paired *t*-test on all 13 facial dimensions (α = .05). On the other hand, the variability of the length dimensions of Korean male pilots was less (ratio in SD = 0.79 ~ 0.97) than US male pilots, while there was no trend for the variability of the width dimensions between Korean and US male pilots. The variability of the facial dimensions was significant by *F*-test on 9 dimensions except face length, face width, lip width, and bitragion-menton arc (α = .05).

Korean Male Pilots vs. Korean Female Pilots

In general, the facial dimensions of Korean male pilots were greater (mean difference = 0.6 ~ 26.1 mm) than Korean female pilots, also the variability of the facial dimensions of Korean male pilots was greater (ratio in SD = 1.03 ~ 1.78) than Korean female pilots (see the Table 1 & Figure 6). In particular, 4 out of 22 dimensions (head height, bitragion-menton arc, bitragion-subnasale arc, and bizygonmatic-menton arc) of Korean male pilots were greater over 10 mm than Korean female pilots on average. Mean differences were significant by paired *t*-test on all 22 dimensions (α = .05). On the other hand, the variability of Korean male pilots' facial dimensions was greater (ratio in SD = 1.03 ~ 1.78) than Korean female pilots except 6 dimensions (head height, bottom lip-menton length, chin- menton length, face width, bitragion-subnasale arc, and bizygomatic-menton arc). The variability of the facial dimensions was significant by *F*-test on only 4 dimensions (head breadth, nasal bridge-chin length, nasal root breadth, maximum nasal bridge breadth; α = .05).

DISCUSSION

The present study selected the 22 facial dimensions related to oxygen mask design by comprehensively reviewing previous research. The present study reviewed 15 studies on facial measurement and selected 22 out of 109 whole facial dimensions which are related to the half-face oxygen mask design. In particular, the present study measured nasal bridge dimensions (e.g., nasal bridge-menton length, nasal bridge-chin length, nasal root breadth, and maximum nasal bridge breadth) (Hack & McConville, 1978; Young, 1966). Therefore, the 22 facial dimensions selected by this study can be usefully applied to various types of half-face masks.

The present study developed its own 3D facial scan measurement system which can automatically measure all dimension types (length, width, circumference) based on face landmarks. This system shortened the measurement time (< 1 sec/person), whereas it takes over 10 minutes for one person if the 3D face is manually measured by the commercial software (e.g., RapidForm 2006, INUS Technology Inc., South Korea).

Through 3D scanning, the present study obtained not only facial dimensions but also the 3D facial shape which can be applied to the oxygen mask design process (e.g., CAD design, virtual fit testing). For example, the present study designed the shape of the nose part of the oxygen mask by using facial dimensions (e.g., nasal root breadth, maximum nasal bridge breadth) and 3D nasal shape (e.g., curve or surface of nose) together. On the other hand, to design a oxygen mask which fits Korean pilots, the 3D facial shape will be applied to a virtual fit testing in a following study. The virtual fit testing is a new method which can virtually evaluate the current and revised oxygen mask in terms of fitness (e.g., pressure, oxygen leakage) and clearance to determine design problems.

To design the oxygen mask and its sizing system for Korean pilots, the facial characteristics of both of Korean male and female pilots should be considered simultaneously. In general, the facial dimensions of Korean male pilots are greater (ratio in mean = 1.03 ~ 1.49) on average and less variable (ratio in SD = 0.29 ~ 0.85) than Korean male civilians. Therefore, the oxygen mask sizing system which will be developed based on Korean male pilots can satisfy a high accommodation rate (e.g., 95%) with a small number of size categories and narrow size intervals. On the other hand, the facial dimensions and the variability of Korean female pilots are less (ratio in mean = 1.02 ~ 1.20, ratio in SD = 1.03 ~ 1.78) than Korean male pilots. Therefore, a certain portion (e.g., male: female = 9: 1) of Korean female pilots' facial sizes should be considered in the development of the oxygen mask sizing system.

The present study determined the design directions of an oxygen mask which would fits Korean pilots by comparing dimensions of Korean and US male pilots. In terms of criteria of the oxygen mask sizing system (face length and lip width), Korean male pilots are longer in face length (mean difference = 4.7 mm) and narrower in lip width (mean difference = -2.4 mm) than US male pilots. Korean male pilots have a wider nasal root (mean difference of nasal root breadth = 5.2 mm) and a narrower nasal bone (mean difference of maximum nasal bridge breadth = -3.4 mm) than US male pilots, which indicates that the shape of nose of the current oxygen mask does not fit Korean pilots. Therefore, an oxygen mask which fits Korean pilots can be designed based on the facial dimensions (e.g., face length, lip width, nasal root breadth, and maximum nasal bridge breadth) of Korean pilots. For example, the shape of nose of the current oxygen mask can be widened to fit to Korean pilots.

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