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Skin-color perception of morphed face images

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The purpose of this study was to verify the interconnection between the perception of face shape and skin color. The hypothesis of this study was that, if there is a relationship between face shape and skin-color perception, a change would be expected in skin-color perception based on the degree of similarity to a face. We conducted three experiments, designed to determine the ability to retrieve from memory the color of human-like faces with several degrees of morphing. The experiments were (i) test of memory for colors of scrambled faces, (ii) test of morphing limits, and (iii) test of further degrees of morphing and more chromatic variations, based on the information gathered from the first two experiments. The first experiment indicated that a lower degree of morphing would impact the final result. The second experiment was important to determine the appropriate degree of morphing, whereas the third experiment widened the range of chromatic staring points, thereby broadening the limits of the experiment. The color-matching results differed according to the completeness of the facial shape. We found that the presence of eyes on morphed images of faces induces the perception of faces. Moreover, it appeared that the starting chromatic point, if too distant from the original stimulus, increased the difficulty of the memory task. This study has shown the possibility of a relationship between skin color and face perception.

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1. INTRODUCTION

Face perception refers to the process of determining whether or not an image is a face. Face recognition refers to the high-level process of judging whether the face is, e.g., a woman's or a man's, or whether it is familiar or unfamiliar [1]. Therefore, face perception is an early stage of face recognition.

In our daily lives, skin color is mostly seen among object colors. Thus, we are sensitive to the changes in skin color due to race, gender, age [2], beauty, and health [3]. In this study, the face-perception stage and skin-color perception will be considered.

A. Face Perception

Face perception has been studied in the field of neuroscience by investigating the response of brain regions using photographs of faces. McCarthy *et al.* identified that face-specific processing occurred in a discrete region in the human fusiform gyrus [4]. The perception of a human face from photographs with re-arranged or occluded facial parts were studied by functional magnetic resonance imaging (fMRI) [5]. Kanwisher *et al.* verified face perception using photographs of human faces [6]. The results showed that the human fusiform face area (FFA) demonstrated high selective trend response to human faces in comparison to objects, houses, scrambled faces, or human hands. It was shown that the perfect shape of human face evoked the best FFA response, related to face perception. Face perception was researched comparing to various faces (humans, cats, and cartoons) and certain perceptible facial characteristics (schematic faces, inverted cartoons, eyes, and cheek views of heads) [7]. In this study, we focused on the similar responses of the FFA to real and cartoon face images. A cartoon-image face could be a facial shape consisting only of lines for our experiment. Thus, in this study, minimal lines were used to create a face image as a stimulus for experiments.

B. Skin-Color Perception

Yendrikhovskij *et al.* [8] stated that the skin could determine an entire picture's naturalness, because of its most critical color. Therefore, skin color of a female face has been used as an essential evaluation factor to qualify for electronic devices [9]. Zeng and Luo [10] confirmed a range of skin colors for digital photographs that fit the elliptical model. It has been shown that brighter skin colors are more preferred in East Asian countries, from studies using photographs of women [11–13]. The preference trend was also shown in a study using illustrations and animated face images [14].

In a recent study, Shimakura and Sakata [15] investigated the interactions among face-color attributes, e.g., saturation, brightness, and whiteness, using face-image patches. To create the patches, a mosaic method was used on face photos to reduce the face visibility. However, it was difficult to control because the photo contained many facial elements. Moreover, it was difficult to quantify the perceptual differences of photographic faces, owing to a variety of factors.

A study has shown a stronger correlation with subjective responses between computer-generated (CG) faces with controlled colors and glosses and abstracted faces with the same image statistics in circle shapes [16]. However, whether skin color or glossiness causes a stronger response remains to be clarified. In this study, the relationship will be defined between a basic face image, using line information, and skin-color perception. Line drawing can quickly and intuitively convey visual information from V1 to V4 rather than colored or shaded images [17].

The hypothesis of this study is as follows: If there is a relationship between facial shape and skin-color perception, a change is expected in the skin-color perception based on the degree of appearance. Thus, the independent variable is *the degree of similarity to a face* and the dependent variable is *the change in skin-color perception*.

2. GENERAL METHODS

A. Apparatus

The experiments were run in a dark room. All stimuli were presented on a color LCD monitor (Coloredge CG245 24.1"; Eizo Corp., 1920 × 1200 pixels) controlled by a PC (Giga-byte Phantasus P27G V2 I7) with 8 bit intensity resolution for each phosphor. The monitor's red–green–blue (RGB) values were calibrated using a Photo Research PR650 spectroradiometer. The monitor's white value was adjusted to D65 white. The subject was situated 57 cm from the LCD monitor. Stimuli were viewed binocularly, with head support provided by a chin rest. A trackball and number pad were used to record the subjects' answers.

B. Calibration

First, gamma curves were obtained from the LCD monitor by measuring R, G, and B luminance values with a PR-650 spectroradiometer at 16 intervals from 0 to 255. Gamma correction was performed using a look-up table (LUT) to determine the stimulus color from the monitor. Maximum luminance of R ($21.734\ \mathrm{cd/m^2}$), G ($58.166\ \mathrm{cd/m^2}$), B ($5.741\ \mathrm{cd/m^2}$), and W ($73.040\ \mathrm{cd/m^2}$) were measured. The average luminance of the background during stimulus presentation was $27.3\ \mathrm{cd/m^2}$. During the task, the R, G, and B values of the matched color of the subject were stored. After the experiment, the colors were reproduced by substituting the R, G, and B values stored in the display and measured using the spectroradiometer. The results were converted to L^*, a^*, and b^*, to obtain the respective experimental results.

C. Color Space

In this study, the CIELAB color space was used to calculate the color distances using L^*, a^*, and b^*. Moreover, Adobe and Autodesk graphic programs, used by illustrators and animators, represent the value of color not only R, G, and B but also by L^*, a^*, and b^*. Therefore, the data from the CIELAB color space would be helpful for establishing the database for the graphic design.

3. EXPERIMENT 1

A. Aim

The subject's memory for skin colors was examined, using images with and without facial shapes.

B. Participants

Ten subjects (five males, five females, ages 23–36) participated in Experiment 1. All subjects had normal color vision, as tested by Ishihara pseudo-isochromatic plates (PIP).

C. Stimuli

Figure 1 shows examples of the experimental stimuli in Experiment 1. Four shapes (Face, Scramble 1, Scramble 2, and Circle) with three skin colors (L^*, a^*, b^*: preferred = 91.92, 13.7, 23.09; dark = 78.72, 10, 16.42; reddish = 80.38, 21.72, 23.19) were used as the stimuli.

"Face" indicates the perfect facial shape of a 16-year-old woman. It was modeled using Autodesk Maya 2016, and its lines were extracted using a vector renderer. "Scramble 1" indicates the scrambled shape of the eyes, eyebrows, nose, and mouth except for the contour and the hair part. "Scramble 2" indicates the scrambled shape of all of the elements of the facial features, where the face contour and hair part were divided into two parts. Meanwhile, "Circle" had only color information with a 10 degree size.

The area of the foundation except for the lines and the hair part was selected and changed into three versions of skin colors. The skin colors used for stimulation were based on preliminary results.

In the preliminary experiment, the subjects selected three skin colors to identify natural skin colors, based on an adjustment method. First, the subjects chose their preferred skin color

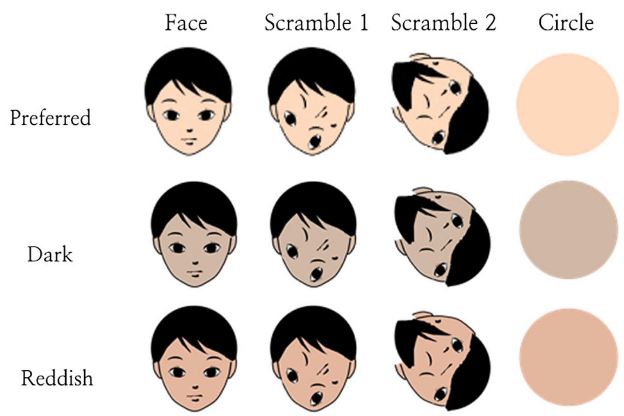

Fig. 1. Shapes of stimuli for Experiment 1. Four shapes (Face, Scramble 1, Scramble 2, and Circle) with three skin colors (L^*, a^*, b^*: preferred = 91.92, 13.7, 23.09; dark = 78.72, 10, 16.42; reddish = 80.38, 21.72, 23.19) were used as the stimuli.

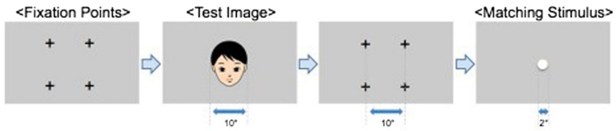

Fig. 2. Task of Experiment 1. ① Dark adaptation, ② background adaptation,③ four fixation crosses (500 ms), ④ test stimulus (10 degree size, 500 ms), ⑤ four fixation crosses (500 ms), ⑥ matching stimulus (2 degree size).

(16-year-old woman) and then chose two additional natural skin colors that they might expect in a 28-year-old male (reddish) and a 63-year-old male (dark). In this study, the selected skin colors were referred to as preferred, dark, and reddish. Based on the preferred skin color, L^* for the dark color was relatively negative, while a^* for the reddish color was relatively positive. The colors were measured using a spectrophotometer.

The test stimulus was a 10 degree size image. The background (x, y) chromaticity coordinates were (0.312, 0.330) with 27.3 cd/m^2 luminance.

D. Procedure

After dark adaptation for 1 min, the subjects were adapted to a gray background for 1 min. First, four fixation crosses spaced 10 degrees apart appeared on the gray background. In a preliminary experiment, one fixation cross prevented the observation of the entire face. The four fixation crosses allowed eye movements within that range so that the face could be observed.

Then, the 10 degree–sized test stimulus was presented for 500 ms. After observing the stimulus, the subject matched the chromaticity and lightness of the given matching stimulus to those of the remembered test image.

The subject selected the remembered color of the stimulus in a 2 degree–sized circle using a trackball, and the data were recorded by clicking the button of the trackball. The test stimuli were presented in random order. This task (see Fig. 2) was repeated three times. The instructions for the experiment were given in the subjects' native language, Japanese.

E. Results and Discussion

Each color was plotted on the CIELAB color space to compare the ranges. There was no significant difference in the values of L^*, a^*, and b^* among the facial shapes (Tukey-Kramer test, $p > 0.05$). Each result was fitted in an ellipse; see Fig. 3. The contours for a given percentile of a bivariate normal distribution were drawn by a program in Past3. The points from each subject for the result of matching skin color depending on each morphed shape were fitted in an ellipse with 95% confidence. For the preferred skin color, the measured color appeared in the ellipses of the a^* b^* and a^* L^* spaces.

The face, the scrambled facial elements, and the circle without any facial elements had different tendencies in the measured stimulus.

To verify the trend, the color distance between the measured (test) stimulus and each color-matching result was calculated thus:

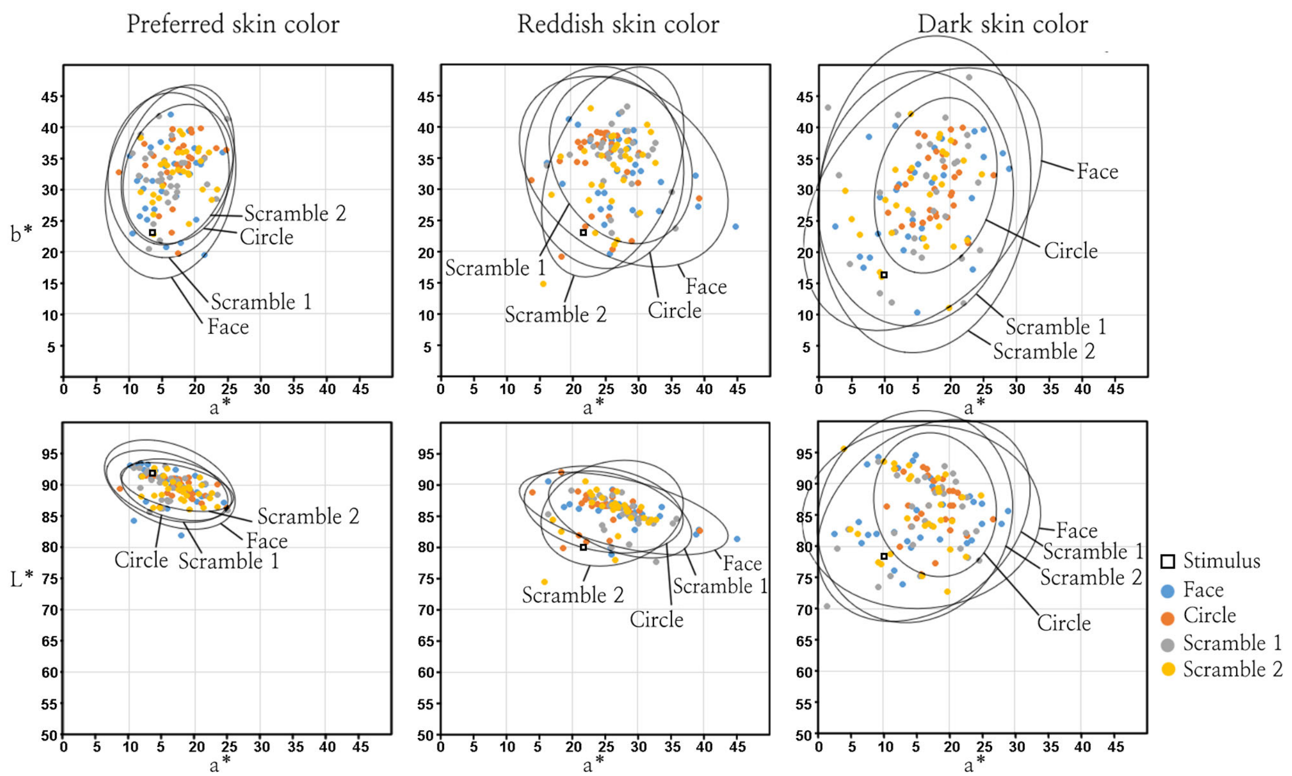

Fig. 3. Result of color matching in Experiment 1. Each result was fitted by an ellipse, according to the shape, with 95% confidence. Top row: a^* b^* color space. Bottom row: $a^* - L^*$ space. Left: preferred skin color. Middle: reddish skin color. Right: dark skin color.

Table 1. Minimum, Maximum, Mean, STD, and SE of the Color Distance in Experiment 1 According to Colors

	ΔE MIN	ΔE MAX	ΔE MEAN	ΔE STD	ΔE SE
Preferred	4.932	16.846	10.150	1.333	0.667
Reddish	4.839	18.012	12.501	0.836	0.418
Dark	5.520	44.780	16.281	1.660	0.830

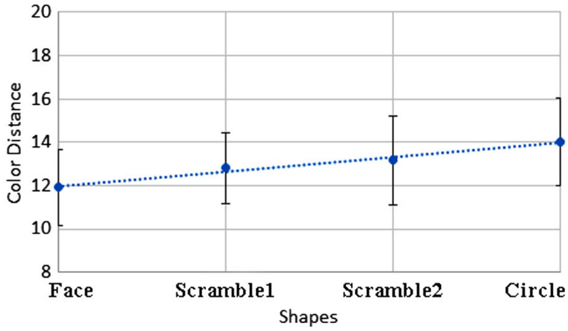

Fig. 4. Color distance according to shapes. The color difference was calculated with Eq. (1) from L^*, a^* and b^* of Fig. 3.

Table 2. Mean, STD, and SE of the Color Distance in Experiment 1 According to Shapes

	ΔE MEAN	ΔE STD	ΔE SE
Face	11.908	3.038	1.754
Scramble 1	12.816	2.838	1.638
Scramble 2	13.167	3.586	2.071
Circle	14.016	3.542	2.045

$$\Delta E_{ab}{}^* = \sqrt{(L_2{}^* - L_1{}^*)^2 + (a_2{}^* - a_1{}^*)^2 + (b_2{}^* - b_1{}^*)^2}. \quad (1)$$

Table 1 shows the minimum, maximum, mean, standard deviation (STD), and standard error (SE) of the color distance results by each subject between the measured stimulus (square in Fig. 3) and the color-matching (circle in Fig. 3) values. The smallest and largest values of the color distances of each subject were 4.839 and 44.78, respectively. The mean value increased in the order of preferred, reddish, and dark skin colors.

The possible factors that influenced this experiment are as follows. First, when the subjects selected a matching color in a 2 degree–sized circle, the first color from the skin-color range could have affected this result. Figure 4 shows the color distance according to the shape. The color distance was calculated with Eq. (1), using the average values of L^*, a^*, and b^* for each shape. The color distance of the face was the closest to the measured stimulus. The other color distance appeared in the order of Scramble 1, Scramble 2, and Circle.

Table 2 shows the mean, STD, and SE based on shapes. The results of the SE show that the Face and Scramble 1 have a relatively small error range within 2, while the error range of Scramble 2 and Circle exceeds 2.

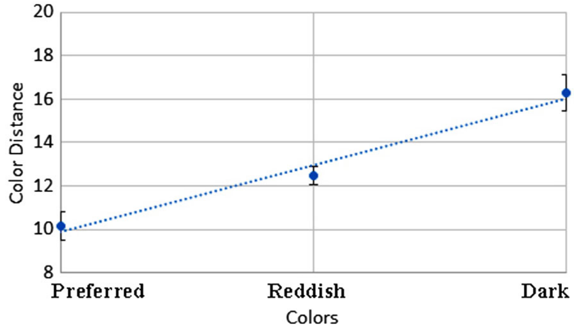

Fig. 5. Color distance according to colors. The color distance was calculated with Eq. (1) from L^*, a^* and b^* of Fig. 3.

Figure 5 shows the color distance according to the color. The color distance was calculated with Eq. (1), using the average of the L^*, a^*, and b^* values for each color, because there was no significant difference in the L^*, a^*, and b^* values. The preferred skin color showed the smallest color distance. The other color distance appeared in the order of reddish and dark skin colors.

The 10 degree size of the test stimulus was selected rather than 2 degree spectral sensitivity specified by the CIE, because it was close to the actual face size. Furthermore, a 2 degree field of view was chosen as the matching stimulus for more intuitive memory-color matching. When a subject adjusts the matching color, the size of the matching stimulus is set to a 2 degree field of view to simplify the memory color task by limiting the influence of the surrounding visual field.

Second, the presence of eyes could be influencing the skin-color judgment, because the eyes still appeared in the scrambled faces, despite the scattered nose and mouth.

Third, the face contour, which did not completely deviate from the shape of the face, could be affecting the skin-color judgment.

The colors used in Experiment 1 belonged to the natural skin-color range. However, there may be a slight difference in the skin-color judgment based on the degree of facial judgment. Therefore, it is necessary to verify the experiment using unnatural skin colors.

4. EXPERIMENT 2

A. Aim

In this experiment, we increased the amount of image morphing. Despite the scattered eyes, nose, and mouth in Scramble 1 and 2 from Experiment 1, some of the subjects considered the stimulus to be a face. This is similar to the work of Picasso, a representative Cubist artist, where the shape of the eye itself is maintained, even if the eyes are arranged in a line [18].

Tong *et al.*, using fMRI, reported the FFA reaction to images of eyes [7]. This means that the subjects perceived an image of eyes as a face. Therefore, in this experiment, the shape of the eye was also morphed. The subjects evaluated their degree of face perception in the morphed images. The result was applied to Experiment 3 to define the correlation between face perception and skin-color judgment.

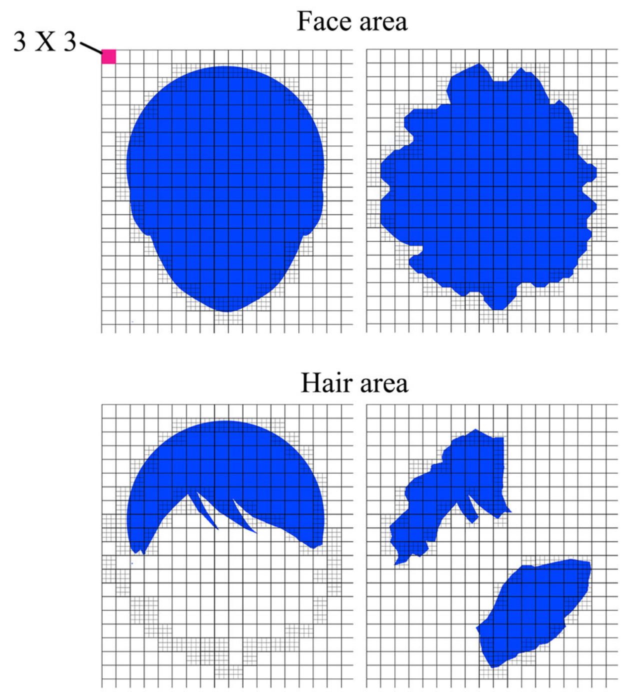

Fig. 6. Areas of stimuli. Top: face area (1720 pixel). Bottom: hair area (762 pixel). One pixel in Fig. 6 was the conceptual pixel unit for creating stimuli. The final experimental stimuli were adjusted to 10 degree size.

B. Participants

Seven subjects (four males, three females, ages 23–39) participated in Experiment 2. Because this experiment only required the subjects to judge shapes, their color vision was not tested.

C. Stimuli

"Face," a face consisting of lines and color planes, was created as a stimulus. The skin-color area used in Face was calculated in pixels. This area was maintained when the face and hair were morphed (Fig. 6), using Autodesk Maya 2016 computer-animation and modeling software. Fifty morphed images were used. The images were divided into groups of five units, and one image was selected from each group, for a total of 10 images. These 10 images plus Face were used as stimuli in Experiment 2.

Considering the elements contained in Face, the morphing technique of Autodesk Maya 2016 was used to change the position and angle of each element. The software was set at 24 frames per second (film format) to obtain 50 frames of conversion process images including a perfect face (Frame 01 of Fig. 7) and a totally broken face (Frame 50 of Fig. 7). Eleven experimental images with different degrees of face perception were selected for the experiment because it was inefficient to use all of the 50 frames.

One block in Fig. 6 represents 3 $\times$ 3 pixels. One pixel was a conceptual pixel unit for creating stimuli. The final experimental stimuli were adjusted to 10-degree sizes.

First, 1720 face pixels were morphed into a star shape (off the face). Then, 762 hair pixels were split into two and morphed.

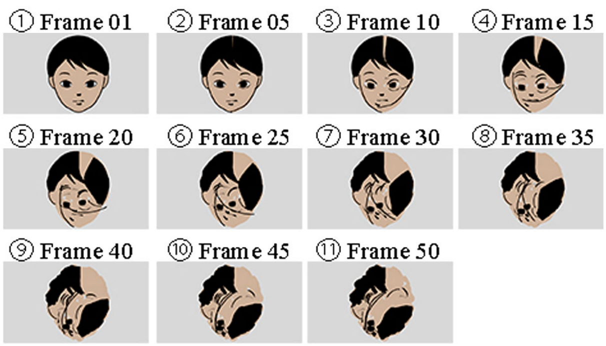

Fig. 7. Stimuli for Experiment 2. Considering the elements contained in Face, the morphing technique was used to change the position and angle of each element by Autodesk Maya 2016.

The pixels of the color plane remained the same when the shapes were morphed.

D. Procedure

The 10 degree–sized stimuli were represented on an LCD monitor in random order. The background (x, y) chromaticity coordinates were (0.312, 0.330) with 27.3 cd/m^2 luminance. The subjects evaluated the degree of facial appearance for the presented image using a five-step Likert scale method, where 0 means "looks least like a face" and 4 means "looks most like a face." The evaluation result was recorded by pushing a number on the number pad. The time limit was 1 min. This task was repeated three times. The instructions for the experiment were given in Japanese.

E. Results and Discussion

The degree of face perception according to the morphed images was determined as shown in Fig. 8. Table 3 shows the mean, STD, and SE based on face morphing. Frame 01 (Face) had the smallest SE of 0, and all subjects judged the stimulus as a perfect face. However, Frame 25 had the largest SE of 0.447.

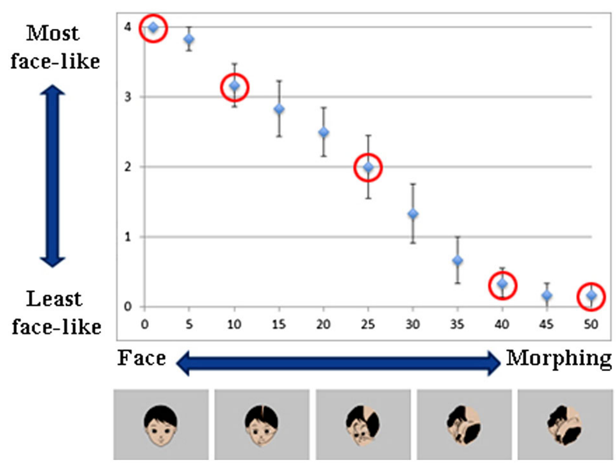

Fig. 8. Degree of face perception according to morphing images. Red circles were the selection of morphing shape in Experiment 3, as the experimental stimuli.

Table 3. Mean, STD, and SE of the Color Distance in Experiment 2

	ΔE MEAN	ΔE STD	ΔE SE
Frame 01	4.000	0.000	0.000
Frame 05	3.833	0.408	0.167
Frame 10	3.167	0.753	0.307
Frame 15	2.833	0.983	0.401
Frame 20	2.500	0.837	0.342
Frame 25	2.000	1.095	0.447
Frame 30	1.333	1.033	0.422
Frame 35	0.667	0.816	0.333
Frame 40	0.333	0.516	0.211
Frame 45	0.167	0.408	0.167
Frame 50	0.167	0.408	0.167

According to Tong *et al.*, the degree of face perception could be judged by the shape of the eyes alone [7]. In Frame 40 in Fig. 7, the shape of the eyes is no longer maintained. Therefore, the face-degree score dropped sharply, as shown in Fig. 8. The degree of face perception according to the morphed images was determined as shown in Fig. 8. This shows that the shape of the eye and the facial contours influences the judgment of the degree of facial appearance.

5. EXPERIMENT 3

A. Aim

The effect of the facial shape and morphed images on the skin-color judgment was examined with the addition of unnatural colors. This experiment was intended to complement the problem in Experiment 1.

B. Participants

Six subjects (four males, two females, ages 23–37) with normal color vision (using the same procedure as in Experiment 1) participated in this experiment.

C. Stimuli

The complete face (Face) and four morphed images (Morph 1, Morph 2, Morph 3, and Morph 4) were selected from the 11 images in Experiment 2 as the experimental stimuli (Fig. 9). Moreover, five colors (the three skin colors from Experiment 1 as well as orange [L^*, a^*, $b^* = 79.74, 23.03, 63.26$] and a bluish color [89.58, −7.06, −17.02], which are far from skin colors) were used to determine the skin-color judgment for each color (Fig. 10). Based on the results of Yendrikhovskij *et al.*, the subjects reacted to natural skin colors rather than unnatural skin colors [8]. To define skin-color perception, it was required to incorporate unnatural skin colors (orange and bluish color) in this experiment.

D. Procedure

This experimental method included color matching, as in Experiment 1. The background luminance and chromaticity and the basic procedure were the same as in Experiment 1,

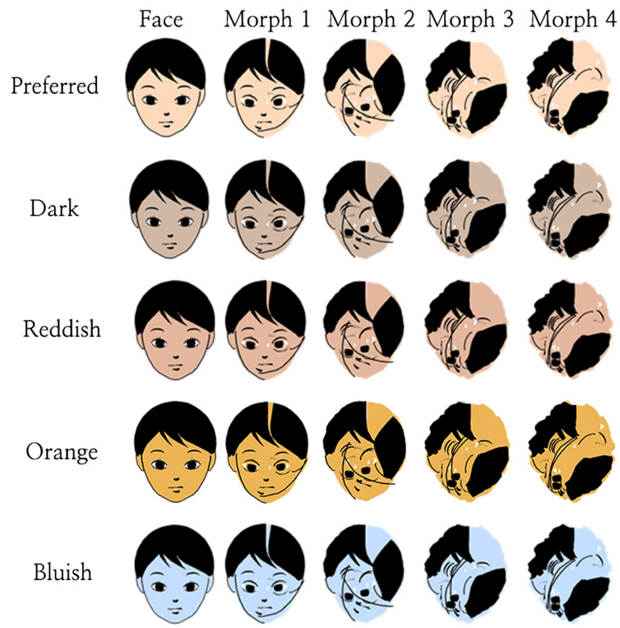

Fig. 9. Stimuli of Experiment 3. Five colors (L^*, a^*, b^*: preferred = 91.92, 13.7, 23.09; dark = 78.72, 10, 16.42; reddish = 80.38, 21.72, 23.19); orange (L^*, a^*, $b^* = 79.74, 23.03, 63.26$) and a bluish color (89.58, −7.06, −17.02) were applied to five shapes.

except that the starting color in the 2 degree circle for color matching was changed to white ($X = 81.776$, $Y = 85.998$, $Z = 95.900$, $73.040\ \mathrm{cd/m^2}$). The task was repeated four times. The instructions for the experiment were given in Japanese.

E. Results and Discussion

Each color was plotted on the CIELAB color space to compare the ranges. Compared to the results of Experiment 1 (Fig. 3), the range was wider. This means that the color-matching task was more difficult, partly because the initial color of the 2 degree–sized circle was white.

There was no significant difference in the natural skin colors (preferred, dark, and reddish) based on the change of facial shapes (Tukey-Kramer test, $p > 0.05$). However, there were significant differences between Face and Morph 4, Morph 2 and 4, and Morph 3 and 4 in b^* of orange. In addition, there were significant differences between Morphs 2 and 4 in b^* of bluish color (Tukey-Kramer test, $p < 0.001$). Moreover, the judgment of b^* in unnatural skin color was changed based on the change of facial shapes.

Each point was the result of a single subject, while the ellipse was the result of fitting all of the subject results. Each result was fitted in an ellipse, according to the shape, with 95% confidence (Fig. 10). The calculation of these ellipses assumed the bivariate normal distribution.

In the preferred, reddish, and dark skin colors, the measured color appeared in the ellipses of the a^* b^* and a^* L^* spaces. For the orange and bluish colors, the measured color did not appear in the a^* b^* ellipses. In addition, while the measured orange color did not appear in the inner range of the color-matching L^*, the measured bluish color did appear in the inner range of the color-matching L^*.

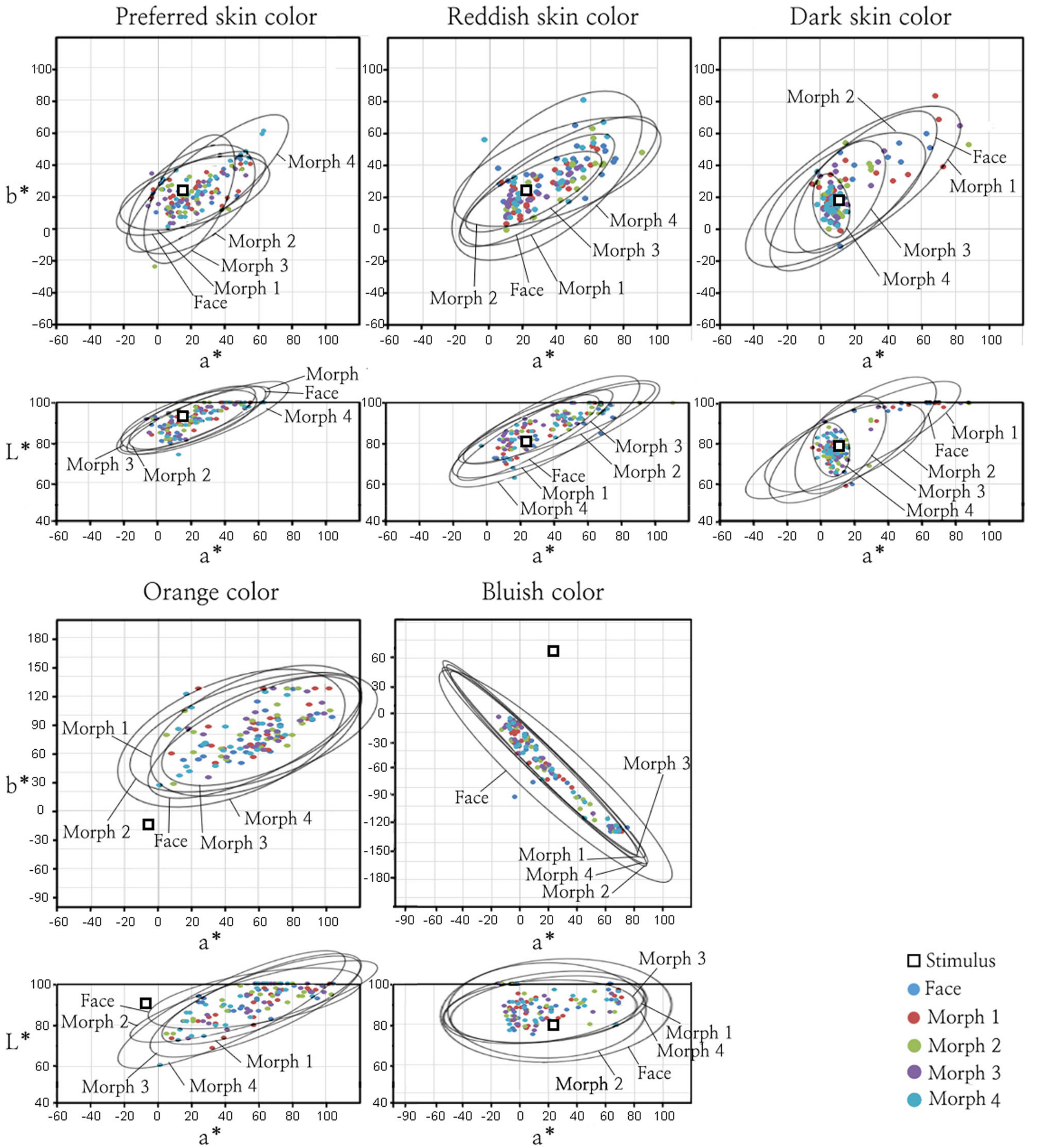

Fig. 10. Result of color matching in Experiment 3. Each result was fitted in an ellipse, according to the shape, with 95% confidence. Upper: a^* b^* color space. Lower: $a^* - L^*$ space.

Therefore, the face and morphed image stimuli had different tendencies for the measured stimulus. To verify the trend, the color distances between the L^* a^* b^* for the measured stimulus and the L^* a^* b^* for each color-matching result were calculated.

Table 4 shows the minimum, maximum, mean, STD, and SE of the color distance results of each subject, from the measured stimulus (square in Fig. 10) to the color-matching (circle in Fig. 10) values. The smallest color distance was 2.701, while the largest color distance was 134.307.

SE results of preferred and dark colors were less than 2, while that of reddish, orange, and bluish were more than 3. In particular, bluish color had the largest error range of more than 4.

Figure 11 shows the color distance according to the shape. The color distance was calculated with Eq. (1), using the average of the L^*, a^*, and b^* values for each form because there was no significant difference in L^*, a^*, and b^*. For Face, the color distance from the measured stimulus was the largest. The color

Table 4. Minimum, Maximum, Mean, STD, and SE of the Color Distance in Experiment 3 According to Colors

	ΔE MIN	ΔE MAX	ΔE MEAN	ΔE STD	ΔE SE
Preferred	8.449	53.270	9.391	4.215	1.889
Reddish	8.697	33.522	9.614	3.746	1.675
Dark	2.701	58.557	15.818	7.851	3.511
Orange	19.365	89.944	38.834	7.647	3.420
Bluish	6.096	134.307	47.362	9.309	4.163

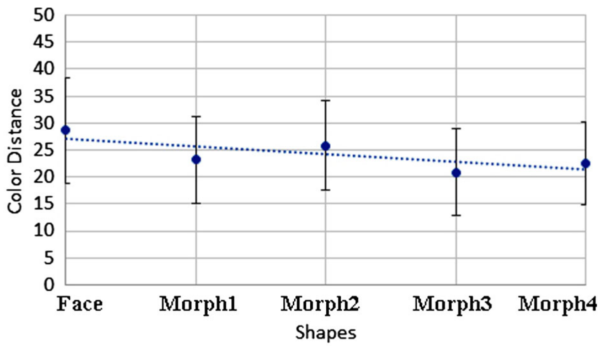

Fig. 11. Color difference according to shapes. The color distance was calculated with Eq. (1) from L^*, a^*, and b^* of Fig. 10.

Table 5. Mean, STD, and SE of the Color Distance in Experiment 3 According to Shapes

	ΔE MEAN	ΔE STD	ΔE SE
Face	28.634	21.782	9.741
Morph 1	23.153	17.781	7.952
Morph 2	25.831	18.765	8.392
Morph 3	20.883	18.090	8.090
Morph 4	22.518	16.978	7.593

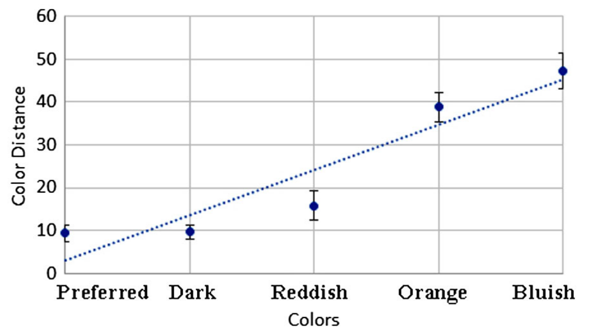

Fig. 12. Color distance according to colors. The color distance was calculated with Eq. (1) from L^*, a^* and b^* of Fig. 10.

distances appeared in the order of Morph 2, Morph 1, Morph 4, and Morph 3.

Table 5 shows the mean, STD, and SE of the color distances based on shapes. SE results show that Face (most face-like) had the largest error, while Morph 4 (least face-like) had the least error.

Figure 12 shows the color distance according to color. The color distance was calculated with Eq. (1), using the average of the L^*, a^*, b^* values for each color. The preferred skin color showed the least color distance. The other color distances appeared in the order of the dark and reddish skin colors, then the orange and bluish colors.

The color matching of the preferred skin color, based on the remembered color, was the most accurate (Fig. 12). This was the same result as in Experiment 1. The further the color was from preferred, the more difficult the color matching was. Therefore, the preferred skin color affects the color matching in the face image.

6. CONCLUSION

The purpose of this study was to investigate the interconnection between the perception of the face shape and skin color. Three experiments were presented to measure the subjects' ability to retrieve from memory the color of human-like faces with several degrees of morphing. A face image with simple lines and flat coloration was used as an experimental stimulus for this study.

Experiment 1 was the test of memory for colors of scrambled faces. The color distance of the face image was the smallest, compared to the other stimuli, while in Experiment 3, the color distance of the face image was the largest. The scrambled face image contained elements of the face, and some elements could be perceived as a face, because the eye and the facial contour were not completely broken. In the circle, the skin color was judged differently, because the area did not include any facial elements.

Experiment 2 was the test of morphing limits. The perfect facial shape had the smallest SE of 0, while the face that underwent 50% of the maximum morphing had the largest SE of 0.447. Meanwhile, the subjects were confused as regards the face judgment, because the eye shape was not completely broken in the latter image, confounding the subject's judgment as the face still remains.

Experiment 3 was the test of further degrees of morphing and more chromatic variations, based on the information gathered from the first two experiments. The contours of the eyes and face were completely changed to reduce the elements of face perception. As a result, the results of Experiment 3 differed from those in Experiment 1. The color-matching results differed according to the completeness of the facial shape. We found that the presence of eyes on morphed images of faces induces the perception of faces. In addition, the starting chromatic point, if too distant from the original stimulus, increased the difficulty of the memory task.

Three experiments logically follow each other. The first experiment indicated that a lesser degree of morphing would impact the final result. The second experiment was important to determine the appropriate degree of morphing, while the third experiment increased the chromatic staring point, thereby broadening the limits of the experiment.

There was no significant difference in the natural skin color (preferred, dark, and reddish) based on change in facial shapes in Experiments 1 and 3. However, there were significant differences in b^* of unnatural skin color (orange and bluish). It was confirmed that the judgment of b^* in unnatural skin color was changed according to the change in facial shapes.

It has been known that the preferred skin color, related to memory color, plays an important role in color reproduction

[19–23]. The importance of the preferred skin color in determining the skin color was also revealed in the results of this study. Figures 5 and 10 revealed that the starting color for the color matching did not significantly affect the result of the smallest color distance from the measured stimulus. Specifically, it was difficult to judge the skin color when it was far from the preferred skin color.

Komatsu *et al.* conducted a study to measure the color selectivity of single units in the infero-temporal cortex of the macaque [24]. Based on this result, phenomenological opponent color information can be understood as processing at a stage before V4.

The color-perception mechanism of the two opponent color channels differs in the processing pathways in the brain. Parvo-cellular processing of red–green color information occurs in the ventral stream, while yellow–blue is processed by the konio-cellular pathway in the dorsal stream. Skin color, related to desaturated and bright red, pink, would be considered to be related to the processing at parvo-cells in the ventral stream before V4.

Meanwhile, V4 responds only to the same wavelength [25]. Neurons in the inferior temporal (IT) cortex have color-selective properties that respond to a narrow range of colors and saturation [26]. Certain neurons in IT are sensitive to desaturated pink, which can be associated with skin color.

As the neurons are not sensitive to white, their sensitivity to the brightness of skin colors would be considered by the involvement of the dorsal pathways, requiring further study of the interaction at higher levels.

Furthermore, there were differences between the perception of natural and unnatural skin colors based on the degree of face-like. The differences were evident in the b^* value of the CIELAB color space. If the differences of b^* are related to the s-cone and dorsal streams, it requires further physiological experiments to justify it. In addition, color spaces such as DKL color space and Macleod–Boynton chromatic diagram would be needed to clarify the differences based on the cardinal axes corresponding to the opponent color character in the lateral geniculate nuclei (LGN).

Finally, the skin-color matching according to the morphing face image was different. Therefore, we need to consider the interaction of face shape and skin-color perception. It is speculated that the interaction takes place in the processing of visual information in the temporal lobe, which is considered to be responsible for face perception (FFA)and skin perception (IT). The interaction between the face and skin-color perceptions requires further study at higher levels.

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