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The Effect of Chromatic and Lightness Components for Preferred Skin Color Reproduction on a Display

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Abstract. *It is essential to understand preferred skin colors for color reproduction in the display industry. This article presents three psychophysical experiments that were conducted to determine the preferred skin color ranges of East Asian women by East Asian observers on the chromatic and lightness components of CIELAB color space displayed on a standard sRGB-gamut display. In the first experiment, the preferred skin color was searched using various settings of correlated color temperatures (CCTs) and luminance levels on the screen. The results indicate that the most preferred skin color on a display had small differences between various images varying in CCT and luminance level. In the second experiment, a more precise preferred skin color center was produced. The preference scores were analyzed, and the preference map of skin colors was presented on the CIELAB a^*b^* plane. The final experiment examined the relationship between the lightness of facial skin color and the perceived preference on a display. It was conducted to examine the effect of the lightness component on the preference of facial skin color. It was found that the (C^*_{ab}, h_{ab}) value of the most preferred skin colors of East Asian women is (25.4, 50.5), with an L^* value of 65.*

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INTRODUCTION

In natural images, the facial area is often the main evaluated object in a visual task. Human complexion analysis plays a vital role in achieving image quality. Effectively reproducing pleasing skin colors is a crucial factor in the color reproduction of color application systems.[1] Various skin color reproduction methods have been proposed.

For color reproduction, skin color adjustment can be designed according to subjective evaluation. Observer preference is a crucial measure for image quality evaluation: it indicates the degree of observer satisfaction with a particular image. The image quality can be improved effectively by transforming the skin color in images to the preferred skin color. Therefore, it is essential to realize the preferred skin color for color reproduction.

Bartleson et al.[2–4] examined printing samples of preferred Caucasian skin color reproduction and found that the preferred skin tone appeared yellower and more chromatic than the real skin tone. Bartleson and Bray found that the preferred skin color for Caucasian complexions has the same chroma as the mean memory color of the skin tone. Hunt et al.[5] examined the preferred color reproduction of reflection prints in color photography and concluded that the preferred Caucasian skin color had almost the same purities as the real skin color but was slightly yellower. Yano and Hashimoto[6] indicated that the preferred complexion of Japanese women shifted to a slightly higher chroma and was more reddish than the real complexion of Japanese women. They found that the preferred complexion of Caucasian women was orange in the hue component, the same as the real complexion of Caucasian women, and that the color shift of saturation of Caucasian women was larger than that of Japanese women.

Novick[7] indicated that the chromaticity of preferred Caucasian skin reproductions displayed on a color television system is situated at $u = 0.271$ and $v = 0.335$ when viewing the screen image under a tungsten ambient illumination of approximately 40 lx. The averaged gray point of images was set at $u = 0.212$ and $v = 0.321$. Tarczali et al.[8] examined long-term memory colors using a color CRT monitor with a 6500 K white point setting and 116 cd/m^2 luminance. They found that East Asian skin and Caucasian skin had similar chroma, that East Asian skin was slightly yellower, and that Caucasian skin was considerably lighter than East Asian skin. Zeng and Luo[9,10] conducted experiments to verify preferred skin colors and examine inter-observer variation and tolerance on a TFT LCD display that was close to a D_{65} white point and a gamma of 2.2. Their results indicated that

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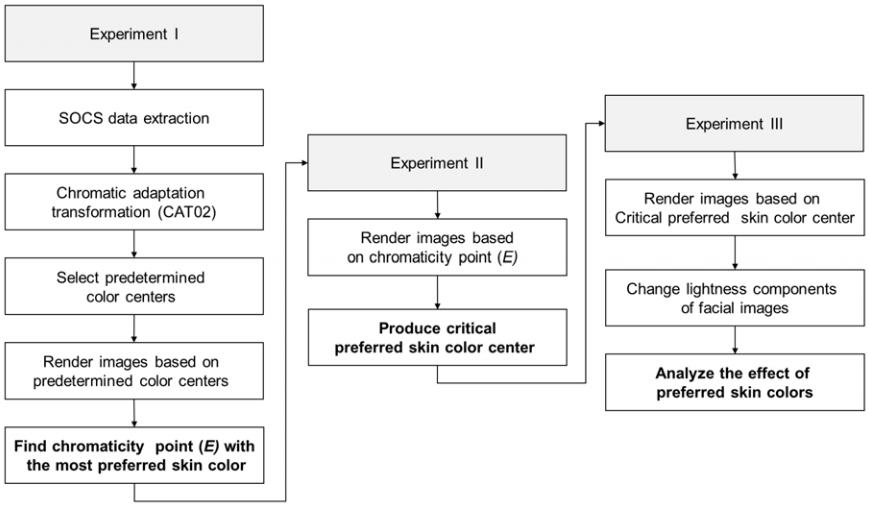

Figure 1. The workflow of this study.

the preferred skin colors are more chromatic than the real skin colors. Observer variances in skin color preference are larger in chroma than in hue. The preferred skin color center for overall testing of skin colors was approximately 21 and 24 for a^* and b^* values, respectively, with a metric hue angle of 49° for a D_{50} illuminant. The preferred Caucasian skin color is slightly yellower than the average real Caucasian skin color, and the preferred East Asian and African skin colors are slightly more reddish than their real skin colors.

Yoshikawa et al.[11] examined the metric lightness and perceived whiteness of facial skin, which is a crucial element in beautiful skin, especially for East Asian women. The experiment was conducted on a CRT monitor with a white point of D_{50} and peak luminance of 68.4 cd/m^2. They concluded that reddish skin appears whiter than yellowish skin in a high-lightness region, and that skin color with low chroma appears whiter than that with high chroma.

Most of the previous studies[7–11] on preferred skin color on displays considered only limited conditions, such as daylight conditions, D_{65}[9] or D_{50},[10] at a fixed luminance level. In this study, the first psychophysical experiment was conducted to determine the chromatic components of preferred skin color regarding the correlated color temperatures (CCTs) and luminance levels on a standard sRGB-gamut display. The second experiment refined the potential skin color region of preferable skin color and examined the relationship between the representative skin color and the score of preference.

Few studies have focused on the relationship between metric lightness and the preference of facial skin on a display. The third psychophysical experiment examined the whitening effect of the lightness component for preferred skin color.

SUBJECTIVE EVALUATION

Experimental methodology

Psychophysics is the scientific study of the relationships between the physical measurements of stimuli and the sensations and perceptions that are evoked by those stimuli.[12] A consistent conclusion is that the preferred skin colors differ from the actual skin colors. For display color reproduction, skin color adjustment can be designed according to subjective evaluation. We used psychophysical experiments to analyze the effects of changing the chromatic components and lightness of the preferred skin color. Observers rated the preference of the displayed images under various situations. The experimental design is shown in Figure 1. Three psychophysical experiments were conducted to determine a preferred skin color region.

(1) Experiment 1: To identify the color region of the preferred skin color with various settings of correlated color temperature and luminance level.
(2) Experiment 2: To refine the most preferred skin color.
(3) Experiment 3: To examine the effect of the lightness component on the preferred skin color.

Test images

The skin tones of East Asian women were investigated here. Four commonly used standard facial images were selected for all three psychophysical experiments conducted here (Figure 2). They are mainly used for assessing the image quality of imaging devices or for testing different image-processing algorithms. These are Sony standard images for Images 1 and 2, Industrial Technology Research Institute (ITRI) standard for Image 3, and ISO 12640-2 for Image 4, respectively. They were all presented in sRGB color encoding. The test images were adjusted in advance. The facial parts in the images were first segmented from the background, and the parts of the background behind the faces of people were adjusted to a mid-gray. The global luminance in the images was subsequently adjusted to be the average luminance factor value of all test images, i.e. the original mean Y values of 12.8, 14.9, 23.5, and 7.1 for Images 1, 2, 3, and 4, respectively. The average luminance value is 14.6.

Apparatus and experimental condition

Two similar computer-controlled LCD monitors (EIZO ColorEdge 241W with hardware calibration) were used to

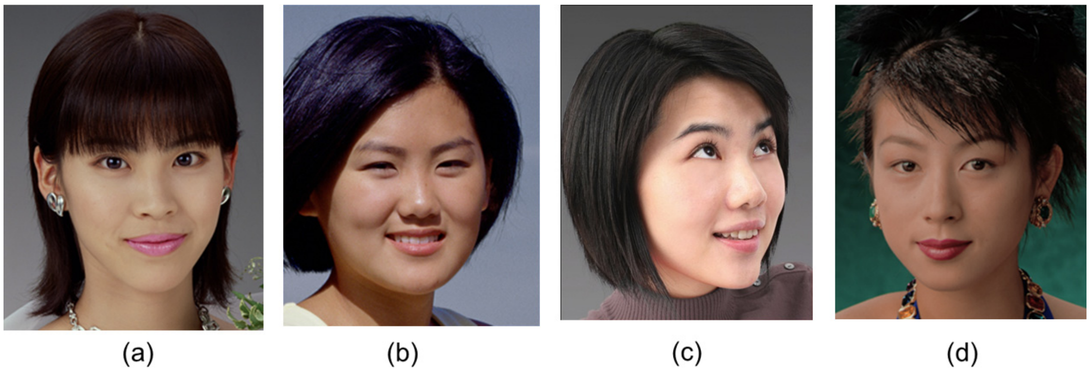

Figure 2. Test images.

display the images in a room with an illumination of 64 lx. Each monitor had a diagonal measurement of 24.1 in and a resolution of 1920 × 1200. The participants were seated in front of the monitor at a distance of 35 in. The first monitor showed the test images, and the second monitor showed the reference images.

An X-Rite EyeOne Pro spectrophotometer and Color-Navigator calibration software were used to calibrate the monitors. Within the sRGB gamut, 12 ICC profiles were generated for the monitor color characterization with a gamma value of 2.2 under combinations of four CCTs (5000 K, 6500 K, 9300 K, and 10,000 K) at luminance levels of 60 cd/m^2, 100 cd/m^2, and 200 cd/m^2.

To quantitatively check the color accuracy of the test monitors, a set of 32 color patches was created for analysis (Table I). The color patches were displayed on the screen using 12 ICC profiles, and they were measured with an X-Rite EyeOne Pro spectrophotometer. Table II shows the maximal and mean color difference (ΔE^*_{ab}) between the measured data and the color characterization data using the ICC profiles. The mean ΔE^*_{ab} values were 0.95 for Monitor 1 and 0.87 for Monitor 2. The analyzing result indicated that the color accuracy for the two test monitors using the ICC profiles was approximately 1 ΔE^*_{ab} unit on average. The color consistency between both monitors was acceptable.

Participants

East Asian observers between the ages of 22 and 45 participated in each experiment. All observers passed the Ishihara color vision test. Five color experts skilled in color imaging technology participated in Experiment I. Fourteen observers participated in Experiments II and III.

EXPERIMENT I: TO IDENTIFY THE COLOR REGION OF THE PREFERRED SKIN COLOR WITH VARIOUS SETTINGS OF CORRELATED COLOR TEMPERATURE AND LUMINANCE LEVEL

The psychophysical experiment was conducted to find the colorimetric specification of the preferred East Asian complexion with various settings of CCTs and luminance levels on a display.

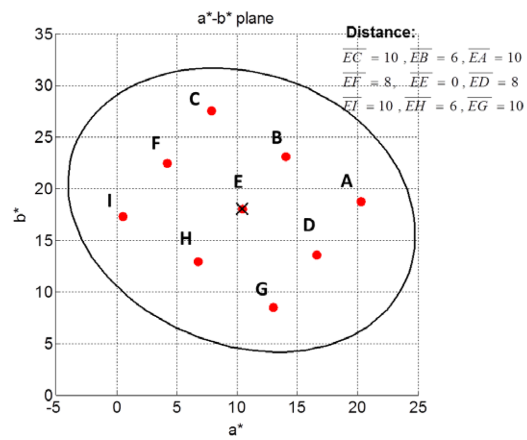

Figure 3. The nine predetermined color centers.

Skin color region

A skin color region extracted from the Standard Object Color Spectra (SOCS) database[13] was used to establish a gamut range covering skin colors adapting from 4000 K to 25,000 K for observers. This was conducted to apply chromatic adaptation transformation (CAT02)[14] to transform the tristimulus values under illuminants varying from 4000 K to 25,000 K to tristimulus values after color adaptation under the D_{65} reference illuminant. A set of nine predetermined color centers was uniformly chosen within the skin color ellipse on the CIELAB a^*b^* plane (Figure 3).

Experimental procedure

Four facial images of East Asian women were used as test images. The skin colors of each test image were mapped for the nine predetermined color centers within the skin color region on the CIELAB a^*b^* plane, and the other non-skin colors were maintained. Figure 4 is the block diagram for skin color adjustment.

The 8-bit RGB values of each pixel in a test image were first converted to the tristimulus values according to the sRGB standard procedure. Subsequently, the corresponding CIE $L^*a^*b^*$ values were transformed into $L^*d^*n^*$ color space using Eq. (1).[15] Note that the $L^*d^*n^*$ values were designed as an opponent color space. They were obtained by rotating the a^* and b^* axes to d^* and n^* axes at a constant L^* level. The a^* and b^* axes were rotated at a hue angle of h_s

Table I. 32 color patches.

No.	Color patch	8-bit RGB value	No.	Color patch	8-bit RGB value	No.	Color patch	8-bit RGB value
1		(0, 0, 0)	12		(127, 0, 255)	23		(255, 127, 127)
2		(0, 0, 127)	13		(127, 127, 0)	24		(255, 127, 255)
3		(0, 0, 255)	14		(127, 127, 127)	25		(255, 255, 0)
4		(0, 127, 0)	15		(127, 127, 255)	26		(255, 255, 127)
5		(0, 127, 127)	16		(127, 255, 0)	27		(255, 255, 255)
6		(0, 127, 255)	17		(127, 255, 127)	28		(16, 16, 16)
7		(0, 255, 0)	18		(127, 255, 255)	29		(32, 32, 32)
8		(0, 255, 127)	19		(255, 0, 0)	30		(64, 64, 64)
9		(0, 255, 255)	20		(255, 0, 127)	31		(96, 96, 96)
10		(127, 0, 0)	21		(255, 0, 255)	32		(160, 160, 160)
11		(127, 0, 127)	22		(255, 127, 0)			

Table II. The color differences between the measuring data and the color characterization data using the ICC profiles.

		Monitor 1		Monitor 2	
No.	ICC profile	Maximum (ΔE^*_{ab})	Mean (ΔE^*_{ab})	Maximum (ΔE^*_{ab})	Mean (ΔE^*_{ab})
1	5,000 K, 200 cd/m^2	2.73	0.60	2.20	0.60
2	5,000 K, 100 cd/m^2	2.59	0.77	1.93	0.69
3	5,000 K, 60 cd/m^2	2.50	0.93	3.06	1.19
4	6,500 K, 200 cd/m^2	4.11	0.81	4.54	0.74
5	6,500 K, 100 cd/m^2	3.20	0.91	3.49	0.73
6	6,500 K, 60 cd/m^2	3.72	0.20	2.84	0.92
7	9,300 K, 200 cd/m^2	4.60	0.88	3.51	0.70
8	9,300 K, 100 cd/m^2	4.80	0.90	5.57	1.02
9	9,300 K, 60 cd/m^2	5.25	1.09	3.86	0.96
10	10,000 K, 200 cd/m^2	4.54	1.05	3.97	0.84
11	10,000 K, 100 cd/m^2	5.16	1.08	4.38	1.01
12	10,000 K, 60 cd/m^2	5.17	1.18	4.23	1.09
	Average	4.15	0.95	3.63	0.87

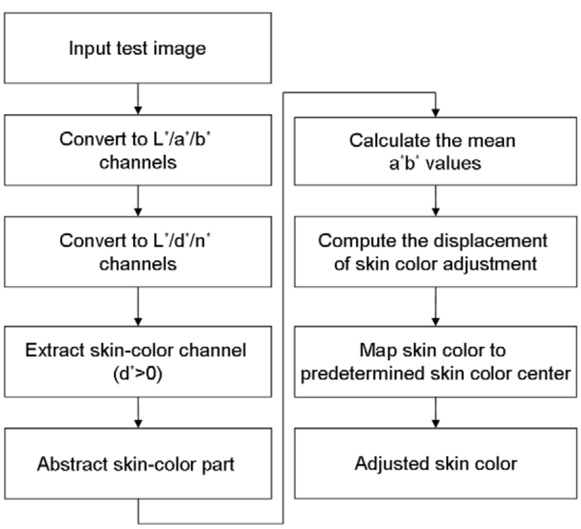

Figure 4. The block diagram for skin color adjustment.

using a 2 by 2 orthogonal matrix in Eq. (1), where h_s is the predetermined hue angle of the familiar color. As shown in Figure 5, a positive hue angle h_s is defined as rotating in a counterclockwise direction from the a^* axis, and it is defined in the radian range of $[0, 2\pi]$.

$$\begin{bmatrix} d^*(x,y) \\ n^*(x,y) \end{bmatrix} = \begin{bmatrix} \cos(h_s) & \sin(h_s) \\ -\sin(h_s) & \cos(h_s) \end{bmatrix} \begin{bmatrix} a^*(x,y) \\ b^*(x,y) \end{bmatrix}. \quad (1)$$

Here, the hue angle metrics of familiar colors were computed at 64° for facial skin color. Note that the current set of familiar colors was derived from the long-term memory color data of Tarczali et al.'s experiment[8] performed on a color-calibrated CRT monitor with a white point of 6500 K; the average hue angle for the memory colors (Caucasian/East Asian skin) was used as the references for familiar colors in this study.[8] After rotating the hue

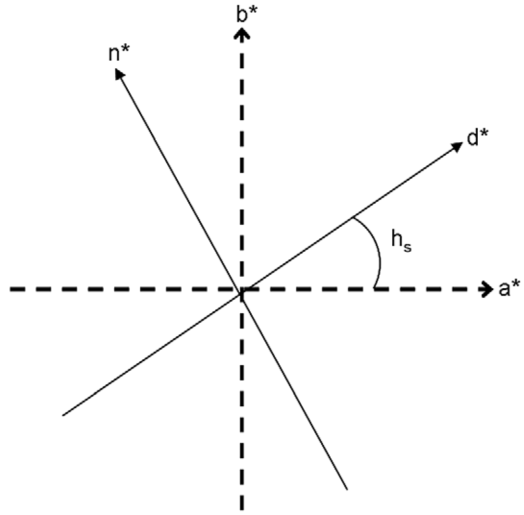

Figure 5. The concept of d^*–n^* opponent color.

angle of the familiar color, the color values (d^*, n^*) were obtained, which were expressed in the dominant skin color and non-dominant skin color respectively. After restoring the L^* values, the three orthogonal axes were formed in the new $L^*d^*n^*$ color space.

When a color image was transformed into the $L^*d^*n^*$ color channels, the dominant skin color area in an image was extracted from the d^* channel with a predetermined threshold. A predetermined threshold can be used to accurately extract the colors of the familiar objects in an image. For example, the color components with $d^* > 0$ represent a skin color in the facial skin, a cyan-blue color in the sky, or a green color in the grass. Then, the abstracted skin colors were subsequently adjusted by mapping for the predetermined color centers on the CIELAB a^*b^* plane. The displacement of skin color adjustment was the distance between the mean a^*b^* values of the extracted skin colors and the predetermined color centers.

The nine rendered images for each test image were randomly displayed on a color-calibrated LCD. The images were examined on an LCD using 12 ICC profiles, which were combinations of four CCTs (5000 K, 6500 K, 9300 K, and 10,000 K) and each at luminance levels of 60 cd/m^2, 100 cd/m^2, and 200 cd/m^2. Five color experts participated in this experiment. The observers first adapted to an 18% mid-gray background on the display until he/she felt adapted (about 1 min). For each test image, the observers were asked to view nine rendered images on the display and to choose the most liked and disliked ones. When changing to the next viewing condition, they observed the gray background until they felt adapted. These images were randomly displayed

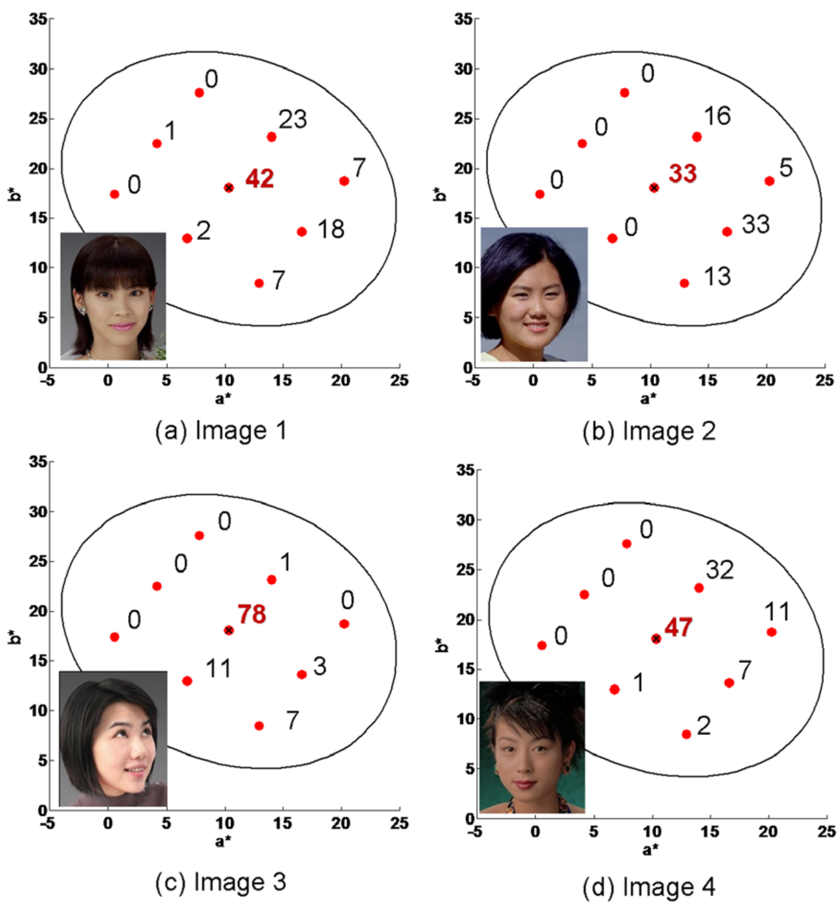

Figure 6. The preference probability (%) for each test image.

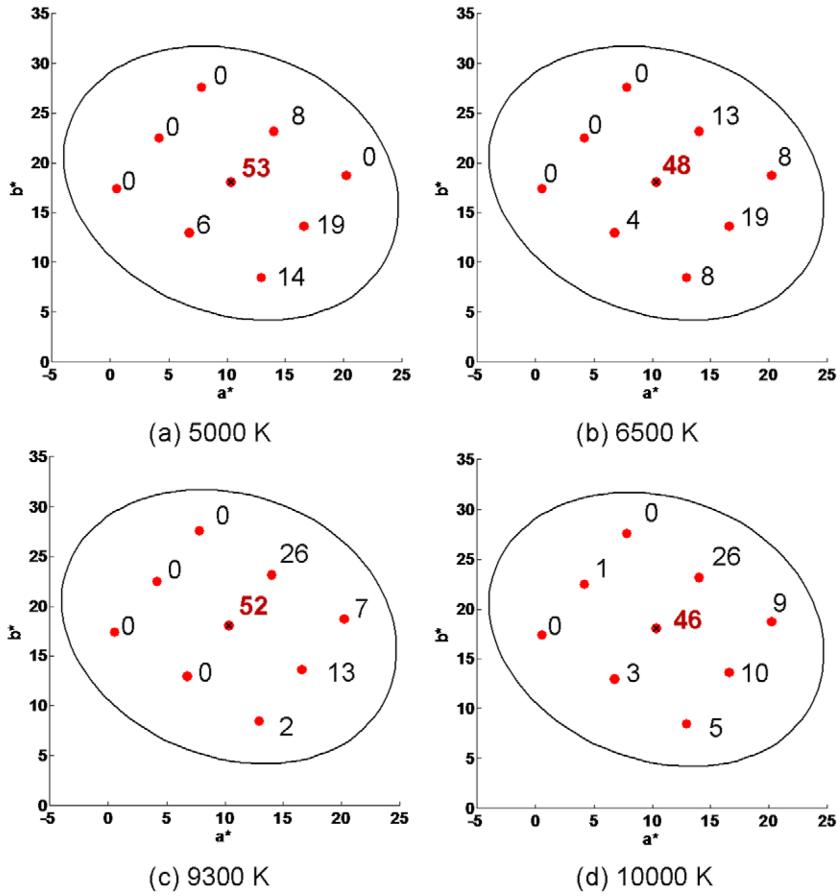

Figure 7. The preference probability (%) for each CCT.

in various locations on the display. They evaluated each rendered image twice.

RESULTS AND DISCUSSION

Figures 6–8 show the results of the rendered images in units of probability (%). The probability is defined to add up to 100% for each image. Fig. 6 shows the evaluation results of the four test images. Similar results at different chromaticity and luminance level were obtained for all test images. The "E" point with (a^*, b^*) value of (10.4, 18.1) or (C^*_{ab}, h_{ab}) value of (20.8, 60.1) was the most preferred skin color for all observers. Figs. 7 and 8 show that the "E" point was the most preferred skin color. A small difference was observed in preference because of the variability of the images, CCTs, and luminance levels. The "I" point with (a^*, b^*) value of (0.5, 17.4) or (C^*_{ab}, h_{ab}) value of (17.4, 88.4) was the least preferred skin color. The reason why the most preferred skin colors are invariant for different viewing conditions varying in CCTs and luminance levels is CIELAB itself includes a von-Kries type of chromatic adaptation. It seems to predict the present results well. It is well known that CIELAB can predict well for daylight illuminants like those daylight sources and that it performs badly for illuminants far away for daylight sources, such as F2, F11, and A illuminants.[16] In addition, a detailed inspection showed that there are some differences between CCTs, i.e. a shift of color center to be slightly red hue for 5000 K and 6500 K, and a shift towards slightly higher chroma for 9300 K and 1000 K. Figure 9 shows the trends of different CCTs analyzed by a 95% confidence ellipse. It shows that the most preferred center shifts a little. Another possible reason for the small difference was that the present nine predetermined color centers were too coarse.

For evaluating the nine rendered images of each test image with 12 ICC profiles, the color difference (ΔE^*_{ab}) values between each observer's preferred skin color centers from the first judgment and preferred skin color centers from the second judgment were used to analyze intra-observer variability. The second row in Table III shows the average ΔE^*_{ab} value of each observer for all rendered images. The average ΔE^*_{ab} from all observers for all images was 1.85. The results also show that only small differences were observed between the skin regions under various CCTs at the examined luminance levels.

EXPERIMENT II: TO REFINE THE MOST PREFERRED SKIN COLOR

Experiment II was conducted to refine the earlier skin color region around the predetermined preferred skin color center to examine the relationship between the representative skin color and the score of preference and to find a more accurate preferred skin color.

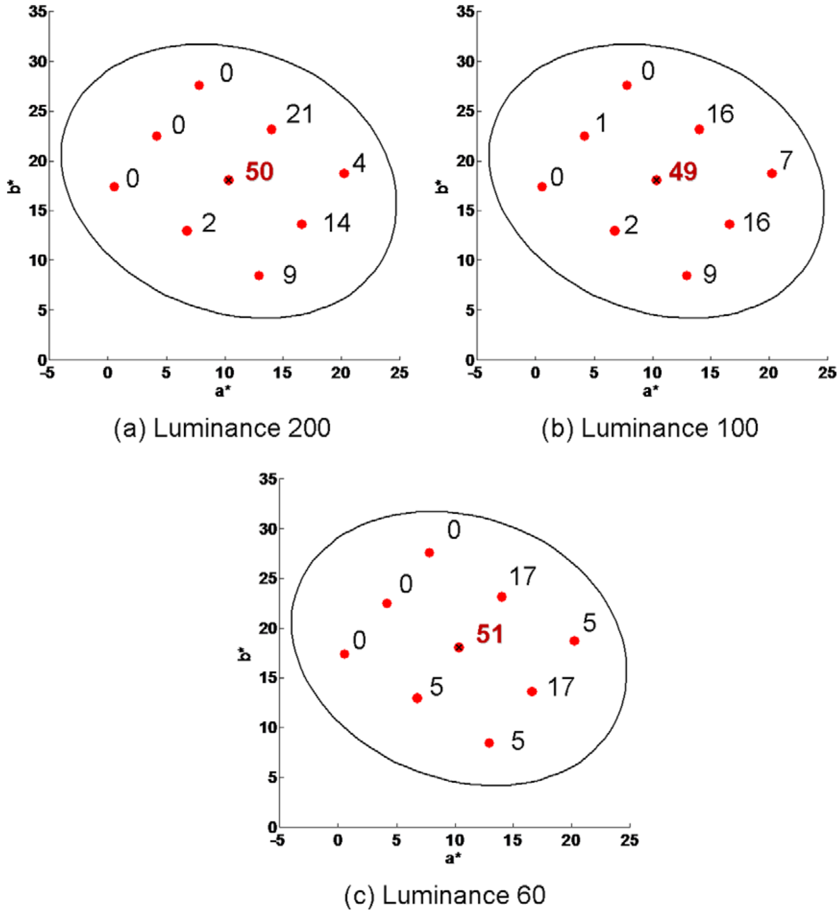

Figure 8. The preference probability (%) for each luminance level.

Table III. The intra-observer variability for experiment I.

	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5	All observers
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Mean	**2.22**	**1.69**	**1.74**	**0.59**	**3.00**	**1.85**
Maximum	9.88	9.88	9.88	6.29	14.71	10.13

Experimental procedure

The same four facial images of East Asian women from Experiment I were used in Experiment II. Sixty-one facial image candidates for each test image surrounding the color center "E" (obtained in Experiment I) were generated (Figure 10). Two sets of reference test images were chosen from all candidates by five color experts.

The LCD was set at 200 cd/m^2 and 9300 K, the most common conditions for TV systems in East Asia; the results of Experiment I indicated that the preferred skin colors on a display are independent of the CCT. The test images were displayed in random order. Eight male and six female observers participated in this experiment. The 14 observers were asked to grade the degree of preference using a 6-point category scale, in which Grade 1 was defined as *extremely disliked* and Grade 6 was defined as *extremely liked*. The observers first viewed an 18% gray background on the display until they felt adapted (about 1 min). Each observer performed the same experiment twice.

RESULTS AND DISCUSSION

Figure 11 shows the mean evaluated scores of all test images from all observers. The most preferred skin color was the "R" point with (a^*, b^*) value of (16.2, 19.6) or (C^*_{ab}, h_{ab}) value of (25.4, 50.5). Fig. 11a and b show that no obvious difference in preference score occurred because of the variability of various reference images. The average category scaling results shown in Fig. 11c indicate that the preferred color has a smaller hue angle (redder) and higher chroma compared with the center point "E" obtained in Experiment I. Figure 12 shows the relationship between preferred ratings and the average chromatic coordinates of the skin-representing pixels on the CIELAB a^*b^* plane, which were described using a bivariate Gaussian distribution.

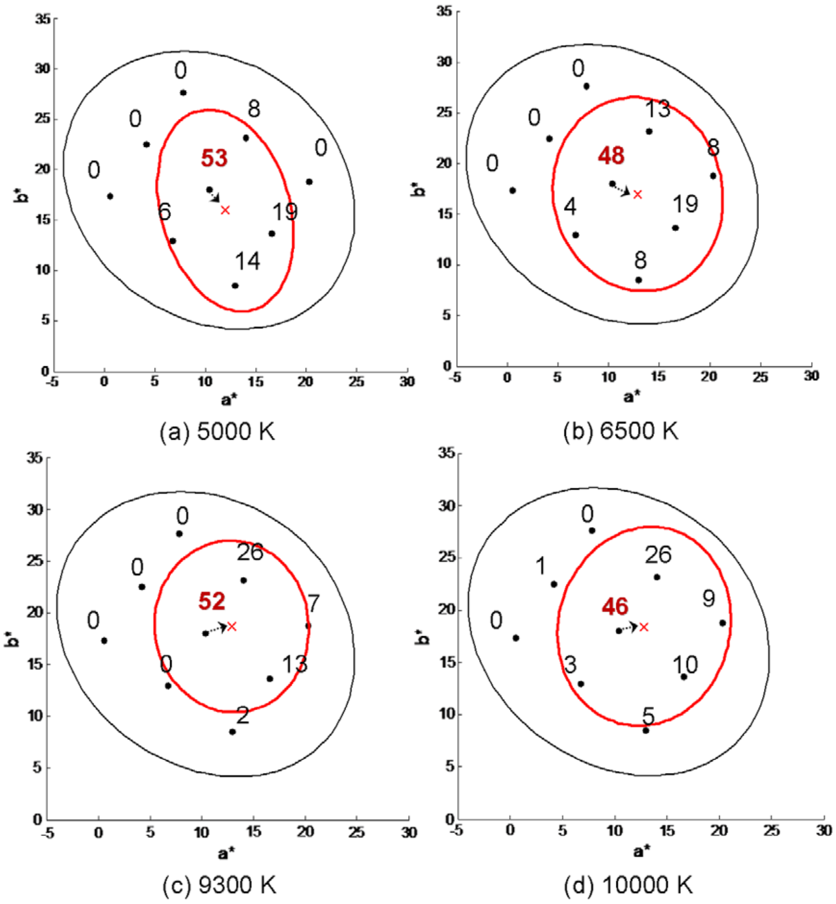

Figure 9. The preference probability (%) for each CCT and 95% confidence ellipse.

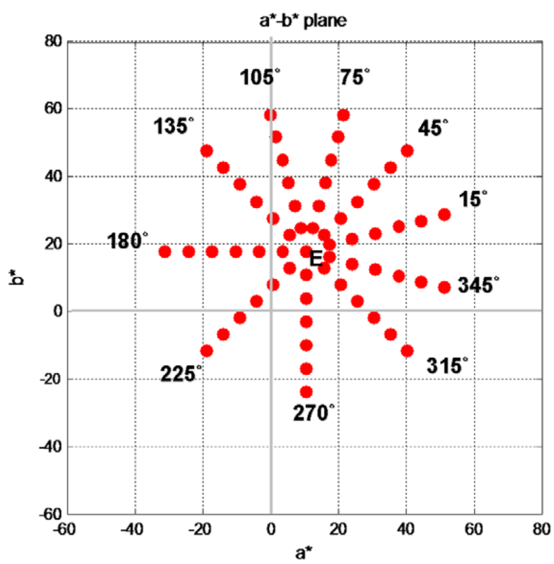

Figure 10. The 61 facial image candidates.

Only the preferred ratings with high scores from 4 to 6 were used for the calculation, because they are closer to the preferred center. The Pearson correlation coefficient between mean ratings and fitted values was 0.79.

A bivariate Gaussian distribution $R(a^*, b^*)$ (Eqs. (2)–(5)) was fitted to the preferred ratings using nonlinear curve fitting in the least-squares method.[17]

$$X = \begin{pmatrix} a^* \\ b^* \end{pmatrix}; \quad X_c = \begin{pmatrix} m_3 \\ m_4 \end{pmatrix}; \quad \Sigma^{-1} = \begin{bmatrix} m_5 & m_7 \\ m_7 & m_6 \end{bmatrix}; \tag{2}$$

$$d^2(a^*, b^*) = (X - X_c)^T \cdot \Sigma^{-1} \cdot (X - X_c); \tag{3}$$

$$S(a^*, b^*) = \exp\left(-\frac{1}{2}(d^2(a^*, b^*))\right); \tag{4}$$

$$R(a^*, b^*) = m_1 + m_2 \cdot S(a^*, b^*), \tag{5}$$

where X is the chromatic coordinates of the skin colors. The distribution center X_c represents the mean of samples, whereas the shape and orientation of the distribution are determined by the inverse of the covariance matrix Σ. The m_1 to m_7 coefficients were optimized to fit the visual data. The function $d(a^*, b^*)$ describes the Mahalanobis distance between the averaged a^*b^* coordinates of the skin-representing pixels and the preferred color chromatic coordinates. m_1 and m_2 were introduced to account for observer variability and scaling. m_3 to m_7 represent the similarity distribution $S(a^*, b^*)$.

The coefficient of variation (CV) is used to indicate the agreement among the results of observers.[18] The CV is defined in Eq. (6). Table IV shows that the mean CV values for each reference image are similar. This indicates

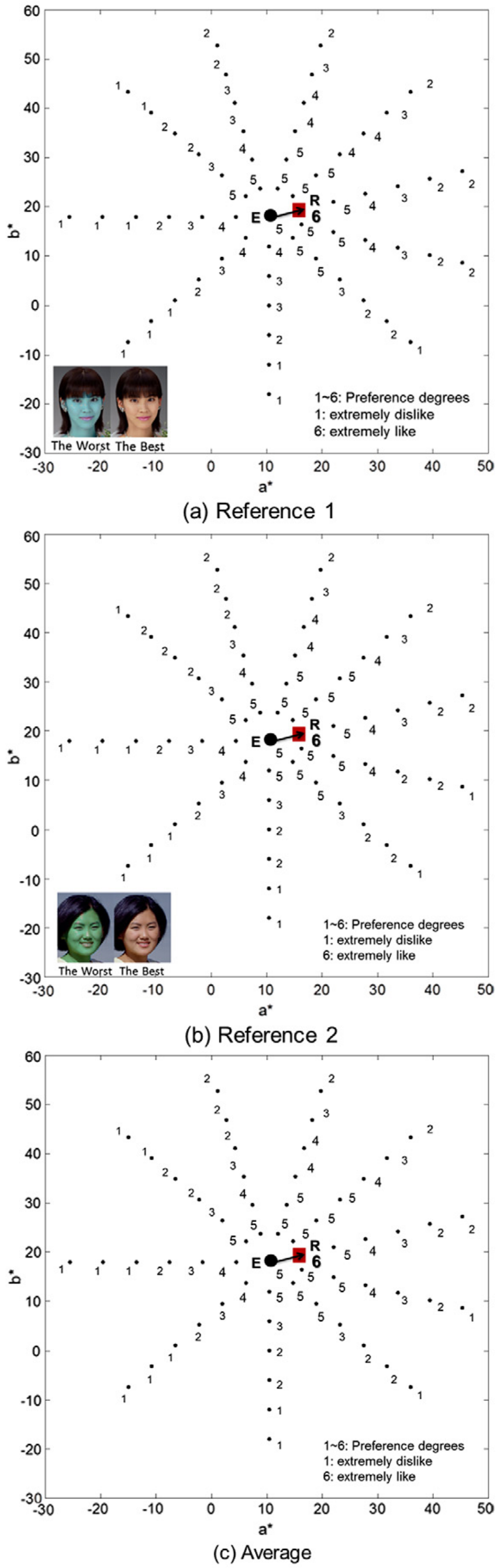

Figure 11. The category scaling results on chromatic components.

Table IV. The intra-observer variability (%) for experiment II.

Phase	CV	All observers
Reference 1	Minimum	17
	Mean	**31**
	Maximum	44
Reference 2	Minimum	19
	Mean	**31**
	Maximum	44
Average from two phases	Minimum	17
	Mean	**31**
	Maximum	42

that observer repeatability was not significantly affected by the content of the reference images. The overall mean CV was 31%,

$$\mathrm{CV} = \frac{100}{\bar{y}}\sqrt{\frac{\sum(x_i - y_i)^2}{N}}(\%) \tag{6}$$

where N is the number of facial image candidates, and $\bar{y}$ is the mean value of all y_i, where i is 1 to 14 (14 observers). x_i is the data from the first judgment of all observers, and y_i is the data from the second judgment.

Figure 13 shows a comparison of the present preferred skin color data with similar studies and an example of real skin color. The figure shows that all skin color data adapted to D_{50} on the CIELAB a^*b^* plane. The symbol "o" represents East Asian preferred skin color ("Present" in the figure). The symbol "•" represents the chromatic coordinates of East Asian real skin color from the RIT and Oulu spectral data sets ("Real Skin" in the figure).[19–21] The symbol "+" represents the East Asian preferred skin color indicated by East Asian observers on a display from the study by Zeng ("Zeng et al." in the figure).[10] The symbol "∗" represents the Japanese preferred skin color indicated by Japanese observers from the study by Yano ("Yano et al." in the figure).[6] The results indicated that all preferred skin colors appeared redder and more chromatic than the real skin colors. Yano indicated that the Japanese preferred skin that was redder than the East Asian preferred skin. This may have occurred because of differing experimental conditions, such as the use of real female models under various illumination colors. However, similar to the study by Zeng, we used a display.

EXPERIMENT III: TO REVEAL THE EFFECT OF THE LIGHTNESS COMPONENT ON THE PREFERRED SKIN COLOR

Experiment III was conducted to examine the skin preference at different lightness levels of the facial parts in each images and the effect of the lightness component on the preferred facial skin color.

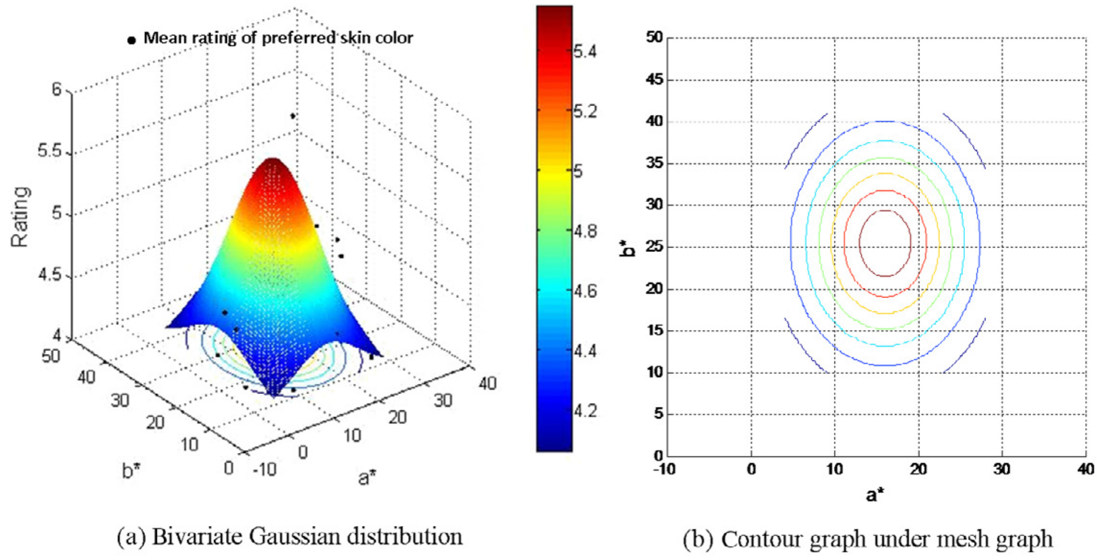

Figure 12. The three-dimensional rating map of preferred skin color fitted by a bivariate Gaussian surface and its rating contour maps on the CIELAB a^*b^* plane.

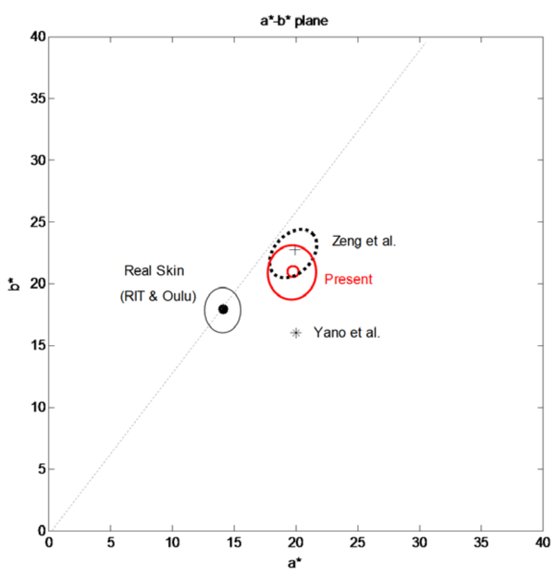

Figure 13. Comparison of preferred skin color data on the CIELAB a^*b^* plane.

Experimental procedure

The same four facial images of East Asian women were used to examine the lightness effect. First, the skin colors of each test image were mapped for the preferred skin color center ("R" point in Fig. 11) obtained in Experiment II. The lightness components of the skin colors of all test images were normalized by the average lightness value of the test images. The average lightness value was 59, relative to the lightness value of peak white of the display ($L^* = 100$). The lightness values of the facial images were subsequently adjusted from level −30 to level 30 with an interval of 3. In total, 21 facial image candidates were generated for each test image.

The test images were randomly displayed on the LCD. The reference images were chosen from all candidates in advance by five color experts. The test LCD was set under CCTs of 5000 K and 9300 K at a luminance level of 200 cd/m^2. Fourteen observers (seven men and seven women) were asked to grade the degree of preference using a 6-point category scale. The observers first adapted to an 18% gray background on the display until they felt adapted (about 1 min). Each observer conducted the same experiment twice.

RESULTS AND DISCUSSION

Figure 14 shows the evaluation results of the various test images. Similar results were obtained for each test image. The ΔL^* values of the preferred colors ranged from 3 to 12. The results indicated that the lightness component of the images changed the preferred degree of skin colors on a display, regardless of the image.

Figure 15 shows the assessment scores of all test images with various CCTs. As shown in Fig. 15a, the black solid line represents the scores for 9300 K, and the gray dashed line represents those for 5000 K. The results indicated that no significant difference in preference was observed between both CCTs.

The average category scaling results of lightness variation with various CCTs is shown in Fig. 15b. The mean score of original lightness (average $L^* = 59$) was 4.6, and the ΔL^* values of the preferred colors ranged from 3 to 12. The highest mean score was 5.2 when ΔL^* was 6. The setting of $L^* = 65$ was most preferred for all observers. When the lightness component increased, the assessment scores decreased after exceeding a certain lightness level ($L^* = 65$). The assessment scores decreased gradually with the lightness component. In general, lightness values covering the range from 62 to 71 were preferred by the observers. As regards the intra-observer variability, Table V shows that the mean CV values for each CCT are similar. This indicates that observer repeatability was not considerably affected by CCTs. The overall mean CV was 31%.

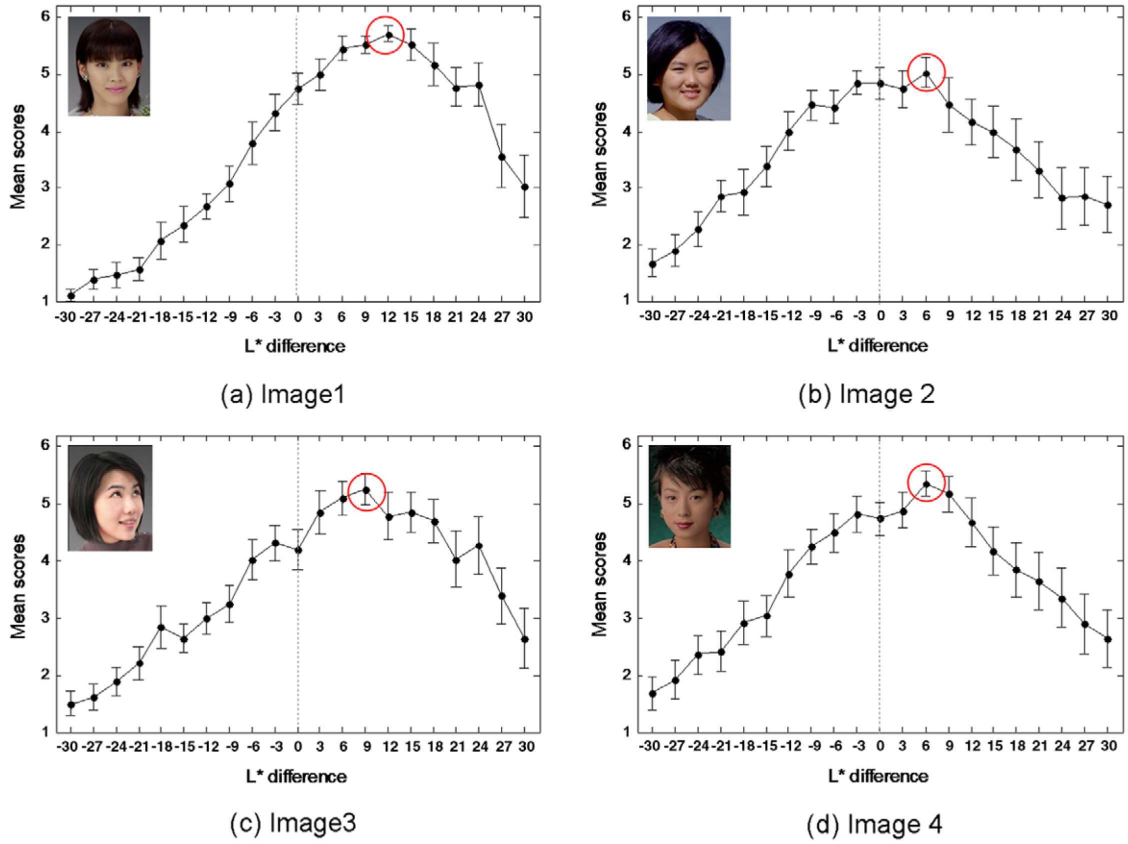

Figure 14. The category scaling results of lightness variation with different test images (L^* difference = 0 means original $L^* = 59$).

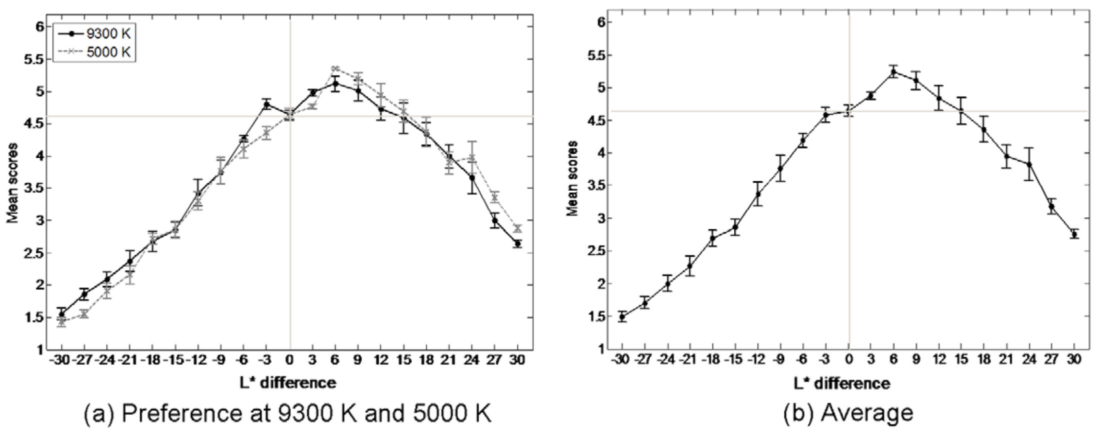

Figure 15. The category scaling results of lightness variation with different CCTs (L^* difference = 0 means original $L^* = 59$).

Yoshikawa et al.[11] examined the metric lightness and perceived whiteness of the actual facial skin of Japanese women. They concluded that reddish facial skin appeared brighter or whiter than yellowish facial skin in high-lightness regions, and that low-chroma facial skin color appeared brighter or whiter than high-chroma facial skin.

In this study, the most preferred skin color was the "R" point with (C^*_{ab}, h_{ab}) value = (25.4, 50.5). The preferred color was redder and had higher chroma compared with the center point "E" obtained in Experiment I. For skin colors mapped to the preferred chromatic point, the higher lightness ($L^* = 65$) was most preferred for all observers. The result is similar to that obtained by Yoshikawa et al.; that is, reddish and high-lightness facial skin is most preferred because it may appear brighter or whiter to observers. Note that increasing L^* of skin colors at fixed C^*_{ab} means a reduction of saturation (Eq. (7)).[22] This results in an increase of whiteness as found in the experiment.

$$\text{Saturation} = \frac{C^*}{L^*} \tag{7}$$

Table V. The intra-observer variability (%) for experiment III.

Phase	CV	All observers
9300 K	Minimum	17
	Mean	**31**
	Maximum	63
5000 K	Minimum	16
	Mean	**31**
	Maximum	46
Average from two phases	Minimum	16
	Mean	**31**
	Maximum	63

CONCLUSION

To achieve preferred skin color for enhancing facial images on a display, this study examined the recommended CIELAB specification of the most preferred facial skin colors under various settings of the peak white of luminance level and color temperature on a display.

Three psychophysical experiments were conducted to determine the preferred skin color ranges on the chromatic components and the lightness component of CIELAB color space displayed on standard sRGB-gamut displays. The experimental results indicated the preferred chromatic specification of the skin colors of East Asian women on a display to have small differences of all the images investigated in CIELAB space. The (C^*_{ab}, h_{ab}) value of (25.4, 50.5) resulted in the highest assessment score of skin color preference. This implies that the chromatic adaptation transform in CIELAB performed well. Note that CIELAB could perform not so well for non-daylight illuminants such as illuminant A. The lower CCTs (5000 K, 6500 K) showed a slightly reddish color, and higher CCTs (9300 K, 10,000 K) showed a slightly colorful appearance. The variances in skin color preference are larger in chromatic component than in the hue component.

Finally, the assessment scores of lightness component variation decreased after exceeding a certain lightness level when the lightness component increased. The mean L^* value of 65 was the most preferred for all observers and for all images. The results indicated that the lightness component of images does affect the preference scores of skin colors, regardless of the images and the CCT.

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