Effect of Chromatic Components on Facial Skin Whiteness

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Abstract: Although the color measurement of facial skin becomes more common in dermatology and cosmetics, little is known about the relationship between subjective color perception and colorimetric values in facial skin. In this study, the possible relationships among perceived whiteness and the metric lightness, chroma and hue angle of Japanese females' facial skin color were investigated. First, the perceived brightness of the facial skin of Japanese females was evaluated visually and compared with metric lightness, chroma and hue angle, and the effect of hue and chroma on the perceived brightness was discussed. Second, a psychophysical experiment on the whiteness of the facial images and synthesized skin color plate images was conducted for examining the effect of hue and chroma on the perceived whiteness more precisely and independently. The results of two experiments showed that in regard to the facial skin color of the Japanese female, metric lightness disagrees with perceived whiteness or brightness in a narrow lightness range. The reddish facial skin color appeared brighter or whiter than that of a yellowish one in high lightness regions, and the low-chroma facial skin color appeared brighter or whiter than a high-chroma one. However, in the color plate images, a change in perceived whiteness by hue could not be confirmed, and the change in perceived whiteness by chroma was weaker than that from facial images. These results indicated that a higher-level process of face recognition affected whiteness perception, and the criterion of facial skin whiteness was determined by facial skin color distribution. © 2011 Wiley Periodicals, Inc. Col Res Appl, 37, 281 – 291, 2012; Published online 15 July 2011 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.20685

Key words: skin color; whiteness; lightness; psychophysical experiment; facial recognition

INTRODUCTION

Subjective evaluation of facial skin color is widely used not only in dermatology and cosmetics but also in daily life, because facial skin color is a simple indicator of one's health condition and a criterion for choosing makeup color. In addition, objective evaluation of facial skin color using colorimeters is also common because it gives a stable evaluation quickly.[1–4]

However, some disagreements between subjective color perception and the colorimetric values have been reported with regard to the skin color. Suzuki and Munakata[5] reported that the redness–yellowness perception of skin color patches was affected only by metric lightness except for the middle lightness of facial color, regardless of hue angle. The patches appeared to be reddish in high lightness and yellowish in low lightness, regardless of hue angle. Suzuki[6] also conducted an impression evaluation of facial images of various facial skin colors. The result showed that facial skin color that has a low chroma appears to be bluish, even though both a^* and b^* are positive. These results are of interest and imply that the criterion of color perception is changeable in targeting skin color. On the other hand, little is known about a possible relationship between metric lightness and the perceived

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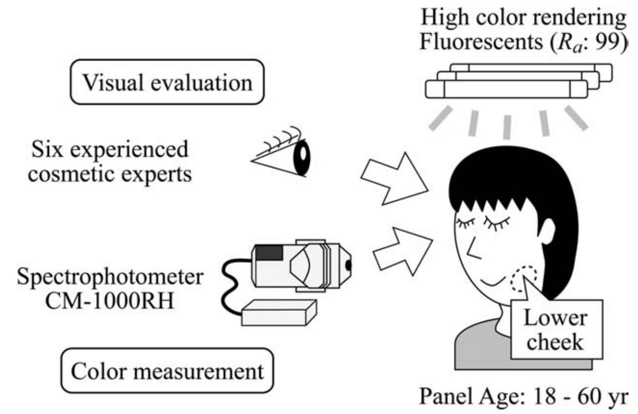

FIG. 1. Schematic illustration of the visual evaluation and the measurement of the facial skin color (experiment 1).

whiteness or brightness of facial skin, which is one of the most significant elements in skin beauty, especially for Asian women. We framed a hypothesis that perceived whiteness or brightness of facial skin color would be affected not only by lightness but also by chromatic components (hue and chroma), based on our preliminary experiment that used printed reddish and yellowish faces on paper.

To examine this hypothesis, two experiments were conducted. First, the perceived brightness of the facial skin colors of Japanese females was evaluated visually and compared with metric lightness, chroma and hue angle. Second, a psychophysical experiment on the perceived whiteness of facial images and skin color plate images was conducted for examining the effect of hue and chroma more precisely and independently.

EXPERIMENT 1

Method

Figure 1 shows a schematic illustration of experiment 1. To investigate the disagreement between perceived brightness and metric lightness of facial skin and the effect of chromatic components on perceived brightness, brightness evaluations and color measurement of facial skin were conducted with 120 Japanese females (age: 18–60 years) as subjects. The brightness of the lower cheek was evaluated by six experienced cosmetic experts visually. The visual evaluation was performed in a special room illuminated by high color-rendering fluorescent lamps (R_a: 99, correlated color temperature: 4818 K; FL20SN-EDL, Toshiba Lighting & Technology, Tokyo) at 920 lx (vertical illuminance at the subject's face level). The experts graded the brightness on a five-point scale; dark gets 1; slightly dark, 2; standard, 3; slightly bright, 4; and bright, 5.

The spectral reflectance of the lower cheek was also measured by a spectrophotometer (CM-1000RH, Konica Minolta Sensing, Tokyo), and L^*, C^*_{ab} and h_{ab} of CIE 1976$L^*a^*b^*$ color space (CIELAB) were calculated from spectral reflectance, the color-matching functions of 2° field, and the spectral power distribution of the fluorescent lamp used in the visual evaluation. C^*_{ab} was converted to corrected metric chroma C_c, as mentioned in the next section. The brightness scores were compared with L^*, C_c and h_{ab}.

Correction of C^*_{ab}

Munsell color system can be regarded as one of the color order systems based on human color perception. CIELAB is the approximate color space of the Munsell color system, considering the development process. The color attributes of CIELAB (L^*, C^*_{ab} and h_{ab}) can be calculated from X, Y and Z by simple formulas quickly. Therefore, the color attributes are suitable for our experiment to manipulate the massive color data from facial images. However, the contours of constant Munsell chroma plotted in the a^*–b^* plane shows that CIELAB metric chroma (C^*_{ab}) is distorted, especially near 5Y when compared with Munsell chroma.[7] Because of the distortion, reddish skin is transformed into lower C^*_{ab} than a yellowish one with the same Munsell chroma.

To rectify the distortion of C^*_{ab}, a correction formula was developed from 144 Munsell color data in the skin color range. The 144 color data were selected based on Japanese female facial skin color distribution, and the data were composed of six 'hues' (7.5R, 10R, 2.5YR, 5YR, 7.5YR and 10YR), six 'values' (5, 5.5, 6, 6.5, 7 and 7.5), and four 'chromas' (2, 3, 4 and 5). The data were transformed from X, Y and Z under Illuminant C to the corresponding colors under the lamps used in the visual evaluation using CIECAM02.[8] The viewing condition parameters used in CIECAM02 were as follows. Averaged surround, L_A: 318 cd/m^2 and Y_b: 20. Six corresponding colors that have the same value and chroma (e.g., 7.5R–10YR 6.5/4) in a hue became a set of data, and the difference between C^*_{ab} of each corresponding color and the average C^*_{ab} of the data set (ΔC^*_{ab}) was calculated in six hues. ΔC^*_{ab} was estimated from L^* and h_{ab} by multiple regression analysis. As a result, the corrected C^*_{ab} (C_c) was expressed by the following equation.

$$\begin{aligned} C_c &= C^*_{ab} + \Delta C^*_{ab} \\ &= C^*_{ab} + 0.02L^* - 0.17h_{ab} + 7.89 \end{aligned} \quad (1)$$

Figure 2 shows a comparison between the two metric chromas (C_c and C^*_{ab}) and Munsell chroma. The correlation coefficients between C_c and Munsell chroma was 0.992, and it was better than that between C^*_{ab} and Munsell chroma, 0.975, in 120 facial skin color data. In conclusion, C_c was a useful chroma index that showed the quick transformation of color data, which corresponded to human color perception, although it was effective for only the skin color range.

Results and Discussion

Figure 3 shows the relationship among the measured L^*, C_c and h_{ab} and the brightness scores. In Fig. 3, the circle size shows the averaged brightness scores. Briefly, the brightness score was thought to increase with an increase in L^*. However, the brightness score seemed to be affected by h_{ab} and C_c with regard to the narrow L^* range. The L^* value was divided into six categories by step of value of 1.5; 64.0, 64.0–65.5, 65.5–67.0, 67.0–

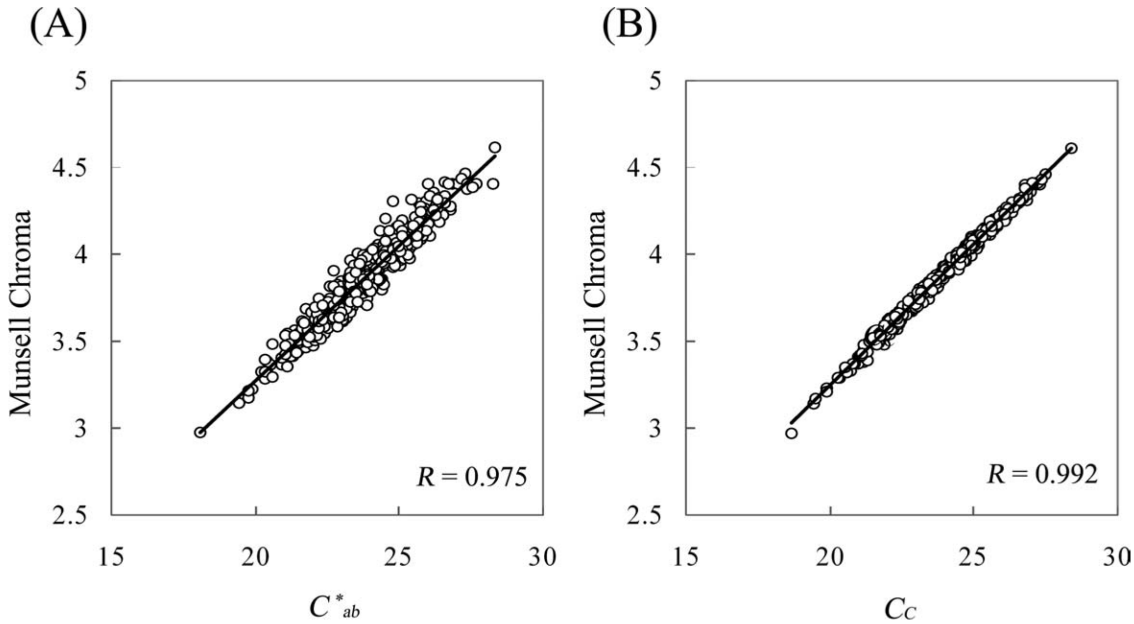

FIG. 2. Comparison between two colorimetric chromas and Munsell chroma. (A) CIELAB metric chroma C^*_{ab}. (B) Proposed metric chroma C_c. The solid lines are regression lines calculated by the method of least squares, and R is the correlation coefficient.

68.5, 68.5–70.0 and 70.0. Table I shows the correlation coefficients between the brightness scores and L^*, those and C_c, and those and h_{ab} were calculated in each category for investigating the hue and chroma effects on the brightness score.

The brightness score showed a poor correlation with L^* except in the category 6 and a negative correlation with h_{ab} except in categories 6 and 4. The brightness score also showed a negative correlation with C_c, especially in the high L^* category, suggesting that in categories 6 and 4, the different results from other categories were caused by an insufficient number of samples and the narrow range of h_{ab}, respectively. Figure 4 shows the relationship between the brightness scores and L^*, those and C_c, and those and h_{ab} in category 2. From these results, a low-hue angle or reddish facial skin color was found to appear brighter than a high-hue angle or yellowish one with almost the same metric lightness. A low-chroma facial skin color was also found to appear brighter than a high-chroma one with almost the same metric lightness. However, the brightness evaluation of actual facial skin color had a possibility of being affected by other factors, e.g., features, wrinkles and sagging. Furthermore, the effects of hue and chroma could not be investigated independently in experi-

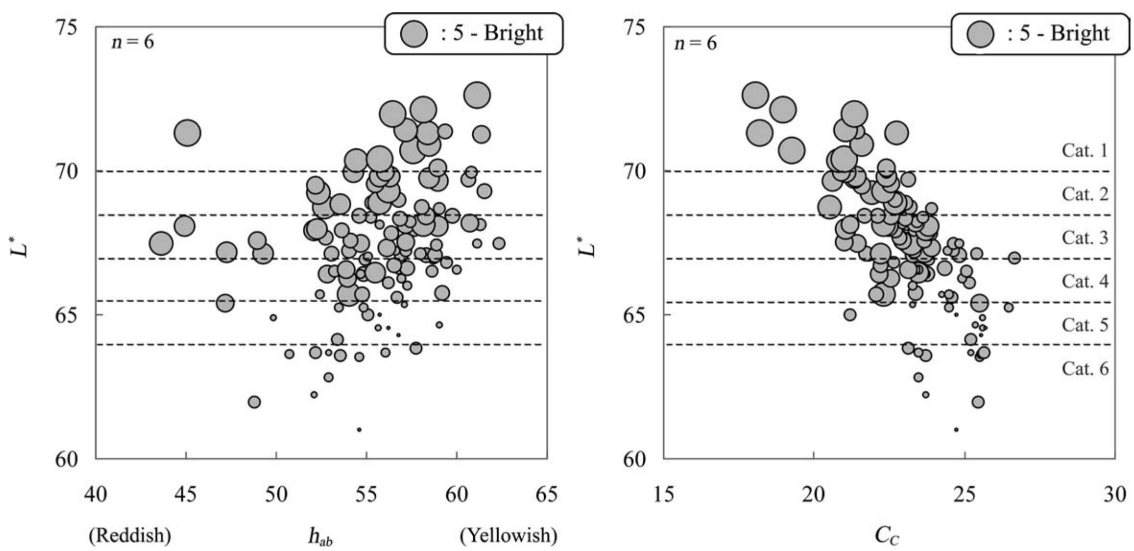

FIG. 3. Relationship among the brightness scores and L^*, h_{ab}, and C_c. The size of the closed circles shows the averaged brightness scores. In the upper right corner of both graphs, the circle shows the size of score 5 (bright); n is the number of observers.

TABLE I. Characteristics of L^* categories and the correlation coefficients between brightness scores and CIELAB attributes.

Category	L^* range	Sample number	h_{ab} range	Correlation coefficients[a] L^*	C_c	h_{ab}
1	70.0∼	13	16.28	0.16	−0.62	−0.49
2	68.5–70.0	20	9.41	0.04	−0.55	−0.69
3	67.0–68.5	40	18.70	0.03	−0.37	−0.59
4	65.5–67.0	24	7.56	0.07	−0.44	−0.25
5	64.0–65.5	12	11.83	0.31	−0.20	−0.70
6	∼64.0	11	8.93	0.51	0.12	−0.20

[a] Correlation coefficients between the brightness scores and L^* these and h_{ab} and those and C_c were calculated.

ment using actual human beings. Therefore, it was necessary to adopt a single standard facial image the h_{ab} and C_c of which could be changed independently as stimuli.

EXPERIMENT 2

Method

To examine the effect of hue and chroma on perceived whiteness more precisely and independently and the interaction of hue and chroma effects, a psychophysical experiment using artificial images was conducted. Instead of 'brightness', 'whiteness' was used as an evaluation word in experiment 2. Whiteness is thought to be more suitable for the expression of facial skin color change from light to dark, because it is commonly used in facial skin evaluation.

Correction of C^*_{ab}

The correction of C^*_{ab} was conducted using the corresponding colors under the CIE supplementary standard illuminant D50 by CIECAM02 in the same way as experiment 1. As a result, the corrected C^*_{ab} (C_c) was obtained by the following Eq. (2):

$$\begin{aligned} C_c &= C^*_{ab} + \Delta C^*_{ab} \\ &= C^*_{ab} + 0.02L^* - 0.15h_{ab} + 7.12 \end{aligned} \qquad (2)$$

The correlation coefficient between C_c and Munsell chroma was 0.996, and that between C^*_{ab} and Munsell Chroma was 0.964 in 560 facial skin color data. The former was better than the latter.

Stimulus

An artificial facial image of a young Japanese female and a skin color plate image were used for examining the effect of facial recognition on perceived whiteness. These images are shown in Fig. 5. The features of the facial image were morphed into those of an averaged young Japanese female face, which was made from 40 females, for minimizing the effect of features on the evaluation. The facial image had a visual angle of 16.6° × 12.9°. The skin color plate image was a uniformly colored square 10.1° × 10.1° that had the same area as the skin color area of the facial image. These images were displayed with a 20% gray background and a white reference frame of 1.2° having the chromaticity coordinates of D50.

The color change of the facial image was applied to averaged L^*, C_c and h_{ab} of the skin color area. The area was determined by trial and error and defined as $20 \leq L^* < 90$, $0 \leq a^* < 50$ and $0 \leq b^* < 50$. Color change variation was determined using 560 facial skin colors that were the averaged colors of the forehead, upper cheek, lower cheek and neck of Japanese females. 'Scale images', which simulated the facial skin color change from dark skin to light skin naturally, were used as references in the experiment. They were prepared for having L^*: 56–73 with an interval of 1, average h_{ab} and appropriate C_c ($C_{c,ap}$) for each L^*. Figure 6 shows the relation between L^* and C_c of the 560 facial skin colors. The $C_{c,ap}$ could be derived from the relation between L^* and C_c of the facial skin colors because metric chroma correlated strongly with metric lightness in the facial skin color. The calculation equation for obtaining $C_{c,ap}$ was the following Eq. (3):

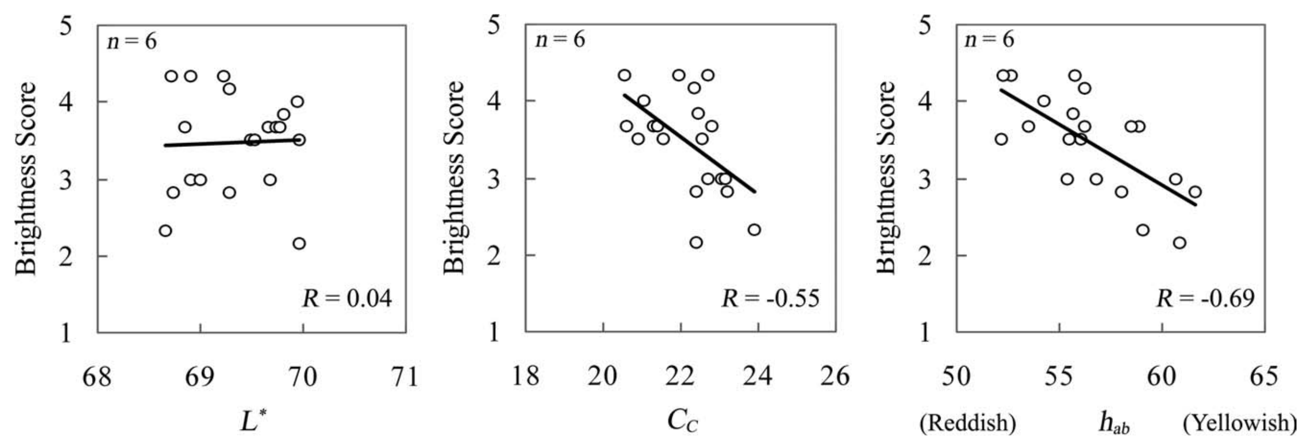

FIG. 4. Relationship between the brightness scores and L^*, those and C_c, and those and h_{ab} in category 2. The solid lines are regression lines calculated by the method of least squares, R is the correlation coefficient and n is the number of observers.

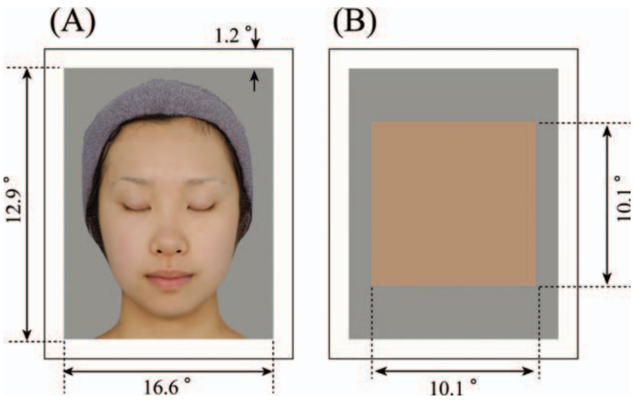

FIG. 5. Facial image (A) and skin color plate image (B).

$$C_{c,ap} = -0.50L^* + 56.0 \quad (3)$$

The colors of all images are shown in Fig. 7. ‘Test images’ were evaluated for their whiteness in the two experiments. Examples of the test images (facial image, L^*: 64) are shown in Fig. 8. In a hue change experiment, test images were prepared for having L^*: 60–68 with an interval of 2 (5 L^* series), h_{ab}: 45–60 with an interval of

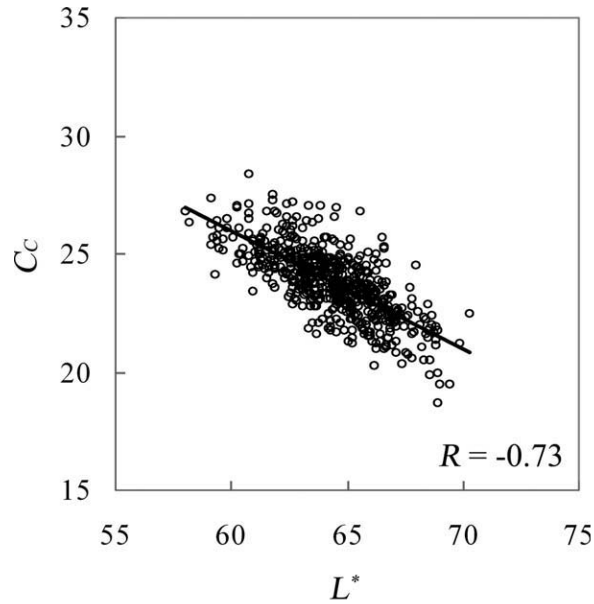

FIG. 6. Relationship between L^* and C_c of facial skin color of Japanese females (the averaged colors of the forehead, upper cheek, lower cheek and neck). The solid line is a regression line calculated by the method of least squares, and R is the correlation coefficient.

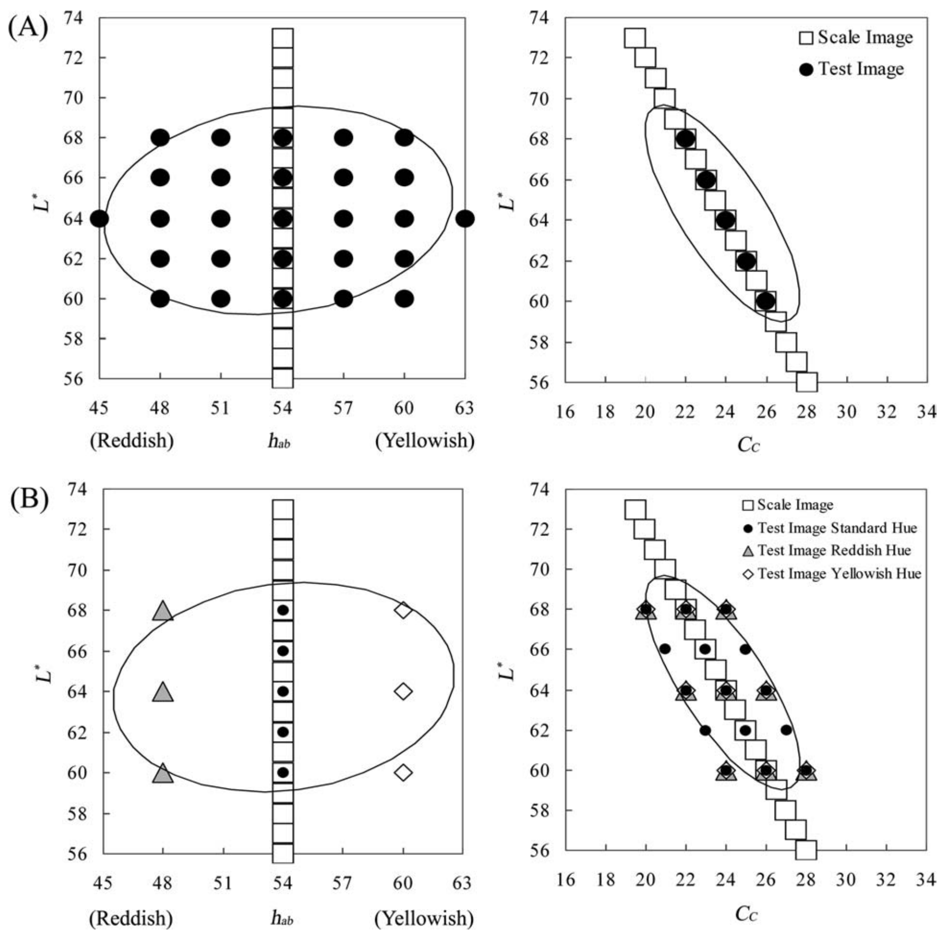

FIG. 7. Scale images and test images used in experiment 2 were plotted with various kinds of marks in the h_{ab}–L^* and C_c–L^* planes. (A) Hue change experiment. (B) Chroma change experiment. The ellipses are 95% confidence ellipses of the facial skin color of Japanese females.

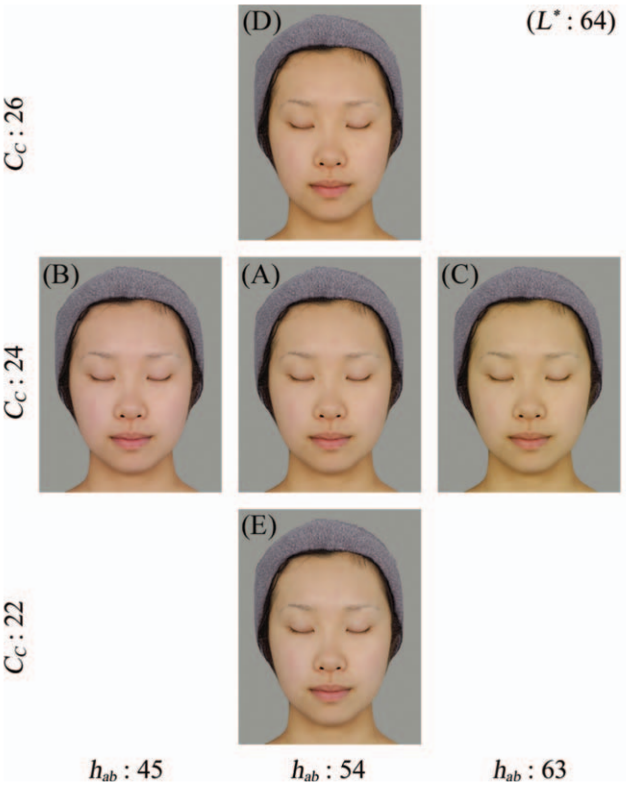

FIG. 8. Examples of test images (facial images, L^*: 64). (A) Standard hue, $C_{c,ap}$. (B) Reddish hue, $C_{c,ap}$. (C) Yellowish hue, $C_{c,ap}$. (D) Standard hue, $C_{c,ap} + 2$. (E) Standard hue, $C_{c,ap} - 2$.

3 and $C_{c,ap}$ for each L^*. In a chroma change experiment, they were prepared for having L^*: 60–68 with an interval of 2 (5 L^* series), h_{ab}: 54 (standard) and $C_{c,ap}$ for each L^*, $C_{c,ap} + 2$ and $C_{c,ap} - 2$. Additionally, reddish and yellowish hues were used for examining the interaction of the effect of hue and chroma on perceived whiteness. These images were prepared for having h_{ab}: 48 (reddish) and 60 (yellowish) and L^*: 60, 64 and 68 (3 L^* series) and the same $C_{c,ap}$ variation as the standard hue. The interval of the stimulus was determined based on the reproducible accuracy of the display.

Apparatus

Figure 9 shows the apparatus of experiment 2. An observer was seated at a distance of 0.60 m from the screen in a dark room. The stimuli were displayed on a CRT display (CDT2141A, TOTOKU Electric, Tokyo), the white point of which was set at D50 with 68.4 cd/m^2 of peak luminance. The calibration of the display was made by a spectroradiometer (CS-1000, Konica Minolta Sensing). The reproducible accuracy was checked by 15 target colors from the facial skin color range of Japanese females. The averaged ΔE^*_{ab} between the target color data and the reproduced color measured by the spectroradiometer was 0.85, which was enough for our experiment.

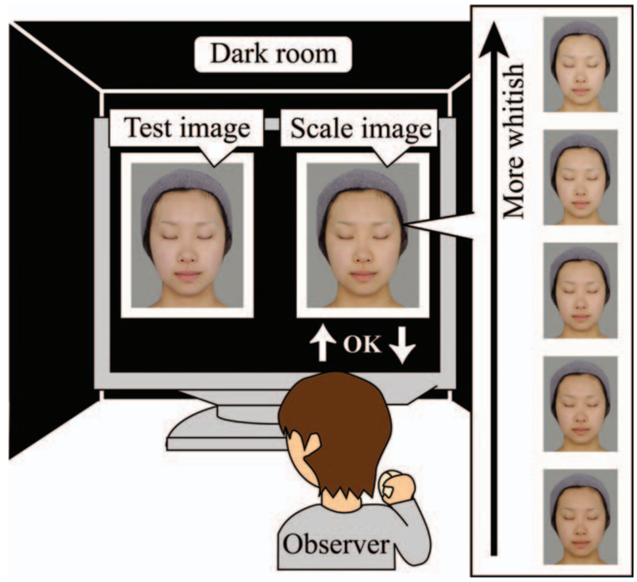

FIG. 9. Scheme of experiment 2 in the case of the facial images. An observer selected one of series of scale images that matched the whiteness of the test image using up and down arrow buttons.

Procedure

Figure 9 also shows the procedure of experiment 2 in the case of the facial image. A matching experiment using a method of adjustment was conducted by 20 Japanese female observers having normal color vision. Half of the observers were in their 20s and the rest were in their 50s. They had never participated in this kind of experiment and were not informed about the purpose of the experiment. After they adapted to the dark room and white point for a minute each, they were instructed to adjust the L^* of the scale image to match the perceived whiteness of the scale image with that of the test image using up and down buttons. L^* of the matched scale image corresponds to the perceived whiteness of the test image. The type of scale image (facial image or skin color plate image) was the same as the test image.

Results and discussion

L^*s of the matched scale images were grouped into those of the observers in their 20s and 50s. The data of each group were averaged separately. Figure 10 shows the results of the hue change experiment with observers in their 20s for the facial images and the skin color plate images. Figure 10 showed that (1) a low-hue angle or reddish hue increased perceived whiteness, (2) a high-hue angle or yellowish hue decreased perceived whiteness in the facial image having light skin color and (3) the change in perceived whiteness by hue could not be confirmed in the skin color plate images. Significance tests for regression slopes in linear regression analyses showed that L^*s of the matched scale images were inversely correlated with h_{ab}s significantly in L^*: 68, 66 and 64 of the facial images, and uncorrelated with h_{ab} in all L^*s of the

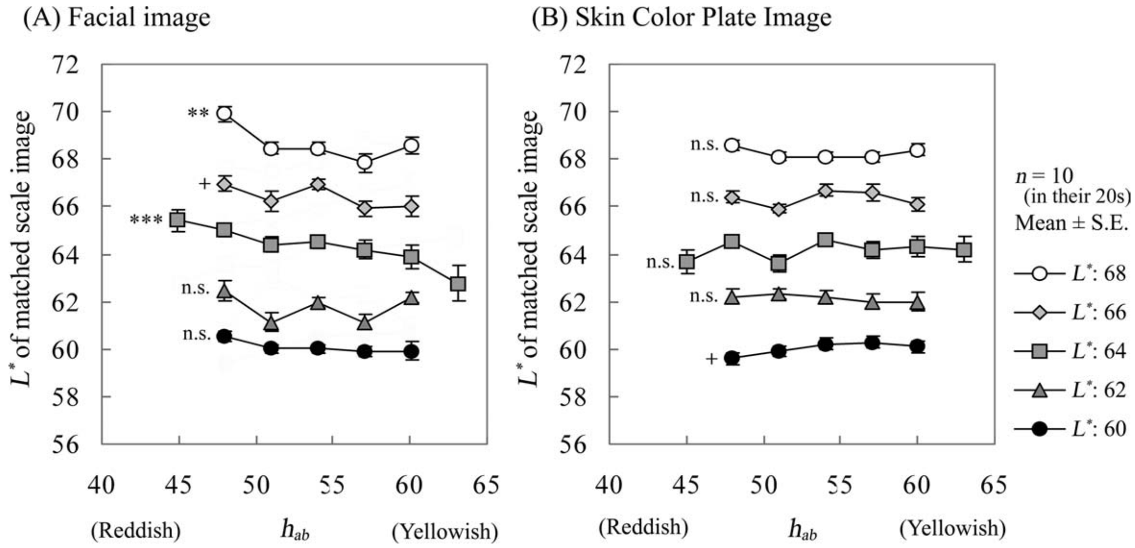

FIG. 10. Results of hue change experiment with observers in their 20s. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of h_{ab}. The symbols represent L^* of the test images. Error bars show the mean standard errors. $+\ p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. not significant; n is the number of observers.

skin color plate image except L^*: 60. These results indicated that a higher-level process of facial recognition affected perceived whiteness. Therefore, it is reasonable to assume that the criterion for the whiteness of facial skin color was determined by its distribution. Figure 11 shows the facial skin color distribution of Japanese females (the averaged colors of the lower cheek, upper cheek, forehead and neck). The hue angle correlates weakly with metric lightness, and the lightness decreases with a decrease in hue angle, which corresponds to becoming reddish. As a result, making facial skin color reddish without a decrease in lightness increased the perceived whiteness. The phenomenon was never observed in skin color plate images because the hue angle failed to correlate with metric lightness, except in facial skin.

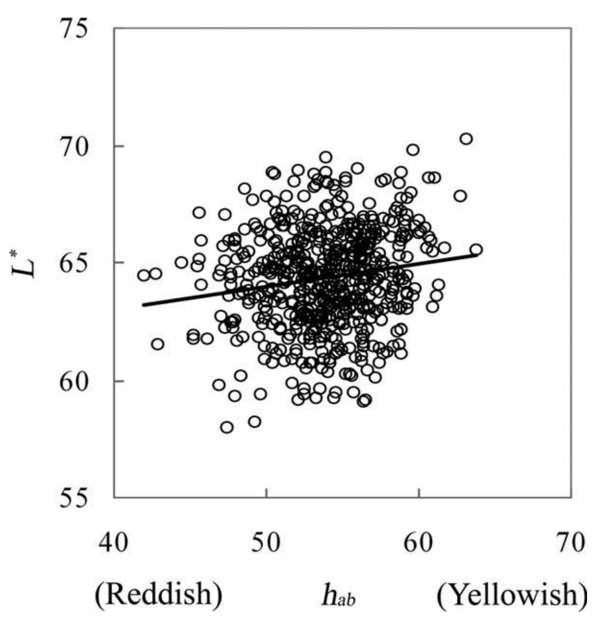

FIG. 11. Facial skin color distribution of Japanese females (the averaged colors of the lower cheek, upper cheek, forehead and neck). The solid line is a regression line calculated by the method of least squares.

Figure 12 shows the results of the chroma change experiment with observers in their 20s for the use of the standard hue in the facial image and the skin color plate images. Figure 12 clearly shows that (1) low-chroma increases perceived whiteness, (2) high-chroma decreases perceived whiteness and (3) the change in perceived whiteness by chroma in the skin color plate images is weaker than that in the facial images. Significance tests for regression slopes in linear regression analyses show that L^*s of the matched scale images were inversely correlated with C_c significantly in all L^*s of the facial images and skin color plate images. In general, brightness increases with increasing chroma at constant lightness, which is known as the Helmholtz–Kohlrausch effect.[9] However, the results indicate the opposite trend of the Helmholtz–Kohlrausch effect. Consequently, this trend is similar to the whiteness of the Natural Color System (NCS),[10] which increases sharply with decreasing chroma at constant lightness in the high lightness region of the vicinity of Y50R that corresponds to the facial skin color of Japanese females. The whiteness of skin color, the definition of which was not communicated to the observers, was thought to be the concept similar to the whiteness of NCS. Additionally, in the skin color plate images, a very weak Helmholtz–Kohlrausch effect, which was thought to be a phenomenon found only in a simple color plate, decreased the trend of whiteness. Therefore, it is reasonable to conclude that the increase in whiteness by a decrease in chroma of the skin color plate images was weaker than that in the facial images.

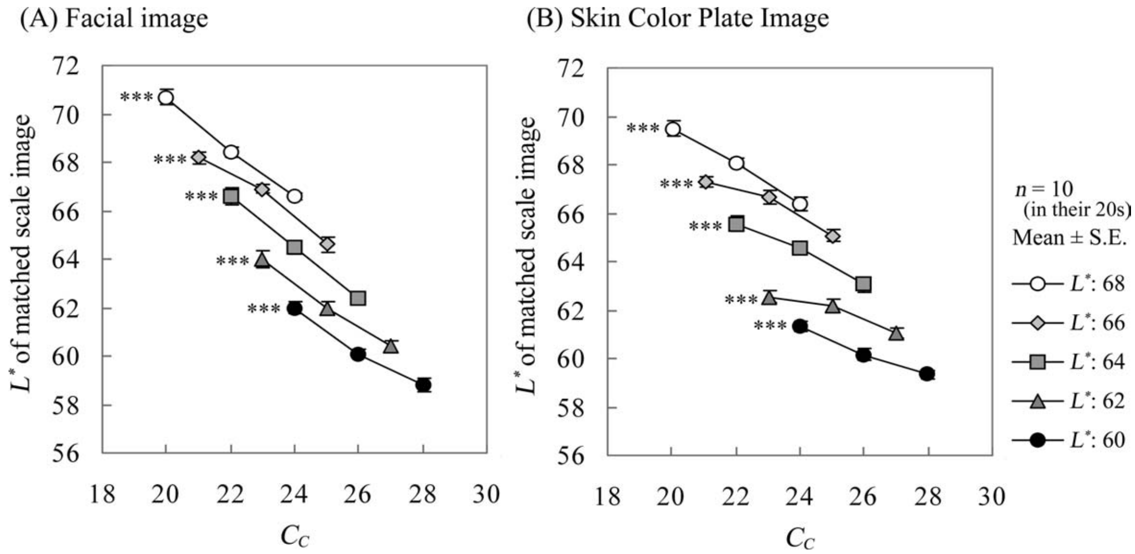

FIG. 12. Results of chroma change experiment with observers in their 20s. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of C_c. The symbols represent $L^*$of the test images. Error bars show the mean standard errors. $+\ p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. not significant; n is the number of observers.

Figure 13 shows the results of the chroma change experiment with observers in their 20s for the use of reddish, standard and yellowish hues in the facial images and the skin color plate images. The slopes of three hues of L^*: 60, 64 and 68 were found to be similar to each other. The result indicate that the interaction of hue and chroma effects on the perceived whiteness was unconfirmed. In conclusion, hue and chroma affect the perceived whiteness independently.

Figure 14 shows the results of the hue change experiment with observers in their 50s for facial images and skin color plate images. Figure 15 shows the results of the chroma change experiment with observers in their 50s for the use of the standard hue in facial images and skin color plate images. In these observers, the change in perceived whiteness by chroma was similar to that of those in their 20s. On the other hand, the change in perceived whiteness by hue was not confirmed in the facial images, the yellowish hue increased perceived whiteness, and the reddish hue decreased perceived whiteness in the skin color plate images. Regression analyses showed that L^*s of the matched scale images were uncorrelated with h_{ab}s in all L^*s except L^*: 66 of the facial images, and inversely correlated with h_{ab}s significantly in all L^*s except

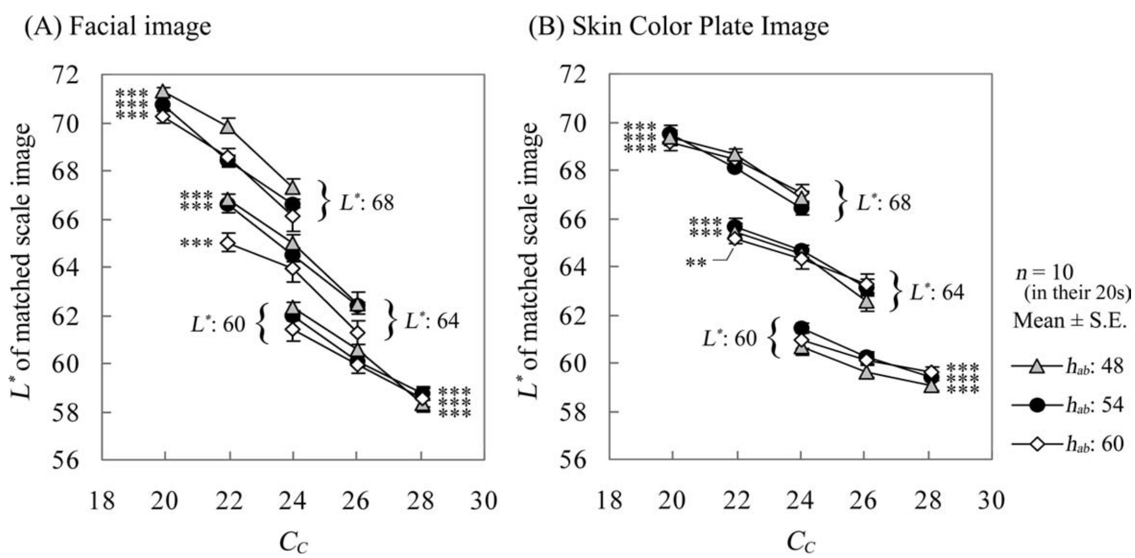

FIG. 13. Results of chroma change experiment with observers in their 20s for the use of the reddish, standard and yellowish hues. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of C_c. The symbols represent h_{ab} of the test images. Error bars show the mean standard errors. $+\ p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. not significant; n is the number of observers.

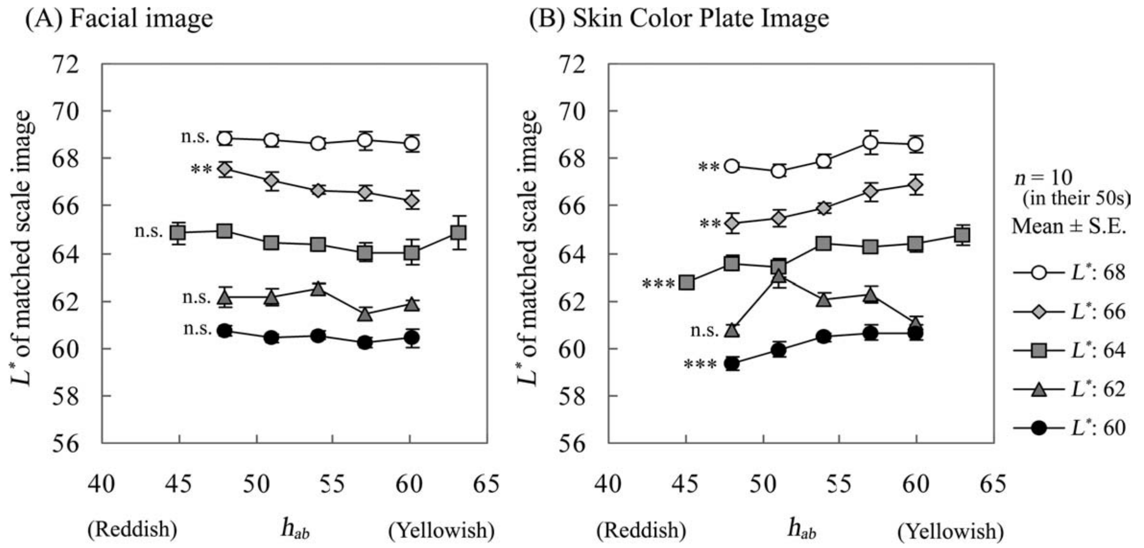

FIG. 14. Results of hue change experiment with observers in their 50s. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of h_{ab}. The symbols represent $L^*$of the test images. Error bars show the mean standard errors. $+ p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. not significant; n is the number of observers.

L^*: 62 of the skin color plate images. But the results of the hue change experiment were different from those of the observers in their 20s. Concerning the color plate images, the results of the observers in their 50s indicated that the reddish hue increased perceived whiteness, the yellowish hue decreased perceived whiteness in the facial images, and the results were thought to be similar to those of the observers in their 20s.

There is a possibility that the yellow discoloration of the lenses in the eyes with aging raised these results of the observers in their 50s. Figure 16 shows the results of the chroma change experiment of the observers in their 50s for the use of the reddish, standard and yellowish hues in the facial images and the skin color plate images. The slope of the yellowish hue was found to be smaller than those of the other hues, especially in high L^* in the skin color plate images, and L^* of the matched scale images was uncorrelated with C_c only in L^*: 68 and h_{ab}: 60 of the skin color plate images with the observers in their 50s. The results suggest that the apparent chroma of the yellowish hue stimulus decreased due to the difficulty of distinguishing between white or light gray and yellowish skin color caused by yellow discoloration of the lenses. As a result, the yellowish hue increased the

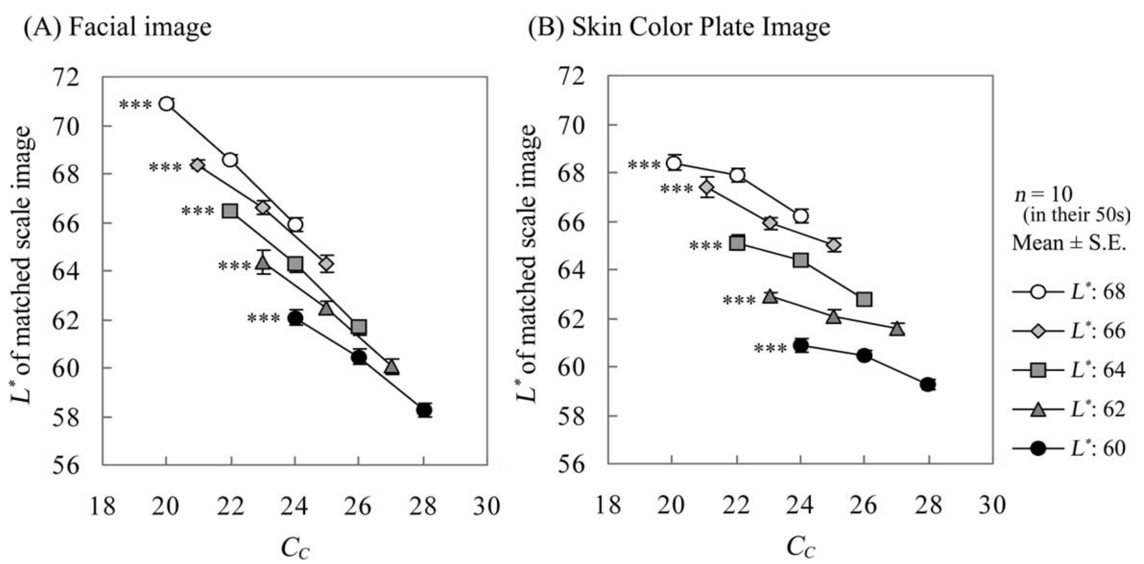

FIG. 15. Results of chroma change experiment with observers in their 50s. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of C_c. The symbols represent $L^*$of the test images. Error bars show the mean standard errors. $+ p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s. not significant; n is the number of observers.

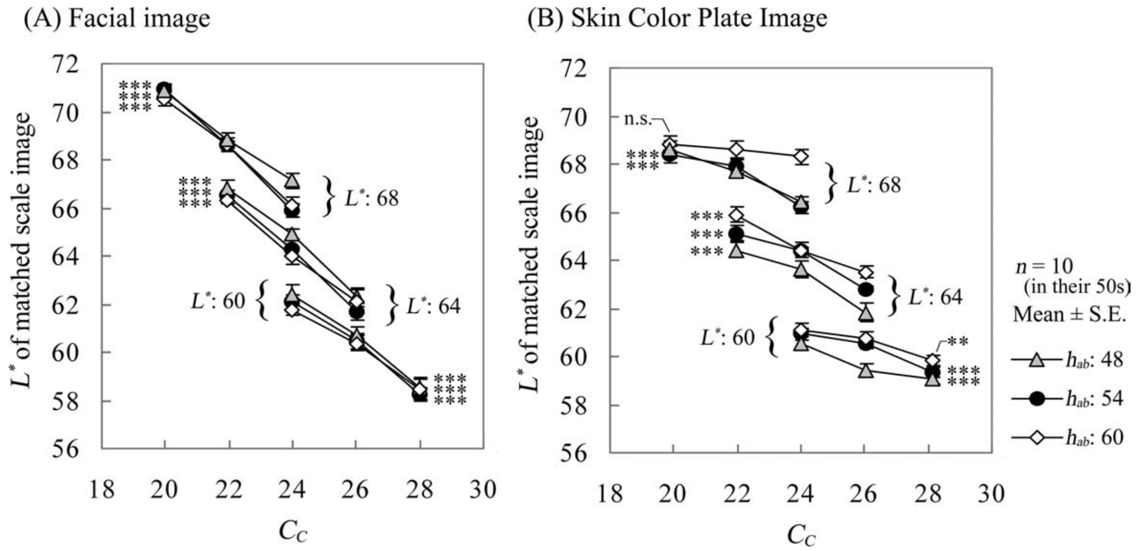

FIG. 16. Results of chroma change experiment with observers in their 50s for the use of the reddish, standard and yellowish hue. (A) Facial images. (B) Skin color plate images. L^*s of the matched scale images were plotted as a function of C_c. The symbols represent h_{ab} of the test image. Error bars show the mean standard errors. $+ p < 0.10$; $^* p < 0.05$; $^{**} p < 0.01$; $^{***} p < 0.001$; n.s. not significant; n is the number of observers.

perceived whiteness in the skin color plate images. On the other hand, the decrease in the slope of the yellowish hue stimulus was unconfirmed in the facial images with the observers in their 50s. The difficulty in distinguishing between white or light gray and yellowish skin color due to the yellow discoloration of the lenses could not be found in the facial images because the color complexity of the facial images presumably served as a cue to distinguish between white or light gray and yellowish skin color. The relationship between the results of the observers in their 50s and the yellow discoloration of the lenses requires further study.

From the results of observers in their 20s and 50s, it was concluded that (1) reddish skin color appeared whiter than that with a yellowish one in the facial images having light skin color, and (2) a low-chroma skin color appeared whiter than a high-chroma one. It is also concluded that (3) in the skin color plate images, the change in perceived whiteness by hue was unconfirmed and that (4) the change in perceived whiteness by chroma was weaker than that in the facial images.

Metric lightness measured by a colorimeter probably disagrees with perceived whiteness in the evaluation of facial skins with different hues. For example, when facial skin becomes reddish by the expansion of blood capillaries, when the amount of blood circulation increases, skin color measurement by a colorimeter results in a decrease in lightness because of the increase in absorption by hemoglobin in the blood. Hemoglobin has an absorption peak at $\sim$550 nm, and it is very close to the peak of spectral luminous efficiency, $V(\lambda)$, which is 555 nm. On the contrary, the facial skin is perceived to become whiter or have the same whiteness because of its redness. The perceived whiteness of facial skin of Japanese female was proved to be a unique index affected not only by lightness but also by hue and chroma. Therefore, the whiteness should be evaluated by a specialized lightness that is the function of metric lightness, hue and chroma. Further study is necessary to develop a whiteness index of facial skin.

CONCLUSION

To investigate factors affecting the perceived whiteness of the facial skin of Japanese females psychophysically, the brightness evaluation of the actual facial skin of Japanese females, and the whiteness evaluation of the facial images and the skin color plate images, which simulated the facial skin, of Japanese females were conducted. From two experiments, it is concluded that reddish facial skin color appears whiter than that of a yellowish one in high lightness region, and a low-chroma facial skin color appears whiter than a high-chroma one. However, in the color plate images, the change in perceived whiteness by hue was unconfirmed, and the change in perceived whiteness by chroma was weaker than that in the facial images. Hue and chroma also affect perceived whiteness independently. These results indicate that a higher-level process of facial recognition affected whiteness perception, and the criterion of whiteness for facial skin was determined by the facial skin color distribution.

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1. Caisey L, Grangeat F, Lemasson A, Talabot J, Voirin A. Skin color and makeup strategies of women from different ethnic groups. Int J Cosmet Sci 2006;28:427–437.

2. Estanislao R, Suero M, Galzote C, Rivera Z, Li J, Kim HO, Thomas S, Khaiat A, Cheong EJ, Mangubat MI, Moideen R, Tagami H, Wang X. Characterization of Asian skin though in-vivo instrumental and visual evaluations: Influences of age, season and skin care habits. In: Proceedings of 6th Scientific Conference of the Asian Societies of Cosmetic Scientists, Manila, 2003. pp 263–269.
3. Takata S, Akimoto M, Murui Y, Munakata A, Takahashi M, Kumagai S. Distribution of skin colors of World population and its application for preparing make-up products. Proceedings of 2000 AIC Meeting, Seoul, 2000. pp 188–192.
4. Yoshikawa H, Kikuchi K, Takata S, Yaguchi H, Development of a visual and quantitaive evaluation method for facial skin color, Proceedings of 11th Congress of the AIC, CD-ROM, Sydney, 2009.
5. Suzuki T, Munakata A. The analysis of the psychological criterion for the perceptual classification of the skin colors. J Color Sci Assoc Jpn 2001;25:2–11 (in Japanese).
6. Suzuki T. The effect of complexion's image color for preferred skin color. Hiyoshi Review of Natural Science Keio University 1991;10: 1–18.
7. Robertson AR. The CIE 1976 color-difference formulae. Color Res Appl 1977;2:7–11.
8. CIE Publ 159. A Colour Appearance Model for Colour Management Systems: CIECAM02. Vienna: CIE Central Bureau, 2004.
9. Sanders CL, Wyszecki G. L/Y ratios in terms of CIE-chromaticity coordinates. J Opt Soc Am 1962;48:389–392.
10. Swedish Standard SS 01 91 00E, 1990.

BOOK REVIEW

The Art and Science of HDR Imaging. By John J. McCann and Alessandro Rizzi. Hoboken, NJ: Wiley, 2012, 389– pp. US $135.00

There are to my knowledge two books on the topic of High Dynamic Range Imaging (HDR). In the interests of full disclosure, you will find my name on the back cover of one of them—the "other book." This is a review of "The Art and Science of HDR Imaging" by John McCann and Alessandro Rizzi.

For those readers not familiar with the term, HDR involves the capture of high dynamic range images and displaying them on low dynamic range display monitors and in print media. As such, it delves deeply into image and video encoding techniques, camera calibration and response functions, display and printer technologies, and of course the psychophysics of visual perception, particularly perception-based tone reproduction, tone-reproduction operators, and image quality metrics. It is a rich and fascinating field of study.

Happily, there is ample room for two full-length textbooks on the topic. The "other book" mostly addresses computer graphics researchers and software developers with a comprehensive overview of the field, while this book offers an entirely different perspective based on visual glare, color constancy, and one particular family of image processing algorithms, the Retinex model. The "art" in its title comes from the surprising history of HDR, which can be traced back to Renaissance painters like Rembrandt and da Vinci.

The central thesis of this book is that our perception of high dynamic range scenes—either physical or reproductions—is driven by the competing forces of veiling glare and postreceptor spatial (i.e., neural) image processing. It does not matter that the display monitor has a (claimed) dynamic range of a million-to-one; the limiting factor is glare due to intraocular scattering. The authors argue that it is pointless to even consider global tone-reproduction operators; only Edwin Land's Retinex model and its many variations are valid. (By comparison, the Retinex model is allocated a brief three pages of description in the "other book," while glare is considered only in the context of computer graphics rendering techniques.)

The book is organized in six sections. Section A, "History of HDR Imaging," correctly notes that paintings such as da Vinci's "Lady with an Ermine" are early examples of HDR imaging. More surprising, however, is how HDR imaging techniques were developed and refined by 19th century photographers. In one example by Edouard Baldus, a beautiful image of sunlit church cloisters was made from 10 paper negatives of varying exposures—in 1853. It embodies all the principles of what we recognize today as HDR imaging.

The section then proceeds to an examination of Ansel Adam's Zone System of photography, followed by electronic imaging and computer graphics. Most of the emphasis, however, is on photography, where emulsions are carefully engineered to exhibit an S-shaped response that successfully compresses the highlights and shadows of a typical scene with a dynamic range of 1000:1 into the 30:1 dynamic range of monochrome and color prints. This is the basis of most global tone-reproduction algorithms later developed for computer graphics. In contrast, Ansel Adams' use of manually dodging and burning prints was an example of today's local tone-reproduction operators used in computer graphics.

Section B, "Measured Dynamic Ranges," provides an in-depth discussion of camera and visual responses to HDR scenes and the consequences of scattered light in both camera lenses and the human eye. Regardless of the dynamic range of the film or electronic sensor, it is glare that inevitably determines the dynamic range of the scene recordings, and of our perception of both the original scenes and their reproductions.

Section C, "Separating Glare and Contrast," identifies intraocular glare as a major part of vision theory and examines its effect on the retinal image. Our perception of lightness of uniform color spaces in particular is influenced by scattered light that transforms scene radiances into UCS lightnesses, and also by the effects of color-opponent neural processing that compensates for retinal cone crosstalk. Most important, the post-retinal neural processing mechanism tends to cancel the effects of glare. The authors argue that these effects invalidate the global ("pixel-based") HDR image processing algorithms developed by computer graphics researchers.

(*Continued on page 260*)