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Facial redness perception based on realistic skin models

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Abstract

Facial redness is an important perceptual attribute that receives many concerns from application fields such as dermatology and cosmetics. Existing studies have commonly used the average CIELAB a value of the facial skin area to represent the overall facial redness. Yet, the perception of facial redness has never been precisely examined. This research was designed to quantify the perception of facial redness and meanwhile investigate the perceptual difference between the faces and the uniform patches. Eighty images of real human faces and uniform skin colour patches were scaled in terms of their perceived redness by a panel of observers. The results showed that the CIELAB a* was not a good predictor of facial redness since the perceived redness was also affected by the L* and b* values. A new index, RIS was developed to accurately quantify the perception of facial skin redness, which promised a much higher accuracy (R^2 = 0.874) than the a* value (R^2 = 0.461). The perceptual difference between facial redness and patch redness was also discussed.*

Introduction

Facial redness is an important attribute that directly describes people's perception of facial colour appearance and thus receives many concerns in application fields such as dermatology and cosmetics. For example, facial redness is considered the most common and recognisable clinical sign of many facial dermatoses [1]. As the most prominent colour affecting psychological functioning in humans, perceived redness also has influences on people's affect, cognition, and behaviour in attraction contexts [2]. Skin redness is usually determined by perfusion with oxygenated blood and conveys information such as cardiovascular fitness and emotional state [3]. Perceived facial redness has positive effects on preference evaluations, including increasing the perceived health and facial attractiveness in both female and male faces [4], [5]. Increased facial redness is also associated with perceived anger as modulated by facial masculine features [6]. Interestingly, facial redness perception has shown special salience that the visual sensitivity is greatest at discriminating colour changes in facial redness compared to changes in facial yellowness or luminance [7].

In different research and application areas, quantifying facial redness is of great importance, yet very little research has been concerned with the perception of facial redness. Although skin colour measurement can be easily achieved by instruments, e.g. spectrophotometer, those methods only give colour information of the target point area and don't include any perceptual aspects of the colour appearance. In the area of dermatologic diagnostics, analysis of facial redness is commonly conducted by the subjective evaluation of the dermatologists and the self-assessment of the patients. The accuracy and consistency largely depend on the individuals' experiences and viewing conditions. As assisting tools of diagnosis, some image analysis methods (e.g. pixel or area of the red region) have been used, which also disconnected from visual perception and couldn't achieve consistent results with the dermatologists' diagnosis so far [8]. On the other hand, there is a large number of studies concerning the effects of perceived facial redness on psychological functioning in humans including several mentioned above [4]–[7]. In those studies, the overall facial redness was simply and unexceptionally measured by the average CIELAB a^* value of the skin areas of the face. Even though in CIELAB uniform colour space the a^* represents the value along the red-green dimension, there is no evidence showing whether the a^* is an accurate measure of the subjective colour perceptions of 'facial redness'. Considering that natural skin colour is not uniformly distributed on human faces and is restricted to a certain range of the skin colour gamut [9], it is worthwhile to investigate the facial redness perception on real human faces and assess the relationship between perceived redness and the CIELAB colorimetric values.

Furthermore, the distinctiveness of facial colour from nonface objects in terms of colour discrimination and perception has been noted by previous studies [10]–[12]. For example, in Yoshikawa et al.'s study, the effect of chromatic components on whiteness perception was only found on faces but not in the perception of uniform colour patches, which suggested a higher-level process of face recognition existed and affected the perception of skin whiteness. Regarding facial redness perception, it is far from clear whether there is an influence of other chromatic components or any perceptual difference between faces and nonface objects.

Considering the above, the objectives of the current study are to precisely examine and quantify the perception of facial redness based on realis skin models, and meanwhile to explore the perceptual difference between the face stimuli and the uniform patch stimuli in terms of redness perception.

Materials and Methods

Stimulus Description

The visual stimuli for perceived redness assessment were 80 high-res facial images and 80 face-shaped colour patches. Eighty images of real human faces, including 40 Caucasian faces and 40 Chinese faces, selected from the Liverpool-Leeds Skin-colour Database (LLSD) were used in this study [9]. Those facial images were captured under CIE D65 illumination and later processed with only the facial area left (the hair, ear, clothes, etc, were removed) and against a mid-grey background for experimental use. An example could be seen in the top image of Figure 1. The 80 corresponding uniform colour patches that have the same appearance with each of the facial images (the 80 matched colour patches were obtained by a colour appearance matching experiment in our previous study) were also used in this study to investigate whether the facial feature would affect appearance assessment of perceived facial redness.

The mean colour specification, in terms of CIELAB coordinates (L^*, a^*, b^*), of the 80 test facial images were calculated as the overall mean of each pixel in the facial area, excluding the mouth, nose, eyes, and eyebrows, as shown in.

The areas other than the facial skin were masked manually for each image, and the calculations were performed in MATLAB.

Psychophysical Experiment

Psychophysical experiments were conducted and each pair of faces and uniform colour patches were scaled regarding their perceptual redness by a panel of observers. The experiment was separated into two sessions, one to scale the facial images and the other to scale the uniform colour patches. The order of the two sessions was fully randomised. Using the technique of magnitude estimation, the redness of all faces and patches was assessed on a scale of 0-100 where 0 represented the least red face/patch, and 100 represented the reddest face/patch. A reference image of redness 50 was given by the side of the test image (see the example in Figure 1). The reference face image was an average face derived from 20 Caucasian faces and 20 Chinese faces, and the reference patch had the matched appearance colour of that average face. Apart from the 80 pairs of test facial and patch images, 10 randomly selected images were repeated to test the consistency of each observer in both sessions. In total, each observer scaled the colour appearance of 90 facial images and 90 corresponding uniform colour patches.

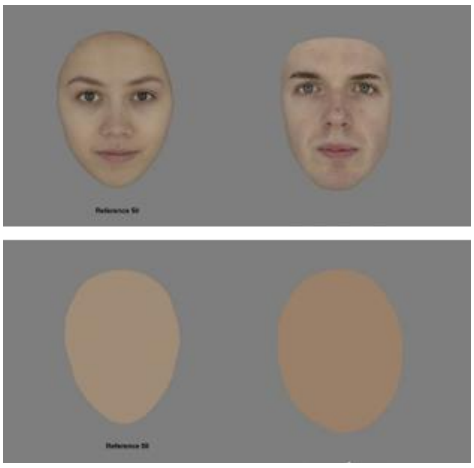

Figure 1. The experimental interface: an example of the facial image (top) and the uniform patch (bottom) to be scaled.

Results and discussion

Observer and variations

A panel of 43 observers took part in the experiment, including 23 Caucasians (7 males; mean age ± SD = 24.65 ± 4.61) and 20 Chinese (9 males; mean age ± SD = 25.70 ± 5.27). All the observers had normal colour vision according to the Ishihara test. The coefficient of variation (CV) was used to verify the observer variation. The intra-observer agreement was 11.5 for the face stimuli and 13.6 for the patch stimuli. The inter-observer agreement was 10.8 for the face stimuli and 14.4 for the patch stimuli. The intra- and inter-observer variability was close for both the face and patch perception, indicating similar performance within an individual observer and between observers. Smaller CV values were obtained for facial image scaling compared to uniform patch scaling, which suggested that observers found facial redness was easier to scale or they shared more common criteria of facial redness compared to the patch redness.

The relationship between perceived redness, and L^*, a^*, and b^*

The Pearson correlation coefficients were calculated between the perceptual redness and the CIELAB colorimetric values (L^*, a^*, and b^*). Figure 2 shows the correlations for the face stimuli (left) and the uniform patch stimuli (right), respectively. Facial skin redness was found to have strong correlations with both the a^* value ($r = 0.68$, $p < 0.001$) and the b^* values ($r = -0.69$, $p < 0.001$) and at a similar significant level. Perceived facial redness was positively associated with the a^* value but negatively associated with the b^* value. For the uniform colour patches, the perceived redness was found more strongly and positively correlated with the a^* value ($r = 0.85$, $p < 0.001$), and it was also negatively associated with the b^* value ($r = -0.56$, $p < 0.001$).

For a long time, the average a^* value in the CIELAB space of a face has been taken for granted as the representative of the overall facial redness in a large number of studies on facial impressions. However, our results showed that, within the constraint of the real skin colour range, the perceptual facial redness was not simply a correlate of the CIELAB a^* value, but had an equally strong relationship with the b^* value. Compared to facial redness perception, the perceived redness of uniform colour patches could be more accurately represented by the a^* value, which indicates the perceptual difference existed between the face and the patch stimuli.

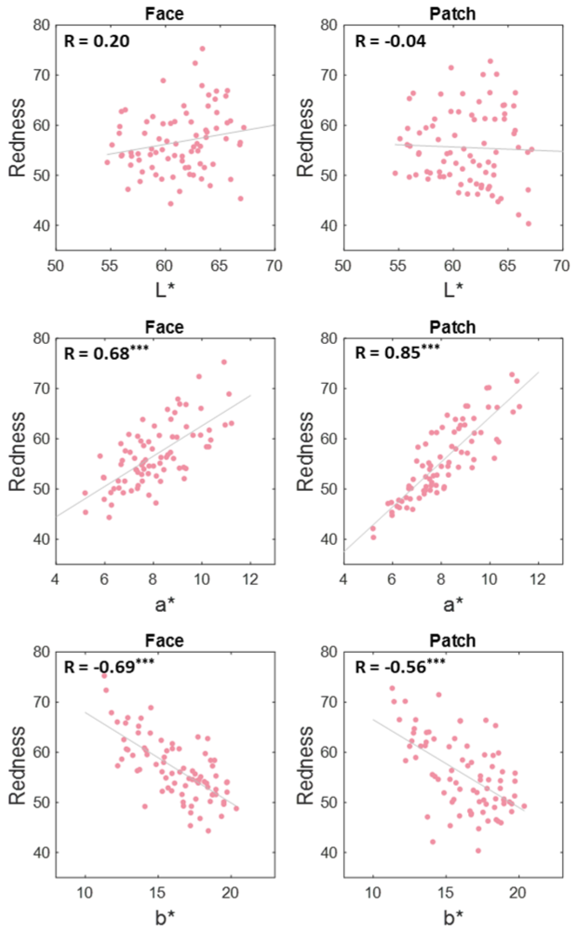

Figure 2. Correlations between the redness perception and the three CIELAB coordinates, L (top), a*(middle), and b* (bottom) of the 80 facial images (left) and the 80 uniform colour patches (right). The Person correlation coefficients and the significance of the correlations are shown at the left top of each subplot. *P≤0.05, ** P≤0.01, ***P≤0.001.*

A new redness index for skin colour

Considering the perceived facial redness was influenced not only by the single variable a^*, it was reasonable to assume that these perceptual colour attributes could be more accurately quantified and predicted by the L^*, a^*, and b^* values together than just a^*. Thus, multiple linear regression models were set up to predict facial redness, and the model performance was compared with the simple linear regressions of the a^*. Table 1 summarises the results of the regression analysis.

Table 1. *Simple linear regression model and multiple linear regression model in predicting facial redness.*

	Perceived Facial Redness			
	β	SE	*t*	P
Regression 1: Redness ~ a^*				
Model	$F_{1,78}$=68.67; P<0.001***; Adjusted R^2=0.461			
(Intercept)	32.375	2.975	10.884	<0.001***
L*	3.020	0.364	8.287	<0.001***
Regression 2: Redness ~ L^*, a^*, b^*				
Model	$F_{3,76}$=183.6; P<0.001***; Adjusted R^2=0.874			
(Intercept)	24.415	12.535	1.948	0.055
L*	0.424	0.142	2.995	0.004**
a*	3.281	0.246	13.361	<0.001***
b*	-1.239	0.175	-7.087	<0.001***

NS= not significant; *P<0.05; **P<0.01; ***P<0.001.

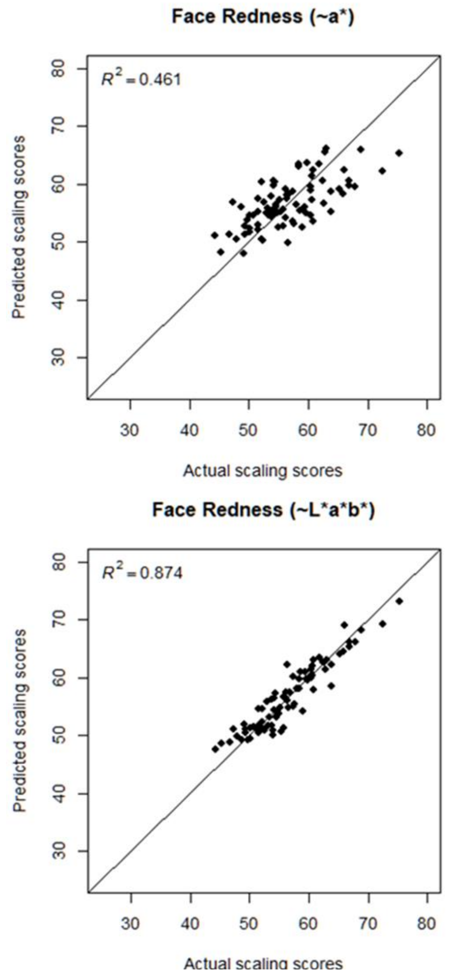

Figure 3. *The model performance of the simple regression model (top) and the multiple regression model (bottom) in predicting facial redness.*

The simple linear regression only explained 46.1 per cent of the variance in perceived facial redness, which again indicated the a^* value is not a good predictor of facial redness perception. Compared to the simple linear regression, the multiple regression model did give a better performance in predicting perceived facial redness, and the model fit was largely improved from an R^2 value of 46.1% (simple regression) to an R^2 value of 87.4% (multiple regression). Figure 3 shows the model performance. The multiple regression model on the bottom shows a lower level of dispersion of the data points from the diagonal line and suggests a better performance of the model compared to the simple regression model on the top.

Based on the multiple linear regression, a new Redness Index for Skin (RIS) was developed using the CIELAB coordinates. It was the first time that the perceived facial redness is accurately quantified and predicted. The formula is given below:

$$\text{RIS} = 0.424\overline{L^*} + 3.281\overline{a^*} - 1.239\overline{b^*} + 24.415 \quad (1)$$

Effects of L* and b* on redness perceptions

Finally, the effects of L^* and b^* on the redness perception of real human faces and patches were discussed. The results above suggest that more than a single dimension of the CLELAB space affects facial redness perception. Considering the realistic skin models, the influence of L^* and b^* on redness perception could be influenced by some intrinsic correlations between L*, a*, and b* as they were not independent variables within the real skin colour gamut [13]. Thus, efforts were made to divide the a^* values into five subgroups by a step of 1 a^* unit and then show the influence trend of L^* and b^* on the redness perception within each subgroup where the a^* value was kept at an approximately same level.

The results are shown in Figure 4. The top row shows the influence of L^* on facial redness perception (left) and patch redness perception (right), and the bottom row shows the influence of b^* on redness perception. A regression line is drawn for each group, and Table 2 summarises the slopes of all the regression lines for the face stimuli and the patch stimuli, respectively. Within each group, both facial skin redness and patch redness were influenced by the L^* value, and a higher L^* value increased the perceived redness (positive slopes). The perceived redness of the face stimuli was more sensitive to the change of L* compared to that of the patch stimuli (slopes of the face were steeper than the patch in all groups, see Table 2). The effects of b* on redness perception were similar between the face stimuli and the patch stimuli that a higher b* value decreased the perceptual redness of both the facial skin and the uniform patch (negative slopes). In general, for both the face stimuli and the uniform patch stimuli, it was found that the perceived facial redness could be enhanced by an increasing L^* value but weakened by an increasing b^* value. There were perceptual differences between the face and the patch that facial redness was easier affected by the change of the L^* value,

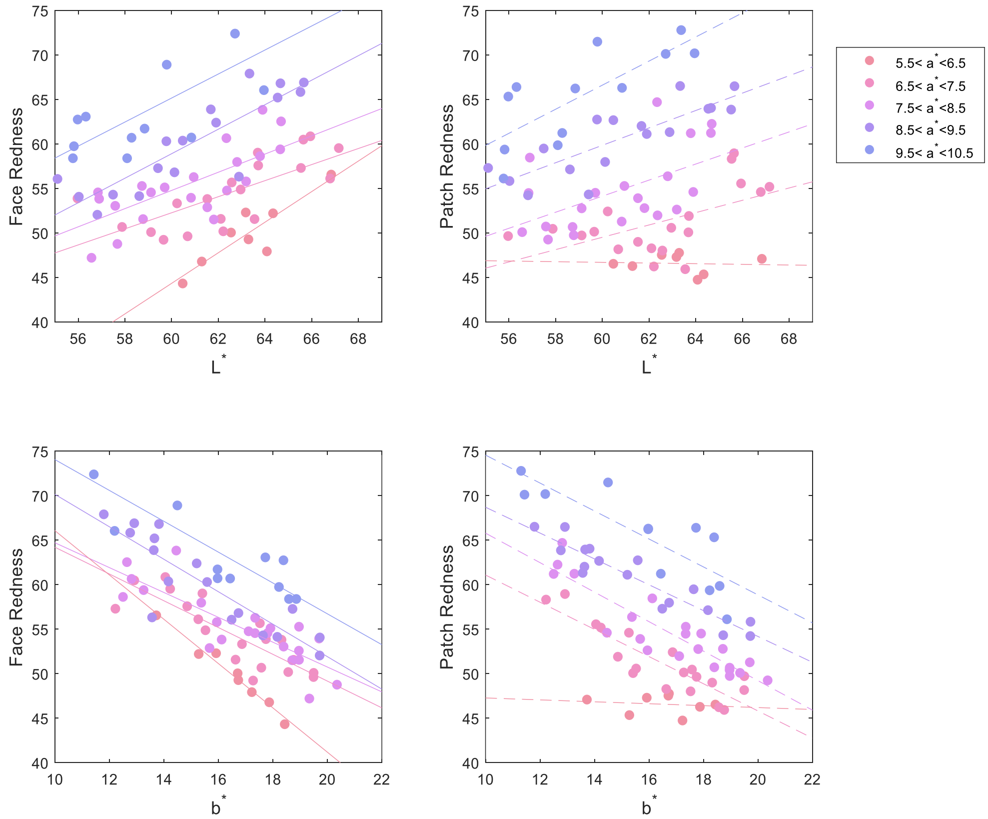

Figure 4. *Relationships between redness scores and L* (top), and redness scores and b* (bottom) for facial colour perceptions (left) and patch colour perceptions (right). A regression line was drawn for each group.*

which also suggested the influence of facial features or face recognition on facial redness perception.

Table 2. *Summary of the slopes of the regression lines in Figure 3.*

Group	a* Range	Redness - L*		Redness - b*	
		Face	Patch	Face	Patch
1	5.5-6.5	1.72	-0.04	-2.49	-0.11
2	6.5-7.5	0.90	0.69	-1.50	-1.53
3	7.5-8.5	1.02	0.90	-1.40	-1.66
4	8.5-9.5	1.38	0.98	-1.82	-1.45
5	9.5-10.5	1.35	1.35	-1.73	-1.57

Conclusion

In this study, the perception of facial redness based on realistic skin models was examined and the perceptual difference between the face stimuli and the patch stimuli was investigated. Psychophysical data was collected to quantitatively model the perceived redness of facial colour appearance using the technique of magnitude estimation. Results showed that the CIELAB a* was not a good predictor of facial redness perception. The accurate relationships between perceived facial redness and the CIELAB colorimetric values, L^*, a^*, and b^* were revealed. A new index, RIS, was developed to quantify facial skin's perceptual redness, which promised a much higher accuracy of prediction (R^2 = 0.874) than the prediction of a^* only (R^2 = 0.461). The perceptual differences between the face stimuli and the patch stimuli were discussed. In general, the perceived redness was not an independent perceptual attribute within the context of human skin colour. With the same level of a* values, lighter faces or less yellowish faces were perceived as more reddish.

Limitations

The variations of facial redness in Caucasian and Chinese populations were covered in this study by using a large set of images of real human faces. But the skin colour of other ethnic groups was not considered in this study. The current RIS needs to be further limited to the redness range of all real human skin, which is not very clear so far. It also needs to be invetigated whether thr RIS is suitable for predicting perceptual facial redness of faces of other ethnicities. Moreover, the influence of lighting on perceptual facial redness could be studied in the futrue as the colour appearance changes under different illuminations [14].

References

[1] C. Dessinioti and C. Antoniou, "The ‘ red face ’ : Not always rosacea," *Clin. Dermatol.*, vol. 35, no. 2, pp. 201–206, 2017, doi: 10.1016/j.clindermatol.2016.10.015.

[2] A. J. Elliot and M. A. Maier, "Color psychology: effects of perceiving color on psychological functioning in humans," *Annu. Rev. Psychol.*, vol. 65, no. 1, pp. 95–120, Jan. 2014, doi: 10.1146/annurev-psych-010213-115035.

[3] D. E. Re, R. D. Whitehead, D. Xiao, and D. I. Perrett,

“Oxygenated-blood colour change thresholds for perceived facial redness, health, and attractiveness,” *PLoS One*, vol. 6, no. 3, p. e17859, 2011.

[4] C. A. Thorstenson, A. D. Pazda, A. J. Elliot, and D. I. Perrett, “Facial Redness Increases Men’s Perceived Healthiness and Attractiveness,” *Perception*, vol. 46, no. 6, pp. 650–664, Jun. 2017, doi: 10.1177/0301006616680124.

[5] A. D. Pazda, C. A. Thorstenson, A. J. Elliot, and D. I. Perrett, “Women’s facial redness increases their perceived attractiveness: mediation through perceived healthiness,” *Perception*, vol. 45, no. 7, pp. 739–754, 2016, doi: 10.1177/0301006616633386.

[6] S. G. Young, C. A. Thorstenson, and A. D. Pazda, “Facial redness, expression, and masculinity influence perceptions of anger and health,” *Cogn. Emot.*, vol. 32, no. 1, pp. 49–60, Jan. 2018, doi: 10.1080/02699931.2016.1273201.

[7] K. W. Tan and I. D. Stephen, “Colour detection thresholds in faces and colour patches,” *Perception*, vol. 42, no. 7, pp. 733–741, 2013, doi: 10.1068/p7499.

[8] Y. Chen, W. Hua, A. Li, H. He, L. Xie, and L. Li, “Analysis of facial redness by comparing VISIA ® from Canfield and CSKIN ® from Yanyun Technology,” *Ski. Res. Technol.*, vol. 26, no. 5, pp. 696–701, Sep. 2020, doi: 10.1111/srt.12856.

[9] K. Xiao *et al.*, “Characterising the variations in ethnic skin colours: a new calibrated data base for human skin,” *Ski. Res. Technol.*, vol. 23, no. 1, pp. 21–29, Feb. 2017, doi: 10.1111/srt.12295.

[10] M. Hasantash, R. Lafer-Sousa, A. Afraz, and B. R. Conway, “Paradoxical impact of memory on color appearance of faces,” *Nat. Commun.*, vol. 10, no. 1, pp. 1–10, 2019, doi: 10.1038/s41467-019-10073-8.

[11] H. Yoshikawa, K. Kikuchi, H. Yaguchi, Y. Mizokami, and S. Takata, “Effect of chromatic components on facial skin whiteness,” *Color Res. Appl.*, vol. 37, no. 4, pp. 281–291, Aug. 2012, doi: 10.1002/col.20685.

[12] H. Shimakura and K. Sakata, “Desaturation-Induced Brightness in Face Color Perception,” *Iperception.*, vol. 10, no. 3, p. 204166951985478, May 2019, doi: 10.1177/2041669519854782.

[13] Y. Lu, K. Xiao, J. Yang, M. Pointer, C. Li, and S. Wuerger, “Different colour predictions of facial preference by Caucasian and Chinese observers,” *Sci. Rep.*, vol. 12, no. 1, p. 12194, Jul. 2022, doi: 10.1038/s41598-022-15951-8.

[14] C. Li, M. Ronnier Luo, G. Cui, and C. Li, “Evaluation of the CIE colour rendering index,” *Color. Technol.*, vol. 127, no. 2, pp. 129–135, 2011, doi: 10.1111/j.1478-4408.2011.00287.x.

Author Biography

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