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Asian Skin Preference in a Mirror Lighting Application with Enhanced Red Content

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Abstract

High quality lighting is a key element in retail and hospitality interiors. In recent years, with the interest of energy saving, incandescent lamps commonly used in these applications have been replaced with LEDs. As LEDs have different spectral characteristics from the conventional sources, this has raised concerns over colour perception and preference. Mirror lighting is of particular interest in this study because it can have a significant influence on customer decision and satisfaction. A psychophysical experiment was conducted to investigate the perceived colour preferences of face, arm and hand skin tone under three different illuminated Colour Rendering Indexes (CRI). Sixty-three participants completed the evaluation of their skin complexion under a cluster of warm-white LED (CCT 3000K) in a full-scale booth. The results confirmed that a high CRI light source with a depleted R9 content (strong reds) is less preferred than the medium CRI with high R9 content.

Keywords: Colour Rendering, Preference, Asian Skin, Mirror Lighting, Spectral Characteristics

1. Introduction

Today, most renovations and new constructions, including department stores, hotels, restaurants, offices are interested in energy saving and have started changing from incandescent lamps to light-emitting diodes (LED) replacements. Hospitality lighting is of significant interest because they are motivated to achieve energy saving as well as enhancing guest satisfaction and amenity relative to colour perception. More specifically, the lighting used in front of mirrors is generally considered a priority for high quality lighting in terms of both light distribution and spectral characteristics that ultimately impact the perception of skin colour.

Lighting in front of mirrors or in an area that has mirrors such as vanity areas, powder rooms, changing rooms, salons or cosmetic counters should be illuminated with appropriate lighting as it should reflect original light conditions to reveal the face and skin complexion. Appropriate lighting depends on the position of the light source, light spatial characteristic and spectral power distribution (SPD) of the light source. A good light source should have high efficacy, long life time, no ultraviolet (UV), no infrared (IR), and wide spectral distribution characteristics. The visual quality for light sources can be estimated by using the CIE Colour Rendering Index (CRI, Ra). Although CRI is widely used to examine the colour quality of a light source, it has been raised by many researchers (1-8) that CRI may not be adequate by itself to predict colour preference of skin tone. The International Commission on Illumination (CIE) has also acknowledged the limitation of a colour fidelity index such as CRI, and indicated that (21) more studies on colour quality of LED light sources related to perception and preference for different applications and demographics for different regions of the world are needed. Asian preference is a major concern for this study, while a minor concern is differentiation of visual appreciation between male and female of their own skin tone.

2. Literature Review

In order to research preferences for specific light sources relative to skin complexion, the issues of light source spectrum, distribution characteristics, experimental setup and preference assessment methodology must be reviewed. The following is a sequential review.

2.1 Light Source

In the study made by Wei et al. (9), two different LED lamps were used, one with a CRI of 85 and the other with a CRI of 97. These lamps were tested to see perceptual responses on skin tone and teeth. In this study there was no preference difference between either the lamps with CRI 85 or CRI 97 within the Asian participants. For teeth, they appeared to be whiter under CRI 97, and this was preferred from all ethnicities.

In another study by Jost et al.(1) a LED cluster of white, blue, green, amber, and red was used under different SPD at 2700K to study the preferences of observer complexion. Asians particularly were sensitive to saturation and showed preference for their skin illuminated with a three cluster of white, green and red, while blue and amber were at zero. From those clusters of LED, the colour icon saturations overfilled the circle more in green and red colour. This also applied to Africans' skin preference as well. The most preferred cluster of all Asian and non-Asian contained cool white, green, amber and red. This lamp almost perfectly filled the circle and resulted in a CRI 92. This particular lamp also produced high scores in other metrics.

Other research (10) has studied the skin preference of illumination from LED A19 lamps with a different technology: blue pump phosphor LED (BP-LED) and diminished yellow emission (YD-LED) at the same CCT of 3000K. This study showed no significant preference between the two lamp types among Asians. However, Asians did show a preference for the YD-LED when viewing a wood material most likely because of the higher red content.

While the YD-LED of Wei et al. (10) had a colour icon saturation similar to the LED cluster from the study by Jost-B. et al. (1), the results are somewhat contradictory. From the different studies reviewed, there did not appear to be a direct correlation between CRI and the ability to predict colour preferences for Asians.

2.2 Light Distribution

Recommendations for mirror lighting applications generally suggest the avoidance of glare and harsh shadows, using soft and diffuse distribution characteristics (12). In previous experimental settings, researchers employed a polycarbonate diffuser to cover the light boxes on both sides of mirror to provide homogeneous illumination distribution (1). In order to achieve uniformity in illuminance levels, illuminance ratio between observer face and room ambient was set at 10:9 ratio (14).

2.3 Experimental Setup

Previous research on determining preference differences have focused on two different approaches. One approach involves side-by-side comparisons using a simultaneous comparison. The second approach involves a single viewing condition with sequential variations in light source type. A simultaneous viewing booth is normally used to compare two to three different types of light source with the same setting of objects inside the booth or to experiment on matching the brightness of existing light sources with the one proposed to replace the existing one (2,9,11).

When a real size room is constructed the viewing condition can be separated to demonstrate two main settings; the first is an expanded side-by-side viewing booth constructed as a full scale environment, allowing for a more practical setting containing a variety of materials and a wider dimension (10). The second method of real size room experimentation is similar to a single viewing booth (9) but constructed at a larger scale allowing more practicality in examining preferences of hair and skin tone colour that participants experience in a real environment (1).

Although the study of Jost-B. et al. (1) made a thorough examination of these conditions, the experiment set up omitted one important layer of light, as it did not include a light source situated above the participant. It has been recommended that this additional layer of light from above should be included to help observers to see more clearly (12). To summarise, to achieve a good quality of lighting while facing the mirror, light sources should be arranged to include illumination from above and from either side of the mirror (12,13).

2.4 Preference Assessment

Flynn (15), reported that the effect of light on subjective impression and attitude are identified in three categories: perceptual, behavior and overall preference.

- Perceptual: visual clarity, spaciousness, colour tone, and glare.
- Behavior: public vs private and relaxing vs tense space.
- Overall preference: preference (like - dislike) and pleasantness.

Preference of likes - dislike has been studied by Jost-B. et al. (1) with a 1 to 7 point scale. Wei et al. (10) studied this with a 9 to 6 point scale, a forced choice, to avoid "neutral" responses. Naturalness was investigated on perceived colour quality by Jost-B. et al. (11).

2.5 Conclusion

According to the previous studies on preferences of Asian observer skin complexion, the results obtained were contradictory. In Jost-B et al., Asians showed preference for their skin illuminated with a three cluster of white, green and red while blue and amber were at zero. Although the spectra of the LED cluster used by Jost-B were similar to one of those used by Wei et al., there was no particular preference observed among Asian participants. Nevertheless the adjustable LED clusters of white, red, green, blue and amber used in the previous study were considered appropriate for this study as it allowed a variation of the main spectrum. However, the correlated colour temperature at 3000K was chosen instead of 2700K because it would represent a typical light source used for hospitality interior in Thailand.

It was also suggested that light distributions for mirror lighting should come from the front as well as the top and should generate soft and diffuse light. A diffuser was used in the previous experiments to achieve this, but this might affect the SPD characteristics of light reaching the participant face and skin. Finally, the preference assessment was based on Flynn's approach and the number of scale usually tried to avoid neutral response. Categories of assessment included subjective responses such as Visual Clarity (Clear - Not Clear) and Preference (Like - Dislike). The experimental set up and subjective assessment method employed in this study was developed accordingly, though the preference scale used in the main experiment was 1 to 10 points as a typical scale in daily life.

3. Research Methodology

3.1 Experiment Setup

For the experiment, an actual size booth was constructed for participants to sit inside and evaluate their appearances in front of the mirror (Figure 1). Details are as followed :

3.1.1 Apparatus

The apparatus included a full scale mirror booth with 1400x1400x2250 (L x W x H millimeters) of internal space. The interior was painted in a matt white finish. A mirror sized 1100 x 1100 (W x H millimeters) was installed on one side of the wall inside the booth. Behind two sides of the mirror, left and right, the light sources were installed as an indirect detail and run continuously to the ceiling. The experiments were conducted under indirect diffuse lighting to avoid any potential spectral changes due to the use of translucent diffuser materials.

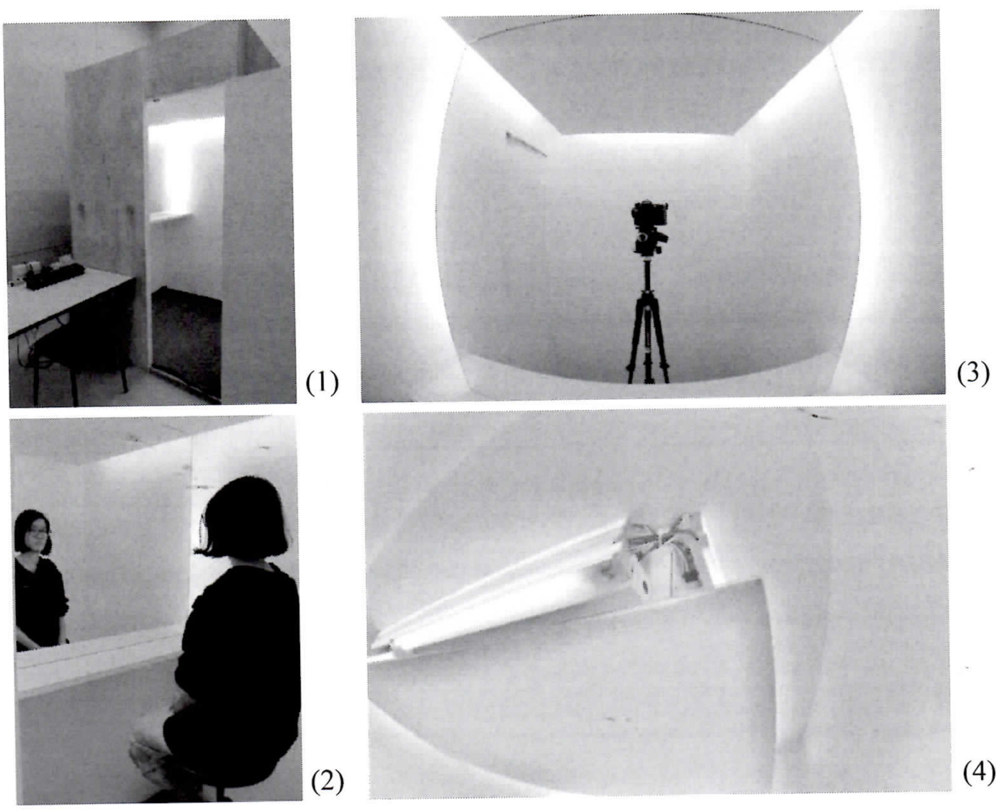


Fig 1. Full scale booth installation (1) Full scale booth (2) Participant sitting inside the booth to evaluate their appearance (3) View inside the booth (4) Installation detail of LED cluster and fluorescent lamp

3.1.2 Selection of Preference Assessment

A survey questionnaire was used to investigate the "Preference Assessment". The objective of this was to establish the appropriateness of using the words: visual clarity and preference in the larger study.

Fourteen participants (6 male, 8 female) participated and were involved in this survey-questionnaire. All of them were Thai, educated with minimum bachelor degree and none of them working related to lighting design field; six of them were young observers (18-25 years old); seven young adults (26-40 years old) and one an adult (40-50 years old).

From the result, keywords of visual clarity and preference were found to be appropriate in adequately describing potential variations in preference when evaluating light sources.

3.1.3 Selection of Light Sources

According to the literature reviews, it was concluded that the results of two studies are contradicted (1,10). With similar measurements of SPDs of the light source from the CQS (Colour Quality Scale), one research found that Asian participants liked (10) this arrangement, and another disliked (1).

It is interesting to actually know what Asians who reside in Asian countries like or dislike. This experiment attempted to set up light to be similar to the study of Jost et al. (1) by using a LED colour cluster of red, green, blue, white and amber. However, during the setup of the light source, it was found to be difficult to replicating the exact spectral distribution. The researcher ran pilot tests with similar light settings, in order to initially test the variations in Asian preference. Subsequently, results of the pilot tests were used to establish the final settings of light sources for the main experiment.

3.2 Photometric Measurements

A Minolta CL200 illuminance meter was used to measure vertical illuminance. A Minolta CL500 illuminance spectrophotometer was used to measure colour temperature, CRI, chromaticity, and spectral power distribution. Both light meters were installed with tripods standing in the centre of the mirror at the same height and distance as of the observers'eyes (Figure 2).

SPDs of light source were measured in the booth while the door was closed during measurement also when observer sat inside.


(1)

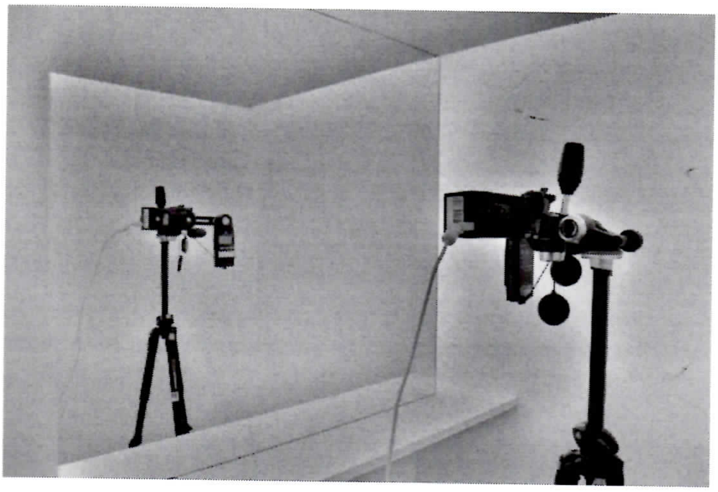

(2)

Fig 2. Measurement equipment and set up distance (1) Minolta CL500 and CL200
(2)Equipment set up inside the booth

3.3 Main Experiment

3.3.1 Light Source

There were three scenes of light sources; S730, S830 and S930 (Table 1). This was achieved by adjusting the intensity of each LED colour.

The criteria to get 3 different scenes from the LED clusters are as follows:

- Each scene produced the similar illuminance level on a participants face, 250lx +/- 12.5 lx (5%)
- Each scene produced the closeness as close as possible to CCT 3000K +/- 30K (1%)
- Each scene was chosen to be on Planckian locus or under locus only
- Each scene produced a different Ra value to reach Ra 70, 80 and 90

Scene	Quantity of light control by - DMX 512 controller				
	R	G	B	W	A
S730	0	7	6	64	56
S830	60	38	19	31	46
S930	41	34	12	33	50

Table 1 : RGBWA colour input from DMX 512 controller in 255 scale of each LED - Main experiment

Each LED cluster was given a name as a typical commercial factory might characterise the LED. For example, the scene 730 (S730) was referred to as Ra 70 with CCT 3000K.

Table 2 shows the measured photometric characters of the final three light sources. Histogram, SPDs and CIE1931 properties explain the quality of each light source such as scene 730 have CRI 72 because it lacked red colour which can see from the histogram, with red colour shown in the minus area.

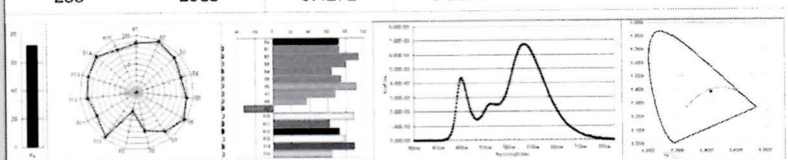
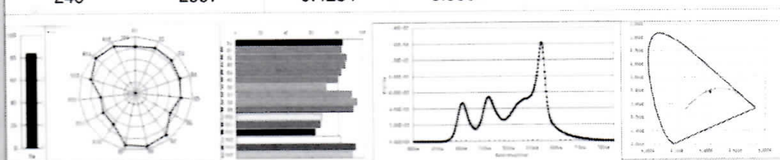
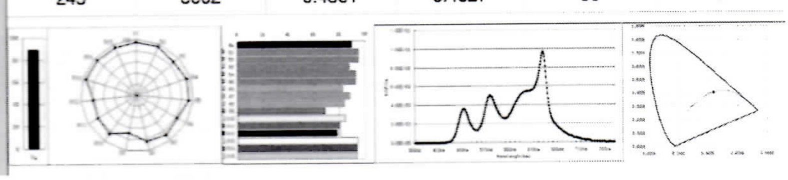
Scene	Light measurement					
	Illuminance level (lx)	CCT	X Coordinate	Y Coordinate	Ra	Locus
730	255	2983	0.4272	0.3820	72	-
						
830	240	2997	0.4284	0.3861	84	-
						
930	245	3002	0.4361	0.4027	90	0
						

Table 2 : Measured of photometric, histogram, SPDs and CIE1931 properties of 3 light sources used in main experiment.

3.3.2 Participants

Sixty-three participants participated in this experiment. Sixty-one of them were Thai and only two were Malaysian. All of them had good colour vision, tested with Ishihara six plates (16). Most of them were young adults. All of them were educated with minimum bachelor degree and most of them had a design background. Although none of them work in a field related to lighting design, which formed the main criteria to select the participants (Table 3).

Gender	Participants
Male	32
Female	31

Age	Participants
18-25	16
26-40	41
40-50	6

Education	Participants
Bachelor D.	40
Master D.	18
Doctorate D.	5

Ocupation	Participants
Engineer F.	6
Design F.	40
Finance F.	4
Sale F.	4
Other F.	9

Table 3: Participant data in four categories

3.3.3 Experiment Procedure

After each participant arrived, he or she received a brief description of the experiment, then signed a consent form and completed a general information questionnaire in the room under illuminated with CCT 4000K, 150 lx at the work plane.

Next, participants were asked to wear a black jacket and roll up their sleeves to the elbow and remove all accessories, in order to ensure that the participant will have no colour bias from their clothing or accessories while examining their face and skin. Then the experimenter escorted each into the experiment booth and asked them to sit on the stool in front of the mirror. The experimenter helped each participant to adjust the height of their eye level to get the right position, at a height of 1600 mm, and 500 mm away from the mirror. Once they had the right position, the experimenter explained in more detail about the experimental process.

The specific text used:

"In this experiment, we want you to examine your face, arms and hands skin tone under 3 lights illumination. Please look carefully to the rendering on your skin. We will ask you to scale your preference of lighting with a questions in a 10 point scale. To give you an idea, say 10 if you really like your appearance, if you really dislike it say 1. Do not be afraid to use the entire scale and try to be as consistent as possible within the different light sources. After you finish with the first illumination, you will be asked to close your eyes during the change of light for 10 seconds. After you are asked to open your eyes, you will have to wait until the experimenter asks the question to you then you will give the answer. There will be approximately 30 seconds before giving your answer, for your eyes to accommodate. There will be 3 of these trials in total. Please be concentrated on the target of the question and ignore any other colours. If you have any comments concerning the light, your appearance, what you like, what you dislike or what influences your final decisions, please do not hesitate to let the experimenter know. Thank you very much for your kindness in participating this experiment."

During the instruction, inside the booth was illuminated with fluorescent light to permit chromatic adaptation to CCT for 5 mins approximately. Then the experiment was started. Observers were alone in the experimental booth; the door was closed during the test (Figure 1). The experimenter, who sat outside to control the light, asked the questions and recorded the answers. The lighting scene was fixed as was the pattern in which the lights were turned on, to avoid bias from different orders; each light was on for about 1 minute. After finishing the experiment, the experimenter turned on the fluorescent light for a colour vision test inside the experimental booth. Each session lasted approximately 15 minutes, with 10 minutes spent in the booth.

4. Analysis and Results

4.1 Data Analysis Procedure

The results were constructed by sorting raw data according to the general information of the participant's gender, age, education, occupation and nationality as independent variables and the appreciation of three different lighting scenes as dependent variables.

The Mann-Whitney U test was performed on the appreciative scores to determine whether there were significant effects on gender and nationality (17). The Kruskal-Wallis test was performed on the appreciative scores to determine whether there were significant effects on age, education and occupation (18). The Spearman Rank correlation was performed to find the relationship between appreciation of three scene settings (19) (Table 4).

Independent variables	Measure	Dependent variables	Measure	Statistic performed
ender	Nominal			Mann-Whitney U test
Age	Scale	Appreciation score		Kruskal-Wallis test
Education	Ordinal	S730 S830 S930	Ordinal	Kruskal-Wallis test
Occupation	Nominal			Kruskal-Wallis test
Nationality	Nominal			Mann-Whitney U test

Table 4 : Independent and dependent variable relationship to find the suitable statistic performance

For all analysis, the acceptable error (α, alpha) was set to 0.05 (5%). Therefore, a difference was considered significant when;

- p-value > α = Failed to reject Null Hypothesis.
- p-value < α = Null Hypothesis is rejected.

4.2 Results Light Source Preference

To interpret the data from the preference study, descriptive statistics were performed using the Frequency analysis. Frequency of mean, median, mode and sum seem to have no significant difference (Table 5, Figure 4). On the other hand the Spearman Rank Correlation showed that there is a relationship between S730 and S830 with a significant correlation (Table 6).

The null hypothesis is rejected as there is a relationship among these three scenes and a significant correlation between S730 and S830. The correlation coefficient varies from 0 to 1 (perfect linear relationship) (24). It is noted that the preferred scene had a locus below the Planckian curve (Table 2), S930 which has a locus on the Planckian curve, and has the lowest in strongly liked scores and sums score. S830 is the most preferred as forty-four percent are ranked in the top three of the highest scores, with the highest sum score (Figure 4, 5). One reason that the subjects preferred S830 to S730 might be because S730 contains all colours except red with very little green and blue. Whereas, S830 contains all colours especially red. However, S830 is preferred to 930 which contains all colours but features a lesser amount of the colour red (Table 1).

Statistics

		S730	S830	S930
N	Valid	63	63	63
	Missing	0	0	0
Mean		6.5397	7.0635	6.2381
Median		7.0000	7.0000	6.0000
Mode		7.00	8.00	7.00
Sum		412.00	445.00	393.00

Table 5 : Descriptive statistics performing the frequency of each lighting scene

Correlations

			Scene Ra 70 CCT 3000K	Scene Ra 80 CCT 3000K	Scene Ra 90 CCT 3000K
Spearman's rho	Scene Ra 70 CCT 3000K	**Correlation Coefficient**	1.000	.524**	.146
		Sig. (2-tailed)	.	.000	.255
		N	63	63	63
	Scene Ra 80 CCT 3000K	**Correlation Coefficient**	.524**	1.000	.114
		Sig. (2-tailed)	.000	.	.373
		N	63	63	63
	Scene Ra 90 CCT 3000K	**Correlation Coefficient**	.146	.114	1.000
		Sig. (2-tailed)	.255	.373	.
		N	63	63	63

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6 : Spearman Rank Correlation statistics

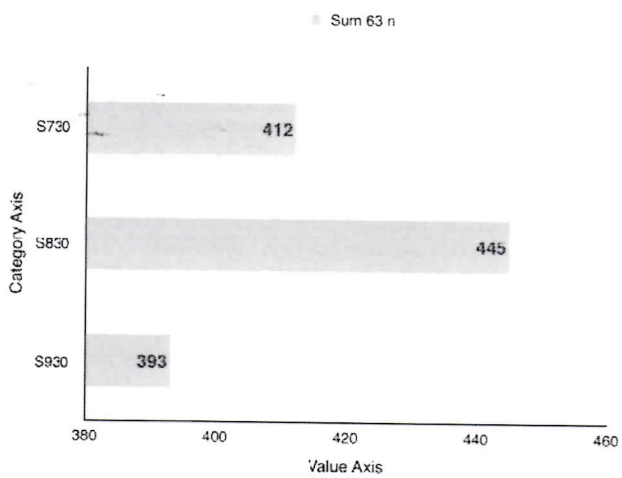


Fig 4. Bar chart showing the sum score of each lighting scene

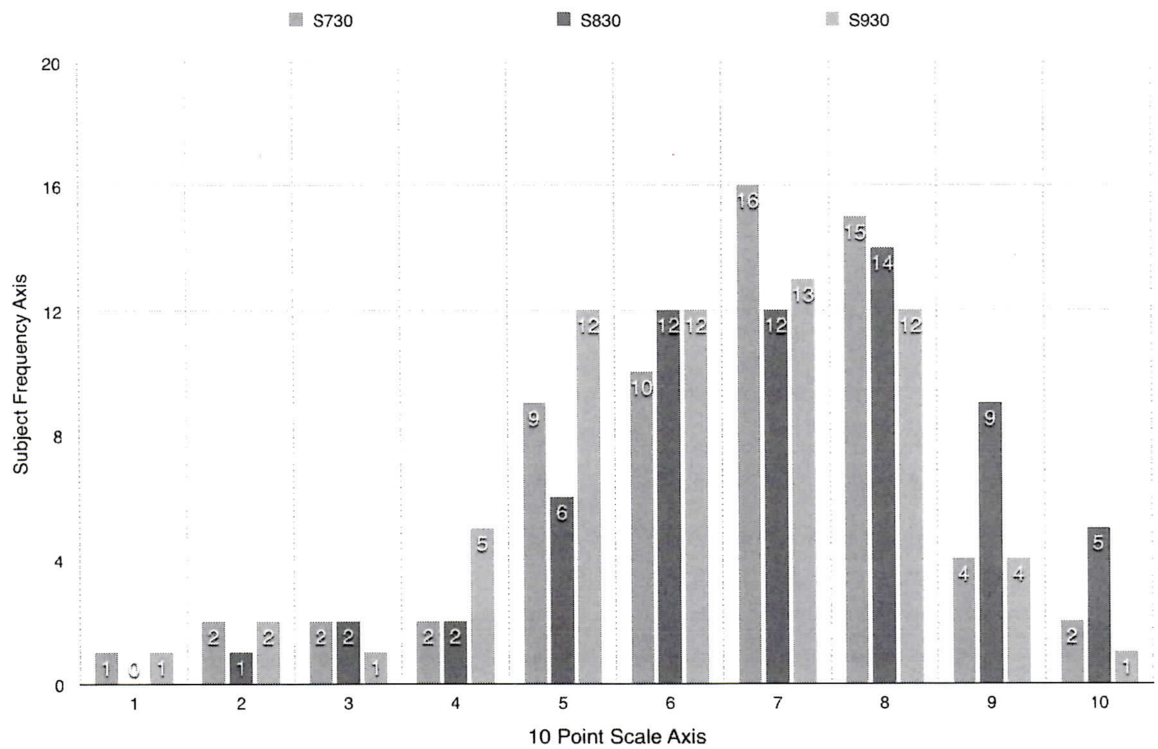


Fig 5. Bar chart showing preference frequency of each scale in three different scenes

4.3 Influence of Gender

There was a failure to reject the null hypothesis, as there is no statistically significant difference of each preference scene setting by gender (Table 7).

Although, Mann-Whitney U test statistics showed that there was no significant between male and females however figure 6 shows, which uses frequency analysis showed that females preferred S730 and S830 more than males who preferred S930, and vice versa.

Ranks

	Gender	N	Mean Rank	Sum of Ranks
S730	Male	32	30.42	973.50
	Female	31	33.63	1042.50
	Total	63		
S830	Male	32	28.41	909.00
	Female	31	35.71	1107.00
	Total	63		
S930	Male	32	32.95	1054.50
	Female	31	31.02	961.50
	Total	63		

Test Statistics[a]

	S730	S830	S930
Mann-Whitney U	445.500	381.000	465.500
Wilcoxon W	973.500	909.000	961.500
Z	-.707	-1.604	-.426
Asymp. Sig. (2-tailed)	.479	.109	.670

a. Grouping Variable: Gender

Table 7: Mann-Whitney U test statistics

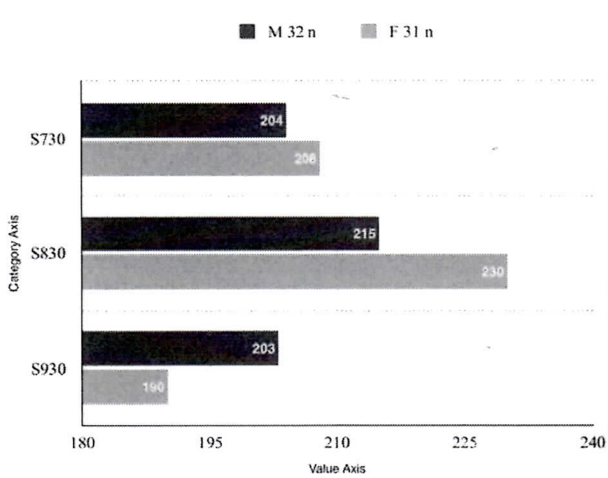


Fig 6. Bar chart showing the sum score of male and female on each lighting scene

4.4 Influence of Other Parameters

There was no statistically significant differences on each preference scene setting by age, education, nationality and occupation.

5. Conclusion

This study investigated visual appreciation/preference of personal skin tone reflection based on a cluster of LED light sources with similar illuminance, CCT, and chromatic coordinates with different CRI, with this information being valuable for application in use for hospitality and retail design projects. Sixty- three participants were asked to assess their skin colour preference under three different illuminants using a10-point preference scale in a full-scale experimental booth.

The results show the following conclusions:

- S830 had the highest preference score in comparison with other two scenes.
- S830 had slightly less colour constituents in comparison with 930 (except for red). It is therefore concluded that the critical factor for preference between these two illuminants is due to the strong addition of red. S830 has approximately 10% more red components than 930. This supports the concept that red is a strong determinant in skin colour preference.
- S830 also showed an increasing preference over 730 due to the increase in colour components across the spectrum. This supports the concept that a broad spectrum of colour is important in general preference.
- CRI in this study seemed not to be sufficient to predict the preference of Asian skin tone. For preference issues related to skin appreciation, it appears that the red content is a strong predictor, and to a lesser extent CRI. At least for skin appreciation preferences, other colour rendition metrics seem to be required. This result is consistent with the Jost et al. (1) study that found that Asians dislike light sources with a less saturated red spectrum even at high CRI. This result also is consistent with several studies (1-8) which found that CRI seems not to be sufficient to predict the skin tone preference.
- Within the same locus, a cluster of all LEDs is more appreciated than a cluster with four colours (green, blue, white and amber). On the other hand, the quantity of LED input presented in cluster is not decisive as the white colour was composed from the phosphor-converted method (25). The influence of the locus in the chromatic diagram seems to be an important factor to determine the preference as S830 and S730, located below the Planckian curve, are more preferred. Meanwhile, the similar SPDs have not much effect as preference on S830 and S930 had no significant relationship as regards S830 and S730. However, this result is not decisive as it shows no significant difference among these three scenes.
- The preference differences between the three scenes were not statistically significant but there were still preference differences. Most likely the reason why large statistically significant differences were not seen is due to the relatively small sample size on this experiment. This research question requires more subjects in a larger study for definitive results.
- The full scale booth approach seems to be a good setup to examine subject preference but the procedure in this experiment only allows one chance for observers to assess their preference. The ability to assess their preference back and forth before giving the answer might be a good protocol for further experimentation.

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