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Evaluating colour preference of lighting with an empty light booth

Q Liu PhD[a,b,c], **Z Huang** BSc[a], **MR Pointer** PhD[b], **M Ronnier Luo** PhD[d], **K Xiao** PhD[b] and **S Westland** PhD[b]
[a]School of Printing and Packaging, Wuhan University, Wuhan, China
[b]School of Design, University of Leeds, Leeds, UK
[c]Shen Zhen Research Institute, Wuhan University, Shenzhen, China
[d]State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou, China

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In our recent work, the colour preference of several LED white lights with different correlated colour temperatures (CCT) was investigated with a wide selection of objects. The results highlighted the dominant effect of light itself on the colour preference of lighting. In this study, we similarly implemented two psychophysical experiments with the same lights but with nothing in the light booth. It was found that the subjective ratings for the lit environment of the empty booth were quite close to those of the previous studies that used various coloured objects. Such a finding corroborates our former conclusion that light dominates colour preference and we suspect that this finding can be attributed either to the colour memory of the observers or to the subconscious effect of human vision. Thus, it seems that for general multi-CCT conditions where the light sources do not have very different gamut shapes or object desaturation/oversaturation properties, the preferred white light could be determined by simply asking the observers to rate their preference for the lit environment of the empty light booth. To verify this wild and interesting conclusion and further clarify its applicability, follow-up studies are needed.

1. Introduction

Colour preference is of crucial importance to the colour rendition quality of a light source.[1,2] In current studies, such an issue has been primarily investigated by psychophysical experiments in which the observers had to rate the colour appearance of certain coloured objects under several experimental lights in a light booth, according to their visual preference.[3–13]

It is widely accepted that colour preference varies with the presented objects.[5,6,8,14] However, there is no agreement among current researchers on which objects should be used in the light booth. The objects included in recent research have varied considerably, and included fruit and vegetables,[5,6,13] skin tones,[3,8] printed images,[8,11] artworks,[15] cosmetic products,[10] consumer goods[7,9] as well as combined objects.[3,4,12] As summarized by Royer *et al.*, little research has focused on discussing the impact of object characteristics on colour preference.[16,17]

To address this issue, therefore, a series of psychophysical experiments was conducted as part of our recent work.[15] A broad range of objects were separately adopted in the experiments, which included four groups of fruit and vegetables with different colours, five

Address for correspondence: Q Liu, School of Printing and Packaging, Wuhan University, Luoyu Road 129, Wuhan, China.
E-mail: liuqiang@whu,edu.cn

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Chinese traditional calligraphies with different background colours, four pieces of artwork with different colour features and a bunch of artificial multicolour flowers. According to Royer *et al.*, these kinds of objects were found to be very crucial when observers evaluated the lighting conditions.[17]

The above-mentioned 14 groups of objects were separately illuminated by certain white lights with uniformly sampled correlated colour temperatures (CCT) ranging from 2500 K to 6500 K. A seven-point rating method or a five-level ranking method was used to quantify the observers' colour preference. Such work systematically investigated and compared the influence of the several contextual factors on colour preference, which included light, object, gender, cultural difference, as well as individual colour preference. Overall, the dominant influence of light on colour preference was well demonstrated.[15] In other words, although the prerequisite and applicability of such a conclusion should be further specified, it can be assumed that at least for general multi-CCT conditions where the light sources do not have very different gamut shapes or object desaturation/oversaturation properties, the light itself is the most important factor to influence which light among several candidates an observer will prefer.

In order to confirm our former conclusion and to further investigate the mechanism of colour preference, two psychophysical experiments have been conducted. These additional experiments followed procedures that were very similar to those used previously with the most noteworthy exception being that there was nothing in the light booth. That is, we asked the observers to directly rate their preference for the lit neutral environment in the booth. To our knowledge, no past studies have been conducted in such a manner.

2. Method

The first experiment strictly followed the procedures of the seven-point rating experiments of our previous work.[15] The illumination was uniformly set to 200 lx (measured by a Testo 540 illuminance meter on the bottom of light booth) for each lighting condition. Forty-five observers assessed the lit environment in the empty booth whose inner surfaces were coated with matt gray paint (Munsell N5), with regard to the same nine lights ranging from 2500 K to 6500 K (500 K interval). Meanwhile, just like the former studies, a randomly selected light source was also used twice (without informing the observers) to test the intra-observer variability for each participant.

The second experiment was similar to the five-level ranking case of the former work.[15] The illumination was again 200 lx in the empty booth and the same five light sources (2500 K, 3500 K, 4500 K, 5500 K and 6500 K) were used. A slight difference was the fact that the 60 participants only needed to choose their most-liked and least-liked light sources, rather than ranking the order for the whole range of light sources. Afterwards, the preference of each candidate source was simply quantified by subtracting the score of least-liked from most-liked (e.g. only three observers chose 2500 K as their most liked source, while 40 observers regarded it as the least liked source, so the final score for 2500 K was −37).

Note that during the experiments, the order of the light sources was randomized and counterbalanced between observers and each participant was asked to keep his/her eyes closed for 15 seconds while the experimenter changed the light source. Such a design had the purpose of eliminating any influence from the previous lighting conditions caused by a short-term memory effect. In the seven-point rating experiments, the observers were asked to give a response after a period of 40 s to allow for chromatic adaptation, while in the five-level ranking case the participants were allowed to take as much time as they wished. It can also be mentioned that none of the observers in these additional experiments had participated in the former studies. For more details of these experiments, please refer to our recent work.[15]

3. Results and discussion

As shown in Table 1, although different in magnitude, the results of the two experiments perfectly match each other in rank order (Spearman correlation coefficient r=1), which demonstrates the repeatability of this work. In addition, the inter-observer and intra-observer variability of Experiment 1 was also tested following the method used in the earlier work[15] and the results were also acceptable: the inter-observer variability was 1.26–1.89 (former study: 0.92–2.21) while the intra-observer variability was 13% (former study: 6–17%).

Figure 1 illustrates the mean preference ratings of the former and the current studies. Note that only the light booth scenarios with the seven-point rating method are shown here. For other scenarios (i.e. the mural painting experiment in a museum, or the ranking based experiments), although their results exhibit similar trends, those values cannot be compared directly due to the difference of experimental settings or scoring rules.

As can be seen from Figure 1, the trends of preference ratings with regard to these scenarios (including the empty-light-booth experiment) are quite consistent. It seems that no matter what is in the light booth, the observers always responded to the lights in a similar way. This serves as good evidence for our previous conclusion: light dominates colour preference in our experimental condition.

The Spearman correlation coefficients (r values) given in the legend of Figure 1 further demonstrate the feasibility of the proposed empty-light-booth approach. It is clear that apart from the orange calligraphy scenario, the ratings of the empty-light-booth experiments are highly correlated to those of the other scenarios. As for the orange calligraphy scenario, as shown in Figure 1 (magenta dotted line), the low correlation ($r = 0.15$) is possibly due to the fact that the average ratings of the 4500 K, 5500 K and 6500 K lights were almost the same. In other words, it is very likely that the true correlation of this scenario was masked by the intra-observer variability of the experiment. Therefore, it should be safe to conclude that the empty-light-booth scenario is representative of the other lighting conditions.

Furthermore, since the observers in each scenario are very similar in age and background (They were all engineering students in Wuhan University, China), we assume that the individual differences between the two groups of observers is small. In fact, our

Table 1 Mean preference rating for the light sources (Experiment 1) and the difference in ranking of the most and least preferred light source (Experiment 2)

	2500 K	3000 K	3500 K	4000 K	4500 K	5000 K	5500 K	6000 K	6500 K
Experiment 1	−1.27	−0.58	0.47	1.00	0.82	0.96	0.91	0.44	0.27
Experiment 2	−37	–	5	–	19	–	22	–	−9

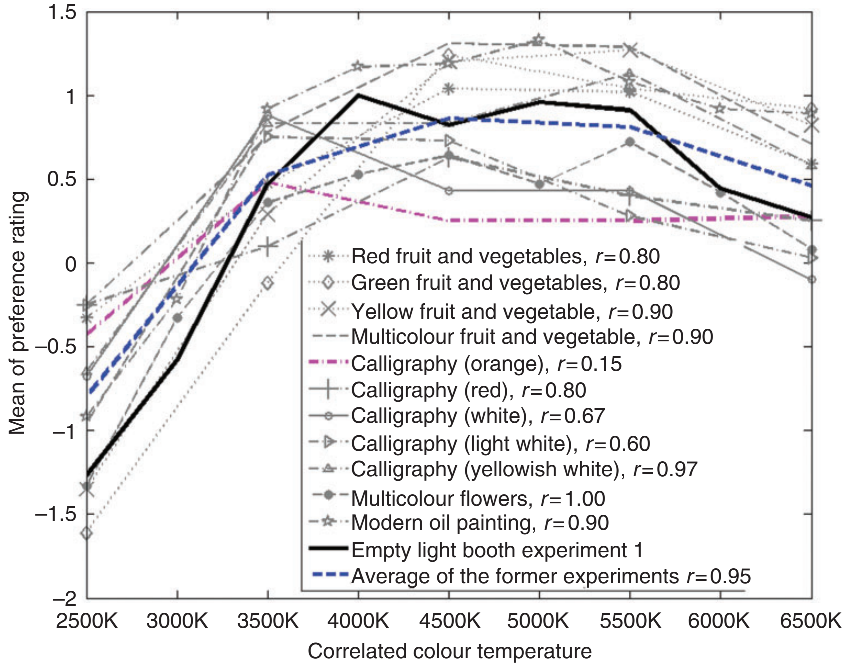

Figure 1 Comparison between the mean preference ratings of the empty light booth (experiment 1) and that of former experiments.[15] The r values in the legend denote the Spearman correlation coefficients between the rank orders of the ratings of a former experiment and the empty-light-booth experiment

Table 2 The p-values of t-tests for each light source examining the effect of the presence or absence of different objects in the light booth. ('F & V' and 'CAL' are, respectively, short for 'fruit and vegetables' and 'calligraphy')

	2500K	3000K	3500K	4000K	4500K	5000K	5500K	6000K	6500K
Red F&V	0.022	–	0.976	–	0.345	–	0.761	–	0.388
Green F&V	0.369	–	0.047	–	0.107	–	0.634	–	0.051
Yellow F&V	0.901	–	0.581	–	0.108	–	0.262	–	0.108
Multicolour F&V	0.426	–	0.221	–	0.058	–	0.188	–	0.248
Orange CAL	0.041	–	0.978	–	0.030	–	0.022	–	0.933
Red CAL	0.014	–	0.196	–	0.456	–	0.107	–	0.987
White CAL	0.120	–	0.171	–	0.145	–	0.115	–	0.352
Light white CAL	0.009	–	0.354	–	0.734	–	0.041	–	0.568
Yellowish white CAL	0.117	–	0.206	–	0.992	–	0.444	–	0.368
Flowers	0.868	0.493	0.731	0.105	0.509	0.119	0.567	0.939	0.680
Oil painting	0.414	0.327	0.123	0.549	0.163	0.185	0.597	0.207	0.117

Note: Underlined p-values indicate rejection of the null hypothesis.

previous work has already demonstrated that compared to the influence of the light, the individual differences between observers is insignificant.[15] A t-test was used to investigate whether the absence of objects in the booth influenced the observers' preference rating.

The p-values shown in Table 2 indicate the statistical significance with regard to the null hypothesis (for the same light source, having an object in the light booth will not influence the subjective preference rating). If $p \geq 0.05$, the null hypothesis is accepted, otherwise, the null hypothesis is rejected. For instance, for the 2500 K lighting condition with the red fruit and vegetable scenario, a p-value of 0.022 indicates that putting such objects in the light booth indeed affects the preference rating. However, it is clear from Table 2 that for most conditions, the presented objects actually have no influence on the subjective ratings, which highlights an interesting question: is it really necessary to put certain objects into the light booth?

Meanwhile, it must be acknowledged that the ease with which we perceive colour preference actually belies the complexity of the underlying visual processing mechanism. Since preference perception is a multidisciplinary issue which relates to physics, ophthalmology, neurology and psychology, it is really difficult to thoroughly explain the underlying mechanism of the above mentioned empty-light-booth experiments. However, as far as we can discern, there may be two possible explanations.

Our first hypothesis concerns colour memory. As several participants mentioned after the experiment, when rating a certain light in the neutral environment of the booth, they imagined, consciously or unconsciously, how a certain scene (e.g. a living room or a dormitory) would look under such a light. Therefore, we suppose that although there was nothing in the light booth, the observers could rate the colour preference according to colour objects rooted in their memories. What is more, such personal memory colour objects may be much more important to each individual observer than the 'typical' objects, such as fruit and vegetables, consumer goods or artworks. Hence, under this assumption the empty-light-booth experiment may serve as sound evidence for our previous conclusion.[15]

The second hypothesis, which might be more important, lies in the subconscious effect of human vision. To date, it has been widely accepted that human vision is affected by conscious and sub-conscious processes over the whole retinal region.[18] Conscious vision is mainly related to the central field of view (the fovea) with an angular subtense of about 2° radius, while subconscious vision corresponds to the regions surrounding the fovea with an angular subtense of about 20° radius. Moreover, it is also reported that even the peripheral regions (an angular subtense of up to 50° radius) around the retina may also influence human vision.[19] For the light booth experiments, when participants were asked to observe certain objects, the foveal response (conscious vision) was mainly desired by the experimenters. However, it is inevitable that the subconscious vision would also affect the subjective response, since the observers simultaneously perceived the lights reflecting from the inner neutral surfaces of the booth through larger angles of view. In this case, therefore, if the subconscious vision regarding the lit environment of the booth was so strong that it even dominated the cognitive process of preference, putting any objects in the light booth may actually turn out to be insignificant. To test this rough assumption, future psychophysical studies which exclude the effect of the subconscious visual process are needed.

4. Conclusion

To sum up, in this study two empty-light-booth experiments were implemented. Although the visual processing mechanism of such experiments is not clearly understood, the results of the experiments profoundly confirmed the feasibility of the empty-light-booth approach. In other words, there seems to be no need to be concerned about the presented objects when evaluating the colour preference of a light source, since an empty light booth with a neutral environment is already sufficient in certain conditions.

It is worth mentioning that, based on the above described hypothesis, the surroundings of the experimental objects (even the neutral background in the booth) may influence subjective preference ratings. This statement highlights the superiority of the real scene experiments, where the psychophysical studies were conducted under immersive conditions.[14,17,20–24] Meanwhile, contrary to the real scene experiments which focus on certain targeted cases, the proposed empty-light-booth approach could serve as a universally applicable method for characterizing the colour preference of lighting for general conditions.

To make a safe conclusion, the prerequisites of this study must be emphasized. This work mainly focuses on the colour preference evaluation of general multi-CCT conditions where the light sources do not have very different gamut shapes or object desaturation/oversaturation properties. For specific usages (e.g. the colour preference of skin or some other specific targeted scenes) or extreme lighting conditions, it is quite likely that the corresponding objects are still needed.

In addition, the precondition and applicability of the proposed empty-light-booth approach actually needs further investigation. In fact, we suspect that the empty–light-booth approach is applicable to a broader range of conditions, since the dominant effect of light on colour preference has also been reported in other conditions.[3,5,6,14] However, the current research can only prove its feasibility for the experimental condition used. Besides, since the parameters of the experimental SPDs (e.g. CCT, Duv, Rf, Rg, etc.) are all varied, in this research we cannot derive any conclusion regarding which parameter contributes most. Fortunately, according to current LED light-tuning technology, it is already possible to hold all but one of those variables constant when generating the light sources, which provides potential for future work using the empty-light-booth format.

Meanwhile, it seems that the results of the empty-booth-experiments described above are highly correlated with the results of research work on the whiteness perception of lighting,[25,26] since they share a similar experimental protocol while mainly differing in the way the observers respond (preference or whiteness). In this sense, the colour preference of the empty light booth could also be considered as 'white tone preference'. In future work, the relationship between these two topics should also be further studied.

Declaration of conflicting interests

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