Relationship of Different Scales for Evaluating the Quality of LED Lighting

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Abstract Existing studies used different scales to evaluate the quality of LED lighting by psychophysics experiments, which viewed specific objects. It is believed that for universal lighting, diverse objects are needed to evaluate color quality. In order to produce a suitable factors space to evaluate the quality of universal lighting, a psychophysics experiment was conducted, which used objects of different color or attribute. The experiments were carried out in darkrooms. In total, 44 observers viewed seven groups of objects to evaluate lighting quality. In this paper, factor analysis was used to reduce the large number of scales into fewer underlying independent factors. The results showed that objects of different color or attribute had an impact on visual perception, and three factors dominate visual perceptions: Attraction, Vividness and Warmth. Basing on this finding, a three-factor space was defined. The work was intended to set up a three-factor space as the help for the construction of LED lighting evaluation and application methods.

Keywords Scale · Factor analysis · LED lighting quality

1 Introduction

The LED technology was gradually accepted and applied in many lighting scenes. However, its specific radiation distribution pattern over the visual spectrum differed from those of standard sources raised questions about conventional CIE colorimetry

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and CRI calculation methods [1]. As some studies showed, CRI metric was not always provide a reliable description of visual perception of color rendering, especially in the case of white LEDs [2–4]. In order to evaluate lighting quality better, existing studies used different scales by psychophysics experiments and showed scales played an important role [5–10].

For example, Zhai [5] clarified three dominating visual factors including Comfort, Vividness and Definition determine the quality of LED lighting for observing fine art paintings; Jost-Boissard [6] suggested that it should be possible to find LED blendings that perform better than halogen or fluorescent in terms of suitability and, in many cases, more attractive in color rendering (i.e. preferred). However, each study used specific objects in order to clarify the relationship of scales, for instance, paintings as objects by Zhai [5], color samples by Ou [8], and fruits and vegetables by Jost-Boissard [6]. In this case, the factors space for specific objects did not work well for universal LED lighting. It is believed that for the universal lighting, diverse objects are needed to evaluate lighting quality.

Starting out from the above considerations, we used objects of different color or attribute and conducted a psychophysics experiment. This aims to produce a suitable factors space to evaluate the quality of universal lighting. The experiment was carried out in darkrooms. Philips Hue intelligent LED was used as the light source in the experiment. One environment was in a standard laboratory suitable for observation and another was in a museum (Wanlin Art Museum, Wuhan University). In total, 44 observers viewed seven groups of objects to evaluate lighting quality. Besides, a variety of objects were selected because the subjective need in color quality of illumination depended on the character of the illuminated object and its familiarity to the observer [11, 12]. Therefore, the aims of the study are as follows: (1) To verify the results of previous experiments and continue studying the relationship of scales; (2) To produce factors space in order to provide help for the construction of LED lighting evaluation and application methods.

2 Experiment

The experiments were approved by the Ethics Committee of Wuhan University. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all observers for being included in the study.

2.1 Environment

In the laboratory, the light source was installed at the top of a light box, with a size of 60 cm × 65 cm × 89 cm. The surrounding and bottom surfaces of the booth were coated with medium gray matt paint (Munsell N5). Figure 1 shows the viewing conditions.

The experiment set the LED light source correlated color temperature (CCT) to 3500 K in the laboratory and 3500 and 6500 K in the museum. The illuminance was set for 200 lx. 6500 K as a higher CCT was selected, in order to form a validation with Zhai [5].

2.2 Objects and Observers

Objects were divided into familiar and unfamiliar in the experiment. Familiar objects included yellow, red, green, multicolored fruit and vegetables, and flowers. Unfamiliar objects included the yellow-white paper of the calligraphy work and three Dunhuang murals copied. There were four gray and non-reflective discs with the same size to contain fruits and vegetables. Most of them kept consistent with the studies by Jost-Boissard [6], Zhai [5], and Liu [7].

Forty-four Chinese observers aged 18–24 participated in the experiment. In the laboratory, there were fifteen male and fifteen female observers. There were seven male and seven female in the museum. It was intended to be able to compare the results between genders. They were from school of the Printing and Packaging, Wuhan University, and each observer was first tested for their color vision by the Ishihara test.

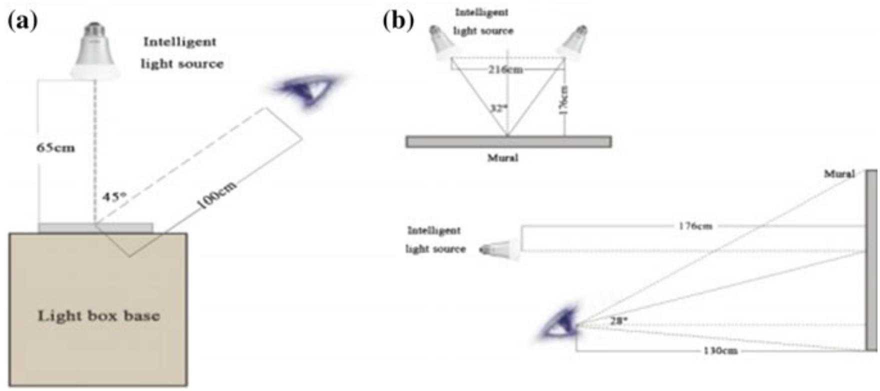

Fig. 1 The viewing condition **a** of the laboratory **b** of the museum

2.3 Scales

12 pairs of scales were used in the experiment. Four of them were associated with the appearance of the objects (Warm/Cool, Fresh/Stale, Bright/Dark, Colorful/Dull), and the others were associated with the atmosphere of the space (Active/Negative, Pleasant/Unpleasant, Attractive/Repel, Soft/Hard, Lively/Boring, Relaxed/Tense, Artistic/Business, Polite/Vulgar), introduced by Zhai [5]. The present study investigated the scales that have been frequently used in early studies [4–7]. Each was scored using a seven-point rating method [13]. Scores 1–3 and −3–1 stood for the range of the positive and negative perceptions, while score 0 stood for there was without positive and negative perceptions.

2.4 Procedure

The experiment was carried out by the experimenter reading out questions that were answered orally by the observers. We did not ask the observers to write an answer for each question. This was to avoid the incomplete chromatic adaption likely to be caused by the observer staring at a questionnaire printed on white paper. In the laboratory, 30 observers evaluated a total of six groups of fruits and vegetables, flowers and calligraphy work using 12 scales under the lighting source with 3500 K. In the museum, 14 observers evaluated three murals using the same 12 scales under the lighting source with 3500 and 6500 K. The orders of the objects in each lighting condition and of the scales for assessing each object were all randomized.

3 Result and Discussion

3.1 Gender Difference

The Pearson product–moment correlation coefficient was used in this study as a measure of gender difference in among 12 scales, based on all objects data under 3500 K, where 3500 K data showed a normal distribution. The coefficients range from −1 to 1, where −1 represents a perfectly negative correlation and 1 a perfect positive correlation. The coefficient of zero indicates a completely nonlinear relationship between two variables.

Active/Negative and Relaxed/Tense scales have low correlation coefficients, 0.47 and 0.40. This suggests that gender difference seem to exist in the two scales Active/Negative and Relaxed/Tense. It is found that the most deviate object on Relaxed/Tense is the red fruits and vegetables, which has a score for male −0.6 and female 1.34. The green fruits and vegetables are most deviate object on Active/

Negative for male −0.27 and female 1.07. Whereas, Most of the correlation coefficients are fairly high with the mean value of 0.7, showing that there is a little gender difference in most scales, consistent with Ou [8].

3.2 Impact of CCT in the Museum

For each scale, the mean rating is calculated. The larger the number is, the stronger the perception to the positive word. When CCT increases, the Warm perception decreases sharply and the Bright perception increases the fastest. In other words, the most obvious impact is that an increase of CCT would lead to a cooler perception, which agrees with our earlier findings [5]. Besides, an increase of CCT would make the environment brighter.

By using the principal component analysis method, three factors are extracted from the 3500 K data, accounting for 70% of the total variance. They are labeled Components 1, 2, and 3. From the 6500 K data three factors are extracted which account for 76% of the total variance. Both the result of 3500 and 6500 K have Pleasant, Lively, Polite and Fresh in Component 1; Artistic in Component 2; Colorful in Component 3. This indicates that 3500 and 6500 K have similar underlying factors of visual perceptions, although several scales are found to fall into different categories such as Active, Relaxed and Warm. Therefore, 6500 K doesn't require analyzed separately.

3.3 Factor Analysis

The next analysis applied to the data in 3500 K is factor analysis, which is intended to reduce the large number of scales into fewer underlying independent dimensions. These could be used as the control parameters for lighting. Principal component analysis and orthogonal rotation were applied in the factor analysis.

3.3.1 Object Difference

To investigate the differences between familiar and unfamiliar objects, the factor analysis is conducted by combining five familiar objects data and two unfamiliar objects data. Three factors are extracted separately from the familiar and unfamiliar objects data, labeled Components 1, 2 and 3. There was one thing to point that Relaxed falls into another factor except three Components for familiar objects, whereas, in Component 2 for unfamiliar objects. When subjects are unfamiliar such as murals and paintings, Relaxed is different from when subjects are familiar including color samples, fruits and vegetables, also noticed by Zhai [5] and Ou [8]

According to the above study, three factors plots are established from the extraction data. The three axes are determined by three factors. In Figs. 2 and 3 present the factor plots for the familiar and unfamiliar objects, respectively.

As shown in these diagrams, most scales, except Colorful, Pleasant and Artistic, are found at similar locations in the two plots. In the familiar objects plot, Colorful is located near Attractive, Lively and Polite, whereas in the unfamiliar objects plot Colorful is located far from all the other scales. This suggests more “colorful” objects of familiar show more “attractive”, “lively” and “polite”. The familiar objects plot shows that Pleasant is near Fresh and Polite, whereas in the unfamiliar objects plot Pleasant is far from all the other scales except Relaxed. This shows “fresh” and “polite” objects of familiar are more “pleasant”, while “relaxed” objects of unfamiliar are more “pleasant”. Artistic is near Relaxed and Polite in the familiar objects plot, whereas near Soft in the unfamiliar objects plot. This suggests that “relaxed” or “polite” objects of familiar give an “artistic” perception, whereas “soft” objects of unfamiliar give an “artistic” perception.

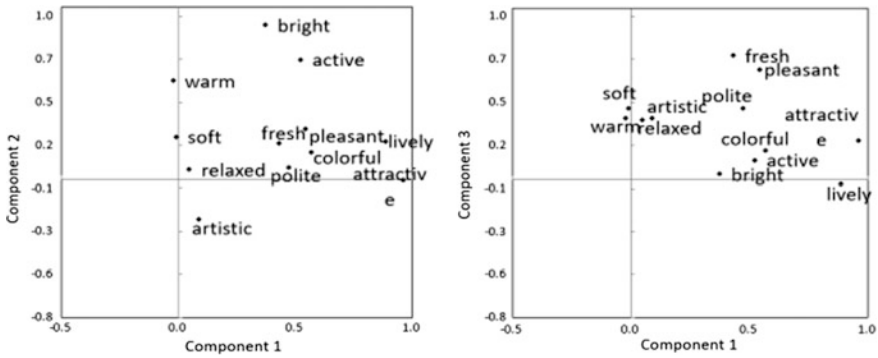

Fig. 2 Three-factor plot of the 12 emotional scales for familiar objects

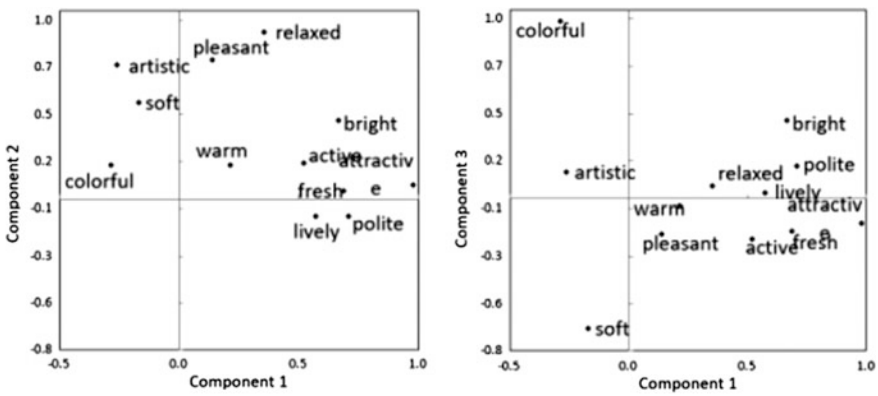

Fig. 3 Three-factor plot of the 12 emotional scales for unfamiliar objects

3.3.2 Factor Extraction

This process excludes four scales, including Colorful/Dull, Pleasant/Unpleasant, Artistic/Business, and Relaxed/Tense. The reason is that Colorful/Dull, Pleasant/Unpleasant, Artistic/Business and Relaxed/Tense produce object difference between familiar and unfamiliar objects, as indicated in the previous section. Besides, Relaxed/Tense produces gender difference.

Three factors are extracted from the remaining color emotions. The names of each factor are based on the word pairs closely related, and they are named Attraction, Vividness and Warmth, respectively. They explain about 60% of the variance, as summarized in Table 1.

The results in Table 1 show that the Attraction factor is more related to the atmosphere perception of the lighting, while Vividness and Warmth factors are more related to the appearance of the objects. Vividness is an important factor about contrast information of objects used in the experiment such as brighter and fresher, which agrees well with Zhai [5]. Warmth factor has been one of the most important scales in early studies [8, 10]. Another factor is Soft and is on its own having a low-variance contribution.

3.3.3 Coordinate Determination

The three factors Attraction, Vividness and Warmth are used to define the three axes in the space. Coordinates of three factors are determined by factor scores. Figure 4 plotted the seven objects along the three factors. The objects at the central area evoke only a small amount of scales and those located at the outer layer evoked strong scales.

At a later stage, the data relating to each individual object are used to conduct factor analysis. The result shows a consistence with most scales among red, multicolored fruits and vegetables and flowers, because the red components of the multicolored object have a considerable influence [6]. Besides, it is found that

Table 1 Factor matrix of scales excluding Colorful/Dull, Pleasant/Unpleasant, Artistic/Business, and Relaxed/Tense

Factor meaning (60%)	1(25%) Attraction	2(19%) Vividness	3(16%) Warmth
Attractive	0.754	0.322	0.270
Polite	0.709	0.037	0.117
Lively	0.683	0.443	0.149
Bright	0.050	0.770	0.067
Active	0.440	0.556	0.318
Fresh	0.423	0.516	0.059
Warm	0.052	0.226	0.970
Soft	0.239	−0.005	0.378

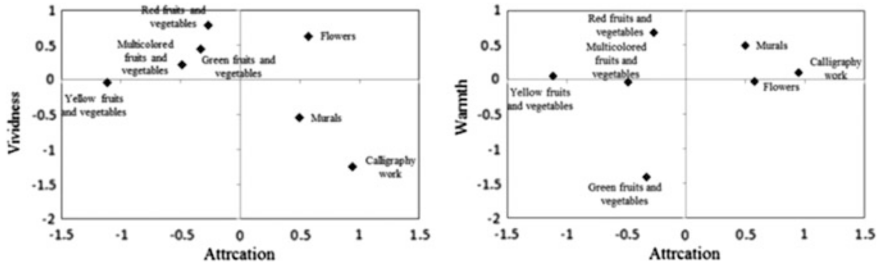

Fig. 4 The three-factor space developed in this study, where the seven objects are plotted along the three factors: Attraction, Vividness and Warmth

objects of different color or attribute had an impact on visual perception. This can be due to the fact that color or attribute for each object is different, and observers evaluate color quality on the basis of color or attribute.

4 Conclusions

A psychophysics experiment was carried out to evaluate color quality of familiar and unfamiliar objects, through which aimed to study the inner relationship of scales and to produce factors space.

It was found that gender difference seem to exist in Active/Negative and Relaxed/Tense perceptions, while not exist in most scales. Also, most scales were consistent in 3500 and 6500 K data, suggesting that there were similar underlying factors of visual perceptions in 3500 and 6500 K.

12 scales were compared between three-factor plot for familiar objects and three-factor plot for unfamiliar objects. Most scales were found at similar locations in the two plots, except Colorful, Pleasant and Artistic.

(a) Colorful: more "colorful" objects of familiar showed more "attractive", "lively" and "polite" while this tendency did not occur to unfamiliar objects.
(b) Pleasant: "fresh" and "polite" objects of familiar were more "pleasant", while "relaxed" objects of unfamiliar were more "pleasant".
(c) Artistic: "relaxed" or "polite" objects of familiar gave an "artistic" perception, whereas "soft" objects of unfamiliar gave an "artistic" perception.

The above three scales and Relaxed were excluded in factor extraction due to the fact that they produce object difference and Relaxed produce gender difference. Then factor extraction revealed three dominating visual factors: Attraction, Vividness and Warmth. These three determine the quality of universal LED lighting. Besides, the three-factor space was defined, which three axes were based on the three factors Attraction, Vividness and Warmth. In later stage, the data relating to each individual object were used to conduct factor analysis. The result showed a consistence with most scales among red, multicolored fruits and vegetables and flowers. And, the inconsistence between the factors for each individual object and the factors for all the objects verified that objects containing different color or attribute are suitably used to evaluate the quality of universal lighting. The work was intended to set up a three-factor space as the help for the construction of LED lighting evaluation and application methods. In fact, it is believed that lighting quality can be impacted by many other factors including CCT, illuminance level and the observers' characteristics (cultural background). The next step is to focus on existing experimental methods into the actual lighting environment, with hope to enhance the level of theoretical analysis on the basis of improve the data.

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