Subjective Assessment of Color Naturalness of Objects Illuminated by LED Light Sources with Various Color Rendering Index and Color Temperature

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Abstract

Subjective evaluation of LED light sources is important because they have characteristic spectral distributions not similar to conventional light sources. Average color rendering index (Ra) is generally used as an index of color reproducibility of light sources. A simple question about "Ra" is that color temperature of light sources is not taken into account to the assessment methodology of color reproducibility. We suppose color temperature of light sources naturally affect to color reproducibility. In this study, we investigated quantitatively how Ra and color temperature of LED light sources affect color reproduction respectively. We prepared 8 commercial LED light sources which have various values of Ra and color temperature. Subjects observed 11 different objects, one by one, under each of the 8 different light sources, and assessed the color naturalness of each object under the 8 different light sources using 5 ranks of subjective score. We calculated correlation coefficients 1) between average color rendering index and subjective assessment, and 2) between color temperature of LED light sources and subjective assessment. Color temperature (correlation coefficients 0.58) showed clearly higher correlation to color naturalness than that of Ra (correlation coefficients -0.24). Thus, our subjective evaluation results have shown that color naturalness of objects is almost independent to average color rendering index of an illumination but evidently dependent to color temperature of the illumination.

1. Introduction

Subjective evaluation of LED light sources is important because they have characteristic spectral distributions which are not similar to conventional light sources. Average color rendering index (Ra) is defined as an averaged color difference between the values of reflected lights from the same eight color charts under two lighting conditions; one is test light source for evaluation, and the other is a reference light source which has the same correlated color temperature with that of the test light source [1] (Fig.1). It is generally believed a light source with high value of the Ra provides natural color appearance. But, there is a possibility that Ra is not always an appropriate parameter for color naturalness because Ra does not take into account any effect of color temperature ; Ra is defined only for light sources with the same color temperature.

Only a few study have been carried out for comparison of effects of Ra and color temperature to color naturalness [2],[3]. In this study, we focused on investigation of how the Ra and color temperature of LED light sources affect color reproduction respectively.

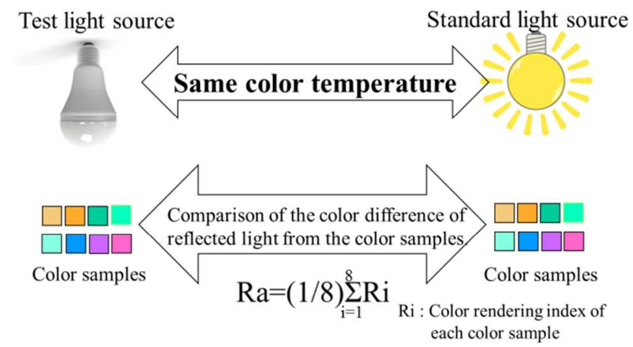

***Fig.1** Calculation method of average color rendering index: Ra.*

2. Experimental Methods

We prepared commercial 8 LED light sources with 3 levels of color temperature (2800 K, 5000 K, 6500 k) and 3 levels of Ra (70 ≦ Ra<80, 80 ≦ Ra<90, 90 ≦ Ra ≦ 100) as light sources to be evaluated. We also used two CIE standard light sources (Illuminant "D65", Illuminant "A") as references. All these 10 light sources are listed in Table 1.

Table 1 Light sources for evaluations.

Average color rendering index (Ra) / Color temperature (K)	70≦Ra<80	80≦Ra<90	90≦Ra≦100
2800	Mitsubishi Electric Lighting LDA7L-H-T2 (Ra 75)	STANLEY ELECTRIC L00LA6ZZED (Ra 85)	CCS LDA14L-H (Ra 97) (Illuminant "A" (Ra 100))
5000	TOSHIBA LIGHTING & TECHNOLOGY LEL-AW7N/D (Ra 70)	Panasonic LDA6NH (Ra 80)	CCS LDA14N-H (Ra 97)
6500	Panasonic LDA8DA1D (Ra 74)	Mitsubishi Electric Lighting LDA11D-G (Ra 80)	(Illuminant "D65" (Ra 97))
	Average Ra = 73	Average Ra = 82	Average Ra = 97

Test sample for observation were 5 real objects (plant, carrot, bell peppers, eggplant, subject's hand) shown in Fig.2 and 6 pictures printed by inkjet printer shown in Fig.3. The six pictures were selected from XYZ/SCID standard color image data provided by The Institute of Image Electronics Engineers of Japan. Subjects were ordered to observe 11 different test objects, one by one, under each of the light sources. They were requested to evaluate color appearance of each object in a light box (Fig.4) under the 10 different light sources using 5 ranks of subjective score. Totally 10 subjects were ordered to answer for the two evaluation items. One is “color naturalness” (max score 5 [looks very natural] to minimum score 1 [looks very unnatural]) and “color preference” (max score 5 [very positive feeling] to minimum score 1 [very negative feeling]).

***(a)** Plant*

***(b)** Vegetables*

***(c)** Subject’s hand*

***Fig.2** Observed real objects.*

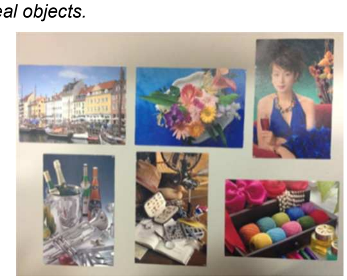

***Fig.3** Observed paper objects (printed by inkjet printer).*

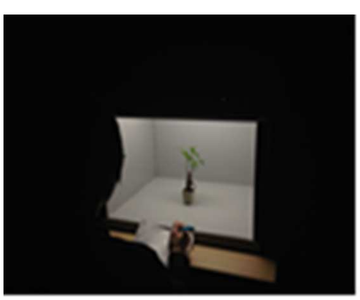

***Fig.4** A scene of subjective assessment in a light box.*

3. Experimental Results

We calculated averaged values of all subjects’ averaged scores on all the 11 objects. Figure 5 shows averaged subjective scores on color naturalness. Averaged values of Ra, 73, 82, 97 were used to plot results of light sources classified to the three ranges of 70≦Ra<80, 80≦Ra<90 , 90≦Ra≦100, respectively. Figure 6 shows an extracted effect of only color temperature, and Fig. 7 shows an extracted effect of only Ra. Figure 8 shows correlation coefficient between color temperature and subjective score of color naturalness calculated using plots of score by each subject. Figure 9 shows, on the other hand, correlation coefficients between Ra and subjective assessment of color naturalness.

Figure 6 indicates clear dependence of subjective score to color temperature. On the other hand, Fig. 7 indicates almost no dependence of subjective score to Ra. The dominance of color temperature is also indicated by Fig. 8 and Fig. 9. A notable value of correlation coefficient was shown only in Fig. 8 as the effect of color temperature.

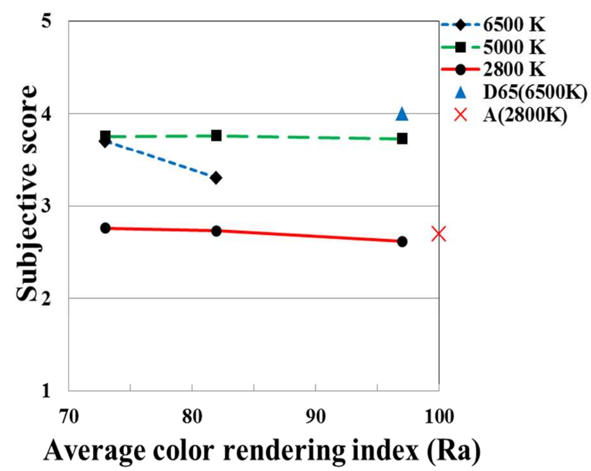

***Fig.5** Subjective assessment of color naturalness.*

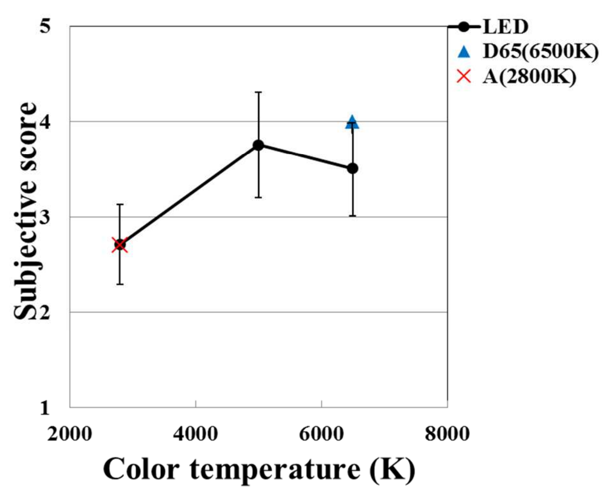

***Fig.6** Relation between color temperature and color naturalness assessment.*

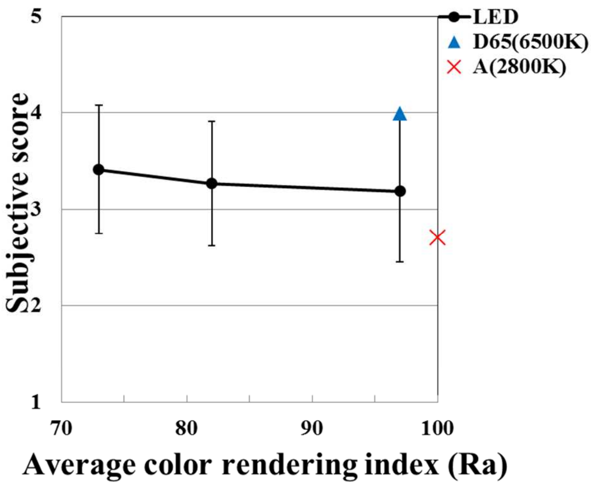

Fig.7 *Relation between average color rendering index and color naturalness assessment.*

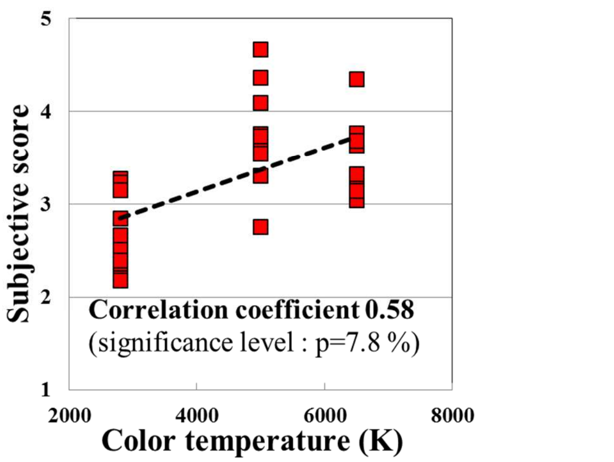

Fig.8 *Correlation coefficient between color temperature and color naturalness assessment.*

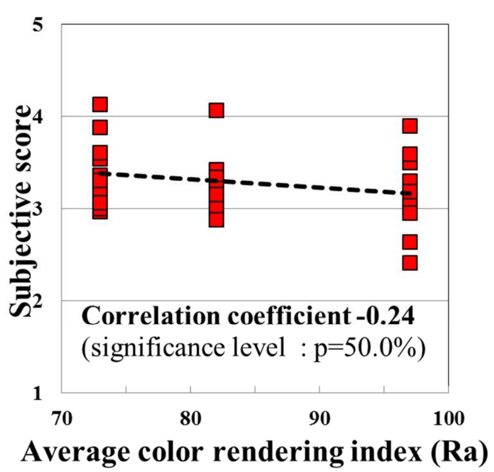

Fig.9 *Correlation coefficient between average color rendering index and color naturalness assessment.*

Figures 10 to 14 shows the same set of results on color preference as those shown by Fig. 5 to 9 on color naturalness. No notable dependence of subjective score to neither color temperature nor Ra is shown in Fig.11 and Fig.12. No notable correlation is shown neither in Fig. 13 nor Fig. 14.

We have thoroughly checked individual evaluation result by each subject in order to investigate if there is really no effect to color preference by color temperature nor by Ra. Then, we have found larger deviation of subjective scores in the extracted dependence to color temperature than that of Ra. The fact is that there were two groups of the subjects; one group gave higher scores for test lights with higher color temperature, and the other group gave higher score for test lights with lower color temperature. This means that color temperature did affect color preference but differently in each person. We calculated differences between the maximum and the minimum values of subjective scores in each subject extracted as dependences to color temperature and Ra respectively for the purpose of quantitative evaluation of deviations of subjective scores. Calculated average value of the score difference in all the subject was 0.89 for color temperature dependence, and 0.39 for Ra dependence. The larger value of the averaged difference for color temperature dependence indicates greater individual effect to color preference by color temperature than that by Ra.

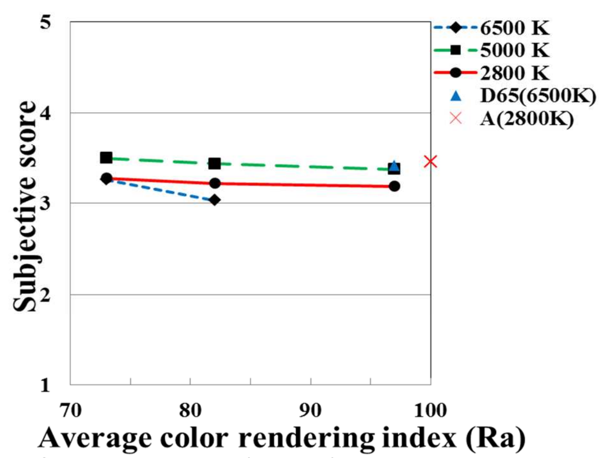

Fig.10 *Subjective assessment of color preference.*

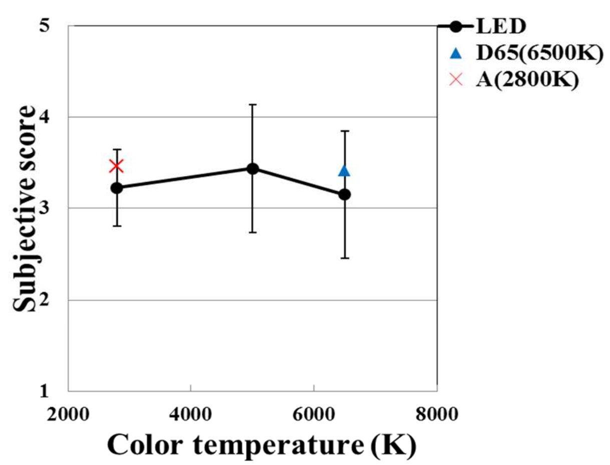

Fig.11 *Relation between color temperature and color preference assessment.*

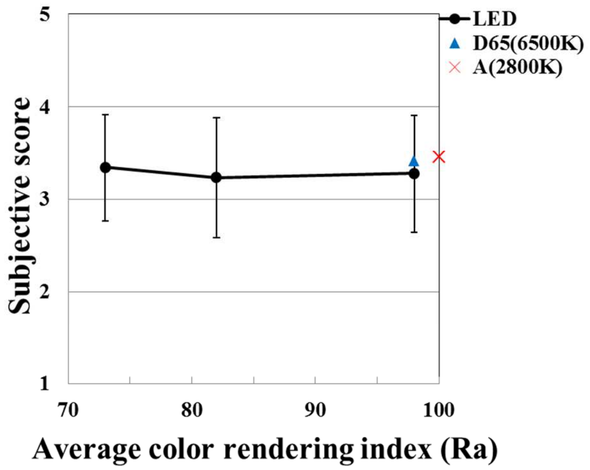

Fig.12 *Relation between average color rendering index and color preference assessment.*

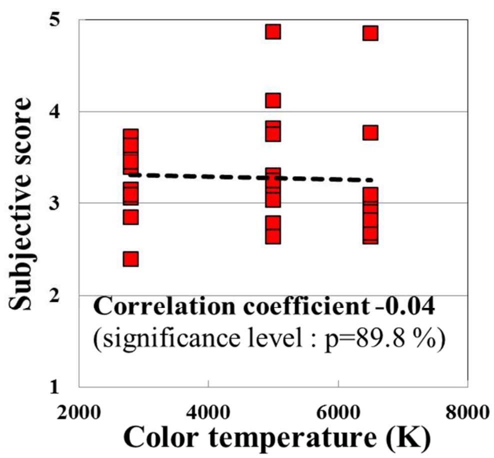

Fig.13 *Correlation coefficient between color temperature and color preference assessment.*

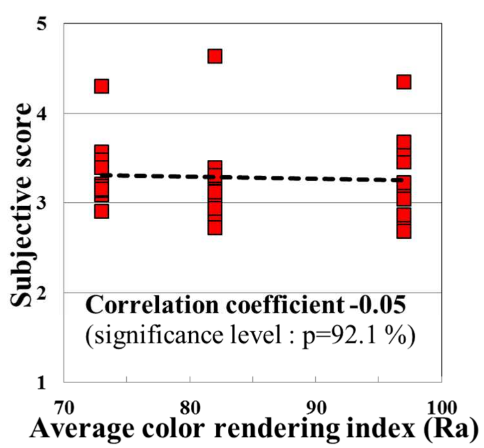

Fig.14 *Correlation coefficient between average color rendering index and color preference assessment.*

4. Discussion

We requested the subjects to evaluate test light in the two aspects, "color naturalness" and "color preference", respectively. The reason was that we had supposed that subjects might wonder whether they should make assessment in a view point of their color preference or in a view point of general color naturalness of the objects, when they were requested simply single score for each test light. Different evaluation results were, as expected, shown for the "naturalness" and "preference". The results of this study indicate color naturalness of objects is dependent to color temperature of the light sources but almost independent to Ra of the light sources. The evaluated results recommend us, if we want color naturalness of objects, to choose light sources with high color temperature (5000～6500 K) without any care about Ra, if Ra is at least over 70, of the light sources. The results of this study also indicate that color preference of objects is tend to be relatively more strongly affected by color temperature of light sources than Ra of light sources. These results indicate that we should care about color temperature than Ra either when we want to choose a light source which assure natural color or which matches individual color preference.

5. Conclusion

In this study, we have investigated quantitatively how the average color rendering index and color temperature of LED light sources affect color reproduction. Essential results are listed as follows:

1) Color temperature of light sources indicated clear tendency of effect to color naturalness and also indicated uncertain individual effect to color preference.
2) Average color rendering index (Ra) did not indicate neither clear tendency to color naturalness nor evident individual effect to color preference.
3) These results suggest us that we should care about color temperature than Ra regardless of our expectation of natural color or individual color preference.

References

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Author Biography

Yohei Sekita was born in 1990. He received his B.E. degree in 2012 from Tokai University. He is expected to receive his M.E. degree from the graduate school of Tokai University in 2014. He is now engaged in a study of color reproducibility of LED light sources.