# EVALUATION OF COLOR DISCRIMINATION UNDER LED LIGHTING BY TWO TYPES OF 100-HUE TEST

Dan Tagawa [1]*, Hitoshi Komatsubara[2], Shinji Kobayashi[2], Nobuyuki Nasuno[2], Yoko Mizokami[1]
and Hirohisa Yaguchi[1]

[1] *Guraduate School of Advantaged Integration Science, Japan.*
[2] *Japan Color Research Institute, Japan.*

*Corresponding author: Dan Tagawa, z9t1543@students.chiba-u.jp

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## ABSTRACT

The light-emitting diodes (LEDs) have become popular, and it is necessary to evaluate the color qualities of LED lighting. Color discrimination is one of the important aspects of color qualities at museums, stores and so on. In this study, we compared two types of 100-hue test under LED and conventional lightings to examine the influence of test samples, especially saturation on the evaluation of color discrimination. One was ND-100 (average $C^*_{ab}$ = 13.43), the other was Farnsworth-Munsell 100-Hue Test (average $C^*_{ab}$ = 25.67). The colors of test lights were daylight, neutral white, and incandescent color. Observers performed two types of 100-hue test under all test lights. Results show that the trend of color discrimination in ND-100 and Farnsworth-Munsell 100-hue test are similar, and there is a little difference between LED and conventional lights in general.

## INTRODUCTION

Light-emitting diodes (LEDs) lighting has become popular because of their advantages such as energy saving, long life. Conventional light sources are getting replaced by LED light sources and we often see LED light sources at stores, at home and at museums. As the color appearance of objects is influenced by light sources, it is necessary to evaluate the color quality of LED lighting.

One of the important aspects of lighting quality would be color discrimination especially for situations that small color difference is critical, such as museums, stores, offices dealing with color management. There are some studies on discrimination task under various lightings, but they do not focus on difference between conventional lights and LED lights. Although some studies used a 100-hue test to evaluate the light sources [1][2], they did not examine the effect of saturation on the performance. In this study, we investigate the difference of color discrimination between conventional lights and LED lights and examine the influences of test colors with low and high saturation on discrimination performances by comparing two types of 100-hue test.

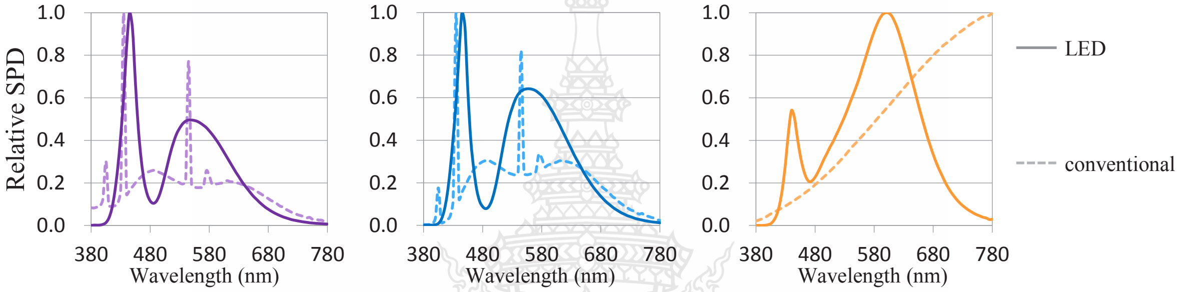
## EXPERIMENT

### *Experimental setup*

A viewing box covered with medium gray (approximately equal to Munsell N6.5) matt paper was used for the experiment. Its size was 60 cm (length) × 89 cm (wide) × 40 cm (height). It was illuminated by one of test lamps and a 100-hue test was placed on the center of its bottom. Horizontal illuminance at the position of a 100-hue test was approximately set to 1000 lx (±10 %).

*Light sources*

We used 3 color types of light (Daylight type, Neutral white type, incandescent color type) for fluorescent lamp, incandescent lamp and LED light sources: fluorescent lamp simulating D65 (approximate correlated color temperature 6200 K, *Ra* 98) and daylight type LED (6500 K, *Ra* 70), neutral white fluorescent lamp (4700 K, *Ra* 97) and neutral white type LED (5000 K, *Ra* 68), incandescent lamp (2800 K, *Ra* 99) and incandescent color type LED (3000 K, *Ra* 84). Figure 1 shows the relative spectral power distributions (SPDs) of the light sources. We compared the combination of fluorescent lamps simulating D65 (D65) and daylight type LED (LED-D), neutral white fluorescent lamp (FL-N) and neutral white type LED (LED-N), incandescent lamp (IL) and incandescent color type LED (LED-L), respectively. It has been already shown that color appearance differs a little under these combinations of light sources in previous studies [3][4].



(a) Daylight (b) Neutral white (c) Incandescent color

**Figure 1. Spectral power distributions (SPDs) of the light sources**

*100-hue tests*

We used two types of 100-hue test for discrimination task. One was ND-100 (Japan Color Research Institute) consisted of 100 color disc samples with low saturation (average $C^*_{ab}$ = 13.43 under D65 illumination), and the other was Farnsworth-Munsell 100-Hue Test (FM-100) consisted of 85 color disc samples with high saturation (average $C^*_{ab}$ = 25.67). Using two types of 100-hue test, we can examine the capabilities of color discrimination for colors with both low and high saturation. Figure 2 shows the appearances under D65 and the chromaticity coordinates in the CIELAB ($a^*$, $b^*$) diagram (under standard D65 illuminant). Each 100-hue test consists of four trays (No.1-4). A discrimination task was carried out for each tray separately.

(a) ND-100 (b) FM-100 (c) Chromaticity coordinates

**Figure 2. Two types of 100-hue tests.**
**Pictures of ND-100 (a) and FM-100 (b) taken under D65. The chromaticity coordinates calculated based on standard illuminant D65 and the spectral reflectance of 100-hue tests (c).**

*Procedure*

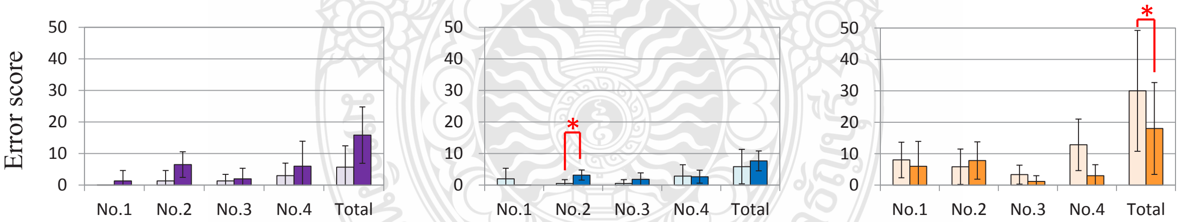
After light adaptation for three minutes, an observer started a discrimination task. They arranged color samples of 100-hue test in consecutive color order. Time for the task was limited to two minutes. Each observer performed the two types of 100-hue test under all test lights, one time for each light condition. Six observers with normal color vision (average age 22.3 years old) participated.

## RESULT AND DISCUSSION

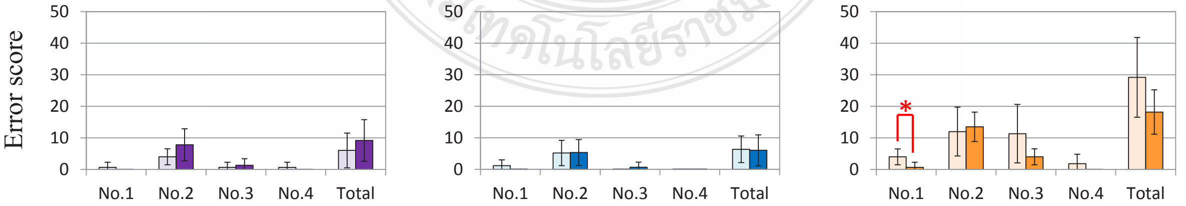
Each color sample was printed the number of correct order in the back. We calculated the error scores from the results of the task for each tray. The calculation of error score is based on the differences of neighboring sample's numbers. With increase of the degree or the frequency of misarrangement, the error score also increases. The calculation methods of error score for ND-100 and FM-100 are slightly different. In this study, however, we calculated the error scores of each 100-hue test by each calculation method because the results of both methods show little difference.

Figure 3 shows the error scores of each tray (No.1 ~ 4) and the sum of error scores for all trays (Total) under each combination of LED and conventional lighting. Error bars show the standard deviations of six observers and asterisks show the results of significance level ($N = 6$; $p < .05$).

The error scores of ND-100 and FM-100 showed similar trend. They tended to be high in greenish color samples (No.2). The difference of the error score under LED and conventional lighting was not large. The error scores of some color samples under LED lighting were a little higher compared to conventional lighting in general. In the case of incandescent color type, the error scores of some color samples under LED lighting were a little lower compared to those under conventional lighting. In most cases, the error scores did not show statistically significant differences between LED and conventional lighting. The error scores and the standard deviations of incandescent color type lighting were larger than the other color types.



(a) Daylight_ND-100 (b) Neutral white_ ND-100 (c) Incandescent color_ ND-100



(d) Daylight_FM-100 (e) Neutral white_ FM-100 (f) Incandescent color_ FM-100

☐ Conventional light ■ LED light

**Figure 3. The error scores for each condition.**
**Error bar indicates Standard Deviation. Asterisks show results of t-test**
**($N = 6$; *, $p < .05$)**

In order to examine the effect of saturation, we also compared the error scores of ND-100 and FM-100 for each condition and carried out the t-test to the results ($N = 6$; $p < .05$). Although the error scores of FM-100 were a little higher than those of ND-100 in most cases, they did not show statistically significant differences.

We calculated chromaticity differences between neighbouring color samples by CAM02-UCS color difference formula [5]. This uniform color space (UCS) can predict color appearance under various viewing conditions and provide better correlation between visual and calculated color rendering values than previous color difference formulae [6]. Comparing the chromaticity of color samples under conventional light and LED light, we found that the chromaticity circle of 100-hue samples under LED light was a little bit distorted. Especially, the chromaticities of yellow and green samples shifted toward green-yellowish direction, and those of blue and red-purple samples shifted toward purplish for both 100-hue tests. These trends are consistent with previous studies [3][4] which shows a small difference in color appearance. These suggest that the color appearances under conventional and LED light are different influenced by the distortion, but the color discrimination is not affected as much as color appearance. At least we did not find the differences of light sources statistically significant enough in the present study.

The results of this study show the possibility that there is a little difference between LED and conventional lighting for color discrimination. Although they did not show enough significant difference, the error score increased with the decrease of color differences between neighbors for some color samples. Because the number of observers and test light sources was limited in this study, the difference of color discrimination between LED and conventional lighting is still unclear and we need further research.

## CONCLUSION

We compared discrimination performances for two types of 100-hue test under LED and conventional lights. Our results show possibilities that there are a little difference in color discrimination under conventional light sources and LED light sources, and little difference in saturation of test samples. However, we need further research because the number of observers and test light sources was limited.

### ACKNOWLEDGEMENT

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