Research on Discrimination Threshold of Brightness for Different Color Temperatures

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Abstract. This article explores the experimental study on the relationship between human eye discrimination threshold of white light under different lighting levels and color temperatures by the psychophysical experimental method. The visual matching method was applied to study the subjective brightness perception under different lighting environments. We try to explore the internal connection between the physical intensity and subjective rating value. The experimental results will do help the development of dimming system for smart lighting.

Keywords. Discrimination threshold, lighting level, color temperature, subjective perception.

1. Introduction

With the improvement of LED technologies, the pursuit of smart and human-centric lighting is increasing. A slight change in the lighting level will cause a change in people's emotional response. According to the Kruithof [1] curve, the observer prefers lower correlated color temperature lighting when the lighting level is lower and prefers a higher correlated color temperature when the lighting level is higher. If the comfort, definition and vividness are taken account, the illuminance level between 200lx to 800lx and the color temperature from 2850K to 4000K will be the comfort zone for people to enjoy the experience[2]. The purpose of this research is to measure the discrimination threshold of human eyes under different color temperatures and different lighting levels, which relates the concept of apparent brightness.

Apparent brightness, is also known as subjective brightness. The industry standard for architectural lighting terms defines the apparent brightness as the visual attribute of the amount of light emitted by a region perceived by human eyes. The apparent brightness studies the light environment more from the perspective of psychophysical and physiophysical quantities. Because the spectral power distribution of traditional white LED light source differs a lot, with the large scale application of LED, the failure of apparent brightness in the traditional photometric evaluation system is more prominent [3-6]. At the same time, the visual brightness discrimination threshold is at different lighting levels. The illuminance and color temperature then play an important role for vision adaptable dimming system.

There are several methods to study the influence of illuminance and color temperatures. Xin Hu [7] completed a brightness-matching task for two side-by-side rooms by asking the experimenter to raise or lower the intensity of the lamps in one room while the other room was maintained at a constant illuminance. K Houser [8] adopted semantic differential scaling to create ratings for seven categories. Davis and Ginther [9] performed room evaluation experiments using two types of fluorescent lamps (2750 and 5000 K; CRI of 89 and 90, respectively) at three illuminance levels (25, 55 and 125 fc). They found color temperature had no effect on brightness perception. In the same way, whether the same results will be achieved by using LED bulbs is waiting for verifying.
2. Experiment: Discrimination Threshold Experiment

2.1. Experiment Purpose
1) To explore the influence of lighting levels changes on the discrimination threshold of perception under different color temperatures.
2) To determine the threshold value of human eyes for different lighting conditions created by the different combination of illuminance and color temperatures.

2.2. Participants
Twenty undergraduates and postgraduates (10 males and 10 females), age from 20 to 25 take part in the tests. All the students participating in the test have corrected visual acuity and no color vision defect. The experiments are carried out in a dark room. The subjects are informed with all experimental procedures before the test begins.

3. Methods
1) Philips HUE system is applied in the experiment. Two 30W dimmable LED lamps with same specification which can be dimmed to change the color temperature and avoid glaring from being too bright in the visual experiment. The HUE software can be used to adjust the percentage of the bulb light output. In this experiment, the lamps can also be set at different color temperatures automatically. The schematic diagram of the experimental design is shown in figure 1.

![Figure 1. Schematic diagram of experimental design.](image)

2) In the HUE software, we set the brightness percentage of lamps to 90%, 70%, 50%, 30% and 10%. Each brightness corresponds to four color temperatures: 3000K, 4000K, 5000K, 6500K. Then totally 20 experimental scenarios can be created. In this experiment, the observer is in front of the lamps, and facing the lamps. The distance from the face to the lamp is 1.5 meters, and the distance from the LED lamp to the middle partition is 0.96 meters.

3) Before the formal experiment, the observers need to familiarize how the light fixture appears in different color temperatures and different lighting levels. Then, the observers close their eyes for relax. Their eyes will be covered with black patch. They can take it off during the tests and take a break for five minutes after a set of tests. Because the high lighting level will stimulate and discomfort the eyes, it is necessary to have a full rest during the test. After the rest, the next group of tests will be carried out. Each person will have 20 groups of tests.

4) When the upper threshold limit is measured, one of the intelligent lamp will be fixed at a specific light output percentage and the examiner adjust the output percentage of another intelligent lamp from high to low in order to match the same brightness sensation. When the lower threshold limit is measured, one of the intelligent lamp will be fixed at a specific light output percentage and the examiner adjust the output percentage of the other intelligent lamp from low to high in order to get the same brightness sensation.

5) The brightness of the two LED intelligent lamps can be adjusted frequently and the observer dictates which LED intelligent lamp is brighter until an error is reported. The examiner record the percentage of light output that the observer reports as incorrect to determine the upper and lower
threshold limits. The test record table is shown in Table 1.

### Table 1. Test Record Table.

|        | 3000K | 4000K | 5000K | 6000K |
|--------|-------|-------|-------|-------|
| 90%    | 100%~90% | 100%~90% | 100%~90% | 100%~90% |
| 80%    | 80%~90%  | 80%~90%  | 80%~90%  | 80%~90%  |
| 70%    | 80%~70%  | 80%~70%  | 80%~70%  | 80%~70%  |
| 60%    | 60%~70%  | 60%~70%  | 60%~70%  | 60%~70%  |
| 50%    | 60%~50%  | 60%~50%  | 60%~50%  | 60%~50%  |
| 40%    | 40%~50%  | 40%~50%  | 40%~50%  | 40%~50%  |
| 30%    | 40%~30%  | 40%~30%  | 40%~30%  | 40%~30%  |
| 20%    | 20%~30%  | 20%~30%  | 20%~30%  | 20%~30%  |
| 10%    | 20%~10%  | 20%~10%  | 20%~10%  | 20%~10%  |
|        | 0~10%   | 0~10%   | 0~10%   | 0~10%   |

### 4. Results and Discussion

The normal distribution test is performed for the light output percentage at each color temperature. The Q-Q diagram basically meets the normal distribution, so the paired T test can be used for analysis. Table 2 to table 5 show the paired T-test analysis between different lighting levels for different color temperatures. As we can see from table 2 to table 5, the greater the difference between the brightness of the lights, the more significant the results.

#### Table 2. Paired sample T test of different lighting levels at 3000K color temperature.

|        | SD    | t     | df | sig  |
|--------|-------|-------|----|------|
| 90%~70%| 1.317 | 1.274 | 19 | 0.218|
| 90%~50%| 1.576 | 4.824 | 19 | 0.000***|
| 90%~30%| 1.473 | 6.147 | 19 | 0.000***|
| 90%~10%| 1.385 | 6.862 | 19 | 0.000***|
| 70%~10%| 1.641 | 3.612 | 19 | 0.002** |
| 70%~50%| 1.358 | 5.433 | 19 | 0.000***|
| 70%~30%| 1.721 | 4.549 | 19 | 0.000***|
| 50%~10%| 0.950 | 1.530 | 19 | 0.142 |
| 50%~30%| 1.389 | 1.369 | 19 | 0.187 |
| 30%~10%| 1.177 | 0.380 | 19 | 0.708 |

Note: *P≤0.05, **P≤0.01, ***P≤0.001, the following tables are all this note

#### Table 3. Paired sample T test of different lighting levels at 4000K color temperature.

|        | SD    | t     | df | sig  |
|--------|-------|-------|----|------|
| 90%~70%| 1.704 | 5.150 | 19 | 0.148|
| 90%~50%| 1.970 | 3.348 | 19 | 0.003***|
| 90%~30%| 1.697 | 4.481 | 19 | 0.000***|
| 90%~10%| 1.860 | 5.291 | 19 | 0.000***|
| 70%~10%| 1.363 | 2.953 | 19 | 0.008** |
| 70%~50%| 1.486 | 3.386 | 19 | 0.003** |
| 70%~30%| 1.495 | 4.863 | 19 | 0.000***|
| 50%~10%| 1.219 | 0.825 | 19 | 0.419 |
| 50%~30%| 1.208 | 2.683 | 19 | 0.015* |
| 30%~10%| 1.267 | 1.765 | 19 | 0.094 |
Table 4. Paired sample T test of different lighting levels at 5000K color temperature.

| SD           | t     | df | sig |
|--------------|-------|----|-----|
| 90%~70%      | 1.079 | 0.311 | 19  | 0.759 |
| 90%~50%      | 1.453 | 2.846 | 19  | 0.010** |
| 90%~30%      | 2.022 | 2.875 | 19  | 0.010** |
| 90%~10%      | 1.626 | 4.744 | 19  | 0.000*** |
| 70%~10%      | 1.488 | 2.555 | 19  | 0.019*  |
| 70%~50%      | 1.824 | 3.003 | 19  | 0.007** |
| 70%~30%      | 1.565 | 4.714 | 19  | 0.000*** |
| 50%~10%      | 0.998 | 1.680 | 19  | 0.109   |
| 50%~30%      | 0.750 | 4.767 | 19  | 0.000*** |
| 30%~10%      | 1.004 | 1.894 | 19  | 0.074   |

Table 5. Paired sample T test of different lighting levels at 6500K color temperature.

| SD           | t     | df | sig |
|--------------|-------|----|-----|
| 90%~70%      | 1.019 | 3.181 | 19  | 0.005** |
| 90%~50%      | 0.793 | 6.347 | 19  | 0.000*** |
| 90%~30%      | 0.716 | 10.925 | 19  | 0.000*** |
| 90%~10%      | 1.094 | 8.278 | 19  | 0.000*** |
| 70%~10%      | 0.805 | 2.223 | 19  | 0.039*  |
| 70%~50%      | 0.866 | 5.295 | 19  | 0.000*** |
| 70%~30%      | 1.117 | 5.205 | 19  | 0.000*** |
| 50%~10%      | 0.930 | 3.005 | 19  | 0.007** |
| 50%~30%      | 1.165 | 3.454 | 19  | 0.003** |
| 30%~10%      | 0.896 | 1.373 | 19  | 0.186   |

The paired T test is used for the analysis of the average of differentials for different color temperatures under the same lighting level (table 6). Table 6 shows that there is no significant effect between different color temperatures.

Table 6. Paired sample T test of different color temperatures at 50% lighting level.

| SD           | t     | df | sig |
|--------------|-------|----|-----|
| 3000K~4000K  | 1.105 | -1.214 | 19  | 0.240 |
| 3000K~5000K  | 0.769 | -1.308 | 19  | 0.206 |
| 3000K~6500K  | 1.658 | -1.281 | 19  | 0.216 |
| 4000K~5000K  | 0.936 | 0.358 | 19  | 0.724 |
| 4000K~6500K  | 1.524 | -0.513 | 19  | 0.614 |
| 5000K~6500K  | 1.262 | -0.086 | 19  | 0.387 |

The discrimination threshold for each color temperature is plotted as a bar chart. Figure 2 is a bar chart of discrimination threshold for each color temperature.
Figure 2. The discrimination threshold for each color temperature.

The analysis shows that the threshold of human eyes decreases with the decrease of light output percentage and the higher the brightness, the greater the threshold for human eyes. After the regression analysis of the threshold in each experimental scene, the threshold changing with the brightness under a certain color temperature can be obtained. Figure 3 is the regression analysis diagram of the threshold with brightness for each color temperature. The discrimination threshold changes exponentially with the lighting levels. The exact value can be applied in the development of dimming control system to match the human eye adaptation.

Figure 3. The regression analysis diagram of discrimination threshold for each color temperature.

5. Conclusion
In this article, the brightness discrimination threshold under different color temperatures and lighting levels is discussed. It can be proved that under the same color temperature and different lighting levels, the higher the brightness, the greater the threshold of human eyes and vice versa. The changes of color temperature have no significant effect on the threshold of human eyes at the same percentage of light output.

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