Paper

Borderline between Comfort and Discomfort of Blinking Light

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ABSTRACT

A visual experiment was carried out to obtain the BCD luminance of a blinking light under the conditions of 0.1 to 100cd/m² of background luminance and a 1 to 16 Hz blink rate. The test light was a circle with diameter of 3 minutes (6.0×10^{-7} sr). The experimental results showed that BCD luminance was highest in the case of a steady light with any background luminance, the BCD luminance was the lowest at around 5 to 8 Hz, and the blinking frequency corresponding to the minimum BCD luminance increased in parallel with an increase in the background luminance. Also it was found that the BCD luminance of the blinking light increased in parallel with an increase in the background luminance, a trend which was similar to the relationship between the BCD luminance of a steady light and the background luminance.

1. Introduction

A blinking light is excellent for attracting attention and for discrimination, and has been used widely for transportation visual signals such as obstacle lights, lighthouses, and traffic signals. However, the fact that these lights attract attention in turn generates discomfort glare, and there have been concerns that they may give discomfort to neighborhood residents. Thus, it has been desirable to elucidate the properties of discomfort glare in regard to the visibility of blinking lights.

So far, the visibility of blinking light in cases with cycle lengths exceeding about 0.2s has been obtained by using Blondel-Rey's equation of effective luminous intensity. However, the Blondel-Rey equation does not predict the existence of discomfort glare nor give its degree, if any, since it was obtained through visual experiments on the threshold of light perception.

In our previous paper¹⁾, a visual experiment was carried out to obtain the BCD (borderline between comfort and discomfort) luminance of a blinking light under various positions of blinking light and frequency. However, the frequency was below 4 Hz and the properties of BCD luminance for frequencies above this level were not obtained. Although there were studies on the relationship between discomfort glare and background luminance with fixed lights^{2,3)}, the relationship between discomfort glare and background luminance with blinking lights has not yet been clarified.

In this study, a visual experiment was implemented to obtain the BCD luminance of a blinking light with a background luminance of 0.1 to 100cd/m² and a frequency of 1 Hz to 16 Hz.

Fig.1 Scheme of experimental apparatus.

2. Experiment

2.1 Equipment

The experiment was implemented in a darkroom. Fig.1 shows an outline of the experiment's equipment. The observation distance was set at 3440mm and the subjects made the observations with their heads fixed on a chin rest. The test light was blinking light (illuminated time and dark time were equal) and a fixed light. The shape of these lights was a circle with a diameter of 3 minutes (6.0×10^{-7} sr). The

diameter of 3 minutes was adopted for the light source since it could be regarded as a point source of light. Lights such as obstacle lights, lighthouses, and traffic signals are usually observed from a long distance and, accordingly, they are observed as point sources of light or as light sources with sizes similar to point sources of light.

The blinking frequency of the test light could be changed by a chopper. As shown in Fig.1, the test light was the white light (chromaticity coordinates $x = 0.43$, $y = 0.41$) of a halogen lamp, which shone through a ND filter, a chopper, a light diffuser, and an aperture. The luminance of the test light could be changed in 0.1 log steps at the ND filter by means of a luminance adjuster button in the hand of the subject⁴⁾. The test light was displayed in the center of a screen of 16 degrees by 16 degrees.

The background luminance (the luminance of the screen) was 0.1cd/m^2 , 1cd/m^2 , 10cd/m^2 , and 100cd/m^2 . To provide the background luminance, a spotlight (100W halogen lamp) shining from the direction of the subject was applied so that the luminance on the screen was almost even. The distribution of the screen luminance is shown in Fig.2.

Fig.2 Luminance distribution on the screen panel.

2.2 Procedure

The subjects were eleven males aged 20 through 29. Artificial pupils were not used and a natural view was applied. Before the experiment, BCD luminance (the lower limit of luminance of light source on which discomfort glare is felt) was explained to each subject and the observation exercise was carried out several times. The experiment was implemented by the adjustment method as described in the succeeding steps.

- (1) In cases with background luminances of 0.1cd/m^2 and 1cd/m^2 , the subjects were adapted to the background luminance for about 10 minutes. The adaptation time for the cases with background luminances of 10cd/m^2 and 100cd/m^2 was about 2 minutes.
- (2) The subject's head was set on the chin rest. The subject continued to watch the test light with both his eyes and

adjusted the brightness of the test light with the hand-held button so that it arrived at the BCD luminance. The initial setting of the test light's luminance was acceptably low compared to the BCD luminance. Although there was no time limit set for the observation, almost all the observations were completed within 1 minute.

- (3) An experimentalist changed the blinking light to the steady light and measured the luminance of the test light. Measurement was done with a luminance meter (Topcon BM-5A), which was set near the position of the eyes of the subject.
- (4) Around 2 minutes after the completion of the measurements in (3) above, steps (2) and (3) were repeated with different blinking frequencies of the test light (including the steady light). The blinking frequencies used in the experiment were 1, 2, 4, 8, 12, 16 Hz and a steady light. The sequence of the applied blinking frequencies of the test light was set at random. The reason why the next observation was made 2 minutes later was to have the subjects recover from deviations in adaptation level due to the observation, as well as to reduce observation fatigue.
- (5) Steps (1) through (4) were repeated with a different background luminance. It was arranged so that each subject made the observation under the same conditions four times.

3. Results

Fig.3 shows the relationships between BCD luminance and blinking frequency, which were obtained by the geometric mean of the observation results for the eleven subjects. The data points marked with circles show the results for a background luminance 0.1cd/m^2 , while the points marked with triangles are for 1cd/m^2 , those marked with squares are for 10cd/m^2 , and those marked with exs (X) are for 100cd/m^2 . For any frequency, the BCD luminance increased in parallel with an increase in background luminance. Also, for any background luminance, the BCD luminance was at the highest value with the steady light and was at the lowest value in the region of 5 to 8 Hz. The blinking frequencies with the lowest BCD luminance, as obtained from the approximation curves in the figure, are 5.0 Hz for a background luminance of 0.1cd/m^2 , 6.0 Hz for 1cd/m^2 , 6.6 Hz for 10cd/m^2 , and 7.6 Hz for 100cd/m^2 . When the background luminance increased, the blinking frequency for the lowest background luminance increased. Although the frequency corresponding to the maximum flicker sensitivity increases in parallel with an increase in background luminance, the results in Fig.3 show similar characteristics.

BCDb/BCDs, which is the ratio of the BCD luminance of the blinking light to the BCD luminance of a steady light, was obtained through the geometric mean of the observation results with the 11 subjects. The relationship

between BCDb/BCDs and frequency is shown in Fig.4. The minimum level of BCDb/BCDs was about 0.5. Thus, it was shown that the blinking light generates a BCD luminance at the level of a half of the steady light, depending upon conditions. Since the test light as used for the experiment has a 1:1 time ratio for light and dark and the luminance of the blinking light is expressed as the luminance in the lighted state, according to Talbot's law the BCDb/BCDs becomes 2 when the blinking cycle lengths exceeds the critical fusion frequency (CFF). Although Fig.4 shows up to 16 Hz reflecting the procedure in the experiment, it is judged that BCDb/BCDs will increase when the blinking frequency increases above 16 Hz and will reach to 2 around CFF.

Fig. 3 Relationship between BCD and blinking frequency. Each point represents a geometric mean for 11 subjects.

Fig. 4 Relationship between BCDb/BCDs and frequency. BCDb is the BCD for a blinking light, and BCDs is the BCD for a steady light. Each point represents a geometric mean for 11 subjects.

4. Discussion

Fig.5 shows the relationship between the BCD luminance and background luminance as obtained through the geometric mean of the observation results on 11 subjects. The line marked with the open circle shows the results for a steady light, and the line marked with a solid circle shows the results in the case of a 4 Hz blinking frequency. The BCD luminance of the blinking light increases in parallel with an increase in background luminance, which is similar to the tendency shown with the BCD luminance of a steady light in relation to background luminance. For the steady light, it is commonly recognized that the BCD luminance increases in parallel with an increase in background luminance. Luckiesh et al.⁵⁾ have obtained BCD luminances for background luminances of 3.4, 34 and 340 cd/m² (size of test light 1.1×10^{-3} sr), and showed that there is the following equation for the relationship between BCD luminance and background luminance.

$$\text{BCD} = 302\text{Lb}^{0.44} \quad (1)$$

Also, Putnam et al.²⁾ did a similar experiment with background luminances of 0.0034 to 34 cd/m², and gave the following equation for the relationship between BCD luminance and background luminance.

$$\text{BCD} = 529\text{Lb}^{0.44} \quad (2)$$

According to the results of this experiment, as shown in Fig.5, the relationships between BCD luminance and background are not linear and cannot be expressed in the form of equations such as (1) and (2). If these relationships are boldly approximated by straight lines and their slope (an exponent of Lb) is calculated, however, they are 0.30 for a steady light and 0.31 for a blinking light of 4 Hz, which are smaller than the 0.44 in equations (1) and (2).

The main difference in these experimental conditions is in the size of the test light. The size of the test light adopted by Luckiesh et al. and Putnam et al. was 1.1×10^{-3} sr, which was larger than the receptive field (in appearance) for discomfort glare. This means that the range of the gathered test light (solid angle) varies depending on the background luminance. The range of gathering is large in the case of a low background luminance and becomes smaller when the background luminance increases. Therefore, the effect of area is large in the zone of low background luminance and it reaches to the BCD luminance even if the luminance of the test light is low. However, the effect of area becomes smaller in the zone of high background luminance and it does not reach to the BCD luminance unless the luminance of the test light is high. This has made the Lb exponent in equations (1) and (2) large. On the other hand, since the test light used in this experiment was so small, 6.0×10^{-7} sr, it could be regarded as nearly a point source of light in either region of background luminance, and its size is considered to allow complete visual spatial summation. In other words,

the range of gathering is the whole test light regardless of the background luminance.

Also, Putnam et al.²⁾ did experiments with varying the size of the test light in the range of 1.1×10^{-3} to 10^{-6} sr. According to this, the Lb exponent becomes smaller in parallel with a decrease in the size of the test light. The Lb exponent was 0.44 for the 1.1×10^{-3} test light size and 0.14 for 10^{-6} sr. Bennet⁶⁾ also did an experiment on the relationship of the size of the light source and background luminance to BCD luminance. However, it showed that the Lb exponent remains unchanged even when the size of the test light is varied in the range of 10^{-3} to 10^{-6} sr.

Fig. 5 Relationship between BCD and background luminance. Each point represents a geometric mean for 11 subjects.

5. Conclusion

A visual experiment was implemented to obtain the BCD luminance of blinking light, in which the relationship of the frequency of blinking light and the background luminance to BCD luminance was obtained. The results are summarized as follows.

- (1) For any level of background luminance, the BCD luminance is highest in the case of a steady light and it becomes lowest around 5 to 8 Hz. Also, the blinking frequency corresponding to the minimum BCD luminance increases in parallel with an increase in background luminance.
- (2) The minimum value of the ratio of BCD luminance of blinking light to the BCD luminance of a steady light is about 0.5.
- (3) The BCD luminance of blinking light increases in parallel with an increase in the background luminance, a trend which is similar to the relationship of the BCD luminance of a steady light to background luminance.

In the future, we would like to perform an experiment with a varied size of test light in order to study the effects of the size of the test light on the BCD luminance of blinking light.

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