Paper

Evaluation of Glare from Color LEDs for Young and Elderly

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1. Introduction

Discomfort glare is said to be perceived differently by the young and the elderly¹⁾⁻³⁾. The clouding of the crystalline lens of the human eye with aging is thought to increase the intraocular scattering of light⁴⁾ and to cause the eye function to deteriorate with age⁵⁾, but these mechanisms have not been fully explained. Meanwhile, the use of LEDs as light sources for illumination and signal lamps has been increasing in recent years. The main factor accelerating the widespread adoption of LEDs is thought to be their increased optical output as a result of remarkable advances in technology. However, the discomfort glare from LEDs is an issue that has been raised before, and increased optical output results in additional problems of discomfort glare. For our aging society of the future, so that lighting environments suitable for all ages or particular age-groups can be constructed, it is important that age differences in the perception of discomfort glare from LEDs are verified and that the mechanisms thereof are explained.

As possible causes of LED glare, spectral characteristics, an extremely biased luminance distribution, a rapidly rising optical output not seen with other light sources, and the like have been considered, but in this study, chromatic effect is investigated. In previous research^{6,7)} by the authors, a discomfort glare experiment was conducted using six types of LEDs with 15 young people as the test observers. Therefore, in this study, a discomfort glare experiment was carried out with eight elderly people using the same test as had been used with the young people in previous research, and the results were compared to investigate the difference by age in terms of intraocular transmittance and sensitivity to brightness.

2. Experiment

2.1 Experimental apparatus

Six types of LEDs, two varieties of red (R_{620} , R_{628}), green (G), blue (B), amber (Am) and white (W), were used as the discomfort glare light sources. Characteristics of the light sources are as listed in Table 1. The

Table 1 Characteristics of stimulus sources

Symbol	Light source	Color	Chromaticity coordinates (x, y)	Dominant wavelength λ_d (nm)
B	LED	Blue	(0.15, 0.04)	459
G	LED	Green	(0.27, 0.70)	542
Am	LED	Amber	(0.55, 0.45)	586
R_{620}	LED	Red	(0.69, 0.31)	620
R_{628}	LED	Red	(0.70, 0.30)	628
W	Blue LED+Yellow phosphor	White	(0.30, 0.31)	Correlated color temperature 6800 K

Figure 1 Apparatus for glare experiment

dominant wavelength was calculated with D65 white. The experiment was carried out in a darkroom at a viewing distance from the stimulus of 3 m, at a height of the observer's eyes position, and with a 1° viewing angle size. Light from LED light sources was presented through a diffusion plate to make the stimulus field as homogeneous as possible. Figure 1 shows the experimental apparatus.

2.2 Observers

Eight elderly observers with normal color vision par-

ticipated in the experiments. Their ages ranged from 66 to 74 years old (mean age of 68). The data of 15 young observers with normal color vision were used for comparison⁶⁷⁾. Their ages ranged from 22 to 30 (mean age of 23).

2.3 Experimental procedure

Observers rated the degree of discomfort glare using the evaluation scale as shown in Table 2. Using the conditions of previous research⁶⁷⁾ as a reference, the luminance level of each stimulus was determined based upon the subjective evaluation of two of elderly observers before the start of the experiment. Table 3 shows the results as logarithmic luminance (cd/m^2) levels. For stimulus B, because the elderly observers were expected to have a greater sensitivity to discomfort glare than the young observers in the preexperimental data, sixth luminance levels (1.6 log luminance) was added below the lowest level that had been condition for young observers. The background luminance was totally dark so that discomfort glare would be maximized.

The luminance level was controlled by the current values of LED via DC power supply. On the days of the experiments, at first, luminance was measured and confirmed that there was no discrepancy between luminance and current value. Luminance was measured using a CS-1000 Spectroradiometer made by Konica Minolta. The experiment was conducted in a darkroom,

Table 2 Scale for subjective evaluation of glare

9	Just noticeable
8	
7	Satisfactory
6	
5	Just acceptable
4	
3	Disturbing
2	
1	Unbearable

Table 3 Luminance levels of presented stimuli (log cd/m^2)

	B (young)	B (elderly)	Am, R ₆₂₀ , R ₆₂₈	G, W
Level 1	—	1.6	2.5	2.5
Level 2	2.0	2.0	3.0	3.0
Level 3	2.4	2.4	3.5	3.5
Level 4	2.8	2.8	4.0	4.0
Level 5	3.2	3.2	—	4.5
Level 6	3.6	3.6	—	—

and at the beginning of each session, 5 min were allocated for dark adaptation. The experiment was carried out in three sessions, with a single session consisting of 31 trials for young observers and 32 trials for elderly (stimuli Am, R620 and R628 being presented at four luminance levels, stimuli G and W at five luminance levels, and stimulus B at five luminance levels for young observers and six luminance levels for elderly). The same stimuli conditions were repeated three times. Apart from the experiment, a single-session experiment was also carried out for each observer as a practice. At least 2h interval was provided between sessions in order to avoid fatigue and adapt to the light stimuli. Light color and luminance of the stimuli were presented randomly, and the observers evaluated the presented stimuli using binocular vision. In order to prevent adaptation during the experiment, the duration time of the stimuli was controlled with an electronic shutter so as to be three seconds, and the time from one presentation of a stimulus until the next presentation of a stimulus was set to be at least 30s.

3. Results

Figure 2 shows graphs comparing the results of the young and elderly observers for each stimulus. The horizontal axes indicate logarithmic luminance, while

Figure 2 Mean subjective evaluation of discomfort glare from each stimulus by young and elderly

Figure 3 Mean value of threshold luminance for each stimulus

the vertical axes indicate the evaluation scale for discomfort glare. For stimuli B, G and Am, the young observers tended to be more sensitive to discomfort glare than the elderly, and the results of two-way analysis of variance showed the effect of age to be statistically significant ($p < 0.05$). For stimuli R₆₂₀, R₆₂₈ and W, no significant difference was apparent.

Luminances evaluated to scale 5 defined the “threshold luminance” of discomfort glare. The threshold luminance for each observer was calculated by linear approximation from the results of the evaluation of glare with respect to logarithmic luminance. The results are shown in Figure 3. The horizontal axis indicates the dominant wavelength or correlated color temperature of each stimulus. For both age groups, the threshold luminance of discomfort glare for stimulus B was lower than for other stimuli, and the results of a Tukey-Kramer multiple comparison method showed that, for both age groups, the differences between the threshold luminance of stimulus B and other stimuli were statistically significant ($p < 0.01$). There was no significant difference among other stimuli.

4. Discussion

In order to verify the cause of the age difference of discomfort glare, two approaches were attempted. One is age-related change in the transmittance of the crystalline lens of the human eye, and another is the predicted threshold luminance for the elderly according to age-related change in the sensitivity to brightness. Data was analyzed using the predicted threshold radiance (W/m^2) of each age group. The threshold radiance is the value of the radiance when the discomfort glare evaluation is “5”. The reason for using threshold radiance is to compare the real amount of optical energy incident upon the eye from the various stimuli. The results are shown in Figure 4. Threshold radiance values for the young and elderly obtained from the discomfort glare experiment are shown as experimental values in a bar graph, and values of threshold radiance for the elderly

Figure 4 Mean values of threshold radiance for young and elderly, and predicted values for elderly based upon transmittance and brightness of each stimulus

that were predicted from the transmittance of the crystalline lens of the eye and in accordance with the experimental values from the young observers are indicated with a circle (○), while values for the elderly that were predicted from the brightness sensitivity are indicated with a triangle (△).

To calculate the transmittance of the crystalline lens of the eye, first, the aging model of crystalline lens optical density $D_L(\lambda)$ of Pokorny et al.⁸⁾ shown in Eq. 1 and Eq. 2 and the spectral transmittance $T_A(\lambda)$ shown in Eq. 3 were used to calculate crystalline lens transmittances for the mean ages of each group, i.e., spectral transmittance $T_{23}(\lambda)$ for the 23-year-old mean age of young and spectral transmittance $T_{68}(\lambda)$ for the 68-year-old mean age of elderly (see Figure 5(a)).

Optical density of the crystalline lens:

$$D_L(\lambda) = D_{L2}(\lambda)\{1.00 + 0.02(A - 32)\} + D_{L1}(\lambda) \quad \text{for } 20 < A < 60 \quad (1)$$

$$D_L(\lambda) = D_{L2}(\lambda)\{1.56 + 0.0667(A - 32)\} + D_{L1}(\lambda) \quad \text{for } 60 \leq A \quad (2)$$

($D_{L1}(\lambda)$, $D_{L2}(\lambda)$): Constant term that depends on wavelength, A: Age)

Spectral transmittance of the crystalline lens:

$$T_A(\lambda) = 10^{-D_L(\lambda)} \quad (3)$$

Then, the light source spectrum $S_{\text{young}}(\lambda)$ that provides the threshold radiance for young people is multiplied by

Figure 5 Data for prediction of threshold radiance for elderly (a) Transmittance of crystalline lens of the eye for 23-yr-old and 68-yr-old. (b) Relative brightness-luminous efficiency for 20-yr-old and 70-yr-old

the reciprocal of the ratio of $T_{68}(\lambda)$ with respect to $T_{23}(\lambda)$, i.e. the change in transmittance due to aging, to predict the threshold radiance for the elderly in response to each stimulus (Eq. 4).

Threshold radiance for elderly

$$= \sum \{ S_{\text{young}}(\lambda) \times T_{23}(\lambda) / T_{62}(\lambda) \} \quad (4)$$

For brightness sensitivity, the age-related change data for spectral luminous efficiency derived by Sagawa et al.⁹⁾ was used. From the spectral luminous efficiency $B_{20}(\lambda)$ value for a 20-year-old and the spectral luminous efficiency value $B_{70}(\lambda)$ for a 70-year-old (see Figure 5(b)), the ages closest to the mean of each age group, the ratio of elderly to young spectral luminous efficiency was derived, and as in the case of the transmittance of the crystalline lens of the eye, the threshold radiance for the elderly was predicted (Eq. 5).

Threshold radiance for elderly

$$= \sum \{ S_{\text{young}}(\lambda) \times B_{20}(\lambda) / B_{70}(\lambda) \} \quad (5)$$

However, because the spectral luminous efficiency data for both age groups consisted of relative spectral luminous efficiency values normalized to 555 nm, experimental and predicted values could not be compared in terms of absolute quantities, and only the changes in threshold radiance among the stimuli were compared. For the spectral luminous efficiency, data normalized to 620 nm, the dominant wavelength of stimulus R_{620} for which the threshold radiance values were nearly the same for both young and elderly observers, was used.

In Figure 4, the elderly threshold radiance (shown with small circles ○) predicted from the age-related change of crystalline transmittance is shown to be in good agreement with experimental values for the long-wavelength stimuli of R_{620} and R_{628} , but discrepancies were observed between predicted and experimental values for the short-wavelength stimuli of B and G, and for the stimulus W that includes short-wavelength components (blue LED+yellow phosphor). This means that the elderly are more sensitive to discomfort glare and/or that the young are less sensitive to discomfort glare, than to predicted values in consideration of the transmittance of the crystalline lens of the eye. As for the elderly threshold radiance values (shown with triangles △) that were predicted from the spectral luminous efficiency, although the increasing and decreasing trends among stimuli are similar, the experimental and predicted values were not in agreement.

5. Conclusion

From this study, when stimuli presented with a 1° viewing angle upon a dark background are observed at the center of one's field of vision, young people were found to be more sensitive than the elderly to discomfort glare from blue, green and amber colored LEDs. For red and white LEDs, no difference by age was observed. Moreover, a comparison of light sources confirmed that, for both age groups, blue LEDs cause discomfort glare at lower luminance levels than for other light sources. The cause of age differences in the perception of discomfort glare could not be explained sufficiently by age-related changes in transmittance of the crystalline lens of the eye and in sensitivity to brightness. To explain the mechanism of discomfort glare, further investigation is necessary, including consideration of the intraocular scattering of light and the like.

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References

- (1) C. A., Bennett: The demographid variables of discomfort glare, *Lighting Design & Application*, 7, pp. 22–24 (1977).
- (2) Yano, T., Kanaya, S. and Ichikawa, K.: The Effect of Correlated Color Temperature on Discomfort Glare for the Aged, *J. Illum. Engng. Inst. Jpn.*, 77, (6), pp. 296–303 (1993) (in Japanese).
- (3) Mochizuki, E., Iwata, T., Tsukami, S. and Kimura, K.: Experimental study on discomfort glare from large light source judged by elder and young people, *Journal of Architecture, planning and environmental engineering (Transactions of AIJ)*, 528, pp. 17–22 (2000) (in Japanese).
- (4) Said, F. S. and Weale, R. A.: The variation with age of the spectral transmissivity of the living human crystalline lens, *Gerontologia*, 3, pp. 213–231 (1959).
- (5) Philip, C. H. and Neer, R. M.: Lighting for the elderly: A psychobiological approach to lighting, *Human Factors*, 23(1), pp. 65–85 (1981).
- (6) Kimura, T., Fujita, Y., Kojima, S. and Ayama, M.: Proc. 2007 Annual Conf. IEIJ, p. 194 (2007) (in Japanese).
- (7) Minoda, T. K., Fujita, Y., Kojima, S. and Ayama, M.: Study on glare of LED lamp and individual variations of brightness perception, proceedings of ISAL 2007, 7th International Symposium on Automotive Lighting (2007).
- (8) Pokorny, J., Smith, V. C. and Lutze, M.: Aging of the human lens, *Applied Optics*, 26, pp. 1437–1440 (1987).
- (9) Sagawa, K. and Takahashi, Y.: Spectral luminous efficiency as a function of age, *J. Opt. Soc. Am. A*, 18(11), pp. 2659–2667 (2001).