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Masafumi Kamei et al.

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CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

EFFECT OF DIRECT GLARE OF LED FLOODLIGHT ON CATCHING A MOVING OBJECT

Kamei, M.[1], Yamada, T.[3], Kohko, S.[3], Ishikawa, T.[1], Ayama, M.[1,2]
[1] School of Engineering, Utsunomiya University, JAPAN
[2] Center for Optical Research & Education, Utsunomiya University, JAPAN
[3] Iwasaki Electric Co.Ltd., Saitama, JAPAN

mt186707@cc.utsunomiya-u.ac.jp

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Abstract

To explore the effect of LED floodlight luminance on visual function and visual task relating to glare in foveal vision, two experiments, Exp.1 and Exp.2, were carried out. In Exp.1, recovery time of visual acuity, afterimage duration, and subjective degree of discomfort glare were measured for 4 levels of glare light luminance with 0.2 and 0.5 sec durations. All results increased with the increase of glare light luminance. In Exp.2, target capture ability was measured for 7 levels of glare light luminance with 2 levels of background simulating outdoor and indoor stadiums. Absolute time difference of observer's response from the perfect catch is employed as an index of catching performance. It is indicated that glare of LED flood light begins to affect the catching performance around at 3 x 10^5 cd/m^2, and gives serious effect over 9 x 10^5 cd/m^2.

Keywords: LED floodlight, Recovery time, After image, Discomfort glare, Capturing a moving object

1 Introduction

In recent years, development LED floodlights for large stadiums is progressing based on the practical realization of high-luminance and large-size modules. They have been already introduced in baseball stadiums, football stadiums, and gymnasiums etc. [1,2]. LED has many advantages such as high energy-efficiency, long life-time, and no-overheating, etc., while glare is one of the disadvantages [3, 4]. CIE has published the technical report on glare evaluation system for the outdoor and sports area lighting [5], however, the system did not consider the LED floodlights at that time. It is well known that radiant angle of LED device is not wide as that of conventional floodlights such as HID lighting that radiates light in all directions. To qualify the illuminance regulations for stadium lighting, LED floodlight shows very high luminance to some directions and it might cause serious disability and discomfort glare. However, few have been reported that how and to what degree the luminance of LED floodlight disrupt visual functions under the viewing conditions that can be applicable to sports scene. Manufacturers are trying to design sports area lighting using LED floodlights based on their own data or published data not to produce disability and/or discomfort glare that hinder players. Unfortunately, sometimes still complains are raised by athletes that light was too dazzling when they happened to view directly. In baseball game, for example, complaints were repeatedly expressed by professional players that they missed the ball due to strong glare in the case of routine fly or line drive.

Based on such a background, objective of the study is to investigate the effect of LED floodlight luminance on visual function and visual task relating to glare in direct vision. Direct here means the light source is seen in foveal vision. Two experiments were carried out. The first one (Exp.1) was to measure how the glare light luminance affects the temporal property of visual function, such as recovery of visual acuity and duration of after image, as well as the subjective evaluation of discomfort glare. The second one (Exp.2) was to measure the luminance to fail a target capturing performance to simulate a fly catch of a baseball game at outdoor and indoor stadiums.

2 Exp. 1: Effect on temporal properties and glare evaluation.

2.1 Apparatus

Visual target was presented on the display that was placed on the direct line from observer's eyes. The white LED installed in stadiums were used as the glare light that was placed orthogonally to the above line and the source image was superimposed on the visual target using a half mirror. This setting was common to the experiments 1 and 2.

2.2 Stimuli, procedure, and observers

Visual target was the white Landolt C of 100 cd/m^2 on the dark background of 5 cd/m^2. Diameter of the ring was 2.9mm on the display with the gap (0.6mm) of which visual angle is 5.5 min corresponding to the visual acuity of 0.18. This is roughly equivalent to the situation seeing a baseball in the visual distance of about 50m. Size of glare light was diameter of 3.2 deg or 1.6 deg, and the presenting duration was 0.2 or 0.5 sec. Six levels of luminance from 0.25 x 10^6 to 2.0 x 10^6 cd/m^2 were employed.

Figure 1 shows the time sequence of the experiment. First, the observer adapted to the gray background, 75 cd/m^2, of the display for 5 min. Then the glare light was presented briefly with a certain luminance described above. At the moment of the glare light presentation, observer could not see the visual target. He was asked to push a key when the gap of the Landolt C was seen. We consider this timing is the recovery of visual acuity, and define as T1. Acuity here means not the visual acuity of each observer, but the one required to see a baseball from several tenth of meter described above. Then, the degree of glare was subjectively evaluated using 2 scales. In the last, observer had to push the key when he felt the after image of glare light disappeared. This timing is defined as T2.

Nine male students in their 20s participated the experiment. All observers have normal visual acuity with naked, glasses, or contact lenses.

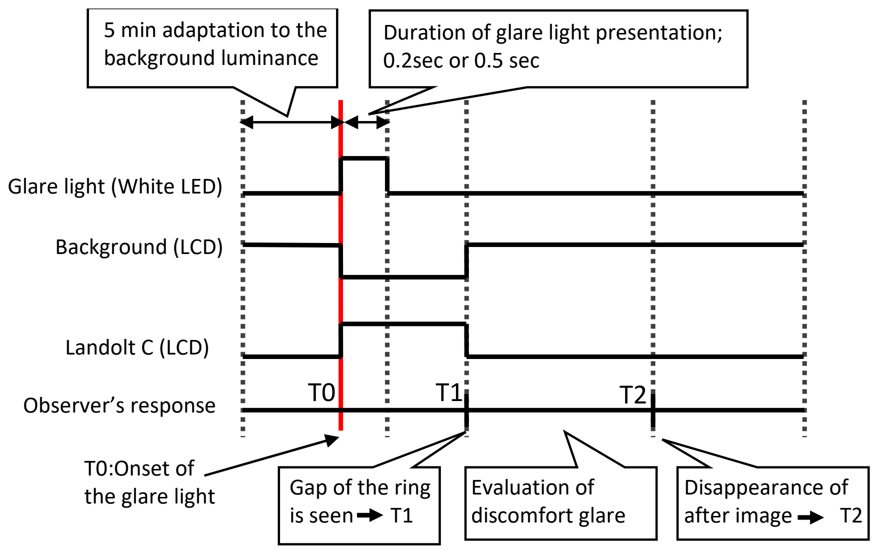

Figure 1 – Time sequence of the change of the LED glare light, background luminance and target on the LCD, and observer's response

2.3 Results

Average results of recovery time of the visual acuity (T1), evaluation of discomfort glare are plotted against the luminance of glare light as shown in Figure 2 (a) and (b), respectively. Note that horizontal axis in (a) and (b), and vertical axis in (a) are logarithmic scale. Rating scores of 1, 2, 3, 4, and 5 in (b) correspond to "not uncomfortable", "hardly uncomfortable", "rather uncomfortable", "uncomfortable", and "very uncomfortable", respectively. Triangles and circles denote the results of diameter of 3.2 deg and 1.6 deg of the glare light, respectively. Filled and open symbols denote the results of 0.2 and 0.5 sec duration, respectively. Error bars denote the standard error among 9 observers.

All results increase linearly as a function of logarithmic luminance of glare light. Effect of the size of glare light is not significant, while in the glare evaluation, the average values of large size are higher than those of small size. Under the condition of the maximum intensity in the present study, 2.0 x 10^6 cd/m^2 with 0.5 sec presentation, it took 7 sec to recover visual acuity, and subjective evaluation was more than “uncomfortable”. Even under the minimum condition of 0.25 x 10^6 cd/m^2 with 0.2 sec presentation, recovering time of visual acuity was longer than 2 sec, and subjective rating is in between “hardly uncomfortable” and “rather uncomfortable”.

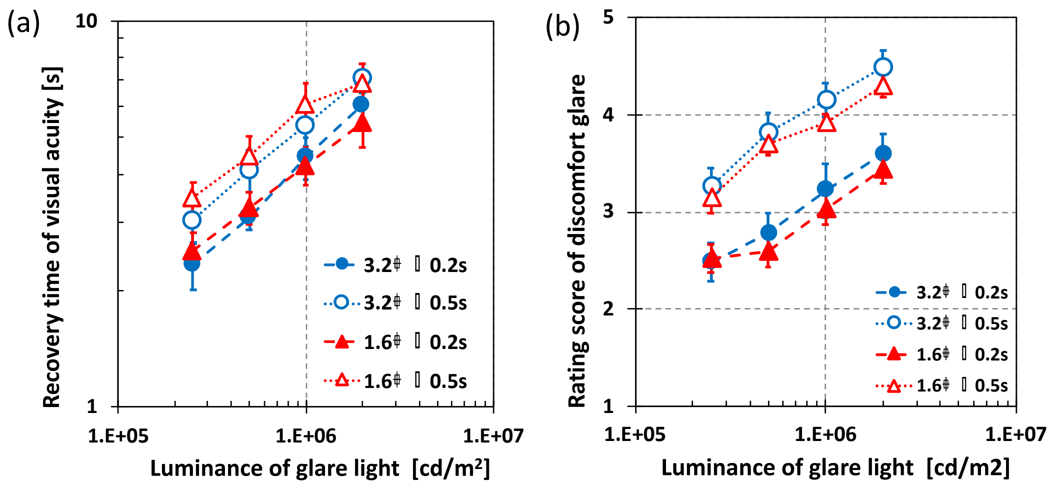

Figure 2 – Results of the Exp.1. Recovery time of the visual acuity (a), and evaluation of discomfort glare (b), respectively.

2.4 Discussion

Results of all conditions are plotted as a function of the product of luminance and duration of glare light in Figure 3. Results of recovery time of visual acuity are 2 to 7 sec which are within the comparable range of previous study using monochromatic lights [6]. As shown in the figure, recovery time of visual acuity increases as a function of the product of luminance and duration of glare light. All points are distributed linearly on the log-log plot. Broken line is the fitted function of which formula is shown below,

$$T_{rec} = 0.058 \times (L \cdot Tp)^{0.35} \quad (1)$$

where T_{rec}, L, and T_p are the recovery time, luminance, and presenting duration of glare light, respectively.

Dotted line is the results of the previous study on recovery time of visual acuity after the exposure of glare light reported by Irikura et al. [7]. Their fitting equation is the same formula as the equation (1), with the coefficient of 0.36 and the power of 0.29. They used 100W halogen lamp for the glare light, and thus luminance of glare light was less than one tenth of the present study, while the durations and the size were comparable. The most marked difference was the procedure that they measured the time to recover each observer’s visual acuity that was measured before the presentation of glare light. Usually visual acuity is the resolution limit of vision of each observer, and thus it might be severer than the criterion here needed to see the official baseball with a distance of about 50m, visual acuity of 0.18. This difference in the criterion seems the main cause of their recovery time about 6 times longer than ours. It is worth noting that the slopes of two functions are close instead of various differences in experimental settings such as light sources etc., criterion, and procedures. These results suggest that when eyes are exposed to some kind of glare light, the recovery time of visual system needed to regain certain degree of resolution depends on total amount of the glare light.

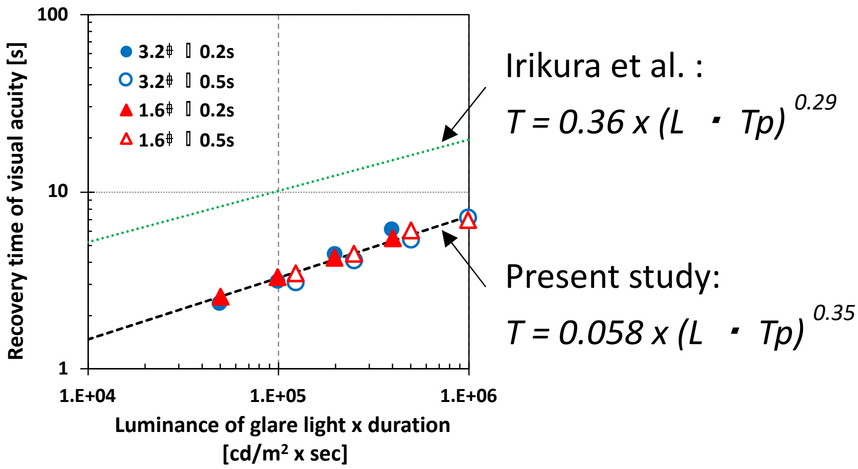

Figure 3 – Recovery time of visual acuity plotted as a function of the product of luminance and duration of glare light

3 Exp.2: Effect on catching a moving object

3.1 Stimuli, procedure, and observers

Short movie stimuli of vertically moving object imitating three kinds of fly balls with different heights were prepared. The ball went up from the bottom of the display and came down from some height in the display along the vertical line, varying the speed and the size just like a liner, middle-fly, or fly. We call them "low", "middle" and "high" conditions, respectively, schematically shown in Figure 4. Catch area for each of the fly balls was indicated in the movie with the upper and lower horizontal lines. Run time of the movie was 4.8 sec. Luminance of the ball was 90 cd/m², that of the background was either 5 or 20 cd/m² simulating outdoor or indoor stadium, respectively. The glare light with the diameter of 3.2 deg in visual angle was presented 3 sec after the start of the movie with the duration of 0.5 sec in the position with the elevation angle of 25 deg. Seven luminance levels were employed from 0 to 1.2 x 10^6 d/m².

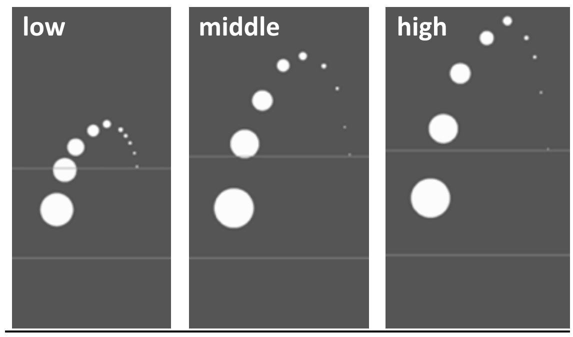

Figure 4 – Schematics of the moving object. In a real stimulus, a white circle moves vertically changing its size and speed as if a ball is coming to the player. Catch area is between the upper and lower horizontal lines.

After 5 min adaptation to the background luminance, the countdown number appeared on the display, and the first movie began. Thirty or 21 trials (10 or 7 repetition x 3 stimuli) at the beginning were no glare light conditions, and subsequent 54 trials (3 repetitions x 3 stimuli x 6 glare light levels) were glare conditions in a session. Five sessions were carried out for each observer. Order of the stimuli presentation and luminance level of glare light was randomized within the glare light part of one session. The observer's task was to push the key when the ball was in the catch range. Without glare light, total of 38 trials were done for each of "low", "middle", and "high" stimuli, while total of 15 trials were repeated for each of 6 luminance levels of glare light.

Eight male students in their twenties participated the experiment of 5 cd/m² condition. Five among them participated the experiment of 20 cd/m² condition. All observers have normal visual acuity with naked, glasses, or contact lenses.

3.2 Results

The correct catch was defined as that the observer could respond in the frames of the movie when the ball is fully or partially in the catch area. Rate of correct catch in the "low" condition was plotted against the luminance of glare light in Figure 5. Correct catch decreases as the increase of glare light luminance, and the rate is lower in the lower background except in the 2 highest luminance conditions. Correct catch rate at these highest and second highest luminance conditions are all lower than 50%. Luminance of these conditions are 9.0 x 10^5 and 1.2 x 10^6 cd/m^2 (logarithmic values are 5.95 and 6.08), respectively. Results here indicate that glare by the LED floodlight gives serious problem on catching performance when the luminance exceeds 9 x 10^5 cd/m^2.

In the "high" and "middle" conditions, the rate of correct catch stays around 70% and 50 to 60%, respectively, in all luminance levels, not showing clear decrease with glare light luminance. Difference between 2 background levels was observed in the "high" condition, whereas no such tendency in the "middle" condition.

We define the perfect catch as that the observer push the key in the timing of the frame where the ball was in the center of the catch area. Such a case rarely happened, and in most cases, observer's response deviated from the perfect catch, either faster or later even in the cases of correct catch. Absolute time difference of observer's response from the perfect catch was analysed, and the average value is plotted against the luminance of glare light. Results of "low" condition with 5 cd/m^2 background are shown in Figure 6. Sharp increase around at 5.5 log cd/m^2 is observed. Similar tendency was found in the 20 cd/m^2 background of the "low", and 5 cd/m^2 background of the "middle" conditions. Luminance of the point of intersection of two linear approximate lines indicated in Figure 6 was obtained. One line is in the lower luminance range showing slow increase, and the other is in the higher luminance range with a steep increase. Logarithmic value of "low" stimulus in the 5 cd/m^2(Figure 6) and 20 cd/m^2 background conditions are 5.428 and 5.551, equal to 2.7 x 10^5 and 3.6 x 10^5 cd/m^2, respectively. That of "middle" stimulus in the 5 cd/m^2 background condition is 5.545, equal to 3.5 x 10^5 cd/m^2, cd/m^2. These results indicate that the LED floodlight begins to affect the catching performance around at 3 x 10^5 cd/m^2. These values are comparable with the results of recent studies carried out in a real baseball stadium and experimental set-up on the effects of luminance of light source illuminating behind a moving ball for ball-disappearance [9,10]. Both studies indicated that a moving ball disappears with a glare light of about at 3 x 10^5 cd/m^2.

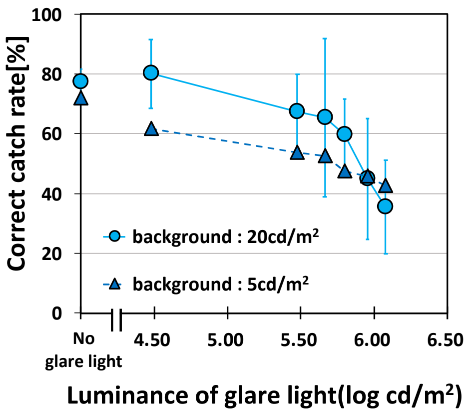

Figure 5 – Correct catch rate plotted against the luminance of glare light in the "low" condition.

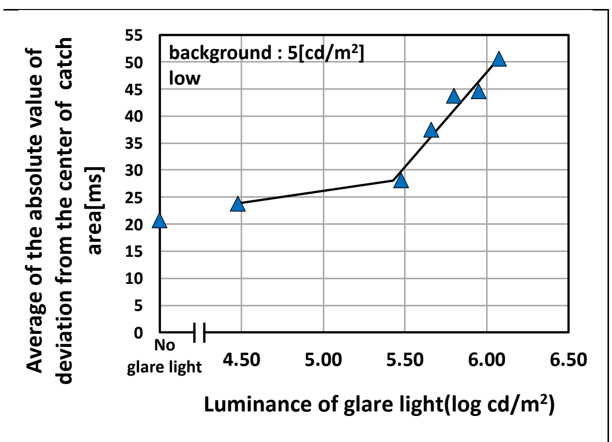

Figure 6 – Average of the absolute value of deviation from the center of the catch area the luminance of glare light in the "low" condition.

4 Conclusions

Our results of Exp.1 clearly showed that luminance and presentation duration of glare light affects visual function and subjective evaluation of glare. Recovery time to regain certain degree of resolution depends on total amount of the glare light. Results of Exp.2 showed the effect of the luminance of LED flood light and background on the task of catching a moving object. It is indicated that glare of LED flood light begins to affect the catching performance around at 3×10^5 cd/m^2, and gives serious effect over 9×10^5 cd/m^2. According to the results of Exp.1 in the same size and duration (3.2 deg, 0.5sec), glare light of 3×10^5 cd/m^2 is evaluated more than “rather uncomfortable” and recovery time needed to see a baseball from outfield is longer than 3 sec. Under the circumstance, it would happen to miss the ball even for professional players. Results of Exp.1 at the luminance of 10^6 cd/m^2, recovery time is over 5 sec and the subjective evaluation is “uncomfortable”, implying serious difficulty to catch the ball correctly. These factors should be taken into consideration in designing LED flood light in sports arenas.

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