# A study on glare in a sports lighting environment using LED lighting and diffusion plates

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*Illumination sources have been rapidly shifting in recent years to light-emitting diodes (LED), which are capable of producing more than 10,000 cd/m2 at maximum luminance. This light intensity is far greater than conventional light sources and has become a social problem. In this study, we installed a combination of LED lighting and diffusion plates at a sports stadium in Hiroshima City, which having a population of more than 700,000 is designated as "an ordinance-designated city, in order to realize a comfortable illumination environment for sports using LED lighting. The results of our study suggest the following: With respect to avoidance behavior in the case of a high-intensity light source, avoidance behavior is affected by the glare of brightness prior to shape recognition. Conversely, the influence of the luminance level of a low-luminance light source is small and is not affected by shape recognition. In between the two extremes, it is assumed that avoidance behavior will be led while affected by both the glare of brightness and shape recognition.*

**Introduction**

Illumination sources have been rapidly shifting in recent years to light-emitting diodes (LED), which are capable of producing more than 10,000 cd/m$^2$ at maximum luminance. This light intensity is far greater than conventional light sources and has become a social problem. The light-emitting area of a mercury lamp is small and has a single point of origin, therefore glare has not hitherto been a topic of discussion (see Fig. 1). If sports lighting at physical education facilities changes from mercury lamp lighting to LED lighting, we must discuss the higher luminance and what is termed "discomfort glare." This will determine whether the conventional index can be applied for LED lighting or not. The unified glare rating (UGR) of the discomfort glare index (GI) can be applied for LEDs on the light source of uniform luminance within the available range. However, UGR does not indicate the luminance distribution of the light source and clarification is needed as to the usable range on luminance distribution, so a new index that indicates the luminance distribution is needed. In addition, different values and ideas on light and illumination to the same action can be shown at the environmental level where illumination itself are required, or where electric power supplies and the illuminators are adequate for the task. It is assumed that the evaluation standard for glare may well be different. In an experiment in which we used LED light sources as illumination at a sports stadium, we sought to achieve two things: 1) to hide the elements of the luminous source for the LED as a simplex, 2) to prevent a drop in downright illuminance. Through these attempts, we were able to realize equalization of the illuminance distribution, realize a reduction in glare, and achieve energy-saving operation at the sports stadium. The ceiling of a stadium can rise at National Sports Festival, World Cup, and Olympics venues. Therefore, high-luminance lighting is generally necessary. To that end, we achieved plane emission by reducing the emission of light at the part of the device that is the high-luminance part of the light-emitting device. Thus we maintain appropriate luminance per unit area.

In this study, we installed a combination of LED lighting and diffusion plates at a sports stadium in an ordinance-designated city, which is designed as having a population of more than 700,000, with the aim of realizing a comfortable illumination environment for sports using LED lighting. In addition, we report some setting examples.

**Glare**

Currently there is no index of glare for LED lighting. The existing index of glare uses the unified glare rating (UGR) and the glare index (GI). However, no index exists for examples in which the light source is viewed directly. In addition, the existing index is not suitable for representing the glare of a high-luminance light source that is a light source greater than 20,000 cd/m$^2$.

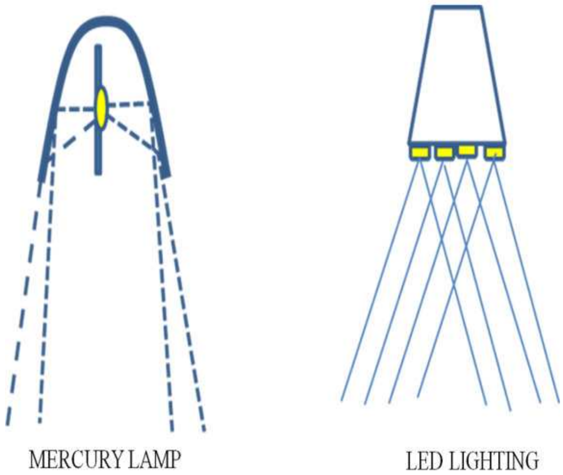



*Fig.1. Mercury lamp and LED lighting.*

In this paper, we conduct experiments using an LED light source. Then, based on the results, we discuss situations in which glare is experienced. Thanks to the cooperation of the Hiroshima Institute of Technology and HI-LAND, the experiment was relatively easy to conduct, and the safety of the subjects of the experiments was assured by using a light source of less than 500,000 cd/m$^2$ based on Environmental Impact Assessment (EIA) standards. To examine the role of LED light equipment in a sports environment, we measured the ranges in which glare is felt. We investigated the following four factors.

Experiment 1: Luminance range at which one can feel glare.

Experiment 2: Luminance range at which one can tolerate the glare.

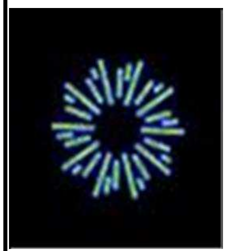
Experiment 3: Visual recognition after directly looking at the light source.

Experiment 4: Form recognition of a light emitting surface after looking directly at a high-luminance light source.

### Basic glare experiment

***Experiment 1: Luminance range in which one feels glare.***

We decided upon the light source used in the experiment (see Fig. 2) and the optimal distance, and we targeted subjects of four age groups (see Table 1). The same light source was used throughout all experiments. The subjects wear goggles, and the experiment is conducted in both a Bright room and a Dark room (see Table 1), for we set the values of luminance. The subjects put on and remove the goggles on our cue, which means they will stare at the light source for two seconds. The subjects are then asked to give their response to the exposure by saying "not dazzling" or dazzling."



400 W mercury lamp equivalent of LED light source

Maximum-luminan 450,000 cd/m$^2$

Light-emitting surface diameter □ 250 mm

*Fig. 2. Test target light source.*

**Table 1**

*Experiment 1 Parameters*

| Environment | | | | |
|---|---|---|---|---|
| Light Source | | | LED Multi-chip, and Ceiling light 250 W | |
| Environment | | | Bright room (250 lux), and Dark room (8 lux). Each luminance is measured at the position of the subject. | |
| Distance | | | 5 m | |
| Looking time | | | 2 sec. | |
| Subjects group | | | | |
| Group | Age | Gender | Affiliation | Head-Count |
| Group 1 | 35 - 54 | Female | PTA Member | 32 |
| Group 2 | 19 - 21 | Males & Female | Sports Club | 15 |
| Group 3 | 32 - 57 | Males & Female | Field Worker | 13 |
| Group 4 | 19 - 23 | Males & Female | Office Worker | 13 |

The results shown there are differences amongst the subjects, but we received "dazzling" from the majority of subjects. The subjects began to feel the glare at a level of about 30,000 cd/m$^2$, with 80% feeling the glare when the lighting threshold exceeded 60,000 cd/m$^2$ or so. It is expected that there is a specific point at which we feel the glare in these ranges (see Fig. 3). However, this result shows there are variations in the response, and that there are differences due to age. Therefore, it is impossible to define the threshold of glare. Moreover, the glare trend is consistent irrespective of whether measured in the Bright room or the Dark room (see Figs. 3 and 4). Therefore, it is understood that the glare trend does not depend on the experimental environment.

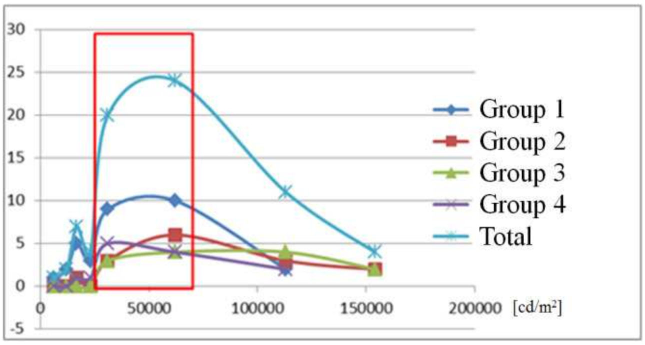



*Fig. 3. Luminance and subjects' measurement results obtained in the Bright room.*

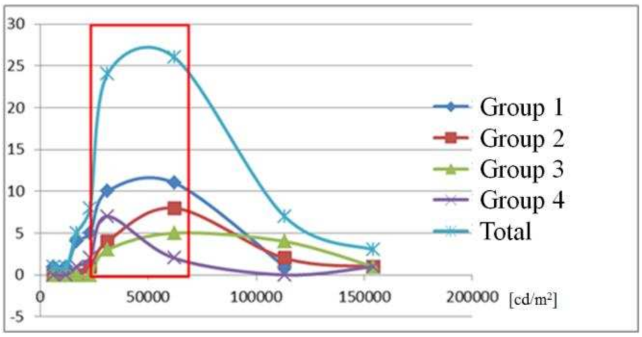



*Fig. 4. Luminance and subjects' measurement results in the Dark room.*

***Experiment 2: Luminance range in the tolerable limit of the glare.***

We conducted Experiment 2 under the same conditions as Experiment 1.

There are some differences between the Bright room and the Dark room, but the luminance range at which subjects cannot stand the glare is different from the luminance range at which the subjects feel the glare in Experiment 1. We divided the luminance range to two groups: "unbearable" in the range of about 60000 cd/m$^2$ to 150000 cd/m$^2$, and "bearable" in the range to 200000 cd/m$^2$. Different characteristics were seen in each group. The first was a group that did not look at a high-luminance light source in everyday life, and the second was a group that was used to high-luminance light sources such as the sun and LED lighting equipment. In other words, we determined that the difference in the living environment in the subjects' everyday life space influenced directly the tolerable limit of the glare (see Figs. 5 and 6). From this point of view, we understood that it is necessary to consider the living environment in everyday life for the participants when we examine illumination in a sports environment. However, doing so in line with this definition may simply make things darker by assuming that we should lower the environmental illumination when we should be aiming to reduce only glare. This can be regarded as another problem. It is crucial in sports environmental lighting not only to judge the luminance range beyond the glare, but also to examine the tolerance level that one can endure and build an environment into which participants can fit.

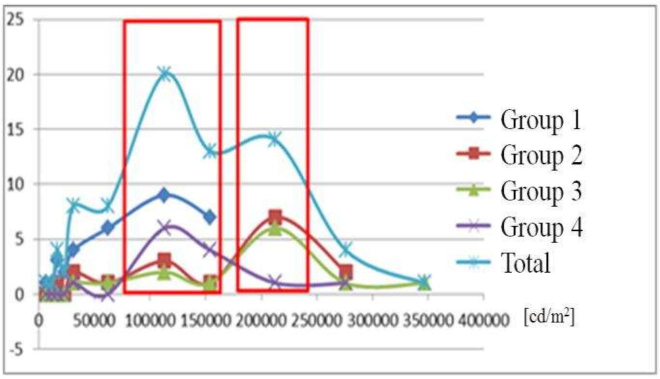



*Fig. 5. Luminance and test result of subjects in the tolerable limit of the glare in the Bright room.*

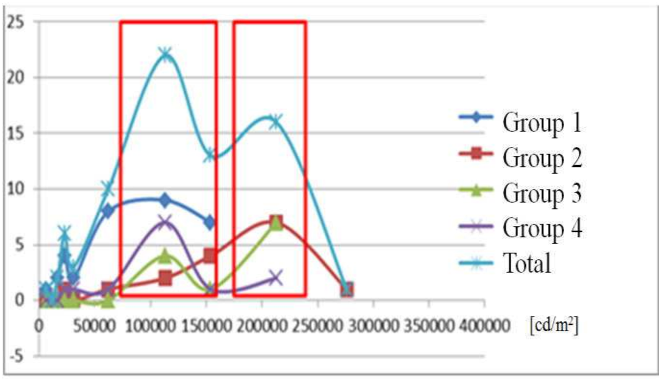



*Fig. 6. Luminance and test result of subjects in the tolerable limit of the glare in the Dark room.*

***Experiment 3: Visual recognition after looking directly at a light source.***

People take evasive action when they see something bright. For example, they look away and narrow their eyes. Based on these considerations, we carry out an experiment on sports players: the recognition of a situation when they look directly into a lighting source. This experiment ascertains the recognition of a situation by sports players who look at a bright object while playing sports. A 500 mm × 500 mm piece of colored paper is pasted behind the light source, and the subjects are asked to state the color of the paper. The distance from the light source to the subject is 5 m (see Fig. 7). We conduct experiments on the same subjects both in a Bright room and in a Dark room. Five colors are used for the test: white, yellow, green, red and blue. The subjects are men and women who are members of an outdoor sports clubs (see Table 2). In the same way as in Experiment 1 and 2, the subjects remove their goggles at the start cue, and don them at the end cue. After leaving the test room, we asked each subject what the color of the paper was. The answers provided indicated the recognition ability of the subject.

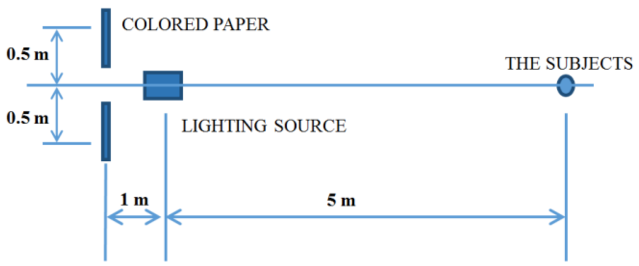



*Fig. 7. Positional relationship among light source, colored paper and subject.*

**Table 2**

*Experiment 3 Parameters*

| Subjects | 28-49 years old | Males 12 | Females 15 |
|---|---|---|---|
| Environment | Bright room and Dark room | | |
| Distance | 5 m | | |
| Looking time | 2 sec. | | |
| Paper size | 500 mm × 500 mm | | |
| Luminance at position of colored paper | Bright room: 160 lux<br>Dark room: 3 lux | | |

**Table 3**

*Experiment 3 Results*

| Environment | White | Yellow | Green | Red | Blue |
|---|---|---|---|---|---|
| Bright room | 14.8% | 14.8% | 11.1% | 3.7% | 3.8% |
| Dark room | 11.1% | 14.8% | 7.4% | 7.4% | 0.0% |

100% : maximum light intensity

The subjects did not have sight of the paper. The results obtained did not depend on the environment (see Table 3). Through this experiment, we ascertained there is a different situation with respect to the concept of background luminance in the standards for conventional glare.

***Experiment 4: Form recognition of a light emitting surface after looking directly at a high-luminance light source.***

A light source in a normal living space has a relatively low luminance. Therefore, people are aware of the light source shape in the adjustment range in their field of view. However, there is no literature book or data describing shape recognition when people look at a high-luminance light source. The results of Experiment 3 showed that situational awareness of a surrounding high-luminance light source becomes difficult after two seconds. The authors themselves have observed the time required for recognition, and consider that 4 to 5 seconds is necessary. This experiment was conducted only on the authors and experimental subjects in the Dark room. The authors had carried observations at a light-source intensity of 500,000 cd/m$^2$ or more. The distance from the light source to the subject is 3 m. The subjects look directly at the light source for 4 to 5 seconds and turn off the power to the light source when they recognize the light source. Subsequently, we compare the recognized form of the subject with the measurement image that is sampled. We detect the approximate form image. Each image is tested using four different high-luminance light source forms, and we confirmed our findings by repeating the experiment.

From the experimental results, shape recognition was found to approximate a binarization of about 10% to 30%. At the same time, the form in a light source at maximum luminance is difficult to identify, so it cannot be determined.

This condition is considered to have been visually saturated by the light source in direct vision. Therefore, the luminance distribution of the internal light source cannot be recognized, and recognition was possible only in the form recognition (see Fig. 8).

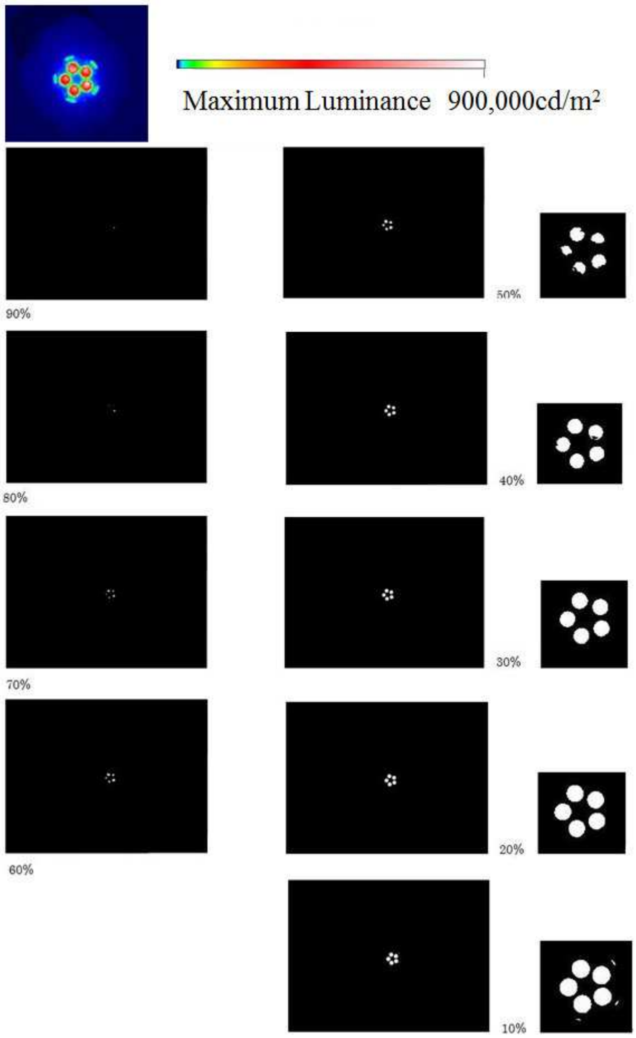



*Fig. 8. Light source image and binarized sampling image.*

**Changes in glare**

Based on the results obtained during our previous experiments, we consider the relationship between the glare of the light source and the subject. Even if the subject is looking directly at the glare of a high-luminance light source, the results are not affected by the subject being in either the Dark room or the Bright room. The definition of an index by which one feels glare in the existing standards showed variations in the course of the experiment. Therefore we focused on the scope of the limit of tolerance. The limit of tolerance of glare depends on the living environment of everyday life of a person. In this experiment, we ascertained the match of the affiliation of the experimental content and the subject. Based on the results, we found that in the lighting of a sports environment it is necessary to consider the viewpoint of the participant.

Most sports players could not be recognize the surrounding environment of a high-luminance light source, the color or maximum luminance. This condition is considered to be the result of having been visually saturated by a light source in direct vision. Therefore, the luminance distribution of an internal light source cannot be recognized, and it is possible only in form recognition. From these results, the subjects found that they were not able to recognize the background of the environment when observing a light source directly.

People can recognize form in a low-luminance light source, but they will be in a visually saturated state when looking at a high-luminance light source directly. Based on our previous experiments, extracting the luminance range of a binarized sampling image, the level of glare influence was simulated. The Y value represents the luminance range of form recognition, and the X value represents the percentage of the relationship of form recognition and luminance. If the X value is increased to correspond to the Y value, both are proportional. However, it becomes an S-shaped curve by both being inverted (see Fig. 9).

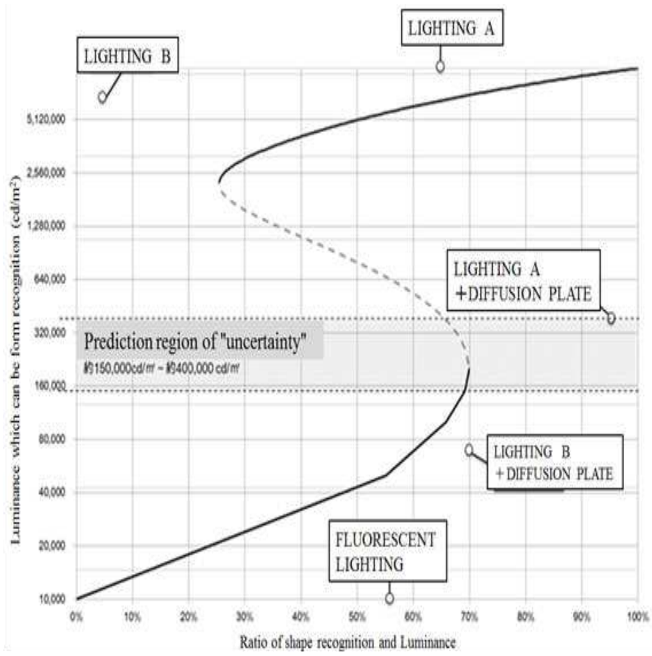



*Fig. 9. Graph of glare effect of shape recognition and area luminance.*

This resultis for applying glare protection for a direct-type LED light source, a situation with the installation of a diffuser is assumed. In a state where a direct LED element is exposed, the target light source has high luminance and the area of shape recognition is low. On the other hand, by decreasing the overall brightness using a diffusing plate, shape recognition improved. With respect to avoidance behavior in the case of a high-intensity light source, avoidance behavior is affected by the glare of brightness prior to shape recognition. Conversely, the influence of the luminance level of a low-luminance light source is small and is not affected by shape recognition. In between the two extremes, it is assumed that avoidance behavior will be led while affected by both the glare of brightness and shape recognition. The boundary at which we cannot recognize forms indicates a branch point. In addition, we considered the required illuminance for a comfortable life. The luminance range added to these conditions shows the uncertainty range. Thus, the luminance area is approximately 150000 cd/m$^2$ to 400000 cd/m$^2$. We measured each light source of 500000 cd/m$^2$. Furthermore, we noted in Fig. 9 the results in the case of using a diffuser to each light source of 500000 cd/m$^2$. A typical fluorescent lamp seems to have remained in the area of shape recognition without being subjected to the effects of brightness effects. Each high-intensity light source can be maintained under the area of the predicted area and uncertainties close to the prediction of uncertainty to place the diffusion plate (see Table 4).

**Table 4**

*Influence of the glare of the area brightness on shape recognition and various light sources.*

| | Lighting A | Lighting A +Plate | Lighting B |
|---|---|---|---|
| Luminance [cd/m$^2$] | 11260000 | 451500 | 6566100 |
| Ratio of form recognition | 67.73% | 96.50% | 6.41% |
| Effect factor | Luminance | Luminance, Form recognition | Luminance |

| | Lighting B +Plate | Fluorescent lighting |
|---|---|---|
| Luminance [cd/m$^2$] | 74200 | 10000 |
| Ratio of form recognition | 70.79% | 56.75% |
| Effect factor | Form recognition | Form recognition |

**Conclusion**

We installed a combination of LED lighting and diffusion plates at a sports stadium in an ordinance-designated city to determine the most comfortable illumination environment for sports using LED lighting. The results of experiments we conducted suggest:

The glare of an LED light source in indoor sport mentioned in the Introduction remains a problem to be solved. Basic experiments on glare were conducted during the process of problem solving as this was essential in order to verify the facts. For sports players to get the best results in sports competitions an optimal environment is required. The results obtained in this study will aid lighting manufacturers improve their products so they can continue to make environmental improvements. Therefore, we expect that this study will help aid the development of sports lighting so as to realize an optimal environmental.

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