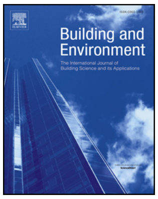
Building and Environment 143 (2018) 48–58

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv



Glare quantification for indoor volleyball

Martijn Pakkert[b,*], Alexander L.P. Rosemann[a], Juliëtte van Duijnhoven[a], Maurice A.H. Donners[b]

[a] *Eindhoven University of Technology, Eindhoven, The Netherlands*
[b] *Signify, Eindhoven, The Netherlands*

ARTICLE INFO

Keywords:
Sports lighting
Glare
Eye tracking
Discomfort
Disability

ABSTRACT

Sports facilities all over the world apply LED lighting. The combination of high luminance and small luminous surfaces causes a high probability of glare and LED lighting contains these specifications. There are specific situations for which validated glare models exist, such as offices or outdoor soccer fields, although indoor sports facilities are not one of them. Additionally, we do not know the degree to which lighting may impact athletes' performance. Contradictory research exists on whether glare decreases task performance, and whether any decrease is due to discomfort glare or disability glare. In the current research, objective performance measurements were conducted on a volleyball court with both amateur and professional athletes from the Dutch national indoor volleyball competition—the Eredivisie. An eye tracker was used to see if gaze data contributed to a better understanding of performance or the subjective experience of glare. The results show that athletes' performance was not decreased due to glare, although the subjective experiences, measured by discomfort and non-acceptance, increased significantly. The current unified glare rating (UGR) glare model has a strong correlation with the discomfort findings, although the combination of source luminance and background luminance predicts discomfort and non-acceptance even better. This paper demonstrates that existing glare models perform well for indoor sports environments.

1. Introduction

LEDs have made their entrance into sports lighting, and some say it is to be expected that its market share will continue to grow [1,2]. This development has major benefits for organizations and their facilities, such as a reduction in energy consumption and maintenance costs [3]. However, LED lighting can be visually uncomfortable due to its small, bright, luminous areas, which are known to cause glare [4–6]. Large-scale studies show that glare has a negative influence on task performance in office settings, where tasks such as detection speed were analysed [7].

Glare is defined as the "condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts" (eILV CIE [CIE], 2014). In general, glare is subdivided into two main categories: disability glare, and discomfort glare; both of these are further subdivided into a total of eight categories, such as dazzling glare or flash blindness, among others [8]. In general, indicators for glare are the luminance of the light source, the luminance reflected from the background surfaces, the solid angle of the light source, and the glare angle [7,12]. Although high illuminances can yield discomfort, this may increase performance in tasks, such as object recognition, reaction times, speed, and accuracy in sports [2,7,9]. For its part, disability glare impairs visual performance and, therefore, may decrease athletes' performance [10]. It has been shown that disability glare is a matter of physiological effects while discomfort glare is a matter of psychological effects [9]. The CIE recommends using glare rating (GR) for outdoor sports venues, and unified glare rating (UGR) for indoor office work [11,13]. Nevertheless, the GR model makes "no further distinction between discomfort and disability glare", while the UGR model demonstrates the level of discomfort [11]. Thus, it remains unknown which of the two is dominant regarding the impact of task performance.

Equation (1) for UGR [11] and equation (2) for GR [13] are as follows:

$$UGR = 8{*}\log\left(\frac{0.25}{L_b}{*}\sum\frac{L^2\omega}{\rho^2}\right), \tag{1}$$

where L_b is the background luminance in cd/m^2, L is the luminance of the luminous parts of the luminaire in cd/m^2, ω is the solid angle of the luminous parts of the luminaire at the observer's eye in steradians (sr), and ρ is the Guth position index for each luminaire.

$$GR = 27 + 24{*}\log\left(\frac{L_{vl}}{L_{ve}^{0.9}}\right), \tag{2}$$

---

[*] Corresponding author. Signify, Boschdijk 525, 5621 JG, , The Netherlands.
E-mail address: martijn.pakkert.m@signify.com (M. Pakkert).

https://doi.org/10.1016/j.buildenv.2018.06.053
Received 17 April 2018; Received in revised form 27 June 2018; Accepted 28 June 2018

where L_{vl} is the veiling luminance of the produced by the luminaires, and L_{ve} is the veiling luminance on the observer's eye produced by the environment. These equations are applicable to all cases.

There is some literature that shows that the GR is also applicable for an indoor sports situation, but in recent research, this was disproven for the case where the glare source has a high luminance, such as LED lighting [5,14]. Further, the GR was designed for an outdoor football environment with a dark sky as background, while the ceiling and walls in sports halls usually have a considerably higher luminance than the night sky [15]. The practical implementation of UGR creates an incentive to test this model for sports, but until now, no glare model has been evaluated for this purpose. Due to a lack of a better alternative, GR is being used for indoor sports venues, but there is, in fact, no glare requirement set for indoor sports, nor any “no specific, quantifiable recommendations” [16]. This lack of a glare requirement is evident in the regulations of popular indoor sports, such as basketball (FIBA): lighting should “reduce glare and shadows by the correct positioning of the lighting equipment”; and volleyball (FIVB): “lamps must not dazzle the players in any way, be too bright nor be placed over the centre line of the court” [17,18]. While bright LEDs are applied increasingly all over the world, the possible adverse effects of these luminaires remain unknown—such as glare—and whether the effects influence sports performance.

In many sports, athletes must adjust their gaze constantly and quickly, thus changing the position index of the luminaire in their field of view. Especially in highly dynamic environments, such as futsal and volleyball, the amount of glare can change dramatically in short periods of time. One of the elements that reoccur in every discomfort glare model is the position index of the glaring luminaire. In some formulae, the position index is expressed as a glare angle, while in others, it is expressed as a rather complex equation, such as the Guth's position index [19]. Nevertheless, all formulae have one thing in common: the position index suits only one static situation.

High performance in sports has a close relation to visual performance, such as the time to recognize objects, the ability to focus on objects quickly, and depth judgments. While performing complex movements, athletes need a constant supply of accurate and reliable visual information from the environment. Therefore, visual performance is crucial in a sports environment [20]. Thus, disability glare does not only affect the performance of general tasks for indoor workplaces [22], specifically, by hampering people's ability for “detecting or processing peripheral information” [23] and when driving [24,25], it can also impair sports performance [10,21]. The main factor for decreased performance disability glare seems to be in increased reaction time, which can have unfortunate consequences in some situations.

As one of the few popular worldwide indoor sports for which the players look in all different directions during a match, we chose volleyball for the current study. Additionally, volleyball requires non-static visual demands, contrast judgments, and significant directional localization demands, while also being highly dynamic [26]. To be able to judge ball spin, for example, a player relies on their visual resolution ability, dynamic visual acuity, contrast sensitivity, and oculomotor function, which are aspects of the player's eye movements. This heavy reliance on visual references makes volleyball players especially vulnerable to glare, since glare impairs most of these aspects of visual performance [24,27,28].

In this paper, we utilize multiple viewpoints to analyse the data. Glare was calculated with existing glare models. Additionally, subjective measurements were conducted on discomfort and acceptance of the light scenes. Meanwhile, objective measurements were done on task performance and gaze behaviour.

- From this study, we endeavoured to learn to what extent it was possible to use task performance as an indicator to quantify glare for indoor sports. In addition, we sought to understand the best method to quantify glare for indoor sports. The literature reveals that increasing discomfort does not necessarily mean a decrease in performance [7]. That said, it is known that disability glare can decrease the amount of information one retrieves visually and that discomfort glare can distract one from a task at hand [7]. Thus, our hypothesis was that an increase in glare would cause a decrease in sports performance for tasks dependent on visual input. Therefore, this paper addresses whether existing glare models, or other indicators, might predict the subjective experience of glare.
- There are no differences in the visual performance of amateur and professional athletes, but only in their perceptual-motor skills [29,30]. Therefore, this paper also discusses whether skill level influences the performance impact due to glare.
- The third aspect under review in the current research is whether eye tracking is a reliable method to contribute to quantifying glare for indoor sports. Volleyball professionals usually require less visual information to execute their task successfully. In other words, volleyball professionals “do not need to track the entire ball trajectory” [31,32]. Additionally, professionals can retrieve a greater amount of information from their peripheral vision [33]. It is possible that a professional can look away from a luminaire while performing at the same level, thus minimizing the adverse effects of glare and achieving a greater glare angle during their activity.
- In volleyball, it has been proven that professional players have a significantly higher skill level than amateurs for measures such as their prediction of the game situation and their estimation of speed and direction of a moving object [27]. Therefore, it is hypothesized that, under the influence of glare, professionals will show a different level of decrease in task performance than amateurs.

2. Methodology

All participants received an oral explanation of the experimental procedures, gave their written informed consent before participating in the study, and received compensation afterwards. All participants were native Dutch speakers.

An eye tracker was used to gain better insights into what players experience during play. Eye tracking has previously been used to evaluate pupil size and viewing direction, but was applied here to incorporate an average glare angle [34–36]. The entire methodology set up was approved by the ethical committee of Signify.

The participants were asked to perform a set of attempts in three different court positions (as shown in Fig. 1a and 1b) in the order 1, 2, and 3. A volleyball team has 6 different positions, for which 3 are ‘attackers’ positions. On these positions, the player will attempt to throw the ball on the field of the opponent. There these 3 starting positions are taken for the measurements. Per each court position, the observed lighting properties did not change much, although the glare angle did. For position 1, the ball came from the direction of the glare source and had to be targeted away from the luminaire. For position 2, the ball came from the direction of the glare source, but then had to be targeted back in almost the exact same direction. For position 3, the ball came from a direction without glare, but had to be targeted toward the luminaire. For each of the three positions, these attempts were done for four different light scenes, labelled ‘B’, ‘BG’, ‘G’, and ‘GG’, which are defined later in this paper.

The scores were converted to radial errors, based on the distance from the centre of the target in meters. Each ring of the circular target was slightly larger than an official FIVB volleyball (21 cm) with a width of 0.27 m. The centre ring had a radius of 0.35 m. The radial error represented the midpoint of each ring (1st ring = 0.485 m, 2nd ring = 0.755 m, 3rd ring = 1.025 m, etc.). The attempts that landed on the border of two rings were counted for the highest radial error.