

Interactions among Light Source Luminance, Illuminance and Size on Discomfort Glare

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ABSTRACT

Discomfort glare from vehicle lighting is more difficult to measure precisely than disability glare, but may have important implications for driver behavior, and in turn on driving safety. Many studies of discomfort glare have found that, as with disability glare, the illuminance at the eyes from a bright light is the primary determinant of the sensation of glare. Nonetheless, the luminance of a light source also can influence discomfort glare, especially when the source is close enough to subtend a relatively large visual angle on the order of a third of a degree or larger. In addition, interactions with the absolute illuminance from a light source are not well understood. The results of an experimental investigation of discomfort glare in terms of light source illuminance, luminance and size are presented and discussed along with implications for automotive lighting applications.

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INTRODUCTION

Glare from automotive lighting can be described in at least three possible ways (Rea, 2000). One, disability glare, is the apparent reduction in luminance contrast that is created when a bright light in the field of view produces scattered light within the eye (Fry, 1954). A second aspect of glare is entitled *glare recovery* and refers to the temporarily reduced level of visual performance that occurs after a bright light is no longer present in the field of view. It is analogous to the diminished visibility that is experienced when entering a darkened theater on a bright, sunny day. After a duration that is dependent upon the amount and duration of light exposure (Skinner and Bullough, 2009), the eye's adaptation level decreases and sensitivity is gained. A third aspect of glare, *discomfort glare*, is the sensation of annoyance or even pain that can be created when a bright light is in the field of view.

While all three of these aspects of glare can be produced by the same lighting conditions, such as oncoming headlamps (NHTSA, 2007), they do not always occur together. For example, vehicle dashboard lights that are excessively bright could reduce a driver's forward visibility (disability glare) but might not produce a painful sensation (discomfort glare).

While the potential safety implications of disability glare and glare recovery are fairly intuitive since these involve reductions in visual performance, the importance of discomfort glare is less well understood. Nonetheless, discomfort glare is unlikely to be of no consequence in

driving safety. In a naturalistic driving study, Bullough et al. (2008) measured various behavioral responses of drivers to oncoming headlamp illumination characterized via a head-worn light sensor that measured the illuminance incident a location very close to the drivers' eyes in that study. The head-worn instrument also contained accelerometers to measure head movements, and increased head movement was associated with greater oncoming headlamp illumination. Similarly, variability of throttle position while driving was increased when higher levels of oncoming headlamp illumination were present. These responses were also found when people were driving along roadway locations that had inherently higher crash frequencies (Bullough et al., 2008), indirectly suggesting a relationship between head movement and throttle variability, and safety.

Previous studies have identified similar relationships between environmental factors that could be thought to induce stress to a driver, such as temperature, and driving behaviors that might be indicators of decreased safety. Daanen et al. (2003) found that when exposed to very high or very low cabin temperatures, drivers exhibited greater variability within their driving lanes, a possible safety-related effect. Since the annoying or painful sensation from discomfort glare might also induce stress, they could result in similar safety-related effects.

A previous study of discomfort glare and the characteristics of a light source related to the glare response

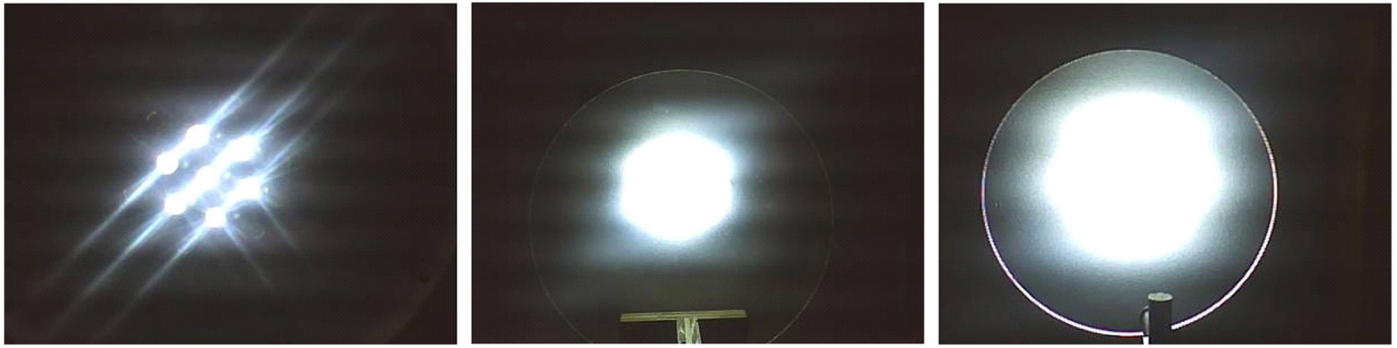


Figure 1. Light source arrays used in the experiment. Maximum source luminances, from left to right, were 1,000,000 cd/m², 50,000 cd/m² and 15,000 cd/m².

found that light sources consisting of arrays of light-emitting diodes (LEDs), either presented directly to observers, or viewed through a diffusing element that reduced the maximum luminance from approximately 1,000,000 cd/m² to 50,000 cd/m² and 15,000 cd/m², elicited discomfort glare responses that were strongly influenced by the maximum luminance of the sources (Bullough, 2011). This occurred even though the illuminance from the sources at observers' eyes was held constant (8 lx).

Bullough et al. (2008) proposed a model of discomfort glare (DG) based on illuminance quantities (from the light source [E_L], from the area surrounding the source [E_S], and from the ambient environment [E_A]):

$$DG = \log(E_L + E_S) + 0.6 \log(E_L/E_S) - 0.5 \log(E_A) \quad (\text{Eq. 1})$$

The quantity DG can be related to values along the De Boer (1967) rating scale of discomfort glare (DB: 1=unbearable, 3=disturbing, 5=just acceptable, 7=satisfactory, 9=unnoticeable glare) according to the following equation:

$$DB = 6.6 - 6.4 \log(DG) \quad (\text{Eq. 2})$$

Bullough (2011) showed that this model would not provide good predictions when the maximum light source luminance (L_L) was very high. (The maximum source luminances in the study by Bullough et al. [2008] averaged about 50,000 cd/m².) Published data from Rosenhahn and Lampen (2004) likewise found that for very small light sources, the source luminance was unimportant to predicting discomfort glare, but when the light source was relatively large, its luminance influenced discomfort glare.

Because an illuminance of 8 lx at the eyes under otherwise dark conditions representative of nighttime driving is quite high in an automotive driving context (although not outside the range of values measured in field studies [Bullough et al., 2005, 2010]), the present study was conducted to characterize subjective discomfort glare

responses to sources differing in the illuminance from the light source, the maximum source luminance, and the size of the light source. The study consisted of two experiments.

METHOD: MAIN EXPERIMENT

The same light sources used by Bullough (2011) were set up in the Levin Photometry Laboratory at the Lighting Research Center, at approximately eye height. The maximum source luminance of the LED array was estimated to be approximately 1,000,000 cd/m². When a plastic diffuser was placed in front of and near the array, the maximum source luminance was 50,000 cd/m². When the diffuser was moved further from the array, the maximum luminance was 15,000 cd/m². Figure 1 shows the appearance of the arrays.

From a viewing distance of 5 m in front of the bare LED array, the direct illuminance at a location 5 ft above the floor was 8 lx. Illuminances from the diffused LED sources were slightly less than 8 lx at the 5 m viewing distance, so observation distances from which the sources produced 8 lx at the same height were marked on the laboratory floor. The differences among the observation distances for each array source were less than 0.5 m. Similarly, from a distance of 10 m from the bare LED array, the direct illuminance was 2 lx. As with the viewing distances near 5 m from the sources, observation distances resulting in 2 lx from each of the diffused sources were marked. Differences among the farther distances were less than 0.75 m. At the 10 m viewing distance the angular size of the bare LED array was 0.31°; at the closer distance and with the diffusers, the angular source size was larger.

Subjects viewed each of the light source arrays from each distance. In addition, they viewed each light source array through a foam core, 0.6 m by 0.6 m window consisting of a frame and a neutral gel filter with a transmission of 33%. The resulting illuminances at the 5-m and 10-m viewing distances were 2.7 and 0.7 lx, respectively, and the resulting maximum luminances of the LED arrays were 330,000 cd/m², 17,000 cd/m² and 5,000 cd/m². Akashi et al. (2009) confirmed that subjective perceptions of lighting configurations viewed