

Visual Recovery and Discomfort Following Exposure to Oncoming Headlamps

Nicholas P. Skinner and John D. Bullough
Rensselaer Polytechnic Institute

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ABSTRACT

A field experiment was performed to measure the effects of oncoming illuminance profiles with different photometric and temporal characteristics on visual recovery and subjective discomfort. Target detection time was correlated with the dosage, and rated discomfort was correlated with the peak illuminance of each profile. Older subjects generally had longer recovery times, but there were no differences between the age groups in terms of rated discomfort. The results suggest that discomfort glare is not predictive of visual disability and that control of luminous intensity at isolated points within the distribution of headlamps alone is not sufficient to minimize glare recovery.

INTRODUCTION

Glare from oncoming headlamps is perceived as an important problem by the U.S. driving public (NHTSA, 2007). Oncoming headlamp illumination can have several effects:

- Reductions in visibility caused by scattered light from headlamps within the eyes of drivers (disability glare)
- Sensations of annoyance or pain while headlamps are in the field of view (discomfort glare)
- Deficits in visibility following exposure to illumination from headlamps that changes the adaptation level of the eyes (glare recovery)

The first two phenomena have been extensively studied in the context of nighttime driving (e.g., Flannagan, 1999; Bullough et al., 2002, 2003). Disability glare is a fairly well-understood phenomenon (Fry, 1954) that can be caused by a veiling luminance (which serves to

reduce contrast). Veiling luminance can be predicted by the illuminance from the offending light source and its location in the field of view.

Discomfort glare is less well-understood, especially in terms of the mechanisms underlying discomfort. Two conditions that produce equivalent amounts of disability glare can produce different amounts of discomfort. De Boer (1967) studied discomfort glare extensively in the context of roadway lighting and developed a nine-point rating scale for discomfort that is still used today. A value of 1 corresponds to unbearable discomfort, 3 to disturbing glare, 5 to just acceptable glare, 7 to a satisfactory level of glare, and 9 to a level where glare is just noticeable.

Exposure to oncoming headlamp illumination temporarily reduces the visual system's sensitivity. Following glare exposure, the photoreceptors must re-adapt to the ambient light level. Upward adaptation (to higher light levels) is accomplished in a short amount of time, but downward adaptation (to lower levels) takes longer, on the order of several seconds under typical nighttime driving conditions (Chen, 2004). Immediately following exposure to a bright light, objects that are close to the visual threshold can be invisible to drivers until their adaptation level is reduced enough to make them visible again (Baker, 1963; Irikura et al., 1999; Lehnert, 2001). Logically, this temporary reduction in visual functioning has implications for nighttime driving safety.

Irikura et al. (1999) investigated the role of light source luminance and duration on visual recovery by measuring the time taken to recover visual acuity corresponding to half of that before exposure to the light source. Recovery times were strongly correlated with the "dosage" (defined by Irikura et al. as the product of luminance and duration) produced by the light source. In comparison,

Sivak et al. (1999) measured discomfort glare of individuals exposed to sources varying in illuminance produced at the eye and in duration. Varying dosage (defined by Sivak et al. as the product of illuminance and duration) resulted in slightly different subjective ratings of discomfort, but the major factor influencing discomfort was the illuminance at the eye. Together, these results lead to a hypothesis that glare recovery and discomfort glare are mediated by different mechanisms. To further explore this hypothesis, Van Derlofske et al. (2005) measured both visual recovery and discomfort ratings to sources producing different illuminances and different dosages (defined as the product of illuminance and duration). The results of that study were consistent with the hypothesis.

The age of a driver plays a role in the amount of time required for glare recovery. Older drivers have been reported to have longer recovery times than younger ones (Schieber, 1994). However, evidence for differences in discomfort glare between age groups is scarce. Dee (2003) measured discomfort from lights varying in intensity and spectral composition and found that the mean ratings from older subjects were nearly identical to those from younger subjects.

Previous work, therefore, supports the notion that glare recovery is related to the dosage of light exposure under conditions representative of nighttime driving and to the age of the driver, but that subjective impressions of the exposure (i.e., how uncomfortable the exposure makes one) are more related to the peak illuminance of an exposure profile, regardless of the driver's age.

This research study tested the same hypotheses as those investigated by Van Derlofske et al. (2005) but with illuminance profiles representative of those experienced by drivers when vehicles pass at night. Participants were selected from different age groups to determine whether the shape of the illuminance profile will impact recovery and rated discomfort of individuals from different age groups.

METHODS

The field study was conducted outdoors on a paved asphalt surface (reflectance ~10%). Figure 1 shows a plan view of the experimental setup. Over the course of two nighttime experimental sessions, eleven subjects (age range 22 to 60 years, divided into two groups with mean ages of 25 and 55 years) were seated in the driver's seat of a 1999 Ford Contour. A set of low-beam halogen headlamps conforming to Society of Automotive Engineers (SAE) requirements for headlamp photometry (SAE, 2006) was placed directly in front of the subjects' test vehicle, aimed to SAE standards, and operated at 12.8 V during all experimental trials. At a distance of 30 m directly ahead of the test vehicle, a 0.3-m high, seven-segment, red light-emitting-diode display was located, which displayed a random digit (between 0 and 9) at 1-second intervals. During the experiment, subjects were instructed to look toward the numerical display. 3 m to

the left of the display (5° off-axis), a theatrical light projector containing a metal halide lamp was positioned such that it projected a beam of light toward the subjects, in a direction parallel to the subjects' line of sight.

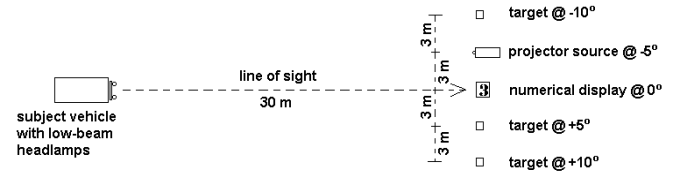


Figure 1. Plan view of experimental layout.

Targets consisting of square flip-dot arrays (10 cm by 10 cm) were located at locations 6 m to the left, and 3 m and 6 m to the right of the numerical display [10° to the left (-10°), 5° to the right (+5°), and to flip 10° to the right (+10°) of the display]. The active elements on the targets were black on one side and white on the other and could be "flipped" from black to white by computer control (approximate transition time was 20 ms). The average reflectance of the flip-dot array in white state was 40%; a sheet of glass (transmission ~70%) was positioned in front of each target so that the apparent reflectance of the target was 20%. The vertical illuminance on the targets at -10°, +5° and +10° due to the headlamp set were 3, 14 and 8 lx, respectively. The intensity of the projector light source, the operation of the flip-dot assemblies, and the timing of the subjects' response were all controlled by a laptop computer; custom written software was used for this purpose.

The experiment began once the subjects became settled in the subject car. The software selected one of the four illuminance profiles shown in Figure 2 and controlled the projector light source such that the illuminance profile was produced at the subject's eyes. Once the selected profile was displayed, the software returned the light source to a darkened state and changed one randomly selected flip-dot target into the white state. The flip-dot target remained white until the subject indicated detection (by activating a switch from within the car) or 10 seconds had elapsed. After detection or time-out, the software returned the flip-dot to black and paused for a short time before displaying the next profile and target combination.

The glare profiles in Figure 2 were selected from among several calculated by Chen (2004) based on photometric data for existing low-beam headlamp systems. The profile with the highest peak illuminance (3 lx) is representative of the shape of the profiles of some properly-aimed headlamps. Another profile was created with exactly half the illuminance values as the first one, since different headlamps can have similar profile shapes but different peak illuminance values (Chen, 2004). The duration of the profiles in Figure 2 correspond to that experienced by