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Drivers' judgments of the effect of headlight glare on their ability to see pedestrians at night

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ABSTRACT

Introduction: Several studies have concluded that pedestrians typically overestimate their own conspicuity to approaching drivers at night. The present experiments extended this research by exploring the accuracy of drivers' judgments of pedestrian conspicuity while facing varying degrees of headlight glare. *Method:* In Experiment 1, participants on an open road estimated their ability to see a roadside pedestrian in each of two clothing configurations and with each of three different glare intensities present. In Experiment 2, participants responded to a roadside pedestrian under the same open road conditions; the participants were naïve with regard to both the position of the pedestrian and to the clothing and glare manipulations. *Results:* Consistent with earlier research, estimates of response distance were, on the average, over three times greater than actual recognition distance. The extent to which participants overestimated conspicuity was greater when the pedestrian wore a retroreflective vest, and participants incorrectly judged that headlight glare would not degrade drivers' ability to see a pedestrian wearing a retroreflective vest. *Conclusions and Practical Applications:* These results confirm that road users' understanding of issues involving drivers' night vision is limited. These misunderstandings may result in road users behaving in ways that increase the risk of nighttime collisions with pedestrians.

1. Introduction

Crashes resulting in pedestrian deaths are more frequent at night and research has documented that pedestrians being insufficiently conspicuous to drivers at night is a direct cause (Owens & Sivak, 1996; Sullivan & Flannagan, 2002). Hazlett and Allen (1968) found that over 20% of drivers involved in a nighttime collision in which their vehicle struck a pedestrian reported not realizing that a pedestrian was present until after the crash had occurred. Researchers using open- and closed-road methods (e.g., Wood, Tyrrell, & Carberry, 2005; Wood et al., 2010) have confirmed the difficulty that drivers can have in seeing pedestrians at night. Importantly, on-road tests have also identified glare from the headlamps of oncoming vehicles (i.e., "headlight glare") as a factor that can significantly and directly degrade drivers' ability to see pedestrians at night.

The fact that headlight glare can be a problem for drivers is well known. Indeed, complaints from drivers who report having been "blinded" by oncoming headlights are not uncommon; over 5,700 complaints have been received by NHTSA to date (NHTSA, 2001). Approximately 30% of respondents in a large survey reported that glare had been "disturbing" to them (Singh & Perel, 2003). The fact that drivers often feel discomfort in the presence of headlight glare may lead them to believe they are also visually disabled. However, it is unclear whether typical drivers are aware of the difference between discomfort glare (the subjective experience of annoyance or pain from opposing headlights) and disability glare (an objectively measured degradation in visual performance). Although typical drivers may be acutely aware of their subjective experiences with glare from oncoming vehicles, they may not understand or appreciate the extent to which their ability to see at night is affected by glare.

Surprisingly, little research has examined the effects of headlight glare on drivers' ability to respond to the presence of pedestrians. Wood et al. (2005) measured drivers' ability to recognize a test pedestrian with and without the presence of a glare source. They found that the effect of glare varied with the pedestrian's clothing. In one condition (black clothing, low beams), young drivers recognized 70% of black-clad pedestrians when glare was absent; no participants responded to the same pedestrian when an opposing pair of headlights were present near the pedestrian. More recently, Wood et al. (2012) asked participants to drive a closed-road course and detect pedestrians while experiencing three different visual conditions (normal vision, blurred vision, and simulated cataracts). Some participants completed the

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experiment with no headlight glare present, while others encountered a glare source positioned near the test pedestrian. Wood et al. reported that both response distances and response rates significantly decreased in the presence of glare, confirming that headlight glare significantly worsens drivers' ability to recognize pedestrians at night.

Theeuwes, Alferdinck, and Perel (2002) examined the effects of glare both on drivers' ability to detect pedestrians and on their subjective feelings of discomfort (measured using the deBoer scale) in the presence of glare. The participants were asked to indicate the point at which they first saw simulated roadside pedestrians. The presence of glare significantly reduced participants' detection distances, and as glare intensity increased, detection distances decreased. Importantly, however, the authors also reported that glare-related discomfort was not predictive of participants' driving performance (e.g., detection distance, speed).

Flannagan, Sivak, Traube, and Kojima (2000) provided further evidence that the visual discomfort resulting from exposure to glare may be dissociated from the effect of glare on visual abilities. The researchers varied two sets of lights (one simulating headlights from an oncoming vehicle and the other simulating the headlights of the participants' vehicle) such that the intensities of both sets were always matched. As expected, increased headlight glare intensity resulted in increased ratings of discomfort. However, pedestrian visibility distances increased (by almost 20%) as the headlamp intensities were increased. The fact that increased intensity of the glare source produced greater levels of discomfort but increases in pedestrian visibility confirms that disability glare can be dissociated from discomfort glare.

To our knowledge, little research has examined the accuracy of drivers' judgments of the effects of glare on their ability to see. It is important to assess road users' judgments of their own visual abilities, as their judgments may inform their driving behaviors (e.g., high beam usage) and decisions (e.g., electing to jog near traffic) at night. Along these lines, Balk and Tyrrell (2011) asked participants to estimate the distance at which they would just be able to determine the orientation of a high contrast, retroreflective Landolt C in the presence of headlight glare. Their estimated recognition distances were then compared with actual recognition distances of the stimulus. Balk and Tyrrell found that even though actual recognition distances were unaffected by headlight glare in their scenario, the participants judged that the glare from the opposing vehicle's high beam headlights would result in significantly shorter recognition distances relative to when the opposing vehicle used low beams. Based on these findings, Balk and Tyrrell concluded that drivers can overestimate the disabling effects of headlight glare on their vision.

A limitation of the Balk and Tyrrell (2011) study was that the high contrast and high luminance that was produced by their retroreflective stimulus may have been relatively robust to the effects of headlight glare (Wood et al., 2005). Additionally, the participants always knew where to look to see the stimulus, thus ensuring that it was fixated. Conversely, pedestrians are often low-contrast, unexpected hazards, and, for a driver who is actively scanning the roadway environment, the image of a pedestrian can first appear in retinal locations that are removed from the fovea. Thus, the question of whether drivers overestimate the disabling effects of headlight glare when they are driving and looking for pedestrians remains untested.

The present studies sought to determine the extent to which drivers under- or overestimate their ability to see pedestrians while experiencing differing amounts of headlight glare. In Experiment 1, participants indicated the distance at which they judged that they would just be able to recognize an imagined pedestrian on the shoulder of the roadway adjacent to a parked vehicle. Asking the participants to imagine the presence of the pedestrian forced the participants to estimate the effect of headlight glare on their ability to recognize a pedestrian at night. Previous research (e.g., Balk, Brooks, Klein, & Grygier, 2012; Balk & Tyrrell, 2011; Stafford Sewall, Whetsel Borzendowski, & Tyrrell, 2014) has demonstrated the efficacy of this procedure in regard to asking observers to estimate the conspicuity of an object (i.e., pedestrians and optotypes, respectively). Both Balk and Tyrrell (2011) and Stafford Sewall et al. (2014) asked participants to imagine the presence of an object that was not present in order to measure judgments of the effect of glare on visual performance. Participants in both studies were able to successfully estimate their own visual acuity using this task. The present study required participants to complete a very similar task with the key difference being that in the current study the participants were told to imagine the presence of a pedestrian.

In Experiment 2, a new group of participants indicated the point at which they first recognized that an actual pedestrian was present in the presence of headlight glare. In both experiments, the intensity of the headlights of the stationary vehicle was manipulated. It was predicted that drivers would overestimate their ability to see the pedestrian and that headlight glare would have a larger effect on estimates of recognition distance than on actual recognition distances.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty one undergraduate students (11 females, 10 males) 18–25 years of age ($M = 19.14$, $SD = 1.11$) participated. Data from two additional participants were eliminated due to technical difficulties. All participants achieved a visual acuity of at least 6/7.5 (20/25), a contrast sensitivity of at least 1.65, and reported having no known visual pathologies (other than corrected refractive error). Participants averaged 4.13 years of driving experience ($SD = 1.36$). On the average, participants reported that 36.5% ($SD = 14.5\%$) of their driving took place at night.

2.1.2. Design

Two independent variables (Glare Intensity and pedestrian Clothing) were manipulated within-subjects. As Fig. 1 depicts, there were three intensities of the glare vehicle's headlights: Low (parking lights only), Medium (low beams and fog lights filtered by neutral density (ND) filters), and High (unfiltered low beams and fog lights). The ND filters used in the Medium condition reduced the amount of illumination transmitted from the glare vehicle's headlights and fog lights to only 6% (1.2 log unit filters). Participants were asked to imagine the pedestrian wearing one of two clothing configurations: Street clothing (khaki pants, dark blue shirt) or Vest (the same clothing plus a retroreflective vest). The dependent variable was the distance at which participants estimated that they would first recognize that a pedestrian were present.

2.1.3. Procedure

For both experiments, participants' binocular acuity (Bailey–Lovie acuity chart) and contrast sensitivity (Pelli–Robson letter sensitivity) were measured in a laboratory immediately prior to the start of the on-road data collection. No data were collected if any inclement weather (e.g., rain, fog) was present or if the roadways were not completely dry. The test site was an open two-lane roadway with relatively low traffic density. The glare vehicle was a 2008 Infiniti EX35 with xenon low beam headlamps and halogen fog lights. The location of the glare vehicle was selected such that sight distance from the perspective of the approaching test vehicle (a 2005 Saturn Vue with halogen headlamps) was more than 200 m, while illumination from an overhead luminaire was minimized. Participants in both experiments held a response keypad connected to a laptop computer. When the designated response button was pressed, the distance that separated the test vehicle from the glare vehicle/pedestrian location was calculated based on the speed of the test vehicle. The test vehicle approached the glare vehicle at a constant speed of 35 mph.

Prior to their drive, each participant in Experiment 1 studied two photographs (see Fig. 2) of a pedestrian standing next to the glare