

THE ACCURACY OF DRIVERS' JUDGMENTS OF THE EFFECTS OF HEADLIGHT GLARE: ARE WE REALLY BLINDED BY THE LIGHT?

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Summary: Headlights must balance two conflicting goals: maximizing visibility for the driver and minimizing glare to other drivers. Yet consumer complaints about headlights tend to focus on glare and not on poor visibility – a known casual factor of nighttime roadway crashes. These reactions may help to explain why drivers tend to underuse high beam headlights. This study explored the relationships among objective (impaired visual performance) and subjective (reports of discomfort and participants' judgments of glare-induced visual impairments) consequences of headlight glare. Sixteen participants sat in a vehicle that moved slowly on a closed road and estimated the distance at which they could determine the orientation of a retroreflective Landolt C. Actual recognition distances and reports of glare-induced discomfort were also assessed. Observers' overestimated the extent to which glare degraded their ability to see the target. Participants' estimates of their own acuity decreased significantly when the opposing vehicle used high beams despite the fact that their actual acuity was unaffected. Overall, estimates of the disabling effects of glare were more tightly correlated with subjective reports of glare-induced discomfort than with actual visual performance. These results, which are consistent with psychophysical data obtained in a laboratory setting, may help explain drivers' reluctance to use their high beams. The results also underscore the need to collect data on disability glare, not only discomfort glare, when evaluating new lighting technologies.

INTRODUCTION

A disproportionate number of roadway fatalities occur at night (NHTSA, 2010). Analyses of the Fatality Analysis Reporting System (FARS) have revealed that about 79% of all U.S. traffic collisions occur in low illumination conditions (Owens & Sivak, 1996) and that crashes are 3-7 times more likely at night (Sullivan & Flannagan, 2002). These analyses have also revealed that pedestrians are at particular risk during low illumination. Indeed, even the relatively small increase in illumination from a full moon has been associated with a 22% reduction in pedestrian fatalities relative to nights with a new moon (Sivak, Schoettle, & Tsimhoni, 2007). Similarly, drivers respond to the presence of pedestrians at significantly greater distances when they use their high beam headlights rather than their low beams (Wood, Tyrrell, & Carberry, 2005). Yet, on-road studies of beam usage have revealed that drivers continually underuse their high beams. Mefford, Flannagan, and Bogard (2006) asked participants to drive instrumented vehicles for 7-21 days. Even when in conditions ideal for high beam usage (dark rural road, no lead vehicle, and no oncoming traffic), drivers relied on low beams 75% of the time. This finding is supported by several on-road observational studies in which only 10-50% of drivers used their high beams

when no opposing or lead vehicles were present (Hare & Hemion, 1968; Sullivan, Adachi, Mefford, & Flannagan, 2004).

Why do drivers underuse their high beams? One possibility is that they appreciate neither the need to improve their forward visibility nor the benefits that high beams provide. Drivers continually receive visual feedback about their ability to maintain lane position, yet only rarely receive feedback that there are objects in the roadway that they fail to see. That is to say, under low light levels, we are able to navigate our environment successfully even while failing to recognize the presence of low contrast objects in our path (Owens & Tyrrell, 1999). Thus a driver who constantly receives feedback that he or she is steering well and maintaining proper lane position may inappropriately assume that illumination from the low beam headlights is sufficient to allow him or her to see well enough to avoid collision with potential hazards.

Another factor that may help explain drivers' reluctance to use their high beams is the desire to minimize glare problems for oncoming drivers. Since the introduction of HID headlamps, complaints of headlight glare have increased. In 2001, NHTSA opened a public docket (NHTSA-01-8885) requesting comments regarding "Glare from Headlamps, Federal Motor Vehicle Safety Standard No. 108; Lamps, Reflective Devices, and Associated Equipment." The comments (typically complaints) readily reveal drivers' dislike of headlights that are "too bright," "painful," or "blinding." Drivers may assume that because they feel discomfort when facing the high beams of other drivers, they must also be visually disabled by the light. Drivers may be reluctant to use their high beams in an effort to minimize the possibility of being responsible for other road users experiencing painful (and potentially impairing) glare.

Indeed, consumer complaints have, in part, recently triggered considerable research on reducing nighttime headlight glare (e.g., NHTSA, 2007). Yet it is unclear whether drivers can accurately judge when they are visually disabled by glare, and reports of discomfort glare have been shown not to be predictive of driving performance (Theeuwes, Alferdinck, & Perel, 2002). Thus drivers who are acutely aware of their own glare-induced discomfort may be incorrect in their assumption that the opposing headlights disrupt their ability to see objects ahead. For example, Flannagan, Sivak, Traube, and Kojima (2000) found that both seeing distances and reports of discomfort were greater when participants faced high beam glare (when using their own high beams) than when they faced low beams (while using their own low beams).

The relationship between discomfort glare (a subjective experience) and disability glare (an objectively measured decrease in visual performance) is complex, variable, and not well understood. As a result, subjective complaints of excessive glare must not be taken as sufficient evidence that headlamp glare is necessarily debilitating. After all, one rarely hears of drivers complaining about their headlamps being too dim despite the fact that nighttime visibility problems are well documented. It would be valuable then, to achieve a better understanding of the subjective and objective effects of headlight glare and, in particular, the extent to which drivers' subjective feelings of discomfort relate to visual performance. Further, a better understanding of how drivers' *think* their own (and other drivers') vision is affected by glare might provide valuable insight about drivers' underuse of high beams. The present study is the second of a series of experiments investigating these topics. The first, a lab-based psychophysical study, asked participants who faced a nearby glare source to estimate their visual

acuity (Balk, 2010). As the intensity of the glare source (and ratings of discomfort) increased, participants predicted that their acuity would significantly worsen even though the glare was not sufficiently intense to reduce actual measures of acuity. These results suggest that the experience of discomfort glare is salient and can lead us to exaggerate the effect of glare on our ability to see. To determine whether this effect also exists in a context that is more similar to night driving, the present study (unlike other glare studies, e.g., Theeuwes, 2002) asked participants in a vehicle to *predict* their own visual abilities in a variety of headlight conditions. It was anticipated that headlight glare would have a greater effect on observers' estimates of visual abilities rather than on direct measures of visual performance.

METHOD

Sixteen college students participated ($M = 20$ years; 18 – 33 years). Each achieved a visual acuity of at least 6/12 (20/40), and had a valid driver's license. Each experimental session took place at least 1 hour after sunset, on nights free of precipitation and fog, on a closed utility road that was free of lane markings and overhead lighting. Participants sat in the front passenger seat of a 2005 Scion xB (the participant vehicle) and were driven toward and away from a stationary 2008 Infiniti EX35 (the glare vehicle). An initial drive toward the glare vehicle was made to provide participants with a baseline marker from which future estimates of visual abilities could be based (glare vehicle: no lights, participant vehicle: low beams). Participants were simply asked to indicate to the driver when they were just able to determine the orientation of a retroreflective Landolt C (16 mm stroke width and gap width), located 1.52 m (5 ft) to the right of the glare vehicle's front tire and 1.17 m (3.83 ft) to the left of the right edge of the roadway (see Figure 1). Once the given orientation of the C was confirmed to be correct, the location was marked with orange traffic cones on either side of the roadway. The participant vehicle was always driven slowly, with an idling engine.



Figure 1. Position of the Landolt C stimulus in relation to the glare vehicle
(both the glare vehicle and the participant vehicle are using high beams; the camera flash was not used)

Next, the Landolt C was hidden under black cloth. Participants were asked to imagine that the C was still present as the participant vehicle was moved and to estimate the point at which they thought they would just be able to determine the orientation of the C if it were present. This was done twice (once driving toward and once driving away) for each headlight combination (Low vs. Low; Low vs. High; High vs. Low; High vs. High). (On the reversing trials participants were asked to judge when they would no longer be able to determine the orientation of the C.) After all estimates were made, the Landolt C was uncovered and the distance at which participants

were able to correctly determine (forward trials) and no longer determine (reverse trials) the stimulus orientation was measured. At each of the estimated and actual recognition distances, participants were also asked to rate their subjective visual discomfort. This was done using the deBoer scale (deBoer, 1967), which involves participants choosing a number from 9 to 1 to describe the magnitude of their glare-induced discomfort, with text labels at 9 (unnoticeable), 7 (satisfactory), 5 (just admissible), 3 (disturbing), and 1 (unbearable).

RESULTS

Estimated and actual measures of recognition distance were defined as the mean of the appropriate forward-moving and backward-moving trials. Participants estimated that recognition distances would be significantly (32%) shorter when the glare vehicle used its high beams (25.1 m; 82.5 ft; see Figure 2) than when it used its low beams (37.1 m; 121.7 ft), $F(1, 15) = 47.91, p < .001, \eta_p^2 = .76$. Participants estimated significantly longer (8%) recognition distances when the participant vehicle used high beams (32.3 m; 105.9 ft) than when it used low beams (29.9 m; 98.2 ft), $F(1, 15) = 13.42, p = .002, \eta_p^2 = .47$.

However, neither glare vehicle headlights ($F(1, 15) = .35, p > .05$) nor participant vehicle headlights ($F(1, 15) = .42, p > .05$) affected actual recognition distances (see Figure 2). That is, the distance at which participants were just able to correctly determine the orientation of the Landolt C was not affected by the manipulation of the headlight beams. Averaged across the beam manipulations, actual recognition distances (37.7 m; 123.6 ft) were significantly longer than estimated distances (31.1 m; 102.1 ft), $F(1, 15) = 8.63, p = .01, \eta_p^2 = .37$.

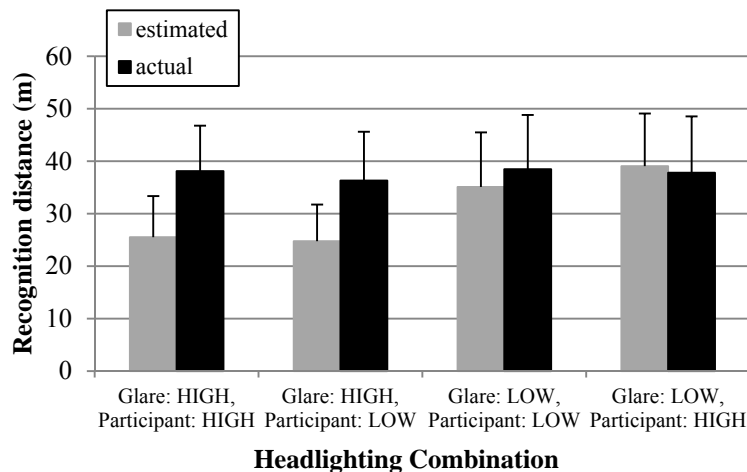


Figure 2. Estimated and actual Landolt C recognition distances (plus 1 standard error of the mean) at each of the four headlight combinations

In order to more closely examine participants' ability to accurately estimate the distance at which the orientation of the Landolt C could be determined, difference (error) scores were created. An analysis of these error scores revealed that the setting of glare vehicle headlights significantly affected the accuracy of participants' estimates of recognition distance, $F(1, 15) = 61.47, p < .001, \eta_p^2 = .80$. Participants underestimated recognition distances both when the glare vehicle used high beams (mean underestimate 12.1 m; 39.6 ft) and when it used low beams (mean

underestimate 1.1 m; 3.5 ft). However, participant vehicle headlights did not significantly affect the accuracy of participants' estimates, $F(1, 15) = 3.22, p > .05$. There was also no significant interaction between glare vehicle and participant vehicle headlights, $F(1, 15) = 3.23, p > .05$.

Participants' ratings of discomfort glare (deBoer ratings) were influenced by the beam setting of the glare vehicle, $F(1, 15) = 95.73, p < .001, \eta_p^2 = .87$, but were not influenced by the setting of the participant vehicle headlights, $F(1, 15) = 1.38, p > .05$ (see Table 1 for means). Further there was not a significant interaction between glare vehicle headlights and participant vehicle headlights, $F(1, 15) = .006, p > .05$. In other words, participant ratings of discomfort were influenced by the glare vehicle's headlights but not by the participant vehicle's headlights.

Table 1. Mean deBoer ratings of discomfort given at estimated and actual recognition distances (numerical and verbal equivalent) based on headlight combination

| | Glare: HIGH, Participant: HIGH | Glare: HIGH, Participant: LOW | Glare: LOW, Participant: HIGH | Glare: LOW, Participant: LOW |
|---------------|---|---|---|---|
| Mean rating | 3.72 | 3.83 | 7.34 | 7.44 |
| Verbal rating | Slightly less discomforting than "Disturbing" | Slightly less discomforting than "Disturbing" | Slightly less discomforting than "Satisfactory" | Slightly less discomforting than "Satisfactory" |

The relationship between mean deBoer ratings and the mean errors with which participants estimated their recognition distances was also examined, yielding an $R^2 = .96, p < .05$ ($y = 2.70x - 21.28$; see Figure 3). This confirms that as participant underestimations of recognition distance increased, subjective feelings of discomfort also increased. Further, participants' reports of glare-induced discomfort were significantly correlated with estimates of visual abilities ($R^2 = .94$), but not actual abilities ($R^2 = .28$).

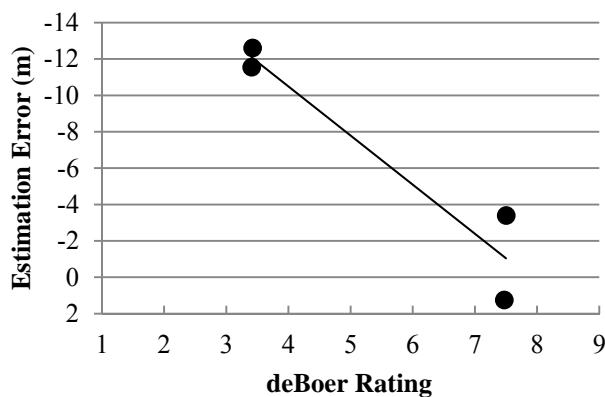


Figure 3. The relationship between subjective ratings of glare-induced discomfort and the participants' mean error in estimating the distance at which they could just recognize the Landolt C stimulus (Smaller values on the deBoer scale indicate greater ratings of discomfort, and negative estimation error values represent underestimates)

DISCUSSION

To achieve a better understanding of the extent to which drivers believe their vision is affected by the headlights of an opposing vehicle, this study assessed the accuracy of drivers' estimates of

their ability to see a high contrast stimulus (a retroreflective Landolt C) on a road at night. The actual distances at which participants were able to determine the orientation of the stimulus were not affected by the beam setting of either the glare vehicle or the participant vehicle. This is not surprising considering that the stimulus was of high contrast. However, participants judged that their ability to see the stimulus would be degraded substantially when the glare vehicle used high beams. In fact, when the glare vehicle used high beam headlights, participants on average underestimated their visual abilities by 32% or 33% depending on whether the participant vehicle was on low or high beam. These errors were on average smaller when the glare vehicle used low beams (an underestimate of 9% when the passenger vehicle used low beams and an overestimate of 3% when the passenger used high beams). Thus, it appears that when drivers are faced with the glare of an oncoming vehicle using high beams, they tend to exaggerate the extent to which the glare degrades their ability to see small high contrast stimuli. Consistent with this is the significant correlation between the estimation errors and participants' reports of glare-induced discomfort ($R^2 = .96$), indicating that participants tended to underestimate their visual performance more when they experienced greater discomfort.

The present results support the hypothesis that drivers can exaggerate the disabling effects of headlight glare. The results are consistent with our earlier psychophysical experiment in which observers in a laboratory overestimated the extent to which their visual acuity would be degraded by glare (Balk, 2010). Taken together, it appears that when the luminance of a light source is high enough to induce discomfort, observers judge that their visual performance is degraded even when it is not. This appears to be true both in the laboratory and on the road at least for high contrast stimuli (similar tests using lower contrast and differently sized stimuli are underway). It should also be noted that only younger adults with healthy vision participated in this study. It is obvious that the visual capabilities of older adults often vary significantly from younger adults (e.g., cataracts, glaucoma, macular degeneration, etc.). As such, while it is expected that older adults will also exaggerate the negative effects of headlight glare, it is also important to remember that it is feasible that an actual visual decrement will be experienced.

These results underscore the fact that complaints of glare-induced discomfort should not be taken as sufficient evidence to conclude that drivers' vision is degraded. When evaluating new lighting technologies, visual performance should be measured and evaluated in addition to measuring subjective discomfort. Further, reports of consumer complaints that a new headlight technology is too "blinding" must be weighed against direct measures of the effects, positive or negative, of the technology on visual performance. It is possible, for example, for a new headlight technology to increase both visual performance and reports of discomfort. This is not to say that annoyances incurred while driving cannot be dangerous. However, it is of critical importance to avoid unnecessarily reducing the amount of light on drivers' forward view of the roadway. This is especially relevant because while linkages between low illumination and crashes have been well documented (particularly with regard to crashes involving pedestrians), strong evidence linking nighttime glare to fatal crashes has yet to be established (Hemion, 1969; NHTSA, 2007). We hope that a better understanding of drivers' subjective and objective responses to headlighting technologies can be leveraged into a measurable increase in roadway safety (both in terms of headlighting design and educational measures).

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