12-2012

Observers' Judgments of the Effects of Glare on Visual Acuity

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OBSERVERS' JUDGMENTS OF THE EFFECTS OF GLARE ON VISUAL ACUITY

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Applied Psychology

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by
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December 2012

Accepted by:
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ABSTRACT

Traffic collisions and pedestrian fatalities increase significantly when driving at night. There is a need for greater roadway visibility when driving at night and the use of high beam headlights can significantly improve the distance at which drivers recognize objects along the roadway. However, research suggests that drivers underuse their high beams. It is possible that drivers do not use their high beam headlights in an effort to minimize glare to oncoming vehicles. The purposes of this experiment were to extend earlier research indicating that the visually impairing effects of glare may often be exaggerated and to investigate the role of stimulus contrast and size in observers' judgments of the effects of glare. Participants were asked to judge the luminance of a glare source sufficient to impair their visual acuity of a target viewed through this glare source; these estimated glare thresholds were compared to the participant's actual glare thresholds. Participants overestimated the intensity of glare required to produce a decline in their visual performance. On average, estimates of glare threshold were 88% lower than actual glare threshold values. Participants took stimulus size into account when making their estimates of glare threshold but did not seem to consider stimulus contrast information when making these judgments. The results of the current study confirm the trend seen in earlier work indicating that drivers exaggerate the debilitating effects of glare and are not fully aware of the actual effect of glare on their visual performance.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Rick Tyrrell, for his help, his patience, and his support throughout this process. I would also like to thank my committee members, Drs. Ben Stephens and Patrick Rosopa for their time and scientific contributions to this experiment. Finally, I would like to thank my lab mate Steph Whetsel for her endless support and creative ideas and our research assistants Rebekah Dixon and Alex Cates. Thank you all so much for everything.

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INTRODUCTION

Vehicle headlights must maximize the visibility afforded to drivers while minimizing glare for oncoming vehicles. The topic of headlight glare has become particularly controversial since the emergence of HID (High Intensity Discharge) headlights with numerous consumer complaints concerning glare. It is important to balance these seemingly competitive goals of maximizing visibility for drivers while minimizing any negative effects experienced by oncoming drivers. The goal of the current study is to examine the actual impact of glare on visual performance and observers' judgments of the impact of glare on their visual performance.

Traffic collisions and pedestrian fatalities increase significantly when driving at night. Approximately half of all fatalities from crashes occur at night despite fewer drivers and pedestrians being on the road (Opiela, Andersen, & Schertz, 2007). Seventy nine percent of US traffic collisions occur under conditions of low illumination, and even when controlling for factors such as fatigue or alcohol consumption, decreased light levels are still a prevailing cause of a majority of nighttime traffic crashes (Owens & Sivak, 1996; Sullivan & Flannagan, 2002). Additionally, there are three to four times more crashes that result in pedestrian fatalities at night than during the day (Plainis & Murray, 2002).

As illumination decreases, the fine detail that can be detected decreases. To an observer in conditions of low illumination, object colors appear to fade, shadows seem to disappear, and object detail is more difficult to detect (Perel, Olson, Sivak, & Medlin, 1983). A re-analysis of data collected over seven years by the Road Accident Great

Britain publications revealed that there were three times more severe crashes on unlit motorways than well- lit motorways (Planis & Murray, 2002). Luminance and visual performance are inextricably linked, and our ability to perceive critical detail cannot occur when luminance values have dropped to scotopic conditions.

The visibility of an object at night is largely influenced by the brightness contrast and the luminance of that object. Contrast is determined by the luminance difference between an object and its background. The visibility of an object in the visual field can be compromised if the luminance difference between the foreground and the background (contrast) is reduced to threshold levels. At this point, the object is no longer perceivable to the observer. In other words, reduced luminance decreases contrast which inhibits object discrimination and visibility.

Despite evidence that decreased light levels are a contributing factor in nighttime crashes and fatalities, the average driver and pedestrian may be largely unaware of visual challenges at night. Research has shown that typical drivers are overconfident in their nighttime driving abilities and unaware of their visual deficits that are triggered by low illumination (Olson & Sivak, 1983; Owens & Sivak, 1996; Owens & Tyrrell, 1999; Wood, Tyrrell, & Carberry, 2005). Driver overconfidence was first made relevant by the selective degradation theory of vision proposed by Hershel Leibowitz and his colleagues (e.g., Leibowitz & Owens, 1977). The selective degradation theory is predicated on the existence of two visual systems, one responsible for visual recognition and one responsible for guidance through the environment. As light levels drop, the visual recognition system, typically assessed by high contrast acuity, becomes progressively degraded. In contrast, the visual guidance system, typically assessed by locomotor tasks, is more robust to drops in illumination. Empirical tests by Owens and Tyrrell (1999) and by Brooks et al. (2005) provided empirical support for this hypothesis by showing that steering performance (a visual guidance task) was unimpaired by reduced luminance even though acuity (a visual recognition task) was degraded under challenging visual conditions. An individual's ability to resolve small objects (discrimination of fine detail) is significantly impaired when driving at night, even while the ability of the person to maintain lane position is relatively uncompromised. Further complicating the night driving situation is the fact that the driver receives consistent feedback that he or she is capable of maintaining lane position and therefore may assume erroneously that he or she is unimpaired while driving at night. Deficiencies of the visual recognition system may go largely unnoticed by a driver.

The visual problems faced during night driving can be improved. Increasing the ambient lighting of the roadway can serve to increase visibility distance when driving at night (IESNA, 2000), but is expensive and may not always be a feasible option. Additionally, the visibility distance of pedestrians can be increased by the use of retroreflective markings or light colored clothing. In a 2005 study, by Wood, Tyrrell, & Carberry, on quantifying drivers' ability to detect pedestrians at night, drivers improved from detecting only 5% of pedestrians (when the pedestrian wore black clothing, the driver used low beams, and there was glare from an oncoming vehicle) to 100% of pedestrians (when pedestrian wore retroreflective clothing positioned on major joints, the vehicle used high beams, and there was no glare). Despite the advantages of retroreflective material, pedestrians do not always fully understand their own visibility and therefore may under-utilize options to increase conspicuity. In one study, when asked to estimate the distance at which he or she would be visible to an oncoming vehicle, pedestrians overestimated their visibility distance (Shinar, 1984). In a similar study conducted by Allen, Hazlett, Tacker, & Graham (1970), a majority of pedestrians estimated their visibility to be up to three times farther than their actual visibility distance. Tyrrell, Patton, and Brooks (2004) found that pedestrians' overestimations of their own visibility were greatest in conditions that minimized visibility (e.g., low beams and black clothing).

Another effective technique for increasing visibility at night is the use of high beam headlights. High beam headlights provide additional illumination in the area in front of the vehicle, on road signs, and on other vehicles (NHTSA, 2007). Increased visibility may serve to reduce collisions while driving at night. In fact, the simple use of high beams while driving at night can substantially increase the distance at which drivers recognize pedestrians (e.g., Wood, Tyrrell, & Carberry, 2005)

In contrast, the use of low beams headlights alone is simply not enough. Low beams headlights are designed to avoid distributing light directly ahead of the vehicle in an effort to maintain the balance between increasing visibility for drivers and reducing glare to oncoming vehicles (Flannagan, Sivak, Traube, & Kojima, 2000). However, low beam headlight use alone is not enough for travel speeds of greater than 20 mph though speeds driven at night are equal to or higher than those driven during the day (Owens & Tyrrell, 1999). This tendency to drive at speeds unsuitable to night visibility is known as “overdriving one’s headlights” (Johansson & Rumar, 1968; Olson & Sivak, 1983; Owens, Francis, & Leibowitz, 1989). In conditions of reduced luminance while driving at normal speeds, the stopping distance necessary to avoid a collision with an object is significantly longer than the visibility distance of that object (Olson & Sivak, 1983; Plainis & Murray, 2002; Shinar, 1984). In an experimental study by Olson and Sivak (1983), subjects were driven along a straight road and were asked to press a button when they identified pedestrians positioned along the roadway. The stopping distance to each of these pedestrians was also calculated for a vehicle moving at a speed of 55 mph. The results indicate that for 45% of trials involving young drivers, the visibility distance of the pedestrian was less than the stopping distance required for a vehicle driving at the specified speed (Olson & Sivak, 1983).

Despite the inadequacy of low beams, drivers under-utilize their high beams even in conditions that are ideal for high beam use: dark rural roads, no lead vehicle, and no oncoming traffic (Mefford, Flannagan, & Bogard, 2006). In Mefford et al., participants driving instrumented vehicles for 7-27 days relied on the vehicle’s low beams 75 % of the time that high beams could have been safely used (rural roads with no opposing or oncoming vehicles). The drivers used high beams headlights during only 3.1% of the distance driven at night. This tendency to underuse high beams has been seen in other on-road observational studies that reported that only 10-50 % of drivers use their high beams even when there are no opposing or lead vehicles present (Hare & Hemion, 1968; Sullivan, Adachi, Mefford, & Flannagan, 2004). Sullivan et al reported that for a total of 1740 vehicles observed on a rural, two lane, unilluminated, straight roadway, high beams were used only 49% of the time that it would have been acceptable to use high beams. Hare and Hemion found an inverse relationship between high beam usage and traffic density (Hare & Hemion, 1968). Interestingly though, drivers in this study dimmed their high beams at a distance insufficient for object detection and at a point prior to when oncoming drivers may have been disabled by headlight glare (Hare & Hemion, 1968). Little research has addressed the reasons why drivers underuse their high beams. It may be due to a limited or inaccurate understanding of their visual impairment at night. There is extensive evidence that drivers do in fact have a limited understanding of their own visual deficits in conditions of low illumination (Olson & Sivak, 1983; Plainis & Murray, 2002; Shinar, 1984). Additionally, drivers may not utilize their high beams out of a desire to avoid “blinding” oncoming traffic.

Disability glare can result from headlights via two mechanisms. Intraocular light scattering can reduce the contrast of the retinal image and can inhibit the ability of the observer to distinguish objects from the background (NHTSA, 2007). In the case of headlight glare, the reduction in retinal contrast results in a decrease in contrast sensitivity that is particularly strong in the area nearest the oncoming headlight. This reduction in contrast sensitivity may impede the detection of pedestrians or other potentially hazardous roadway objects (Leibowitz, Tyrrell, Andre, Groetzinger-Eggers, & Nicholson, 1993). Additionally, photobleaching, the process by which rhodopsin (retinal pigment important to visual perception under low illumination) is depleted, further inhibits the observer’s visual abilities in low light conditions. These problems can continue for up to 30 minutes after exposure to the glare source.

There are two distinct ways to measure the impact of a glare source: disability glare and discomfort glare. Disability glare is encountered when the intensity of the glare source is sufficient to reduce the observer's visual performance. Measuring disability glare requires careful measurements of visual performance both with the glare source present and absent. Discomfort glare is the subjective experience of annoyance or pain produced by the glare source (AAA, 2001; NHTSA, 2007). Disability glare can have direct effects on visual performance and on driving behavior. Discomfort glare, on the other hand, may trigger indirect effects on driving performance if, for example, the driver looks away from the road while driving at night (Leibowitz et al., 1993; Theeuwes, Alferdinck, & Perel, 2002).

Further complicating the issue of glare, drivers may be more aware of how glare makes them feel than how glare impacts their vision (Leibowitz et al., 1993). Discomfort glare is, by definition, highly subjective. For example, in a NHTSA report on driver's perception of glare, it was found that of those surveyed, headlight glare was rated differently by participants of different genders and of different age groups (NHTSA, 2003b). On average, females found glare from oncoming vehicles to be more disturbing than males and those in the 55-64 age range rated oncoming glare to be more disturbing than other age groups (NHTSA, 2003b).

With the visual challenges encountered at night, there is a need for greater illumination of roadways without increasing the risk of disabling oncoming drivers. Low beam headlights facilitate forward visibility while limiting light in areas that would impair the driving performance of oncoming vehicles. Yet, as stated previously, low beam headlights alone are not sufficient for travel above 20 mph and high beam headlights are under used. Drivers' comments about headlights though tend to emphasize the negative effects of headlights. NHTSA opened a public docket on the subject of headlight glare in 2000 that received over 5,000 comments from the public that highlighted the negative effects of headlight glare (NHTSA, 2007). Since then, NHTSA has conducted research on many aspects of the glare problem including, real world headlamp usage, headlight aim, glare recovery, glare risks to drivers, headlamp mounting height, the effects of headlamp color, and the effects of glare on older drivers to name a few (NHTSA, 2008).

The increased use of HID headlights has created controversy about the effects of glare but may also significantly increase drivers' ability to see objects on the roadway at night. As compared to halogen headlights, HID headlights can provide greater roadway illumination in a wider pattern for more efficient detection of pedestrians and other objects along the roadway (Sivak, Flannagan, Schoettle, & Adachi, 2003). Yet as previously stated, the benefits of these headlamps and even normal high beam headlights are often overshadowed by consumer complaints about their "blinding" effects. Greater roadway illumination can benefit visibility when driving at night, but in light of the perceived negative effects of headlight glare, more research is needed to investigate the actual and perceived effects of glare on visual performance when driving at night.

If drivers misunderstand glare's effect on vision, then reports of discomfort in the presence of glare may not always match losses in acuity due to glare. Previous research conducted in this lab examined the relationship between observers' estimates of their own acuity in the presence of glare and their actual acuity in the presence of glare and how these measurements related to reports of discomfort (Balk & Tyrrell, 2011a). In this study, participants estimated their own visual acuity at several pre-set glare intensities. The participants looked through a center ring of light (with variable intensity) toward a stimulus that was twenty feet away. Using both manual and verbal techniques, the participants estimated their acuity at each glare intensity. Actual acuity was then measured at these same intensities. Balk found that under their test conditions actual acuity was not affected by glare even though participants estimated that their acuity was affected by the glare intensity. In other words, the participants incorrectly judged that their acuity would be affected by the glare. Additionally, deBoer ratings (a common scale for assessing discomfort glare; deBoer, 1967) were strongly correlated with estimated acuity values but not with actual acuity values. In this case, participants' feelings of discomfort worsened as the glare from the light source became more intense. The results of this lab experiment were later extended in a closed-road experiment conducted by Balk (Balk & Tyrrell, 2011b) in which participants were driven toward a visual stimulus (Landolt C) positioned adjacent to the headlights of an oncoming vehicle. Participants were asked to indicate the point at which they believed that they would be able to determine the orientation of the stimulus, and between trials the beam pattern (low or high) was manipulated in both the glare vehicle and their own vehicle. The point at which participants were actually able to determine the orientation of the stimulus was also measured. The results of this experiment mimicked the results from the lab experiment conducted by Balk and Tyrrell (2011a), in that participants estimated that their acuity suffered due the glare even though a glare effect was not actually present. Additionally, participants' exaggeration of the effect of glare on their ability to see increased when the glare vehicle used high beams as opposed to low beams. Finally, participants' deBoer values were correlated with their estimates of recognition distance of the stimulus but not with the actual recognition distance of the stimulus.

The stimuli used in the Balk experiments were of maximal contrast. In the Balk and Tyrrell (2011a) lab experiment, black objects on a white background were viewed by the participant. In the closed-road experiment a retroreflective stimulus was used against a black background. However, drivers may have a limited understanding of the highly reflective nature of retroreflective material. Additionally, the artificially high level of contrast may be more resistant to the visually impairing effects of glare (Leibowitz et al., 1993). In the case of this material, the glare source still causes intraocular light scatter, but due to a "surplus" of stimulus contrast, the object may still recognizable in the presence of glare that would mask a lower contrast stimulus.

In response to these concerns about the perceived and actual behavior of retroreflective material in the presence of glare, Stafford, Whetsel, Balk, Ballou, and Tyrrell (2011) recently replicated Balk's closed-road experiment with the use of a non-retroreflective stimulus. This follow-up study used the same methods as Balk and Tyrrell (2011b) to measure estimated and actual acuity but used a non-retroreflective stimulus constructed from white paper instead of a retroreflective material. In addition, the stimulus was larger (in order to compensate for its lower contrast). In this experiment, participants were, on average, accurate in estimating the effects of glare on their ability to see the non-retroreflective stimulus. Specifically, participants correctly indicated that recognition distance of the stimulus would decrease in the presence of increasing glare and that recognition distances would increase when their own vehicle used high beams headlights. Participants were more accurate in judging the actual visibility of the non-retroreflective stimulus though they exaggerated the disabling effects of glare on the visibility of the retroreflective stimulus employed by the Balk study. It thus appears that the contrast of the stimulus to be seen by the observer is an important factor in visibility judgments in the presence of glare in addition to the actual visibility of a stimulus. Drivers may only partially understand the effects of glare, exaggerating the disabling effects of glare on visibility in some situations. In the current study both high and low contrast stimuli will be used to assess the perceived and actual impact of glare on visual acuity.

The purpose of the current study is to advance our understanding of observers' reactions to glare. Unlike both of the Balk and Tyrrell studies (2011) and the Stafford et al. (2011), who manipulated glare and measured participants' estimates of acuity, this study measured estimates of glare and manipulated visual acuity. Specifically, we asked participants to judge the intensity of glare that would be required to impair their visual acuity. The point at which the intensity of glare sufficiently reduces visual acuity has been termed, in this study, glare threshold. Estimated glare threshold then is defined as the glare intensity at which participants *judge* visual acuity to be impaired while actual glare threshold is the actual glare intensity at which the participant's acuity is degraded. To further explore the impact of contrast on perceptions of glare, estimated and actual glare threshold was measured for both high contrast and low contrast stimuli. The observers' discomfort glare was also measured.

METHOD

Participants

Seventeen undergraduate students (5 males and 12 females) participated in this experiment. These participants had been licensed drivers for an average of 3.8 years (SD = 1.3) and on average reported that 43% (SD = 14) of their driving time was spent driving at night. Additionally, when given the choices rarely, "occasionally", "often", and "at every encounter", on average, these participants reported finding the headlights of oncoming vehicles to be "occasionally" troublesome. Visual acuity under normal room lighting, measured using a Bailey-Lovie chart, was tested prior to experiment participation. Each participant was required to achieve a 20/20 or better corrected monocular (right eye only) visual acuity and have no known visual pathologies. Additionally, participants' contrast sensitivity was tested as measured at a distance of 3 meters (9.8 ft.) using a Pelli-Robson Contrast Sensitivity Test (Pelli, Robson & Wilkins, 1988). After initial visual screening, participants were seated six meters (20 feet) from a computer screen at a table with a chin rest to stabilize head position. The testing room was then darkened, and participants remained seated in this position throughout data collection.

Procedure

Glare was produced by a custom-built "glare box" (323 mm high, 325 mm wide, and 42 mm deep; the same glare source that was used by Balk and Tyrell, 2011a) that was positioned 1200 mm (120 cm) from the eye of the participant, between the participant and the computer screen (Figure 1). Participants were asked to look through the center of the aperture (72 mm in diameter) of the glare box which was aligned with the center of the computer screen. This aperture is surrounded by an illuminated white annulus (11 mm in width; 0.53°) and light was reflected through the glare ring toward the participant (Figure 2). Light was generated by six 100-watt tungsten halogen bulbs in the glare box. Light intensity was controlled by a variac that adjusted the voltage supplied to the bulbs as a percentage of the maximum output of the bulbs (100%) (Figure 3). The entire glare box is painted with heat resistant matte black paint with the exception of the light ring which is white in color.

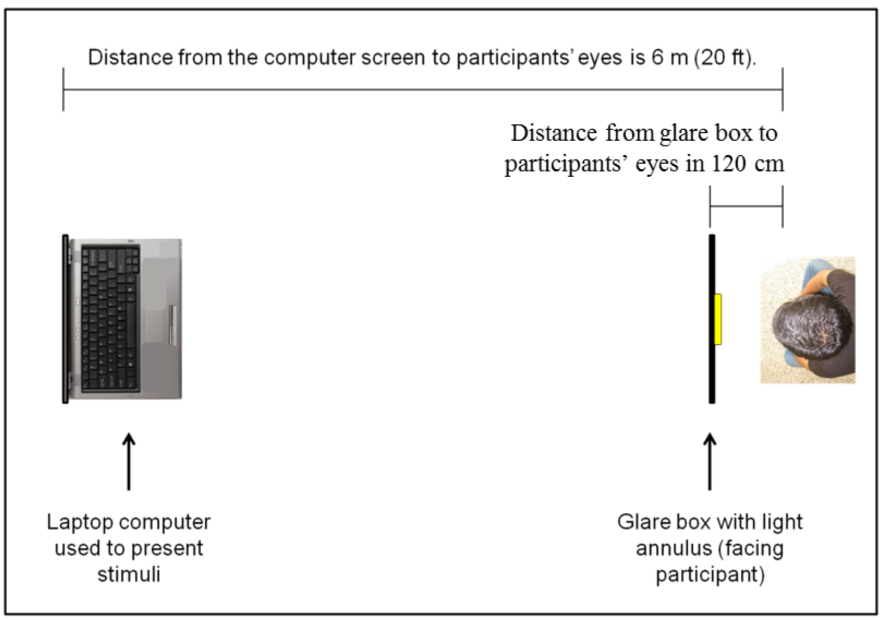

Figure 1. Aerial view of experiment set-up

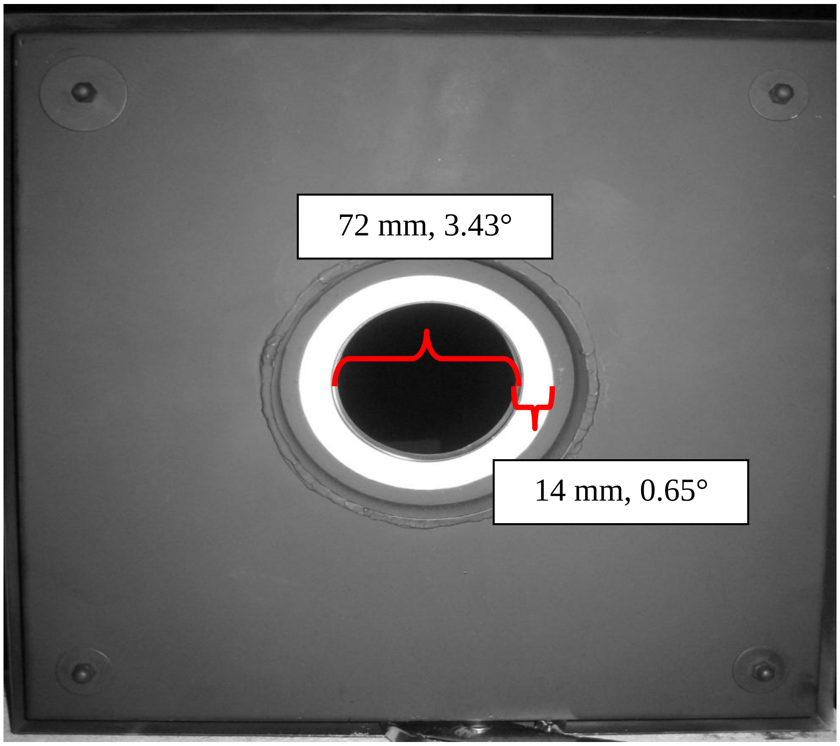

Figure 2. Glare Box

Figure 3. Variac used to manipulate glare intensity

Luminance and illuminance values of the glare source at the eye of the observer were measured before and after data collection. Luminance values were measured at 4 cardinal directions around the glare ring and were averaged for each variac setting (Figure 4). Additionally, illuminance values are presented below (Figure 5). There was a decrease in illuminance and luminance from the pre-experiment to post-experiment measurement. An average of these pre and post values is also presented in the figures below.

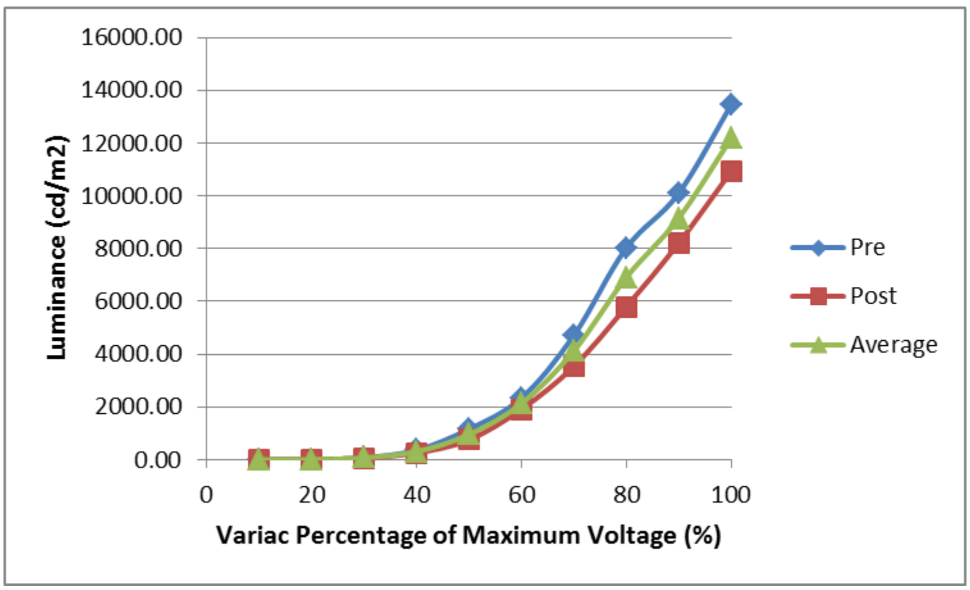

Figure 4. Pre and post experiment luminance (cd/m^2) values of the Glare Box

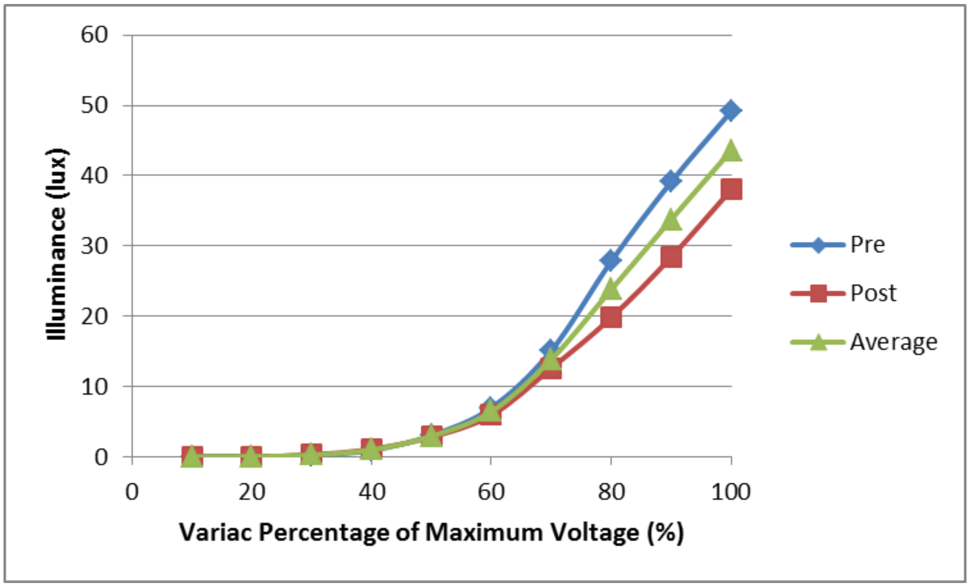

Figure 5. Pre and post experiment illuminance (lux) of the Glare Box measured at the participant's eye

The participant's left eye was occluded by an eye patch during data collection to prevent problems associated with retinal disparity. Monocular vision was used throughout the experiment. Additionally, participants were asked not to squint during data collection.

Five Landolt Cs of different sizes were the visual stimuli (see Table 1). The stroke width of each stimulus is one-fifth its diameter and is equal to its gap width. Each participant viewed all Landolt C stimuli in an individually randomized order. Pilot testing was used to determine the C sizes that were used in this experiment. These specific stimuli sizes were chosen as sizes in which acuity would most likely be impacted by glare.

Table 1. Landolt C sizes and corresponding visual angle and visual acuity measured in logarithm of the minimum angle of resolution (logMAR)

Landolt C	Height (mm)	Gap Width (mm)	Visual Angle (arcmin)	Visual Acuity (logMAR)	Snellen Acuity (meters)
C1	30	6	3.4	0.53	6/21
C2	25	5	2.8	0.45	6/17
C3	20	4	2.3	0.35	6/14
C4	15	3	1.7	0.23	6/10
C5	10	2	1.1	0.05	6/7

The contrast of the Landolt C and the stimulus background also significantly impacts the degree to which glare affects visual acuity. As mentioned above, glare decreases contrast sensitivity at the retina. As stimulus contrast is decreased, glare should have a greater impact on acuity. In this experiment, stimulus contrast was also manipulated to examine the effect of contrast on perceived glare threshold and actual glare threshold. Two contrast levels were chosen to examine the effect of estimated and actual glare threshold on acuity. Each C was displayed centered on an otherwise empty laptop screen. The high contrast stimuli had a background luminance of 0.57 cd/m^2 (R=0, G=0, B=0) with a foreground (the Landolt C) luminance of 23.06 cd/m^2 (R=186, G=186, B=186). The low contrast stimuli had a background luminance of 0.57 cd/m^2 (R=0, G=0, B=0) and a foreground (the Landolt C) luminance of 0.95 cd/m^2 (R=96, G=96, B=96). Background luminance was held constant across contrast condition and only the foreground luminance was manipulated. With both the high contrast and low contrast stimulus, the background is darker than the foreground (the Landolt C). This presentation of a lighter stimulus on a darker background is the reverse of standard acuity charts.

However, in the night driving situation, the headlights from a driver's vehicle illuminate the roadway closer to the vehicle to a greater extent than the roadway further away from the source of the light. Due to this, pedestrians and other roadway objects are viewed by the driver as lighter objects against a darker background because they are more illuminated by the vehicles headlights. The lighter foreground and darker background used in the current experiment may be a closer representation of the night driving situation than the standard acuity chart. Additionally, the decision to change only the luminance of the foreground (Landolt C) and not the luminance of the background is more representative of the stimulus change made from the Balk and Tyrrell experiment to the Stafford et al., experiment. In these experiments, the background (outdoor at night) was not manipulated from the Balk and Tyrrell to the Stafford et al., though the stimulus luminance (and therefore contrast) was changed from one experiment to the next. Michelson contrast was calculated for both high and low contrast stimuli. The contrast value of the low contrast stimulus is 25% and of the high contrast stimulus is 95%. For reference, the Michelson contrast level of the Bailey-Lovie low contrast acuity chart is 10%.

The Modified Binary Search (MOBS) method is a psychophysical technique for assessing sensory thresholds; it was used to measure glare thresholds (Tyrrell & Owens, 1988). The MOBS procedure begins by testing the midpoint of the range of possible glare intensities. In the case of the current experiment, the range of possible glare threshold values was 0-100% of the voltage from the glare source as controlled by the variac. The participant viewed a visual stimulus (Landolt C with a specified glare intensity) and then responded to this stimulus. A “yes” response was given if the participant thought they would be able to determine the orientation of the stimulus (estimates) or provided the correct orientation of the Landolt C (actuals). The MOBS program then indicated to the experimenter how the glare intensity should be adjusted based on this “yes” response. Based on a pre-determined number of reversals (7) and the criteria that the last glare intensity value was smaller than 5% of the total measuring range, the MOBS program determined the glare threshold for each of the stimuli presented. There were a total of twenty glare threshold measurements made in this experiment but the number of MOBS trials (adjustments of the glare source to determine the glare threshold) was different for each participant. The number of MOBS trials was recorded for each glare threshold measurement for every participant.

Estimated Glare Threshold

Participants were asked to make *estimates* of the glare intensity that they believed would just prevent them from determining the orientation of a low contrast (25%) and high contrast (95%) Landolt C stimuli on the laptop screen positioned 6 meters (twenty feet) ahead (Figure 6). Participants were instructed to look through the center of the glare box to the center of the laptop screen. The edges of the laptop were out of the participants’ field of view. Though actual glare threshold was also measured, estimated glare threshold for both high and low contrast stimuli were measured prior to actual glare threshold. The order of stimuli presentation was randomized for each participant. Half of the participants viewed the high contrast stimuli first; the other half viewed the low contrast stimuli first.

The participant was first asked to determine the orientation of an example Landolt C (40 mm height, 8 mm gap width, 0.7, logMAR, Snellen Acuity (m) 6/30) shown on the computer screen for one second. This example C was not used in data collection, but helped to familiarize participants with the appearance of the Landolt C on the computer screen, particularly with regards to its contrast. The participant was told that though the example C would *not* be used in data collection, C’s of different sizes but with the same appearance would be used. Additionally, participants were given time to view the high contrast example C and the low contrast example C side by side to help them to understand the difference between the two contrast levels. Finally, participants were given a chance to practice the experimental task with the practice C. Participants were presented with the practice C and were asked to identify the orientation of the C. This practice task was performed without the presence of glare.

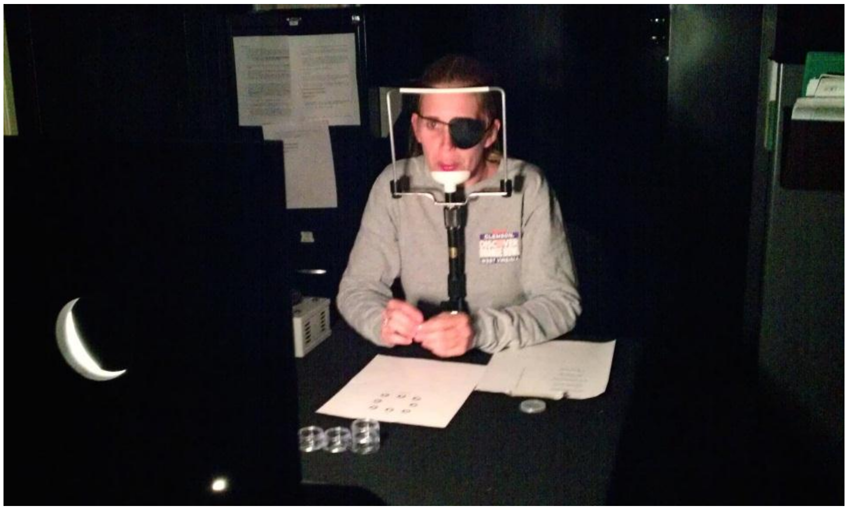

Figure 6. Other researcher performing threshold estimation task

After viewing the example C, participants were handed a cutout (i.e., a physical 3-dimensional representation) of one of five possible Landolt C’s. Participants were asked to imagine that the C cutout they were holding were shown on the laptop screen six meters (twenty feet) in front of them. Participants were reminded of the appearance (not size) of the example C when trying to imagine the C cutout as if it were shown on the computer screen. Participants were asked to become familiar with each C cutout as they would not be allowed to look at the cutout C once data collection started. However, participants were instructed to hold the C in their hands under the testing table for size reference throughout data collection.

The experimenter then turned on the glare box at an intensity of 50% as indicated on the variac dial (Figure 3). The participant viewed a blank screen and was asked to imagine that the C they were holding were shown on the screen. The participant was then asked, “With this light on, would you be able to determine the direction of the gap of the C that you are holding if it were presented on the laptop screen 20 feet in front of you for one second?” Participants then responded “yes” if they thought they would be able to just determine the orientation of the C that they were currently holding if it were visible on the computer screen or “no” if they did not think that they would be able to determine the orientation of the C that they are holding if it were still visible. If “*yes*” the experimenter *increased* the glare intensity (by adjusting the knob on the variac) to the next level of glare as determined by the MOBS algorithm. If the participant responded “*no*” the experimenter decreased the glare intensity to the MOBS specified number. This question was repeated after each adjustment of the glare intensity. The glare source remained on throughout the glare threshold measurement process and increasing and decreasing the intensity of the glare source was repeated until the MOBS procedure terminated and yielded an estimate of the participant's glare threshold for that stimulus. Once MOBS determined the glare threshold for that stimulus the glare source was turned off and the participant was given their next C cutout.

The estimated glare threshold represents the glare intensity at which the participant *estimated* that the glare would just prevent them from being able to discern the orientation of the stimulus. This procedure was repeated for all five of the Landolt C stimuli. The procedure for estimating glare threshold was used for both the high contrast and low contrast Landolt C stimuli. Participants viewed the five high contrast stimuli and the same five C's, in the same order, in the low contrast condition providing a total of ten glare threshold estimates (five high contrast estimates and five low contrast estimates). The order of which contrast level participants saw first was counterbalanced across all participants.

Actual Glare Threshold

The Landolt C stimuli were actually shown to the participant during this portion of the experiment. Participants viewed one of the five Landolt Cs at a time with a specified orientation and glare intensity for one second, they responded with the orientation of the stimulus, and were then shown that C at a different orientation and glare intensity until the participant's glare threshold was reached. Each participant viewed all five C's in the same order that was used in the glare threshold estimates.

Participants were required to indicate the orientation (eight possible orientations) of each C stimulus ("no" responses were not allowed). The MOBS procedure was used again to adjust the intensity of the glare source according to the responses of the participant. If the participant correctly responded to the orientation of the stimulus, the glare intensity of the variac was increased. If the participant was unable to correctly indicate the orientation of the Landolt C presented, the glare intensity was decreased. By increasing and decreasing the glare source in this manner, the participant's actual glare threshold for that particular C was determined. This procedure was repeated for each of the Landolt C stimuli. Each participant's actual glare threshold was measured for the five C's at both the high and low contrast level. Participants responded to a total of ten stimuli (five low contrast, five high contrast) when estimating glare threshold and ten stimuli (five low contrast, five high contrast) when measuring actual glare threshold. There were a total of twenty glare threshold trials per participant lasting approximately one hour. Though the order in which the participant were exposed to the high or the low contrast stimuli was counterbalanced, every participant completed ten trials of *estimated* glare threshold followed by ten trials of *actual* glare threshold so that estimates of glare threshold would not be influenced by the participant's actual glare threshold.

Subjective Ratings of Glare Source Discomfort

After each glare threshold measurement, participants were asked to indicate the magnitude of visual discomfort experienced as a result of the glare source. Participants rated their discomfort using the deBoer scale (see Table 2). This scale ranges from nine (unnoticeable) to one (unbearable). Subjective ratings were made at each glare threshold for all 20 trials.

Table 2. deBoer Scale for subjective ratings of light intensity

Unnoticeable	9
	8
Satisfactory	7
	6
Just Admissible	5
	4
Disturbing	3
	2
Unbearable	1

Finally, participants were asked to complete a short questionnaire on driving attitudes and behaviors (Appendix A). Participants were given the opportunity to ask questions, thanked for their time, and dismissed at this point.

RESULTS

Twenty glare thresholds (estimated and actual glare thresholds at each of five high contrast and five low contrast stimuli) were measured from each participant. These data were first converted from percentage of Variac values to luminance values. Luminance was measured at specific Variac settings (0-100 in increments of ten) both before and after data collection. With these measured luminance values, an ordinary least squares regression was used to predict luminance from Variac setting. The results of curve fitting analyses indicated that both the linear and quadratic Variac terms best predicted luminance values ($R^2 = .99$; $F\ (2, 7) = 1120.13$, $p < .001$). Each participant contributed twenty Variac settings which were transformed into luminance values (cd/m^2) using the following equation, $y = 1138 – 112x + 2.23x^2$.

These luminance values were then screened for outliers. One participant was removed from the analysis for failing to meet the acuity cutoff (20/20); however, this participant was replaced with an additional participant. There were two participants that had several z-scores beyond 3.00. The first of these participants had four outlying scores that occurred only in the actual measurements (high contrast, actual, size 2; low contrast, actual, size 1; low contrast, actual, size 2; low contrast, actual, size 3). For all four, the participant's glare threshold was lower than the glare threshold values of the other sixteen participants (z-scores ranging from -3.24 to -3.75). For this reason, this participant was removed from further analyses.

The second participant with unusual values had three outlying scores that occurred only in the estimated measurements (low contrast, estimates, size 1; low contrast, estimates, size 3; low contrast, estimates, size 4). In this case, the participant estimated glare threshold to be higher than the glare threshold values of the other sixteen participants (z-scores ranging from 3.32 to 3.53). This participant was not removed from the analysis however because all of the outlying values were in the estimates. The goal of this experiment was to examine individual's judgments of their own glare threshold. In this case, though this participant's judgments were higher than other participants it would be in conflict with the goal of this experiment to remove this person from the analysis. After data screening fifteen participants were included in the following analyses.

In several of the actual glare threshold measurements, participants were able to determine the orientation of some of the stimuli even at the maximum glare intensity; as a result of this "ceiling effect," the precise value of the glare threshold in these instances is unknown and in these cases glare threshold was coded as the maximum luminance value allowed by the glare box. Table 3 presents the percentage of participants with maximum glare thresholds and the conditions in which this measurement occurred. The ceiling effect was most prevalent when participants were viewing larger and high contrast stimuli. The presence of this ceiling effect was not anticipated as it was not encountered during pilot testing. The impact of this range restriction is likely to be an underestimation of the true effect of the independent variable on the dependent variable (Sackett, Laczo, & Arvey, 2002). In other words, a ceiling effect should reduce the likelihood of finding a relationship between the range-restricted independent variable and the dependent variable. However, because the results presented below do show a significant relationship between these variables, this ceiling effect was not considered to be a problem.

Table 3. Percentage of participants with glare thresholds at the maximum value

	Actual Glare Thresholds		Estimated Glare Thresholds	
Stimulus Size	High Contrast Stimuli	Low Contrast Stimuli	High Contrast Stimuli	Low Contrast Stimuli
1: Largest	100 %	100 %	0.07 %	0.07 %
2	100 %	93 %	0 %	0 %
3	100 %	80 %	0 %	0.07 %
4	93 %	33 %	0 %	0 %
5: Smallest	60 %	13 %	0 %	0 %

Glare Threshold

Prior to data analysis, homogeneity of variance was examined and Greenhouse Geisser degrees of freedom corrections were used when appropriate (Greenhouse & Geisser, 1958).The threshold data were analyzed with a 2 x 2 x 5 repeated measures ANOVA to examine the effect of contrast (high and low), response type (estimated and actual), and size of stimulus (5 sizes), on glare threshold. The three-way interaction was significant, F (1.62, 22.64) = 5.81, p = .013, η_p^2 = .29, indicating that the difference between estimated and actual glare thresholds was dependent on stimulus contrast and stimulus size, (Figure 7).

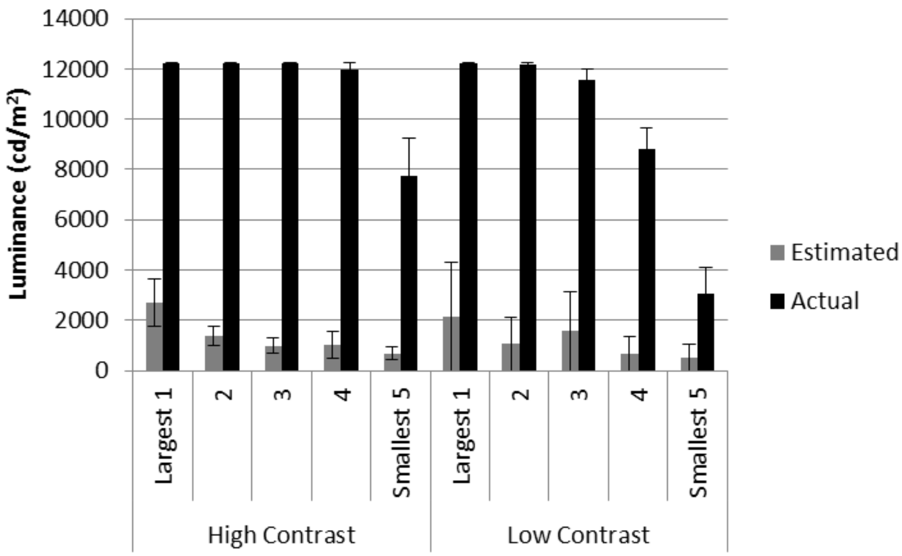

Figure 7. Estimated and actual glare threshold values as a function of stimulus size and stimulus contrast

The differences and similarities in estimated glare thresholds and actual glare thresholds were the most important components of my analysis. For this reason, I began my analysis by looking at the significant main effect of response type on glare threshold values when averaged across stimulus size and stimulus contrast, F (1, 14) = 375.16, $p <$ .001, $\eta_p^2 = .96$. Estimates of glare threshold (M = 1, 273.79 cd/m^2) were on average 88% less than actual glare threshold values (M = 10, 429.33 cd/m^2). Next, I looked at the significant two-way interactions pertaining to response type from the 2 x 2 x 5 ANOVA. For each significant interaction involving response type, I performed separate one-way ANOVAs for estimated glare thresholds and for actual glare threshold to examine the effect of either stimulus contrast or stimulus size on these thresholds.

From the 2 x 2 x 5 ANOVA there was a significant interaction between contrast and response type (estimates and actual) on glare threshold, F (1, 14) = 12.19, p =.004, η_p^2 = .47 (see Figure 8).

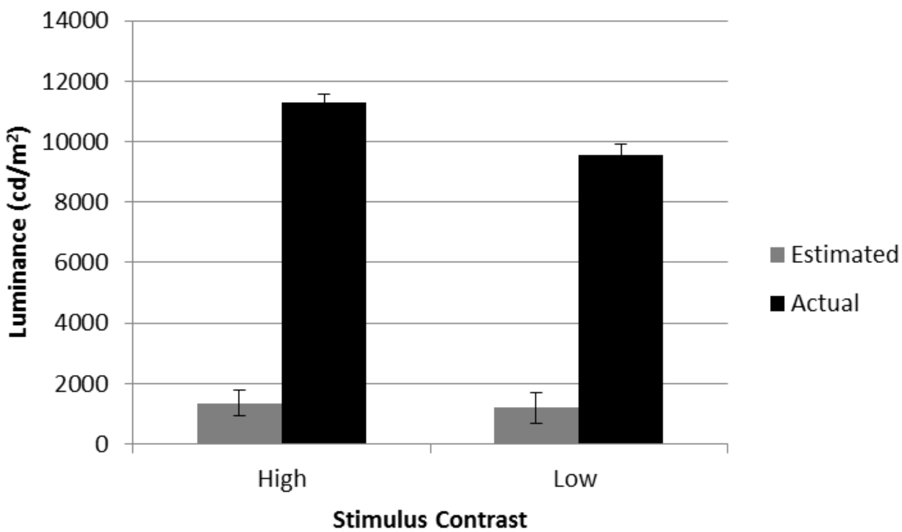

Figure 8. Estimated and actual glare threshold values for high and low contrast stimuli averaged across stimulus size

To examine this effect closer, separate one-way repeated-measures ANOVAs tested the effect of contrast separately on estimated and on actual glare thresholds. There was a significant main effect of contrast on actual glare threshold values, F (1, 14) = 39.79, p < .001, η_p^2 = .74. Actual glare thresholds were 18 % higher when participants were viewing high contrast stimuli (M = 11, 284.11 cd/m^2) than when viewing low contrast stimuli (M = 9,574.55 cd/m^2). I expected that estimated glare threshold would follow the same patterns seen in the actual responses; however, this was not the case. There was not a significant effect of contrast on participants' estimates of their glare threshold F (1, 14) = .20, p = .66, η_p^2 = .01. When averaged across size, actual glare threshold for high contrast stimuli (M = 11,284.11 cd/m^2) was 18 % higher than actual glare threshold for low contrast stimuli (M = 9,574.55 cd/m^2). In comparison, participants' estimated glare thresholds for high contrast stimuli (M = 1,355.88 cd/m^2) were only 14 % higher than the estimated glare thresholds for low contrast (M = 1,191.78 cd/m^2) stimuli.

Next, I looked at the significant interaction of response type and size, F (2.07, 28.97) = 4.96, p = .01, η_p^2 = .56, from the 2 x 2 x 5 ANOVA (see Figure 9). Estimated and actual glare threshold values were once again examined separately with one-way ANOVAs to examine the effect of size on estimated and actual threshold separately. The results of this analysis show that there was a significant main effect of size on actual glare threshold values, F (1.26, 17.62) = 36.28, p < .001, η_p^2 = .72. Actual glare threshold values for the three largest stimuli were not significantly different. Size significantly affected actual glare threshold values at the two smallest stimuli with the most dramatic effect at the smallest stimulus. Actual glare thresholds were larger when participants were viewing larger stimuli. Participant's ability to recognize the orientation of larger stimuli was more robust to glare than when they faced smaller stimuli.

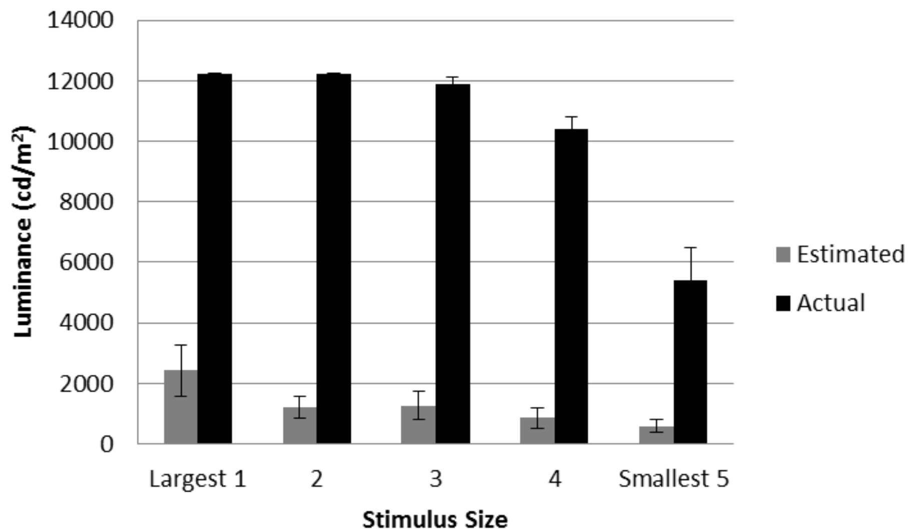

Figure 9. Estimated and actual glare threshold values for differently sized stimuli averaged across stimulus contrast

There was also a significant effect of stimulus size on estimated glare threshold values, F (1.36, 19.09) = 5.88, p = .02, η_p^2 = .30. Estimated glare threshold values for the largest stimulus were significantly larger than estimated glare threshold values of the other four stimuli. The following pairs were not significantly different from each other: sizes two and three, sizes three and four, sizes four and five, and sizes two and four.

Ratings of Discomfort

Each participant provided twenty ratings of discomfort glare using the deBoer scale (a 1-9 scale in which a 1 indicates unbearable discomfort and 9 signifies unnoticeable discomfort). Participants gave discomfort ratings at each of their measured estimated and actual glare threshold intensities. These deBoer ratings were analyzed using a 2 (high and low contrast) x 2 (estimated v actual responses) x 5 (stimulus size) repeated measures ANOVA. There was not a significant three-way interaction of response type, stimulus size, and stimulus contrast on deBoer values, *F* (4, 52) = 1.45, *p* = .23, η_p^2 = .10 (see Figure 10).

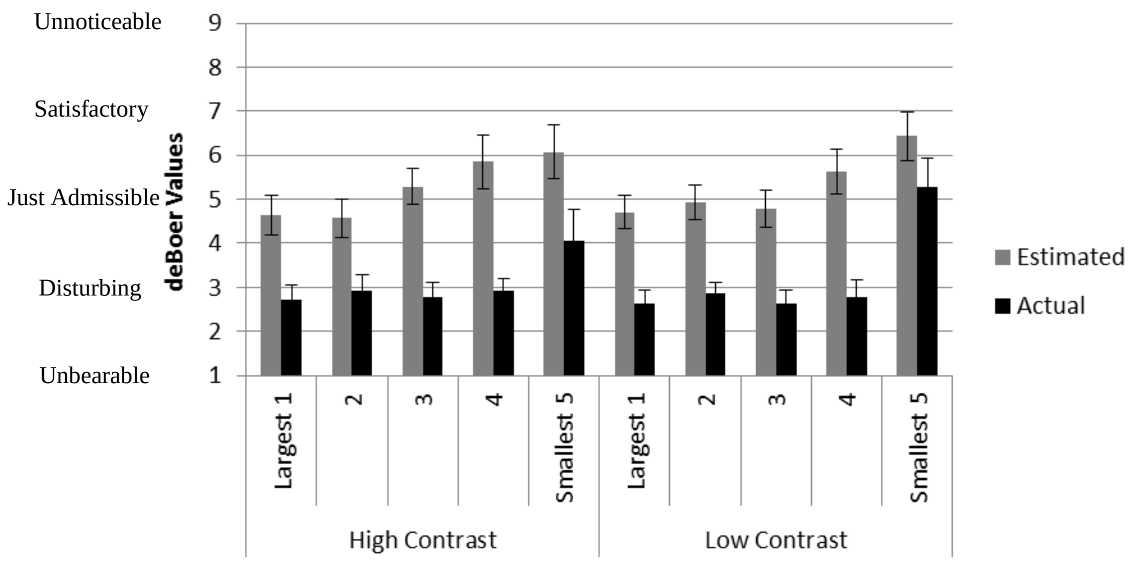

Figure 10. deBoer values (1 is unbearable discomfort and 9 is unnoticeable discomfort) for estimated and actual responses as a function of stimulus size and stimulus contrast

I investigated the significant main effect of response type from the 2 x 2 x 5 ANOVA on deBoer ratings. When averaged across size and contrast deBoer ratings at estimated glare threshold values (M = 5.3, just admissible) were significantly higher (less discomfort) than deBoer ratings at actual glare threshold values (M = 3.2, disturbing), *F* (1, 13) = 23.65, $p < .001$, η_p^2 = .65.

Again, since response type was the variable of interest in this experiment, one-way ANOVAs examined the separate effects of stimulus size and contrast on deBoer ratings measured at estimated glare threshold values and, separately, at actual glare threshold values. For deBoer ratings taken at measurements of actual glare threshold there was a significant effect of stimulus size, *F* (1.43, 18.64) = 11.50, $p < .001$, η_p^2 = .47.

The mean deBoer rating taken after actual glare threshold measurements for the smallest stimulus is different from the deBoer ratings for larger stimuli. No other deBoer ratings pairs were significantly different. The effect of contrast on deBoer ratings at actual glare threshold measurements was not significant, F (1, 13) = .37, p = .55, η_p^2 = .03.

For deBoer ratings following the measurement of estimated glare thresholds only stimulus size had a significant effect on deBoer ratings, F (1.76, 24.58) = 11.19, p < .001, η_p^2 = .44. Examining this effect of size more closely reveals that there was a significant difference between all size pairs with the exception of the difference between the mean deBoer rating of size 1 and size 2. As the stimulus decreased in size, as seen above, glare threshold tended to decrease. When participants were presented with less intense glare at these smaller stimuli deBoer ratings, on average, increased (less discomfort) as stimulus size decreased. The effect of stimulus contrast on deBoers taken at estimated glare threshold values was not significant, F (1, 14) = .18, p = .68, η_p^2 = .01.

MOBS Presentations

Every participant completed twenty glare threshold measurements. Due to the fact that glare threshold was expected to be affected by stimulus size and stimulus contrast, the number of MOBS presentations required to find that glare threshold value was also expected vary in response to the contrast and size of the stimulus. A separate 2 x 2 x 5 ANOVA was conducted to determine the effect of stimulus contrast, stimulus size, and response type on the number of MOBS presentations required to determine each glare threshold.

The number of MOBS presentations required to determine a participant's glare threshold was affected by stimulus contrast, stimulus size and response type (estimated glare threshold measurement or actual glare threshold measurement), F (4, 56) = 5.18, $p < .001$, $\eta_p^2 = .27$ (see Figure 11).

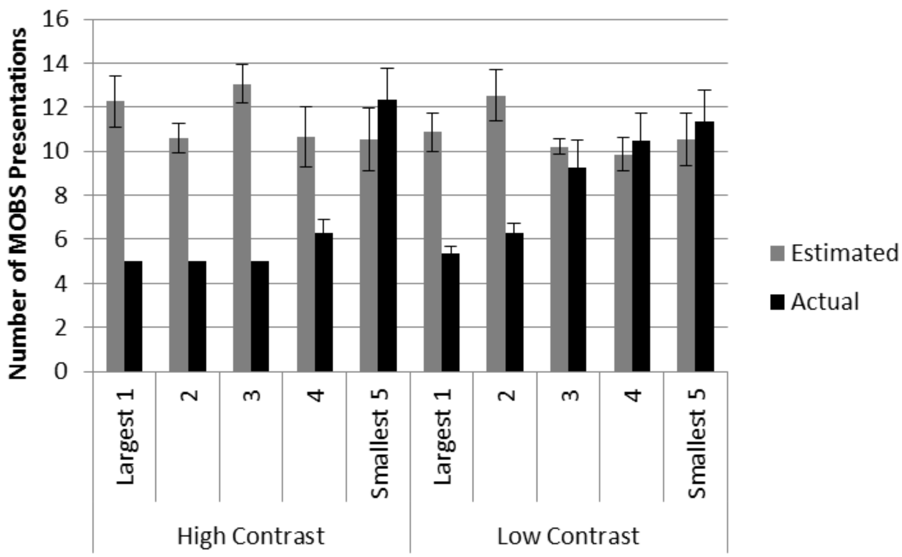

Figure 11. Number of MOBS presentations that were required to reach threshold

Following the same analysis strategies from above I began looking at the number of MOBS presentations by looking at the main effect of response type on this variable, F (1, 14) = 29.70, $p < .001$, $\eta_p^2 = .68$. On average, it took eleven MOBS presentations to reach an estimated glare threshold and seven MOBS presentations to reach an actual glare threshold. Next I looked at significant two-way interactions involving response type from the 2 x 2 x 5 ANOVA and then ran one-way ANOVAs to look at the effect of either stimulus size or stimulus contrast on the number of MOBS presentations to reach estimated or actual glare threshold values. There was a significant interaction of response type and size on the number of MOBS presentations, F (4, 56) = 14.14, p < .001, η_p^2 = .50 (see Figure 12).

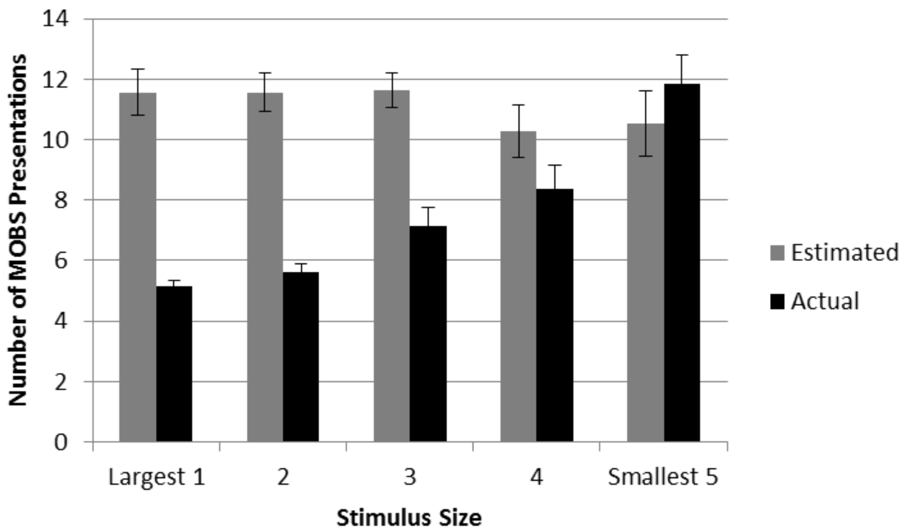

Figure 12. Number of MOBS presentations that were required to determine estimated and actual glare thresholds for differently sized stimuli averaged across stimulus contrast

To examine this interaction separate one-way ANOVAs were conducted to examine the effect of stimulus size on the number of MOBS presentations for actual glare threshold measurements and for estimated glare threshold measurements. For actual glare threshold measurements, the number of MOBS presentations needed to determine that threshold value was significantly affected by the size of the stimulus presented, F (2.23, 31.27) = 24.55, p <.001, η_p^2 = .64.. The difference between all size pairs is significant except for the difference between size 1 and 2 and size 3 and 4. It required more MOBS presentations to determine the actual glare threshold value for the smallest stimulus than for any of the larger stimuli.

For estimated glare threshold measurements, the number of MOBS presentations needed to determine glare threshold was not significantly affected by the size of the stimulus, F (2.49, 37.32) = .34, p = .76, η_p^2 = .02. The number of MOBS presentations required to determine estimated glare threshold values was fairly constant across stimulus size.

Looking at the 2 x 2 x 5 ANOVA there was also a significant contrast and response type interaction, F (1, 14) = 5.04, p = .04, η_p^2 = .27 (see Figure 13). Separate one-way ANOVAs were used to examine the effect of stimulus contrast on the number MOBS presentations for actual and for estimate glare threshold values. For actual glare threshold measurements the number of MOBS presentations was significantly affected by the contrast of the stimulus, F (1, 14) = 13.76, p = .002, η_p^2 = .50. Specifically, more MOBS presentations were required to determine the actual glare threshold value of low contrast stimuli (M= 8.5) than for high contrast stimuli (M = 6.7). For estimated glare threshold measurements there was not a significant effect of stimulus contrast (high contrast M = 11.4, low contrast M = 10.8) on the number of MOBS presentations, F (1, 15) = .49, p = .50, η_p^2 = .03.

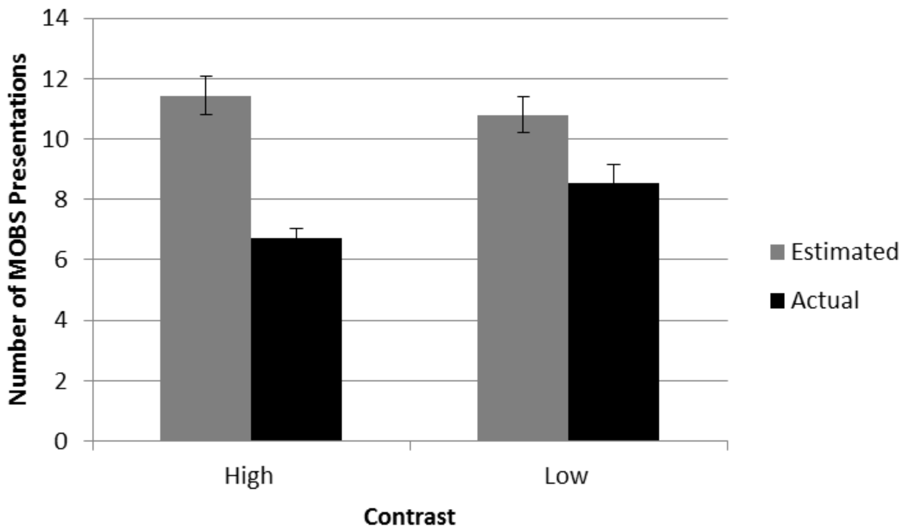

Figure 13. Number of MOBS presentations required to determine estimated and actual glare threshold values for high and low contrast stimuli averaged across stimulus size

DISCUSSION

We are all visually impaired at night but the use of high beam headlights can significantly increase the visibility distance of objects along the roadway. However, high beam headlights are underused. This experiment is one in a series examining the possibility that drivers' misuse of their high beams could be connected to the perceived negative effects of headlight glare. There is evidence to suggest that drivers do not fully understand the effect of glare on their visual performance (Balk & Tyrrell, 2010; Leibowitz et al., 1993). The purposes of this experiment were to extend earlier research that indicated that the visually impairing effects of glare may often be exaggerated and to investigate the role of stimulus contrast and stimulus size in drivers' judgments of the effect of glare. In this experiment participants were asked to judge the luminance of a glare source sufficient to impair their visual acuity of a target viewed through this glare source. Additionally, participants were asked to make estimates of glare threshold based on the size and the contrast of the given stimulus. These estimated glare thresholds were compared to the participant's actual glare thresholds.

In every condition participants' estimates of glare threshold were lower than their actual glare threshold. Participants consistently underestimated their ability to recognize the target through the veiling luminance of the glare source. As mentioned above, on average, estimated glare threshold values (M = 1,273.79 cd/m2) were 88% less than actual glare threshold values (10,429.33 cd/m^2). This tendency to overestimate the debilitating effect of glare on acuity was found in Balk and Tyrrell (2010) in both an on-road and laboratory experiment. The current experiment extends this earlier work and despite a different methodology confirms that drivers tend to exaggerate the impact of glare on their ability to recognize a stimulus.

Next, the impact of the size and contrast of the stimulus on participants' responses was examined. Actual glare threshold values were influenced by both the size and the contrast of the presented stimulus. It was hypothesized that acuity of a smaller or a lower contrast stimulus would be more vulnerable to even low glare intensities. In other words, when viewing objects that were already difficult to recognize (smaller or low contrast) glare would serve to only exacerbate visual difficulties in recognizing these objects. Additionally, those larger or high contrast objects (less recognition difficulty) would require a much greater glare intensity to reduce object recognition (Cobb & Moss, 1928; Leibowitz et al., 1993; Luckiesh, 1944). It appears that participants understand that when viewing smaller stimuli less intense glare would impair their ability to identify the optotype stimuli and that when viewing a larger stimulus that it would take a more intense glare to impair their vision. Though participants were able to use information about the size of the stimulus to inform their estimates of glare threshold they did not seem to understand the glare intensities required to produce decrements in their visual acuity.

Though participants used stimulus size information to make glare threshold estimates they did not appear to take information about the contrast of the stimulus into account when estimating glare threshold. There was a significant difference in the point at which acuity was affected by glare when viewing the set of high contrast stimuli in comparison to the low contrast stimuli. However, participants' estimates of their glare threshold were unchanged whether viewing a high contrast stimulus or a low contrast stimulus. Additionally, participants significantly exaggerated the effect of glare when viewing both the high contrast and the low contrast stimuli. This finding was surprising in light of previous work by Balk and Tyrrell (2010) and Stafford et al. (2011). In these two experiments estimates of the effect of glare were very different due to the differences in the contrast of the visual stimulus used. In the Balk and Tyrrell experiment the target was a retro-reflective Landolt C and participants estimated that their visual acuity declined as glare increased though there was no actual effect of the glare source on their ability to recognize the stimulus. Participants exaggerated the effect that glare would have on their visual performance. However, in Stafford et al. when viewing a lower contrast stimulus (white paper), participants more accurately estimated the effect of glare on their visual performance. One purpose of the current experiment was to determine whether participants would exaggerate the effect of glare on their ability to recognize a high contrast stimulus and more accurately assess the impact of glare on their ability to recognize a low contrast stimulus. In all conditions the participants, on average, underestimated the luminance of the glare source that would be required to disrupt their acuity. Though in the current experiment we do not see accuracy of glare judgments when viewing a low contrast object, stimulus contrast may still play an important role in drivers' glare judgments. There are several reasons why the stimulus contrast manipulation may have not elicited the hypothesized response from participants. For one, it is very difficult, with only the use of a computer screen, to create a high or low contrast condition as dramatic as a dark clad pedestrian or a pedestrian wearing retroreflective material against a night background. Also, a dark-clad pedestrian on the road at night is a sight that many drivers are familiar with and this familiarity may be one possible explanation for drivers' more accurate understanding of the effect of glare on their recognition ability (Stafford et al., 2011). In the current experiment, however, the stimulus was a low contrast gray optotype on a black computer screen and may be an unfamiliar object to drivers. A lack of familiarity and real world authenticity of the low contrast stimulus may be a possible explanation for the discrepancy between the results of this experiment and Stafford et al. (2011).

Participants in this experiment did not understand the intensity of glare sufficient to impair their vision. This finding may provide important insights into the issue of drivers underusing their high beam headlights. It is well established that our visual abilities are significantly impaired in conditions of low illumination and that the use of high beams headlights would significantly increase the distance at which drivers recognize objects, animals, and people along the roadway (NHTSA, 2007; Sivak, Flannagan, Schoettle, & Adachi, 2003; Wood, Tyrrell, & Carberry, 2005). Pedestrians face dangerous situations as a direct result of the visual challenges experienced by drivers at night. Though there is a need for greater roadway illumination and though high beam headlights are an effective way of decreasing visual challenges at night, drivers do not make adequate use of their high beams headlights. This experiment, together with the results of both Balk and Tyrrell (2010) and Singh and Perel (2003), suggests that one reason why drivers may not use their high beams is that they incorrectly assume that even small amounts of headlight glare can produce substantial feelings of discomfort and decrements in the visual capabilities of other road users.

It has also been suggested that drivers' judgments of the effects of glare may be related to the amount of discomfort experienced in the presence of glare rather than the actual impairing effects of glare (Balk & Tyrrell, 2010; Leibowitz, et al., 1993; NHTSA, 2007). deBoer ratings at both estimated and actual glare threshold values were also analyzed in this experiment. Actual glare threshold values were very high (sometimes at a maximum). As such, participants reported more discomfort (M = 3.2: "disturbing") at these more intense glare values. Similarly, estimated glare threshold values were much lower than actual glare threshold values and participants reported less discomfort in the presence of this less intense glare (M = 5.3: "just admissible"). The size of the object to be recognized also affected the discomfort experienced by the participant. On average, participants reported less discomfort when viewing a smaller stimulus. This makes sense in that it required less intense glare to impair the participant's recognition of a smaller stimulus resulting in less discomfort experienced by the participant. If the amount of discomfort experienced by the participant was the primary factor in determining their glare judgments, it would be expected that deBoer ratings would be lower (more discomfort) at estimated threshold values due to the fact that participants exaggerated the effect of glare. Yet, we see the exact opposite results in the current experiment. Discomfort ratings at estimated glare threshold values were higher (less discomfort) than those taken at actual (more intense) glare threshold values. In other words, participants did not base their threshold judgments on the discomfort they experienced. Relatedly, Theeuwes et al (2002), determined that deBoer ratings were not predictive of performance in a pedestrian detection task, and as mentioned earlier, ratings of discomfort can be quite varied depending on individual differences. Yet in the current experiment there seems to be appropriate calibration of discomfort responses to the threshold glare level (lower thresholds were rated less discomforting and higher thresholds as more discomforting).

There are some limitations in this study. When viewing large, high contrast stimuli actual glare threshold values were at a maximum creating a ceiling effect and restricting the range of this variable. Though there is no variability in trials in which the ceiling effect was seen it is unlikely that the results of the ANOVA were affected by this ceiling effect due the balanced design of this experiment. Additionally, as mentioned earlier there is evidence to suggest that this range restriction would most likely result in an underestimation of the true effect. It is possible that if the glare source had been capable of greater intensity the observed differences in estimated and actual glare threshold would have been larger. This ceiling effect could have been avoided by decreasing either the size or contrast of the stimuli presented. Additionally, as with any laboratory study the generalizability of the current work to the nighttime driving environment is a concern. It would be useful to repeat this study outdoors using realistic roadway hazards rather than optotypes in a laboratory setting.

I also examined the number of MOBS presentations required before the program terminated at a participant's threshold value. On average there were more MOBS presentations when participants were estimating glare threshold (M = 11) than when measuring actual glare threshold (M = 7). This difference in number of MOBS presentation might reflect the psychophysical procedure "chasing" thresholds that are more variable during the estimation trials. This difference also is impacted by the ceiling effect seen in some of the actual measurements. In these measurements, MOBS always terminated in five trials (when it hit the maximum glare intensity value) and there is a lack of variability in these trials. Additionally on average, stimuli that were more visually challenging (smaller or low contrast objects) required more MOBS presentations to determine an actual threshold value. The largest high contrast stimulus required on average five MOBS presentations while the smallest high contrast stimulus required twelve MOBS presentations. MOBS presentations also increased from on average five presentations for the largest low contrast stimulus to eleven presentations for the smallest low contrast stimulus. However, there was no statistically significant difference in the MOBS presentations required to determine estimated glare threshold values when viewing objects of varying size or contrast. This experiment has contributed to the growing evidence that drivers may not have a complete understanding of how headlight glare impacts their ability to see while driving at night. In particular, this work further supports the claim that drivers' judgments of glare may be biased toward overestimating the effect of glare on acuity. The current data paint a similar picture as those of Balk and Tyrrell (2010) despite asking participants a very different question about glare and the use of a very different methodology (measuring and estimating visual acuity of high contrast stimuli only at specific glare intensities in Balk and Tyrrell verses measuring and estimating glare threshold intensities with both high and low contrast stimuli at specific visual acuities). This experiment coupled with the on-road and laboratory study performed by Balk and Tyrrell provide convergent validity to the notion that drivers can exaggerate the impact of glare on their ability to see. Future research should continue to explore judgments of glare threshold. In particular, it may be useful to examine glare threshold in the context of actual vehicle headlights. For example, future work could assess what intensity of headlighting is sufficient to impair visual acuity and whether drivers accurately perceive this threshold point. Also, the idea that stimulus contrast is related to the accuracy with which a person is able to assess their own acuity in the presence of glare should be examined further. A study similar to the current work could be conducted with a lower contrast object to see if participants are more accurate in judging their glare threshold when viewing a very low contrast stimulus. Additionally, an on-road experiment may provide a richer contrast experience and may show different glare threshold values. It would be important to measure glare threshold in the context of headlight intensity sufficient to decrease visual acuity, and using realistic roadway hazards as the visual target would likely be more generalizable than relying on optotypes.

There is a need for greater roadway illumination and the use of high beam headlights affords drivers and pedestrians a simple, low cost way to increase nighttime visibility. However, if drivers continue to overestimate their visual capabilities when driving at night and exaggerating the negative effect of glare on their ability to see it is unlikely that high beam usage will improve. It is hoped that the current work and future research can provide greater insight into drivers' understanding of the effect of glare on vision in an effort to improve high beam usage and nighttime roadway safety.

APPENDIX

Participant Questionnaire

Part I. General questions. Please remember that all answers will be kept confidential, so please answer as candidly as possible.

1. How many years of driving experience do you have? _______________

2. Of the total time you spent driving in the last 12 months, approximately what percentage of the time did you spend driving on each of the following types of roads?
   a. in town/city? _________
   b. in suburbs or country? _________
   c. on highways? _________

3. Of the total time you spent driving in the last 12 months, approximately what percentage was done during the nighttime (after sunset and before sunrise)? __________

4. How comfortable do you feel driving *at night in good weather*? (circle one)

   a. Very Comfortable
   b. Comfortable
   c. Neutral
   d. Uncomfortable
   e. Very Uncomfortable

5. How comfortable do you feel driving *at night in bad/stormy weather*? (circle one)

   a. Very Comfortable
   b. Comfortable
   c. Neutral
   d. Uncomfortable
   e. Very Uncomfortable

6. Which of the following driving situations do you generally try to avoid?

(Insert one of the letters listed below to indicate how strongly you avoid each situation.)

N	Never avoid
P	Prefer to avoid
A	Always avoid (except emergencies)

heavy traffic, daylight	_______	heavy traffic, night	_______
rain, daylight	_______	rain, night	_______
fog, daylight	_______	fog, night	_______

Part II. Ease of Driving in Different Conditions

How easy do you feel it is to drive under each of the following conditions? (Assume good weather and daytime conditions unless otherwise specified.)

Assign a number from 1 to 7 to each item using the following scale as a guide:						
1	2	3	4	5	6	7
Not at all Easy						Very Easy

7. through a quiet residential neighborhood ____
8. through a busy shopping mall, parking lot ____
9. in city traffic ____
10. making a right turn in city traffic _____
11. changing lanes on a divided highway/interstate ____
12. entering a divided highway/interstate ____
13. exiting a divided highway/interstate ____
14. making a U-turn on a wide city street ____
15. parallel parking along the curb of a busy street ____
16. pulling into a parking space at the supermarket ____
17. reversing out of a parking space at a supermarket ____
18. on a divided highway/interstate in clear weather, daylight ____
19. on a divided highway/interstate in clear weather, nighttime ____
20. on a divided highway/interstate in rainy weather, daylight ____
21. on a divided highway/interstate in rainy weather, nighttime ____

22. What percentage of the time do you use high beam headlights when driving at night in the following situations?
    a. on city streets __________
    b. on highways/interstates __________
    c. on country roads __________
    d. on suburban roads __________

23. When you are driving on divided highways/interstates at night, how frequently do the headlights of oncoming traffic seem troublesome?
    a. Rarely
    b. Occasionally
    c. Often
    d. At every encounter

24. Estimate the distance at which you can see the following objects when driving at night: (in meters or feet)
    a. Other vehicles: _____________
    b. Cyclists: _____________
    c. Pedestrians wearing white: _____________
    d. Pedestrians wearing black: _____________
    e. Traffic signs: _____________

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