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Motorcycle Conspicuity and The Effect of Auxiliary Forward Lighting

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16. Abstract

A field experiment was conducted with 32 participants to determine whether the conspicuity of approaching motorcycles viewed in daylight may be improved by various forward lighting treatments. The treatments tested included pairs of low-mounted auxiliary lamps (LA), high-mounted auxiliary lamps (HA), both high- and low-mounted auxiliary lamps (LHA), low-mounted LED lamps (LED), and a modulated high beam headlamp (MHB). Participants viewed approaching traffic and indicated when it would be safe (and not safe) to initiate a left turn across the path of approaching vehicles in an opposing lane of traffic. They were not informed that the specific purpose of the study was to examine their reactions to motorcycles. Researchers also recorded participant's direction of gaze continuously with a head-mounted eye tracker. The mean safety margin provided to an approaching motorcycle with various lighting treatments did not differ significantly between any of the experimental lighting treatments and the baseline treatment (illuminated low beam headlamp). However, having either LA or MHB lamps on the motorcycle significantly reduced the probability of obtaining a short safety margin (< 3.44 seconds) as compared to the baseline lighting treatment. Eye tracking data indicated that the average duration of participants' gazes at the motorcycle were significantly longer with the LHA lighting as compared to the baseline condition. These results should be interpreted cautiously in light of differences that were observed between participants who reported using a landmark-based strategy to judge when it was no longer safe to turn in front of approaching vehicles and participants who used other strategies. Overall the results suggest that enhancing the frontal conspicuity of motorcycles with lighting treatments beyond an illuminated low beam headlamp may be an effective countermeasure for daytime crashes involving right-of-way violations.

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Executive Summary

The annual number of motorcycle rider fatalities in the United States increased from 2294 in 1998 to 5290 in 2008 (National Highway Traffic Safety Administration, 2010). Many multi-vehicle motorcycle crashes involve right-of-way violations where another vehicle turns in front of, or crosses the path of an on-coming motorcycle. Improving the frontal conspicuity of motorcycles with auxiliary forward lighting may reduce these types of crashes. This report describes one of four recent studies sponsored by NHTSA on motorcycle conspicuity.

A field experiment was conducted with 32 adult participants to determine whether the conspicuity of approaching motorcycles viewed in daylight may be improved by various forward lighting treatments including pairs of low-mounted auxiliary lamps (LA), high-mounted auxiliary lamps (HA), both low- and high-mounted auxiliary lamps (LHA), low-mounted LED lamps (LED), or a modulated high beam headlamp (MHB). These treatments were compared to a baseline condition where the motorcycle had only a low beam headlamp illuminated (LB).

Participants, who were not informed that the study involved motorcycles, observed approaching traffic from the driver's seat of a research vehicle parked in the center median of a four-lane roadway. As traffic flowed past the research vehicle on the adjacent road, participants were asked to press and hold down a button whenever they thought that they would be able to initiate a left turn across the path of the approaching vehicles and to release the button at the first moment when they were no longer able to initiate a safe turning maneuver. At no time during the study did participants actually drive the research vehicle.

Under normal conditions drivers preparing to initiate a left turn across a lane of oncoming traffic must monitor the oncoming traffic stream for a large enough gap to perform their turning maneuver, but they must also monitor the status of the destination roadway or driveway that they plan to turn onto. The destination road might have pedestrians, bicycles, and other road users or other hazards blocking the way. To mimic these shared demands on drivers' attention, participants in the present study performed a secondary task that was similar to checking for pedestrians or other obstacles on the destination roadway. Participants were asked to monitor and respond to the appearance of a target light mounted on the top of a traffic cone located directly across the street to the participant's left. This secondary task ensured that participants would not be able to fixate continuously on the approaching traffic stream.

Several times during the data collection period, a motorcycle ridden by a researcher drove past the research vehicle within the stream of oncoming traffic. The motorcycle was configured with a different forward lighting treatment on each pass. The participant's eye movements were recorded by a head-mounted eye tracking device. This allowed researchers to evaluate the effects of motorcycle lighting treatments on the frequency, timing, and duration of gaze fixations on the approaching motorcycle.

The primary dependent variable was the time between the participant's indication that it was no longer safe to initiate a turn maneuver in front of the approaching motorcycle and the arrival time of the motorcycle. This time difference was called the "safety margin" for the purposes of this study. Other dependent variables included the frequency and duration of the participants' glances at the approaching motorcycle and the latency of their first glances at the motorcycle. It was hypothesized that each of the experimental lighting treatments would provide greater conspicuity than the baseline condition and would therefore lead to greater safety margins, and earlier, more frequent, and longer duration gazes toward the motorcycle.

Statistical tests of the mean safety margin provided to the approaching motorcycle with various lighting treatments did not reveal any significant differences between experimental lighting treatments and the baseline condition. However, the results indicated that some of the experimental lighting treatments may provide a safety benefit for motorcycles because they were less likely to be associated with short safety margins as compared to the baseline lighting condition. Having either illuminated lower auxiliary lamps (LA) or modulated high beam headlamp (MHB) on the motorcycle significantly reduced the probability of obtaining a short safety margin as compared to the baseline condition with an illuminated low beam headlamp (LB). There was also an indication that the four-lamp enhanced lighting treatment (LHA) reduced the probability of obtaining a short safety margin as compared to the baseline condition but this result was not quite statistically significant ($p = 0.06$).

These results should be interpreted cautiously in light of the differences observed between subsets of participants in the study. In a post-study interview, some participants reported using a landmark strategy to judge when it was safe to turn by comparing the position of approaching vehicles to fixed roadside landmarks. Other participants focused on the approaching vehicles speed, the time until its arrival at the conflict point, or used other strategies. Differences were observed between landmark participants and non-landmark participants in the effects of the experimental lighting treatments. For participants who used a landmark strategy, the influence of the experimental lighting treatments was to reduce the probability of giving a short safety margin, while for non-landmark participants the influence of the experimental lighting treatments was to increase the time spent looking toward the motorcycle.

Future research on motorcycle conspicuity and on the causes of crashes resulting from right-of-way violations may benefit from an expansion in experimental paradigms from an emphasis on time/distance perception and perceptual biases revealed by measures of central tendency to the study of rare events including failures or delays in detection, lapses in attending to detected objects, individual differences in drivers' perceptual strategies, and countermeasures for inattention blindness.

Overall, the results from this study suggest that enhancing the frontal conspicuity of motorcycles with lighting treatments beyond an illuminated low beam headlamp may be an effective countermeasure for daytime crashes involving right-of-way violations.

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1. Introduction

1.1 Motorcycle Conspicuity Project overview

National Highway Safety Administration (NHTSA) issued a Task Order to Westat to investigate daytime frontal conspicuity of motorcycles as it relates to frontal lighting treatments on motorcycles and as it relates to the use of daytime running lights (DRL) within the passenger vehicle fleet. The annual number of motorcycle rider fatalities in the United States has more than doubled from 2294 in 1998 to 5290 in 2008 (National Highway Traffic Safety Administration, 2010). Over the same period, the total number of traffic fatalities has remained relatively stable. Many multi-vehicle motorcycle crashes involve right-of-way violations where another vehicle turning in front of, or crossing the path of an on-coming motorcycle (Longthorne, Varghese, & Shankar, 2007). Improving the frontal conspicuity of motorcycles may reduce the occurrence of these types of crashes. DRL use on passenger vehicles has been shown to have safety benefits (Rune, Christensen, & Olsen, 2003), and daytime use of illuminated lamps on motorcycles has been shown to increase their conspicuity (for a review see Wulf, Handcock, & Rahimi,1989). On the other hand, widespread use of DRL on passenger vehicles may reduce the safety effectiveness of daytime headlamp use by motorcyclists. As drivers become accustomed to searching for two headlamps (i.e., another passenger vehicle), they may inadvertently "overlook" motorcycles with only one headlamp lit. Research is needed to address these questions.

The overall goals of the project were to:

1. Examine if the frontal conspicuity of motorcycles can be improved to reduce their chances of being struck by other motorists who may not have seen them or may not have accurately judged their approaching speed.
2. Determine the impact of passenger fleet daytime running lights (DRL) on motorcycle crashes by analyzing crash data from a country that has mandated fleet use of DRL.
3. Compare the response (e.g. gap size, turning speed) of motorists turning left in front of approaching passenger vehicles with DRL to those without DRL.
4. Evaluate which, if any motorcycle conspicuity treatments might be most likely to improve motorcycle safety (e.g. by increasing the gaps afforded to approaching motorcycles by turning vehicles).

These project goals were addressed by separate studies. This report describes only the work performed on Task 4 (Identify effective motorcycle conspicuity treatments) which was intended to address goal 4 listed above. The study reported here was a field experiment to examine the effectiveness of various auxiliary lighting treatments for improving the frontal conspicuity of motorcycles during the daytime.

1.2 Study objectives

Motorcycles sold in the U.S. have at least one low beam headlamp that is illuminated automatically when the engine is started. The purpose of this study was to determine whether additional frontal lighting will enhance motorcycle conspicuity. The primary objective was to determine whether five different forward lighting treatments differ from a baseline treatment with a single low beam headlamp in helping motorists to notice and respond appropriately to approaching motorcycles. Two more specific research objectives were to determine whether participants' judgments about safe moments to turn left in front of approaching motorcycles are influenced by the forward lighting on the motorcycle and to determine whether participants' eye glances differ when judging an approaching motorcycle with various lighting treatments.

This study complements a previous NHTSA-sponsored project on motorcycle conspicuity as well as an observational study conducted for the current project to determine whether DRL on approaching passenger vehicles influences left turn gap acceptance by turning drivers.

1.3 Background

A previous NHTSA project studied the effects of motorcycle lighting treatments on motorists' speed-spacing judgments of approaching motorcycles (Pierowicz, Gawron, Wilson, & Bisantz, 2011). The first phase of that project consisted of a test track study to measure left turn gap judgments for an oncoming motorcycle with various lighting treatments that was traveling at a predetermined speed. On separate trials, an oncoming automobile traveling at the same speed was used for comparison. As the motorcycle (or automobile) approached, participants, who were in the driver's seat of a stationary passenger vehicle, pushed a button to indicate their judgment of the "last safe distance" at which they would be able to initiate a left turn in front of the motorcycle. Participants reported smaller "last safe distances" for the oncoming motorcycle as compared to the oncoming automobile. This finding is consistent with results of other studies (e.g. Horswill, Helman, Ardiles & Wann, 2005). However, none of the motorcycle lighting treatments tested was clearly superior in terms of encouraging participants to increase the last safe distance for initiating a left turn maneuver. The test track study placed participants in an artificial driving context where they did not have to pay attention to any other aspects of the environment besides a single approaching vehicle. On repeated trials, a single automobile or a single motorcycle approached at a constant fixed speed. This experimental paradigm may have lead participants in this study to adopt simple strategies for judging the last safe distance, such as responding when the approaching vehicle passed a fixed landmark rather doing the more demanding perceptual task of judging the available time for a turn maneuver based on both the speed and distance of the approaching vehicle. Because the speed of the approaching vehicles was always the same, the perceptual task was reduced to making distance judgments. Also, the participants' task, with a singular focus on the approaching vehicle, may represent a "best case" scenario in terms of natural driving behavior because it did not include any of the more complex set of demands on attention that drivers face on active roadways.

In the present study we collected participants' judgments about acceptable moments to initiate left turns across the path of approaching vehicles and analyzed the "last safe moment" to initiate a turn in front of an approaching motorcycle equipped with various forward lighting treatments. As compared to the previous work, the present experiment was conducted in a richer, more naturalistic traffic context. Also, participants were not informed ahead of time that the specific purpose of the experiment was to examine their reactions to approaching motorcycles. They were told that the purpose of the study was to collect information about where drivers typically look as they prepare to make a left turns across the path of oncoming traffic. The present study differed from the previous study in the complexity of the participants' tasks. In the present study participants' attention was divided across two different visual tasks outside of the vehicle. They viewed a stream of approaching traffic (that included the occasional research motorcycle) and indicated when it would be safe to initiate a left turn maneuver. They also monitored the status of a small light located across the street to their left and indicated when the light was illuminated. This secondary task was designed to increase the participant's workload and to prevent them from continuously scanning the forward roadway. This task was designed to mimic a turning driver's need to check for pedestrians or other obstacles on the destination roadway. Researchers in the present study also tracked participants' eye movements to determine whether glances at the approaching motorcycle depended on the various forward lighting treatments tested.

2. Method

2.1 Study design

Six different motorcycle forward lighting treatments were compared in a within-subjects field experiment. The motorcycle lighting treatments included in this study were:

- Baseline condition – only the low beam headlamp was illuminated.
- A pair of high-mounted, white, round auxiliary lights (each 20W tungsten) were illuminated in addition to the low beam headlamp.
- A pair of low-mounted, white, round auxiliary lamps (each 20W tungsten) were illuminated in addition to the low beam headlamp.
- Both high-mounted and low-mounted white, round, auxiliary lamp pairs were illuminated in addition to the low beam headlamp.
- A pair of low-mounted, white, rectangular auxiliary lamps (2W LED array) was illuminated in addition to the low beam headlamp.
- The high beam headlamp was illuminated and modulated at 4 Hz (with the low beam off).

These lighting treatments were selected to improve conspicuity of the motorcycle as seen by other drivers rather than providing additional illumination of the forward roadway for the motorcycle rider. An important consideration was to test relatively low-power lamps because the electrical systems of many motorcycles on the road today were not designed to accommodate the high power requirements of multiple additional lamps.

Researchers recruited licensed adult drivers to participate individually in a field study of eye movements and perception of approaching vehicles. The study was designed to measure participants' perceptions about when it would be safe to make left turns across the path of approaching traffic without actually performing any left turn maneuvers. Eye movements were also measured. Participants observed approaching traffic from the driver's seat of a research vehicle parked in the median of a roadway. Participants were asked to press and hold down a button when they were safely able to initiate a left turn across the path of approaching traffic and to release the button at the first moment when they were no longer safely able to initiate a turning maneuver. At no time during the study did participants actually drive the research vehicle.

Under normal conditions drivers preparing to initiate a left turn across a lane of oncoming traffic must monitor both the oncoming traffic stream and the destination roadway or driveway that they plan to turn onto. The destination road might have pedestrians, bicycles, and other road users or other hazards blocking the way. Participants in the present study performed a secondary task that was similar to checking for pedestrians or other obstacles on the destination roadway. The secondary task provided an ecologically valid distraction from the primary task of monitoring gaps in the approaching traffic stream. The secondary task involved monitoring and responding to the appearance of a target light in a position well off axis from the trajectories of the approaching vehicles. Participants were asked to share their attention between observing oncoming traffic and this secondary task to ensure that they would not fixate continuously on the approaching traffic stream. Several times during the data collection period, a motorcycle ridden by a researcher drove past the research vehicle within the stream of oncoming traffic. The motorcycle was configured with a different forward lighting treatment on each pass. While performing these experimental tasks, the participant's eye movements were recorded by a video-based head-mounted eye tracking device. This allowed researchers to evaluate the effects of motorcycle lighting treatments on the frequency, timing, and duration of gaze fixations on the approaching motorcycle.

The primary dependent variable was the time between the participant's indication that it was no longer safe to turn in front of the approaching motorcycle and the arrival time of the motorcycle (This time difference has been called the "safety margin" for the purposes of this study). Other dependent variables included the frequency and duration of the participants' glances at the approaching motorcycle and the latency of their first glances at the motorcycle. It was hypothesized that each of the auxiliary lighting treatments would provide greater conspicuity than the baseline condition and would therefore lead to greater safety margins, and earlier, more frequent, and longer duration glances at the motorcycle.

The study protocol was approved by Westat's Internal Review Board for the protection of research participants.

2.2 Participants

Researchers recruited 32 licensed adult drivers to participate individually in a field study of drivers' eye movements and perception of approaching vehicles. Participants were not informed that a purpose of the study was to examine their reactions to approaching motorcycles. Volunteers were recruited using an online advertisement in the Washington, DC Craigslist. Each participant was compensated with $60 for a session that lasted approximately 90 minutes. Participants were selected so that the group spanned a large age range and included an equal number of men and women. The mean age of male participants was 39.8 years (range 22 to 67) and the mean age of female participants was 39.1 years (range 19 to 61).

Potential participants were screened with regard to driving experience with different types of vehicles including motorcycles (Appendix A). No experienced motorcycle riders or people who have motorcycle riders in their immediate family were selected to participate so that the study participants would not be particularly attentive to motorcycles. Experience driving other types of vehicles besides motorcycles was not considered in the selection criteria for participants. A few questions about experience driving other vehicle types such as trucks and taxis were included in the screening interview so that potential participants would not suspect that the study was focused on motorcycles. Because the eye glance tracking system used in this study works best when the participant is not wearing glasses, individuals were only eligible to participate if they did not wear glasses while driving. Individuals who wore contact lenses were accepted.

2.3 Field site

The location for conducting this field experiment was carefully chosen to be safe for participants and researchers and to minimize disruptions to the natural traffic flow on the adjacent, active roadway. Other considerations for choosing the study site were:

- Moderate visual complexity of the forward roadway scene.
- Moderate sight distance. Long enough sight distance was needed for a prudent driver of the research vehicle to determine that it would be safe to make a left turn across two lanes

of oncoming traffic. However, sight distance could not be so long as to provide participants with excessively long previews of oncoming traffic. The site chosen afforded approximately 15 seconds of preview time before an approaching vehicle reached the conflict point.

- Moderate traffic volume so that a participant would be afforded frequent gaps in the traffic stream when it would be safe to initiate a left turn, but enough traffic was needed so that the participant would occasionally experience extended periods of time when it would not be safe to initiate a turn.
- Close to Westat's offices to minimize the time and costs associated with transporting participants and researchers to and from the study site.

The study was conducted on Muddy Branch Road, a four-lane divided highway in Gaithersburg, Maryland (Figure 1). The posted speed limit was 45 mph. The road had a 30-foot wide grass median with guard rails that provided the site with some protection from vehicle intrusions. The research vehicle, a Chevrolet Equinox SUV, was parked in the center of the median for the study sessions. The vehicle faced north and during data collection the participant sat in the driver's seat and observed oncoming southbound traffic (Figure 2). The vehicle was parked on a concrete pad that was approximately 21 inches lower than the adjacent roadway surface. The participant's eye height was approximately 35 inches higher than the adjacent roadway.

Oncoming vehicles came into view as they came around a slight left curve and down a slight hill. The nearest traffic control devices to the site were traffic signals about ¾ mile upstream and ¼ mile downstream from the site. Few vehicles joined oncoming traffic from driveways and side streets near the site, so passing traffic was typically not accelerating or decelerating. Because of the distance from the upstream traffic control device, traffic typically was not in tightly bunched platoons, which afforded ample opportunities to make left turn gap acceptance judgments for a range of gap sizes.

All experimental sessions were conducted between 11:30 AM and 2:00 PM so that the angle of the sun would be high and consistent between participants. Sessions were conducted from mid October through late November, so the sun was always somewhat behind the north-facing research vehicle. This orientation helped to minimize glare that could interfere with the eye tracker or be uncomfortable for participants. All sessions were conducted in clear weather with the exception of one, which was conducted partially in light rain.

Three traffic crash barrels were used at the study site (see Fig. 2) to indicate to approaching drivers that some type of maintenance activity or traffic survey was going on. This was done to prevent drivers from reacting to the potential that the research vehicle was a police enforcement vehicle. Although some approaching drivers did slow significantly, most maintained a relatively steady speed.

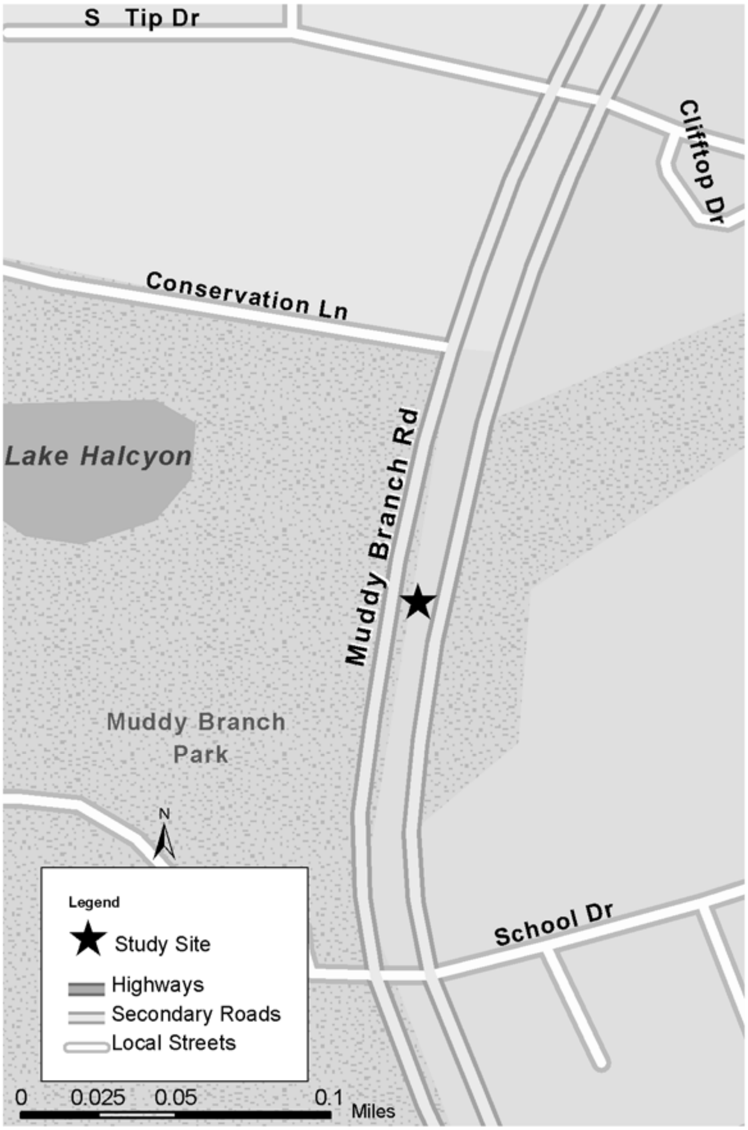

Figure 1. Map of Study Site, Gaithersburg, Maryland

Figure 2. View of Study Site and Research Vehicle Looking North

2.4 Apparatus

Participants' primary task: The primary task involved pressing and holding a spring-loaded switch that was connected to the experimenter's control computer. Participants held the switch in their left hand and used their thumb to depress the "turn button" to indicate when it would be safe to initiate a left turn left across the path of oncoming traffic. Participants were instructed to hold the button down as long as it was still safe to turn, but to release the button the moment that it was no longer safe to begin a left turn maneuver.

Participants' secondary task: The secondary task for the study required participants to press a button when a remotely controlled lamp was illuminated. A similar secondary task has been used in previous studies as a dependent measure (e.g. Handcock,Wulf, Thom, & Fassnacht, 1990). The lamp was located approximately 53 feet from the participant, across the street, and approximately 90 degrees to the left of the participant's forward line of sight. The lamp was mounted on the top of a traffic cone and was controlled wirelessly by computer using a looping routine that ran continuously while the participant was observing traffic. The routine was set up to illuminate the white LED lamp as a stimulus for up to 15 seconds with a dark time between 12 and 28 seconds on a random basis. The LED lamp was mounted inside a small tube that was pointed at the participant (Figure 3). This configuration ensured that approaching drivers would not be distracted by the light. The participant was instructed to monitor the light and when it was illuminated to respond by momentarily pressing a large round button (4-inch diameter) mounted to a cushioned knee board resting on the participant's left leg. A button press sounded an audible “ding” and extinguished the lamp. As long as the participant failed to respond, the lamp remained illuminated for up to 15 seconds and then it was automatically extinguished and the random delay sequence was initiated. Triggering of the light was accomplished via a radio frequency switch.

Figure 3. Participants’ View of Traffic Cones with Detailed Views (Inset) of the Secondary Task Signal Light in ON and OFF States

Experimenter computer: A laptop computer was used by researchers inside the SUV to capture all the responses for primary and secondary tasks through digital input channels. It controlled the triggering of the secondary task through similar digital outputs. All camera and data collection equipment in the observer vehicle were powered by auxiliary batteries to avoid interference or interruption from the SUV’s electronic systems.

Eye tracker: The eye tracker was a head-mounted ASL MobileEye system employing two cameras. One camera recorded a view of the participant’s right eye (using a reflective monocle) and the other camera recorded a view in the direction that the participant’s head was facing (Figure 4). Video from both cameras was captured on digital cassette tape using a SONY digital video recorder as well as on the Dell VOSTRO laptop computer connected to it. The eye tracker was calibrated for each participant using both physical adjustments to the eye tracker and software adjustments using the MobileEye software. During the session, real-time video on the laptop showed the view of the forward-looking camera with overlaid crosshairs indicating the point of the participant’s gaze, allowing the experimenter to ensure that proper calibration was maintained. Each subject's calibration profile was saved on the laptop in case future re-calibration was necessary.

Figure 4. Eye Tracking Apparatus

Motorcycle and rider: The motorcycle used for this study was a 2007 Honda Shadow Spirit with a 750cc engine and stock exhaust pipes. This model was chosen because its common cruiser design was judged by research staff to be prototypical and therefore unlikely to seem unusual to research participants who had been screened before entering the study to ensure that they did not have experience riding motorcycles. This model of motorcycle also was chosen because it has a single headlamp and because it does not have any windscreen or fairing, which would increase the apparent size of bike as seen from the front. A practical consideration in choosing this model was the ease of installing the experimental lighting treatments and other research equipment on the motorcycle. The motorcycle's normally illuminated amber clearance lamps (which also serve as turn signals) were disabled except for when the turn signal function was activated. This was done so that the effects of all the various white experimental lighting treatments could be studied without the possible confounding effects of having additional amber lights present.

The motorcycle rider was dressed in armored clothing to provide maximum protection in the case of a crash or evasive slide. Likewise, a full-face helmet was used for the study. Attire for the rider was intentionally nondescript and relatively dark so as not to draw attention from the participant. The helmet was a matte black color and the rider's outfit was black and gray to support this nondescript appearance. The goal was to isolate the effects of motorcycle lighting treatments from possible effects of conspicuous clothing.

Auxiliary lamps and related equipment: Two pairs of round chrome-plated, "bullet" style lamps and one pair of rectangular LED lamps were installed on the motorcycle as auxiliary lamps for the experimental conditions in this study (Figure 5). The spatial luminous intensity distribution of the auxiliary lamps was measured with the lamps installed on the motorcycle. These measurements are shown in Appendix B. Despite the relatively low power requirements of these lamps, the luminous intensities fell with the range recommended by Rumar (2003) for daytime running lights. Each pair of lamps was controlled by its own pushbutton switch mounted on the handlebars. The auxiliary lighting treatments included:

- One pair of auxiliary bullet lamps was mounted with lamp centers 40.5 inches above the ground, near the handle bars. The centers of the right and left lamps were 15 inches apart. These bullet lamp housings incorporated Philips 12 volt, 20 watt, quartz-halogen incandescent flood lamps with built-in 36° beam angle parabolic reflectors (MR-16 form factor).
- A second identical pair of auxiliary bullet lamps was mounted near the front forks with lamp centers 21 inches above the ground. The centers of the left and right lamps were 15.6 inches apart.
- One pair of Hella 12 volt LED lamps (Part No. 1004) was mounted vertically above the front axle (with the lamp centers 16.5 inches above the ground). Each of these lamps incorporated a black plastic enclosure housing six rows of two adjacent, high brightness LED's behind a flat forward lens assembly that was approximately 1 inch wide and 5 inches tall. Each lamp required approximately 2 watts of power at the nominal 12 volt voltage level. These lamps were manufactured in New Zealand and are used there as daytime running lights for passenger vehicles.
- A headlamp modulator kit (All-in-One Headlight Modulator and Solid State "Relay" Kit, model: AioSR15H4, available from Comagination.com) was installed inside the headlamp housing, and was wired to provide daytime modulation of the high beam only. An attached ambient light sensor insured that the modulation would not occur in low light conditions. Whenever the high beam was switched on during daylight conditions, it was modulated at 4 Hz in conformance with FMVSS 108 (Federal Motor Vehicle Safety Standards) (49 CFR Part 571.108 S7.9.4). The low beam was not modulated in this study.

The modulated high-beam headlamp and the low-beam headlamp were powered by the motorcycles' stock battery and electrical charging system. To provide a constant and consistent power supply for all of the additional auxiliary lamps, an additional electrical supply system was mounted on the motorcycle. This system was independent of the motorcycle's internal electrical system. The auxiliary lamps were powered by a 12V AGM storage battery with 35AH capacity located in rear saddlebag. Voltage to all auxiliary lamps was regulated at 12.8 volts to an accuracy of ±0.05% by means of a DC/DC converter (with a precision pull-up resistor) located between storage battery and lighting wiring harness.

Figure 6 shows the motorcycle rider passing through the study site with various combinations of auxiliary lamps illuminated. The center photo shows the baseline condition where only the low beam headlamp is illuminated. The two upper inset pictures show the upper (left) and lower (right) 20W round auxiliary lamps illuminated. The two lower inset pictures show both upper and lower 20W lamps illuminated (left) and the pair of 2W rectangular LED lamps illuminated (right).

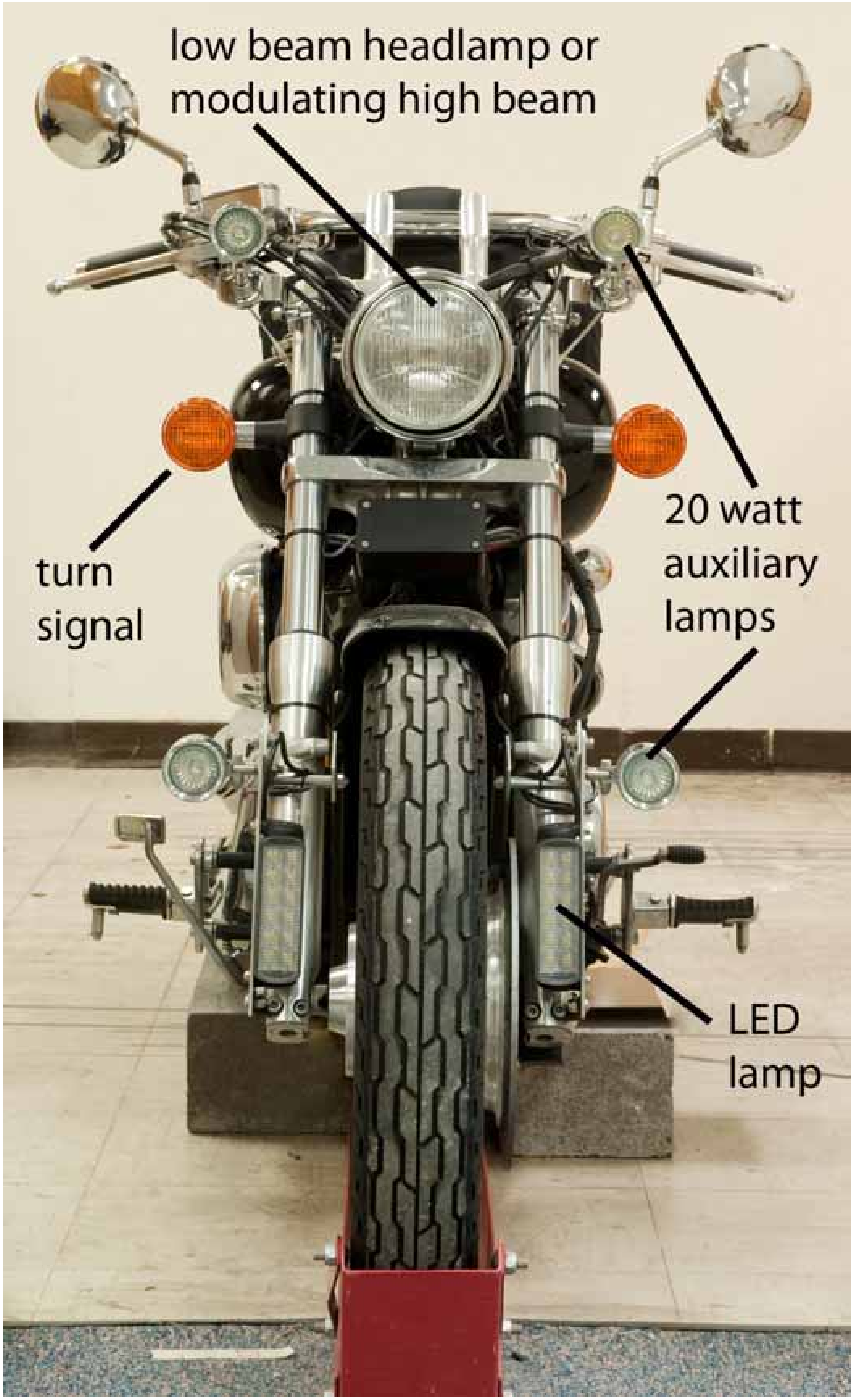

Figure 5. Frontal View of Motorcycle Showing Mounting Locations of Lamps

Figure 6. Motorcycle Rider Passing Study Site with Various Sets of Auxiliary Lamps Illuminated

Note that throughout this report the various forward lighting treatments included in the study have been abbreviated as shown in Table 1.

Table 1. Motorcycle Forward Lighting Treatments

Abbreviation	Lighting Condition
LB	Baseline condition (Low Beam headlamp only)
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)
HA	High-mounted Auxiliary lamps (plus low beam headlamp)
LHA	Low and High Auxiliary lamps (plus low beam headlamp)
LED	LED lamps (plus low beam headlamp)
MHB	Modulated High Beam headlamp

Video Recording: Video recording of activity at the study site and subsequent video data reduction were performed to determine motorcycle speed and to confirm the lighting treatment used on each pass. Three small analogue NTSC "bullet" cameras with 1/3 inch Sony CCD sensors and board camera lenses were used to capture images of passing traffic. All camera feeds were connected to a video multiplexer to allow multiple synchronized views to be captured within a single video output for recording and later coding and analysis. The video was recorded on a digital camcorder which provided portable recording and quick downloading.

Figure 7 shows a single frame from the multiplexed video recorded by the three cameras. One camera (A) with a wide angle lens was mounted to the experimental vehicle’s roof and was aimed upstream to capture an overall view of approaching traffic. A second camera (B) with a wide angle lens was covertly mounted to a crash barrel positioned in the median approximately 160 feet upstream from the research vehicle’s location, and was aimed across the street to capture the moment when approaching vehicles passed a reference point defined by the end of a guardrail. This point was called the “upstream reference point.” A third camera (C) with a wide angle lens was mounted to vehicle roof and aimed across the street to capture the moment when approaching vehicles reached the first traffic cone which represented the conflict point between an (imaginary) left turning vehicle and the approaching vehicle. This point was called the “conflict point.” In subsequent video data reduction the time elapsed between the moment when the motorcycle passed the upstream reference point and moment it passed the conflict point was used to determine its speed. Also, the moment that the motorcycle passed the conflict point was compared to the computer recorded time when the participant indicated that it was no longer safe to initiate a left turn. This required synchronization of the video time base with the experimenter’s computer recorded time for release of the “turn” button. Researchers took great care in setting up the position of the research vehicle and cameras each day so that the video images recorded would be as consistent as possible for all data collection sessions.

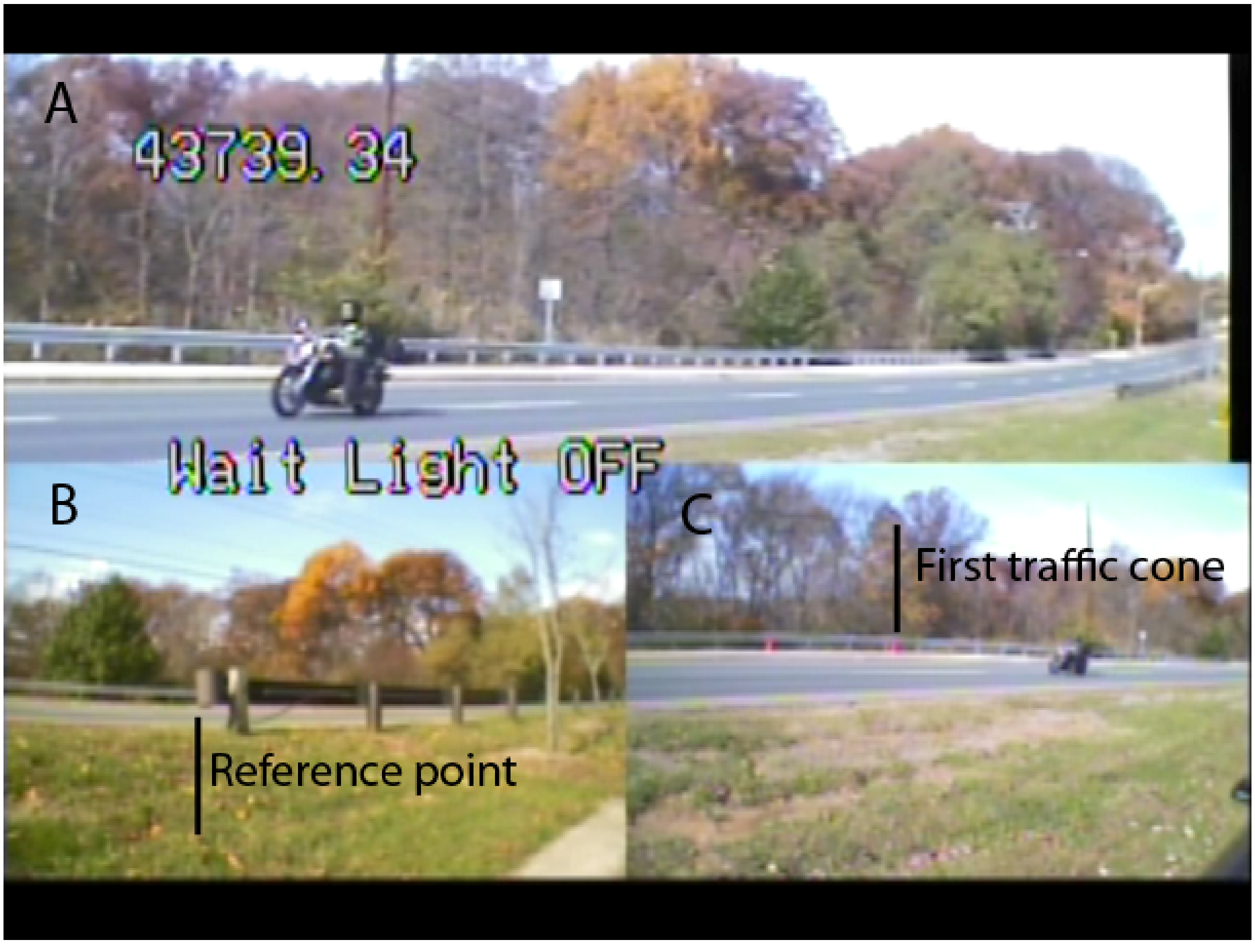

Figure 7. Multiplexed Video Views of Motorcycle Passing Study Site

2.5 Procedure

Each participant arrived at Westat's office and was told about the task that they would perform during the session. They were told that the general purpose of the study was to evaluate drivers' eye movements while they were deciding whether it was safe to make a left turn across the path of oncoming traffic. Participants were not informed before or during the experimental session that the study was comparing different motorcycle lighting treatments because this knowledge may have biased them to pay extra attention to motorcycles. After being informed of study procedures, the participant read and signed an informed consent form (Appendix C). The participant then viewed a Snellen visual acuity eye chart from a standard distance of 20 feet, using both eyes and without wearing glasses, though contact lenses could be worn. The participant was required to be able to read the letters on line 5 of the chart, equating to acuity of 20/40, which is the minimum acuity for which drivers in Maryland are not required to wear corrective lenses.

Next, the participant was driven to the field site by a research assistant. At the site the participant moved to the driver's seat of the research vehicle and was allowed to make seat adjustments to get into a comfortable driving position. Two experimenters were seated in the vehicle with the participant. One experimenter, seated in the front passenger seat, interacted with the participant, managed the eye tracking system, and discretely communicated with the confederate motorcyclist. The other experimenter, seated in the rear right seat, controlled and monitored the experimental apparatus.

The participant was then given a detailed description of the task to perform during the session. A researcher read instructions to the participant. The instructions script is provided in Appendix D. The primary task was to watch oncoming traffic and determine when they would be willing to begin turning left across traffic. Because there was not an actual destination road to turn left on, two red traffic cones were set up 18 feet apart from one another, on the sidewalk across the street to the participant's left and parallel to the road (Figure 3). The participant was told to imagine that the gap between the cones was a road that they could turn on. To indicate when they could start turning safely, the participant was instructed to press and hold a button. When they were no longer able to start turning, the participant was instructed to release the button. The participant was instructed to press the button every time that there was an opportunity to begin turning. When making turning judgments, the participant was also instructed to imagine that they were on paved, level asphalt rather than the grassy median. The participant then practiced making turning judgments by pressing the button.

The participant was also given a secondary task to perform while making turning judgments. A white light was placed atop the leftmost traffic cone representing the edge of the imaginary road for the participant to turn on. During the session, the light turned on at random intervals between 12 and 24 seconds. The participant was instructed to press a large button attached to their left leg every time the light turned on. The location of the secondary task light, to the left of the participant, required the participant to glance away from oncoming traffic toward the imaginary road. This secondary task required the participant to glance in the direction of the left turn and limited their ability to focus solely on oncoming traffic. The participant practiced making left turn judgments and simultaneously monitored the secondary task light until he or she was comfortable with the two tasks.

Once the participant was comfortable with the experimental task, the experimenter placed the eye tracker on the participant and calibrated it so that it would indicate the direction of the participant's glance. Once calibrated, the experimental session began.

The participant pressed and held one button when they were able to begin turning left, and pressed a second button whenever they noticed the light across the street to their left turned on. Once underway, the experimenter stepped out of the research vehicle briefly and used a cell phone to signal to a confederate motorcyclist to begin his series of rides past the experimental site in the flow of oncoming traffic. The motorcyclist entered the road far enough upstream to be able to reach traffic speed before entering the participant's field of view. Rather than traveling at a fixed speed on every pass, the motorcyclist attempted to ride at the approximate speed of other traffic. He also attempted to leave a large enough gap ahead of him so that the participant would feel comfortable making a left-turn ahead of the motorcycle, and he also tried to avoid being passed by other vehicles as he approached the study site. As anticipated, these strategies led to some speed variability of the motorcycle on different passes. During data analysis, statistical modeling techniques were used to control for the effects of motorcycle speed. The motorcyclist always passed the study site in traffic lane closest to the participant.

The motorcyclist rode past the experimental site six times; once with each of six lighting conditions presented in predefined, quasi-random order that was counterbalanced across participants. The goal of the motorcycle staging was to present traffic conditions where the participant would always indicate a left turn in front of the motorcycle. On some passes, traffic conditions were such that the participant did not indicate that they would be willing to turn in front of the motorcycle. On some of these occasions another vehicle entered the traffic stream from a side road, or a speeding vehicle passed the motorcycle before it reached the study site. All such "busted" trials were repeated at the end of the session. The motorcycle passed the participant once every four or five minutes, on average. After all six of the motorcycle lighting conditions were completed successfully, the experimenter ended the session. Most experimental session lasted about 30 minutes, but some were longer if some trials had to be rerun.

At the end of the data collection period, a research assistant drove the participant back to the Westat office. Once they arrived at the office, the research assistant conducted a short post-study discussion with the participant. She asked the following questions.

- *When you were doing the turning task, did you come up with any strategy or rule for making your decisions about when it was safe to go and not safe to go?*
- *Did you pick out a particular spot on the road or some other landmark that approaching vehicles passed to determine when it was no longer safe to go (explain)? If yes, at what point did you start using this strategy?*
- *Do you remember seeing any motorcycles while you were at the field site? (If yes) How many do you remember seeing? Did you notice anything unusual about the motorcycles that you saw?*

After answering these questions, the participant was fully debriefed about the specific purpose of the study and was paid for their time.

2.6 Data reduction

Video data from the location site camera and video data from the eye tracker were reduced by research staff using Interact (Mangold) video coding software. Video of each motorcycle pass was coded to determine the moment (video frame) when the motorcycle reached a reference point (163 feet) upstream from the traffic cones, and the moment when it reached the first traffic cone.

Despite attempts made in the field to replace occasional invalid trials (e.g. where the motorcycle was not in the proper position relative to other traffic) by re-running them, 9 of 192 final runs were excluded from further analysis after reviewing the video and participant response data. Data from these invalid runs were not included in any of the analyses described below.

Videos of the forward scene taken by the participant's head-mounted camera were combined with an overlaid graphic that defined the participant's direction of gaze based on the eye tracking data. The graphic overlay was a 50 pixel diameter red circle corresponding to a diameter of 4.7 degrees of angle within the visual scene. A single frame of this video is shown in Figure 8. In this figure the approaching motorcycle is located with the circular gaze indicator. The terms "gaze" and "gaze events" are used here to describe participants' looking behavior rather than "glances" or "fixations" because the coding scheme did not account for the exact point of fixation within each video frame, nor was there any distinction made between smooth pursuit eye movements and saccades. The goals for reducing the eye tracking data were to determine how frequently the participant looked in the direction of the motorcycle, how much total time was spend looking in the direction of the motorcycle, and how soon the participant first directed their gaze to the motorcycle. Using the circular gaze indicator provided a straightforward way to define when the participant was likely to be attending to the motorcycle for the purposes of data reduction. It should be noted that the participant could be attending to the motorcycle even when he or she was looking in another direction.

Twenty-six participants yielded usable eye tracking data. Eye tracking data for two participants were lost due to a computer error. Therefore, two additional participants were added to the study beyond the 30 originally planned. During the data reduction process, eye tracking data from four other participants were found to be unusable due to unstable tracking and loss of tracking calibration. In the field, researchers frequently encountered difficulties in obtaining and maintaining proper calibration for the eye tracker. High light levels and glare in the research vehicle were challenges for getting good eye tracking results. Some participants' eyes were much more difficult to track than others and it was not always clear to researchers why a particular participant's eyes were difficult to track.

Usable eye tracking data for 26 participants were reduced for video segments corresponding to six motorcycle passes per participant. Video coding segments were defined based on the moment that the motorcycle passed the upstream reference point. From this video frame, the video was reversed 10 seconds to ensure that the motorcycle was far upstream (and out of view) at the beginning of the segment. This point in time defined the beginning of the video coding segment. The end of the video coding segment was defined as the moment when the motorcycle passed the conflict point. Gaze events were coded based on the position of the gaze circle and the image shown by the head-mounted camera according to the following coding categories:

- Gaze on motorcycle (image of motorcycle falls within the gaze tracking circle)
- Gaze on another vehicle
- Gaze on any other region of the forward scene
- Gaze on Task 2 (characterized by a leftward head turn and/or view across the road to the left)
- Uncalibrated eye tracking (gaze tracking indicator disappears)

Transitions between these categories defined the beginning and end of gaze events. For example, if participant's gaze circle included the motorcycle, this event continued as long as the motorcycle remained within the circle. Smooth pursuit eye movements tracking the motorcycle and small amplitude saccadic eye movements near the motorcycle did not lead to a new gaze event as long as the motorcycle image remained within the gaze circle.

Occasionally, the gaze tracking circle disappeared for a few seconds. These epochs of missing gaze position data were coded as "Uncalibrated" if the head-mounted camera view was of the forward scene. However, whenever the head-mounted camera view was shifted to the left, (looking out the driver's side window across the street) the gaze event was coded as "Task 2," even if the gaze tracking circle was temporarily lost.

All video reduction files were checked for errors and data were corrected as necessary. Statistical analyses were carried out with SAS software. An alpha level of .05 was used to determine statistical significance.

Figure 8. View from Head-Mounted Camera with Circular Gaze Indicator

3. Results

All participants were observed to follow the researcher's instructions regarding the primary and secondary tasks and to share their attention appropriately between these two tasks. The purpose of the secondary task was to prevent the participants from continuously looking at approaching vehicles and it seemed to work well in that regard. Based on analyses of participants' eye glance data, the amount of time attending to the secondary task while the motorcycle was in the vicinity of the study site did not differ significantly between lighting treatments. Data regarding participants' responses to the secondary task were not analyzed further because they did not directly address the research questions of this study.

3.1 Perceived safety margin for turning left

In this study "safety margin" was defined as the elapsed time between the moment that the participant released the "turn button" to indicate that it was no longer safe to initiate a left turn, and the moment when the motorcycle arrived at the conflict point. This was the point where the two vehicles' paths would have intersected if a left turn maneuver actually had been carried out. If a driver of the research vehicle had actually initiated a left turn, it is likely that it would have taken a minimum of several seconds (perhaps 3 seconds) to clear the entire intersection and perhaps 2.5 seconds to clear the closest travel lane, which always contained the approaching motorcycle. Assuming a minimum buffer time of one second between the turning and approaching vehicle, a minimum "safe" safety margin would be approximately 3.5 to 4 seconds.

A key research question was to determine if participants provided a greater safety margin to an approaching motorcycle that had various enhanced forward lighting treatments as compared to the baseline condition where the motorcycle had only the low beam headlamp illuminated. Although data were obtained for 32 participants and 6 lighting treatments (total = 192 trials), nine of the trials were invalid, and were excluded from further analysis. Data were examined from the remaining 183 valid trials.

<u>Safety margins</u>

The distribution of observed safety margins for approaching motorcycles (shown in Figure 9) had a mean of 4.97 seconds and standard deviation of 1.91 seconds. Approximately 25 percent of the measurements were less than 3.44 seconds and 25 percent of the measurements were greater than 6.35 seconds. Researchers noticed that some participants tended to be consistently more conservative than others in their judgments about when it was safe to turn. All analyses reported here account for the repeated-measures design of the study and the tendency for data to be clustered by participant.

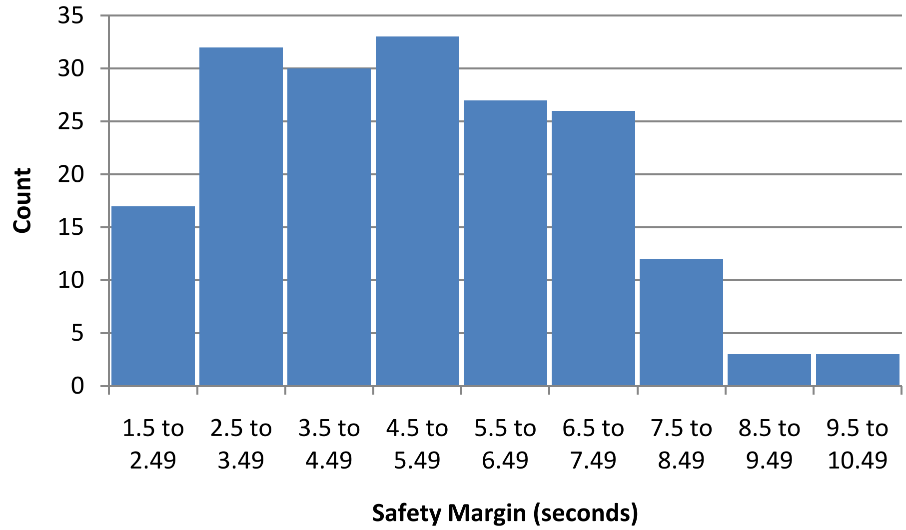

Figure 9. Distribution of Safety Margins for 183 Valid Trials

Motorcycle speeds measured between the upstream reference point and the conflict point varied between trials. The distribution of motorcycle speeds (shown in Figure 10) had a mean of 43.8 mph and a standard deviation of 2.7 mph.

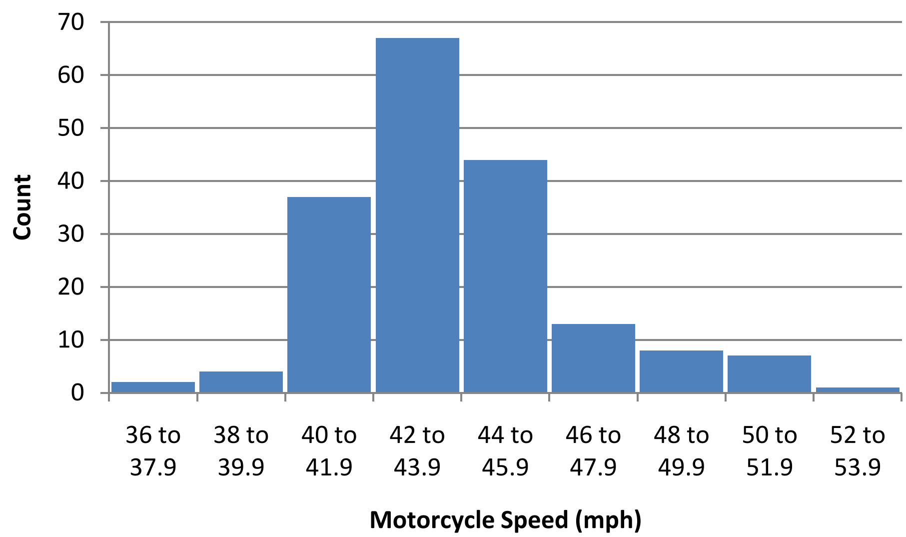

Figure 10. Distribution of Motorcycle Speeds for 183 Valid Trials

To determine whether any of the experimental lighting treatments were associated with significantly longer safety margins than the baseline condition, safety margins were modeled using the SAS Proc Mixed procedure. The model estimated effects for lighting conditions and motorcycle speed and controlled for data clustered within participants. The estimated coefficients for lighting treatments and motorcycle speed effects are shown in Table 2.

Table 2. Effects of Lighting Treatments and Motorcycle Speed on Safety Margins

Effect		Estimate	SE	DF	*P*
	Intercept	8.18	1.64	31	<.0001
	Motorcycle Speed	-.069	0.04	145	0.06
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	-.262	0.26	145	0.32
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	-.250	0.27	145	0.35
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	-.085	0.26	145	0.75
LED	LED lamps (plus low beam headlamp)	-.180	0.26	145	0.50
MHB	Modulated High Beam headlamp	.014	0.27	145	0.96
LB	Baseline condition (Low Beam headlamp only)	0			

None of the model coefficients for lighting treatments and motorcycle speed were statistically significant. However, the negative estimate for motorcycle speed nearly reached statistical significance suggesting that higher motorcycle speeds may be associated with lower safety margins. Further research may help to clarify this relationship.

The same statistical procedure was used to fit a second model to the data. This model included motorcycle speed, lighting treatments, and all of the lighting treatment by motorcycle speed interactions. None of these effects were statistically significant. Motorcycle speed and lighting treatment interaction effects were initially included in all analyses presented in this report, however, they were never statistically significant. Therefore, the final statistical models presented below do not include those interactions.

Cumulative frequency distributions for safety margins obtained with each of the different lighting treatments are shown in Figure 11. Note that the midpoints of the distributions are similar but that the distributions for experimental lighting treatments (thin lines) diverge from the distribution for the baseline treatment (thick line) at short (and at long) safety margins. Also note that for safety margins less than 4 seconds, all of the experimental lighting treatment distributions fall below the distribution for the baseline treatment. Apparent differences in the frequency of short safety margins for different lighting treatments were examined further by applying a statistical model that controlled for the effects of motorcycle speed and differences between participants. This analysis is described below.

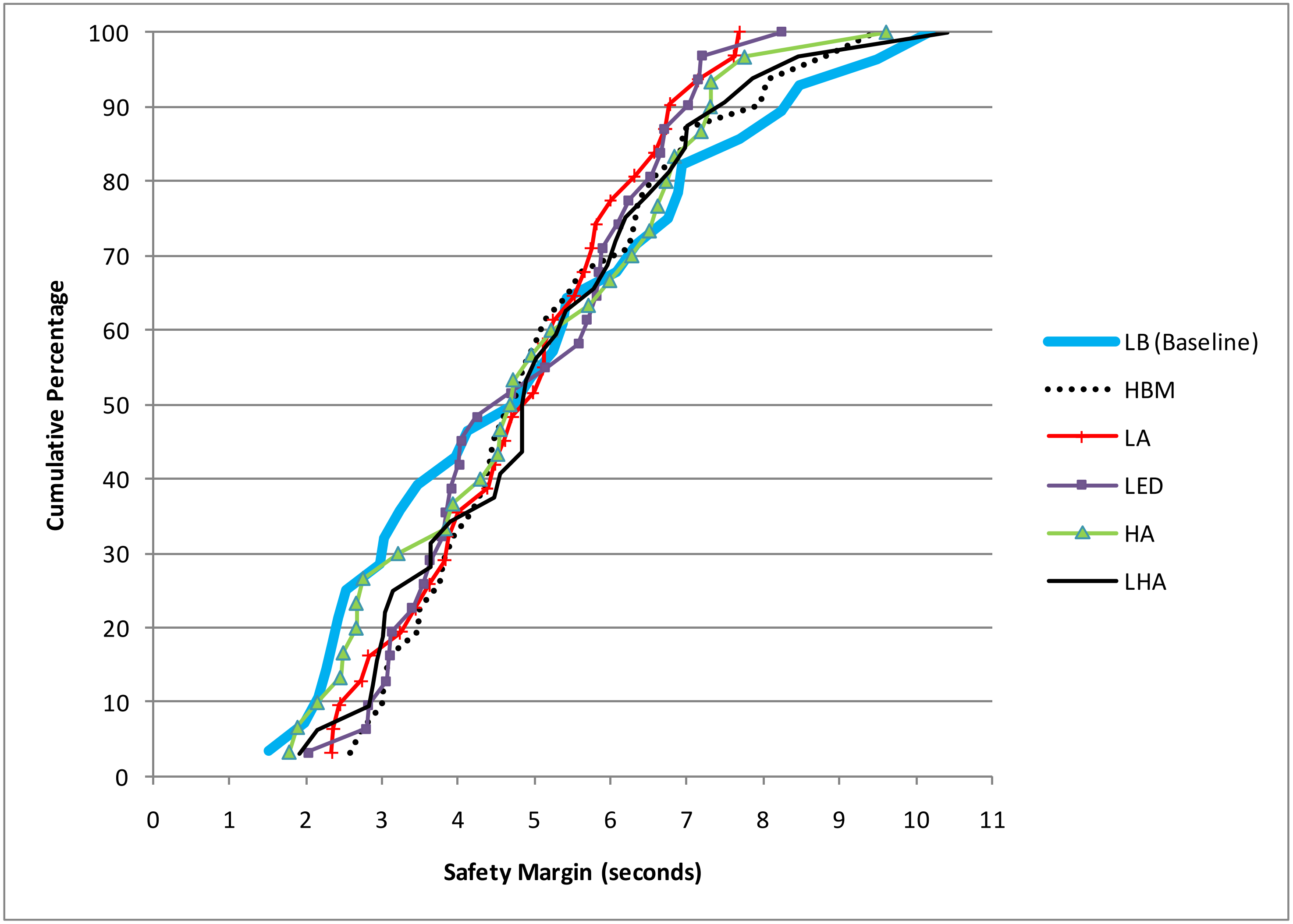

Figure 11. Cumulative Distributions for Safety Margins Obtained with Baseline and Experimental Lighting Treatments

Short safety margins

From the safety perspective, it is most important to examine whether the various experimental lighting treatments were more or less likely than the baseline condition to be associated with short safety margins. If participants were actually making left turns in front of the motorcycle, initiating the turn with only a few seconds remaining before the motorcycle's arrival at the conflict point may lead to a collision or may necessitate an emergency maneuver by one or both vehicles to avoid a collision.

Because the study took place at a location where there was no cross street or driveway, it was not possible to measure how much time would be required for the research vehicle to actually complete a left turn from its starting location. Also, the terrain of the study site included a small grassy slope (21 inch elevation) from the vehicle to the edge of the roadway. Participants were instructed to make their turn decisions by pretending that the entire area was paved and level. Given these complications, it was not possible to precisely estimate how much time would be required for a driver of the research vehicle to safely complete a left turn maneuver while leaving an adequate gap between the research vehicle and the approaching motorcycle. Therefore, for analysis purposes, short safety margins were defined based on the observed distribution of safety margins. Those trials where the measured safety margin fell within the first quartile (less than 3.44 seconds) were defined as short safety margins. Based on researchers' judgment of the study site, it is likely that left turns initiated while the motorcycle was less than 3.44 seconds away would result in the vehicles passing in close proximity of each other and such turns may require the motorcycle rider to brake or perform another evasive maneuver to avoid a collision.
For each lighting treatment, the observed percentage of trials that resulted in a short safety margin is shown in Table 3. The greatest proportion of trials with short safety margins occurred for the baseline condition and the smallest proportion of trials with short safety margins occurred with the MHB treatment.

Table 3. Trials with Short Safety Margins by Lighting Treatment

Lighting Treatment		Valid Trials	Short Safety Margins	Percentage of Trials with Short Safety Margins
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	31	6	19.4
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	30	9	30.0
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	32	8	25.0
LED	LED lamps (plus low beam headlamp)	31	7	22.6
MHB	Modulated High Beam headlamp	31	5	16.1
LB	Baseline condition (Low Beam headlamp only)	28	10	35.7

In order to test the statistical significance of these observed differences, the probability of obtaining a short safety margin (less than 3.44 sec) was modeled using logistic regression implemented with the SAS GENMOD procedure. This model specified a binomial underlying distribution for the outcome variable and a logit link function. The binary outcome variable (short safety margin versus not a short safety margin) was parameterized so that the model predicted the probability of obtaining a short safety margin (mean response) based on lighting treatments and motorcycle speed. A repeated measures (subject) effect was included to account for data clustered by participant. The model used GEE (Generalized Estimating Equations) for parameter estimation.

Table 4 shows the parameter estimates (and empirical standard error estimates) for lighting treatments and motorcycle speed. Motorcycle speed was not a statistically significant predictor of short safety margins. Parameter estimates for LA and MHB were statistically significant and the parameter estimate for LHA nearly reached statistical significance. The negative estimates for these experimental lighting treatment parameters suggest that having either LA or MHB treatments on the motorcycle reduced the probability of a short safety margin as compared to the baseline condition. Note that although not statistically significant, the estimated effects for the other experimental treatments (LHA, LED, HA) are also in the same direction (i.e. to reduce the probability of obtaining a short safety margin as compared to the baseline condition).

Table 4. Parameter Estimates for Modeling the Probability of a Short Safety Margin

Effect		Estimate	SE	Z	*P*
	Intercept	4.58	5.22	0.88	0.38
	Motorcycle Speed	-0.117	0.12	-0.98	0.33
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	-0.927	0.45	-2.05	0.04
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	-0.36	0.39	-0.92	0.36
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	-0.629	0.33	-1.90	0.06
LED	LED lamps (plus low beam headlamp)	-0.725	0.45	-1.62	0.10
MHB	Modulated High Beam headlamp	-1.17	0.52	-2.24	0.02
LB	Baseline condition (Low Beam headlamp only)	0			

3.2 Eye tracking results

Five dependent variables were created to characterize participants' looking behavior as it related to the approaching motorcycle. These included:

- Number of motorcycle gaze events – For each participant, the total number of motorcycle gaze events for each lighting treatment was computed.
- Mean motorcycle gaze duration - For each participant, the mean duration of motorcycle gaze events was computed for each lighting treatment.
- Total motorcycle gaze duration – For each participant, the sum of all motorcycle gaze durations was computed for each lighting treatment.

- First motorcycle gaze duration - For each participant, the duration of the first motorcycle gaze event was computed for each lighting treatment.
- Relative time of the first motorcycle gaze – For each participant, the starting time of the first motorcycle gaze event was examined for each lighting treatment. In order to construct a variable that was comparable across different motorcycle passes, this gaze starting time was subtracted from the time that the motorcycle reached the upstream reference point defined by the end of the guardrail (163 feet upstream from the conflict point). The resulting variable was called the "relative time of the first motorcycle glance." Positive values indicate that the motorcycle was more distant than the upstream reference point when the first glance at the motorcycle occurred and negative values of this variable indicate that the first glance to the motorcycle occurred when the motorcycle was closer to the participant than the upstream reference point. It should be noted that the upstream reference point was used rather than the conflict point because determination of this time was more certain in the video record. Occasionally, the view from the head-mounted camera did not show the motorcycle at the moment that it passed the conflict point.

It was hypothesized that relative to the baseline condition the experimental lighting treatments would be more conspicuous (effective at capturing participants' visual attention) and therefore would capture participants' attention earlier (when the motorcycle was further away). As compared to the baseline condition, it was hypothesized that the experimental lighting treatments would result in a greater number of motorcycle gaze events, longer duration motorcycle gaze events, longer total motorcycle gaze duration, longer first motorcycle gaze duration, and that the first glance at the motorcycle would occur when the motorcycle was further away in terms of time (greater relative time of first motorcycle gaze event as defined above).

<u>Number of gazes at the motorcycle</u>
The frequency of motorcycle gaze events across the 26 participants with usable eye tracking data was analyzed for the six lighting treatments. There were four individual runs with missing data due to invalid traffic conditions as described above. Table 5 shows the number of valid trials (N) per lighting treatment completed by these 26 participants. The mean, standard deviation, minimum, and maximum observed frequency of gazes at the motorcycle per condition are also shown.

Table 5. Mean Number of Motorcycle Gazes per Participant by Lighting Condition

Lighting Condition		N	M	SD	Min	Max
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	26	3.24	1.99	0	8
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	25	3.44	2.14	0	9
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	26	3.04	1.71	0	7
LED	LED lamps (plus low beam headlamp)	26	3.12	1.70	0	7
MHB	Modulated High Beam headlamp	25	3.24	1.64	0	6
LB	Baseline condition (Low Beam headlamp only)	24	3.29	1.65	0	6

Mean gaze frequencies were modeled using the SAS Proc Mixed procedure. The model estimated effects for lighting conditions and motorcycle speed, and controlled for data clustered within participants. None of the experimental lighting treatments differed significantly from the baseline condition for the mean number of motorcycle gaze events. The effect of motorcycle speed was also not significant.

It should be noted that based on the eye tracking data, there were ten valid trials in which the participant's gaze never fell on the motorcycle. A single participant accounted for four of these trials. The trials with no motorcycle gaze events were distributed across lighting treatment conditions; each treatment had one or two trials with no motorcycle gaze events except for the LA treatment, which had 3 trials with no motorcycle gaze events.

Average duration of gazes at the motorcycle

A total of 142 mean motorcycle gaze durations were analyzed using the SAS Proc Mixed procedure. The model estimated effects for lighting conditions and motorcycle speed, and controlled for data clustered within 26 participants. The estimated coefficients for the model parameters are shown in Table 6. Motorcycle speed was not statistically significant. Among the lighting treatments, only the coefficient for LHA was statistically significant. The least squares means and standard errors estimated from the model are shown in Figure 12. Note that all of the experimental lighting treatments produced longer mean gaze durations than the baseline treatment, although most of these differences were not statistically significant. The results indicate that the LHA lighting treatment was associated with significantly longer gazes at the motorcycle than the baseline condition. The mean gaze duration for the LHA condition was 1.63 seconds as compared to 1.04 seconds for the baseline condition (LB).

Table 6. Parameter Estimates for Modeling Mean Motorcycle Gaze Duration

Effect		Estimate	SE	DF	*p*
	Intercept	1.29	1.47	25	0.38
	Motorcycle Speed	-.006	0.03	110	0.85
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	0.08	0.26	110	0.76
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	0.22	0.26	110	0.40
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	0.59	0.26	110	0.02
LED	LED lamps (plus low beam headlamp)	0.10	0.26	110	0.71
MHB	Modulated High Beam headlamp	0.34	0.26	110	0.19
LB	Baseline condition (Low Beam headlamp only)	0			

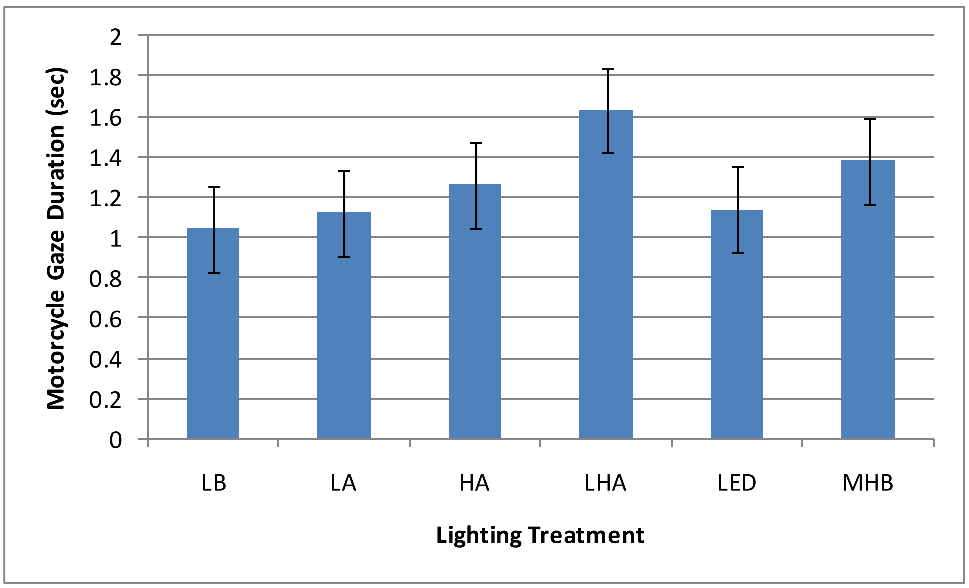

Figure 12. Least Squares Mean Motorcycle Gaze Duration by Lighting Condition

Total time spent gazing at the motorcycle per trial

A similar analysis was conducted for the total duration of motorcycle gazes. For each participant, the sum of all motorcycle gaze durations was computed for each trial. The 142 motorcycle gaze duration sums were analyzed as described above. None of the effects for lighting treatments or motorcycle speed reached statistical significance although it was noted that the pattern of least squares means produced from this model for sums of gaze durations was similar to that for the mean motorcycle gaze durations. Participants were estimated to spend a total of 3.3 seconds gazing at the approaching motorcycle in the baseline condition and a total of 4.0 seconds gazing at the motorcycle in the LHA condition and 4.0 seconds in the MHB condition.

Duration of the participant's first motorcycle gaze event

The duration of each participant's first motorcycle gaze event per trial was modeled in the same way that the mean motorcycle gaze duration was modeled (as described above). The estimated coefficients for lighting treatment effects and motorcycle speed are shown in Table 7. Motorcycle speed was not statistically significant. Among the lighting treatment effects, all experimental treatment had positive estimates indicating longer gazes as compared to the baseline condition. However, only the coefficient for LHA reached statistical significance. The least squares means and standard errors estimated from the model are shown in Figure 13. As was the case for mean motorcycle gaze durations, the results of this analysis indicate that only the difference between treatment LHA and the baseline condition (LB) was statistically significant. The modeling results indicate that the first gaze at the motorcycle was 0.74 seconds longer for the LHA lighting treatment as compared to the baseline condition.

Table 7. Parameter Estimates for Modeling Duration of First Gaze at Motorcycle

Effect		Estimate	SE	DF	*P*
	Intercept	2.50	2.00	25	0.22
	Motorcycle Speed	-0.03	0.04	110	0.50
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	0.25	0.38	110	0.51
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	0.50	0.38	110	0.19
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	0.74	0.38	110	0.05
LED	LED lamps (plus low beam headlamp)	0.23	0.38	110	0.54
MHB	Modulated High Beam headlamp	0.25	0.38	110	0.52
LB	Baseline condition (Low Beam headlamp only)	0			

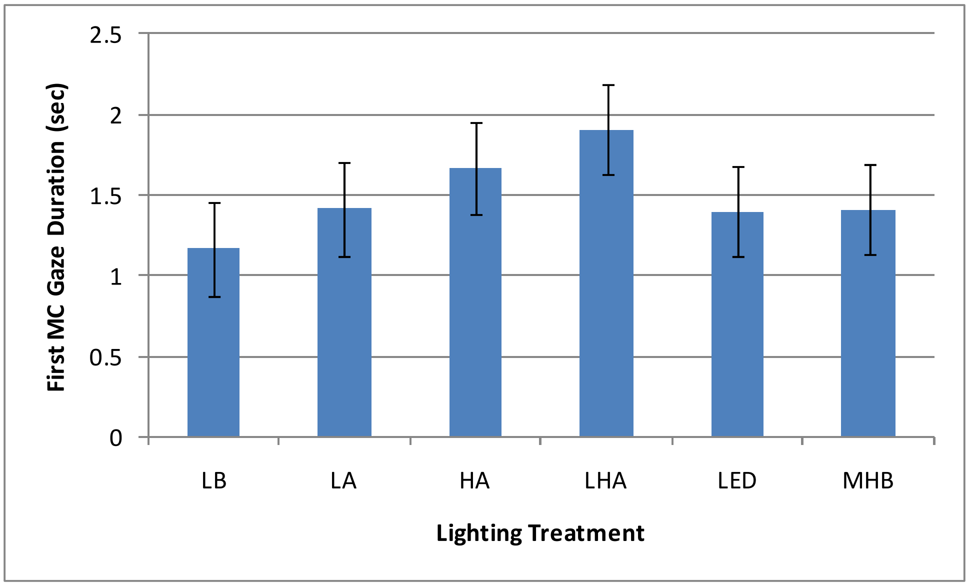

Figure 13. Mean Duration of First Motorcycle Gaze by Lighting Condition

Time when participant's first glance at motorcycle occurred

In order to determine whether any of the experimental lighting treatments would attract participants' attention earlier during the motorcycle's approach as compared to the baseline condition, the starting time of the first motorcycle gaze event was examined for each lighting treatment. For each trial, the relative time of the participant's first glance at the motorcycle was computed by subtracting the time that the participant first fixated on the motorcycle from the time that motorcycle passed the upstream reference point. Larger values of this relative time variable indicate that the participant first gazed at the motorcycle earlier (and further upstream).

For each participant, the relative time of the first gaze at the motorcycle was computed for each lighting condition. The 142 relative times when the first glance at the motorcycle occurred were analyzed with a similar model to those described above. Least squares means for different lighting treatments ranged from 5.2 seconds (LA) to 4.1 seconds (HA), with the baseline condition at 4.4 seconds. However, none of the effects for lighting treatments and motorcycle speed reached statistical significance.

3.3 Debriefing discussions

Based on discussions with participants following their return from the field site, it was apparent that none of them were aware that the true purpose of the study was to compare their reactions to approaching motorcycles with different lighting treatments. All participants reported seeing motorcycles, and their estimates of the number of motorcycles ranged from 2 to 15. Twelve participants remembered seeing only two or three motorcycles, even though the research motorcycle had actually passed by them at least six times.

In response to the question, "Did you notice anything unusual about the motorcycles that you saw?," fourteen of the participants said that they did not notice anything unusual about the motorcycles that they saw. Six participants mentioned that one or more of the motorcycles had a flashing or flickering light. Only one of the other participants mentioned anything about the motorcycles' lights. She said that it was unusual to see motorcycles with their lights on.

At the beginning of the debriefing discussion (prior to any discussion about motorcycles) the researcher asked the participant the following two questions:

- *When you were doing the turning task, did you come up with any strategy or rule for making your decisions about when it was safe to go and not safe to go? (please explain).*
- *Did you pick out a particular spot on the road or some other landmark that approaching vehicles passed to determine when it was no longer safe to go? (please explain).*

Based on the responses to these questions about strategies for doing the primary task, researchers later classified participants based on their use of landmarks as either a "landmark" or a "non-landmark" participant. Some landmark participants mentioned only that they had performed their turn decision task by referencing a fixed landmark on or near the roadway upstream from the traffic cones. Other "hybrid" landmark participants mentioned that they had used a landmark, but also mentioned other factors such as vehicle speed, other approaching traffic in the vicinity, approaching vehicle type, etc. The non-landmark participants did not report using any fixed landmark. They said that they had based their turn decisions on approaching vehicles' speed alone or had used some type of global strategy based on the dynamic situation (such as speed and distance) or they did not articulate any clear strategy but said that they did not use a landmark. Based on this classification, there were 21 landmark participants (15 with valid eye movement data) and 11 non-landmark participants (all 11 with valid eye movement data).

3.4 Reanalysis of data based on participants' self-reported strategies for estimating when it was safe to turn

Safety margin and motorcycle gaze variables described above were modeled separately for landmark and non-landmark participants. The general hypothesis was that participants who used a landmark strategy would watch for approaching vehicles and would release the turn button (indicating that it was no longer safe to turn) when an approaching vehicle reached some participant-defined fixed landmark. Therefore, the safety margins recorded for landmark participants were predicted to depend strongly on motorcycle speed. Faster motorcycle speeds would be associated with smaller safety margins under this hypothesis. For non-landmark participants, motorcycle speed was not predicted to influence safety margins. Non-landmark participants were hypothesized to be more likely than landmark participants to fully account for motorcycle speed in their judgments of when it was no longer safe to initiate a turn. It was hypothesized that non-landmark participants would base their "no-go" decisions on estimates of the amount of time remaining until the approaching vehicle arrived rather than basing their decisions on whether or not an approaching vehicle had passed a fixed reference point. Therefore, motorcycle speed was predicted to be a non-significant effect in models of non-landmark participants' safety margins.

With respect to effects of motorcycle lighting treatments, it was hypothesized that if the experimental treatments affect perceived motorcycle speed, or perceived time until arrival of the motorcycle at the conflict point, then the non-landmark participants would be influenced by the treatments but that the landmark participants would not. Also, if the experimental lighting treatments were truly effective at increasing some participants' safety margins, a statistical model that excludes the landmark participants may be more likely to reveal significant effects of motorcycle lighting treatments as compared to models that include both landmark and non-landmark participants.

3.4.1 Analysis of safety margins for landmark and non-landmark participants

The distribution of safety margins for landmark participants is shown in Figure 14 and the distribution of safety margins for non-landmark participants is shown in Figure 15. In comparison to the distribution for landmark participants, the distribution for non-landmark participants is shifted toward shorter safety margins and is positively skewed.

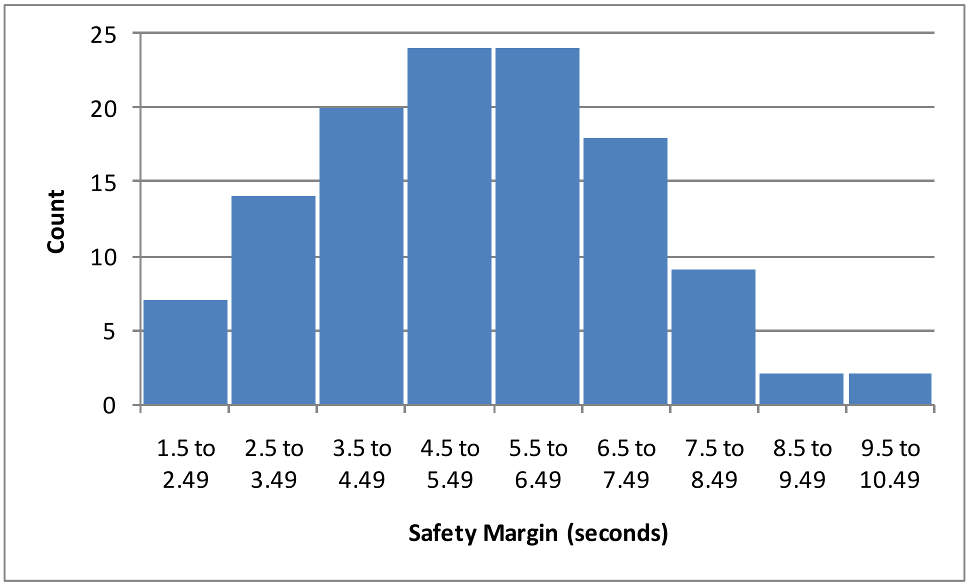

Figure 14. Distribution of Safety Margins for Landmark Participants

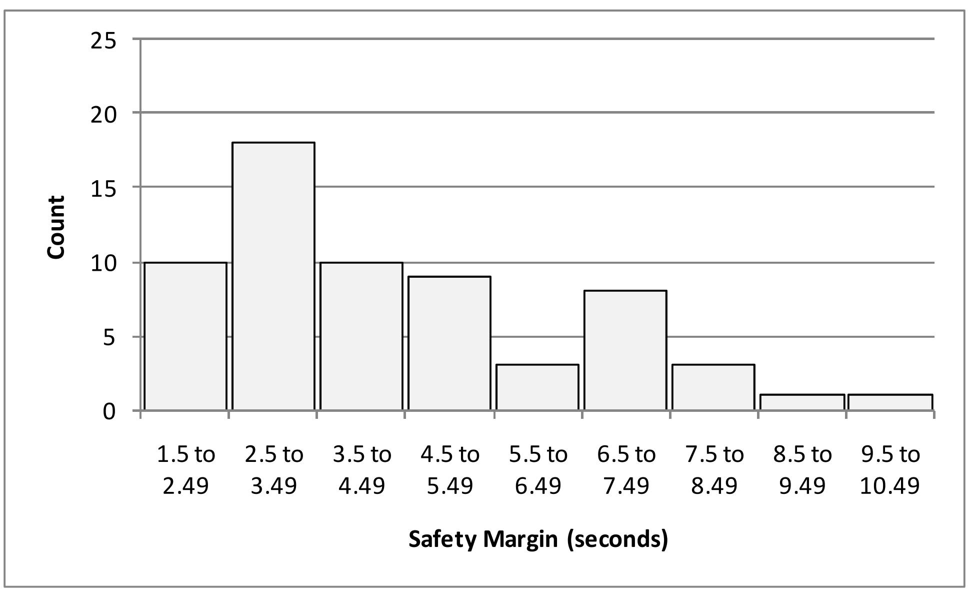

Figure 15. Distribution of Safety Margins for Non-Landmark Participants

To determine whether any of the experimental lighting treatments were associated with significantly longer safety margins than the baseline condition, safety margins for landmark participants were modeled separately using the SAS Proc Mixed procedure. The models estimated effects for lighting conditions and motorcycle speed and controlled for data clustered within participants. As shown in Table 8, safety margins for landmark participants were predicted by motorcycle speed. The statistically significant negative estimate for motorcycle speed implies that higher motorcycle speeds were associated with a smaller safety margins and is consistent with our prediction for participants who used a landmark strategy. Based on the model estimates, none of the lighting treatments significantly increased safety margins as compared to the baseline condition.

Table 8. Parameter Estimates for Modeling Mean Safety Margins by Lighting Treatment and Motorcycle Speed (Landmark Participants)

Effect		Estimate	SE	DF	*p*
	Intercept	11.02	1.88	20	<.0001
	Motorcycle Speed	-0.129	0.04	93	0.003
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	-0.259	0.29	93	0.38
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	0.007	0.30	93	0.98
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	-0.150	0.29	93	0.60
LED	LED lamps (plus low beam headlamp)	0.034	0.29	93	0.91
MHB	Modulated High Beam headlamp	0.197	0.29	93	0.51
LB	Baseline condition (Low Beam headlamp only)	0			

A similar analysis was performed on safety margin data from non-landmark participants. In this case, the effect of motorcycle speed was not significant ($p = 0.85$) as would be expected for participants who account for motorcycle speed in their judgments of when it is safe to turn. None of the effects of lighting treatments reached statistical significance.

Short safety margins for landmark and non-landmark participants

As defined above, short safety margins were those less than 3.44 seconds. For the group of landmark participants 20 of 116 trials (17%) resulted in short safety margins while for non-landmark participants 25 of 67 trials (40%) resulted in short safety margins.

The probability of obtaining a short safety margin was modeled separately for landmark and non-landmark participants using logistic regression implemented with the SAS GENMOD procedure as described above. The models predicted the probability of obtaining a short safety margin based on lighting treatments and motorcycle speed. A repeated measures (subject) effect was included to account for data clustered by participant.

Table 9 shows the landmark participants' parameter estimates (and empirical standard error estimates) for lighting treatments and motorcycle speed. For this group of participants, motorcycle speed was a statistically significant predictor of short safety margins. The negative sign of the estimate indicates that as motorcycle speed increased the probability of obtaining a short safety margin decreased. Note that the direction of this effect was not expected based on the previous analysis of landmark participants' safety margins which indicated that as motorcycle speed increased safety margins decreased.

Parameter estimates for LA, LED, and MHB were statistically significant and the parameter estimate for LHA very nearly reached statistical significance. The negative estimates for these effects indicate that having these experimental lighting treatments on the motorcycle significantly reduced the probability of obtaining a short safety margin as compared to the baseline condition.

Table 9. Parameter Estimates for Modeling the Probability of a Short Safety Margin for Landmark Participants

Effect		Estimate	SE	Z	*P*
	Intercept	14.13	4.77	2.96	0.003
	Motorcycle Speed	-0.339	0.11	-3.22	0.001
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	-1.809	0.78	-2.32	0.02
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	-0.742	0.56	-1.32	0.19
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	-0.870	0.45	-1.92	0.055
LED	LED lamps (plus low beam headlamp)	-1.748	0.75	-2.33	0.02
MHB	Modulated High Beam headlamp	-1.672	0.70	-2.40	0.02
LB	Baseline condition (Low Beam headlamp only)	0			

A similar analysis was conducted to model the probability of obtaining a short safety margin with non-landmark participants' data. The results indicated that motorcycle speed was not a statistically significant predictor of short safety margins. Also, none of the estimates of effects for lighting treatments in the model were statistically significant indicating that for non-landmark participants, the experimental motorcycle lighting treatments were not predictors of obtaining a short safety margin as compared to the baseline condition.

3.4.2 Eye tracking data for landmark and non-landmark participants

Average duration of motorcycle gazes for landmark and non-landmark participants

A total of 87 mean motorcycle gaze durations from 15 landmark participants were analyzed using the SAS Proc Mixed procedure. The model estimated effects for lighting conditions and motorcycle speed, and controlled for data clustered within participants. Least squares means for the different lighting treatments ranged from 1.17 sec. (LED) to 1.55 sec. (HA) with the baseline condition at 1.20 sec. However, none of the effects for lighting treatments were statistically significant and the effect of motorcycle speed also was not statistically significant.

A similar analysis was conducted for 55 mean motorcycle gaze durations measured from 11 non-landmark participants. Table 10 shows the parameter estimates (and empirical standard error estimates) for lighting treatments and motorcycle speed. As for the landmark participants, motorcycle speed was not a statistically significant predictor of motorcycle gaze duration for non-landmark participants. However, the results indicate that for the non-landmark participants, LHA lighting treatment was predictive of significantly longer gazes at the motorcycle as compared to the baseline condition. The least squares mean motorcycle gaze duration for the LHA lighting treatment was 2.21 seconds as compared to 0.77 seconds for the baseline condition (LB). None of the estimated effects for other experimental lighting treatments were statistically significant. It was noted that the least squares mean gaze duration for the MHB treatment was 1.35 seconds, nearly 0.6 seconds longer than the baseline condition, although this difference did not reach statistical significance, perhaps due to the small sample size.

Table 10. Parameter Estimates for Modeling Mean Motorcycle Gaze Duration (Non-Landmark Participants)

Effect		Estimate	SE	DF	*P*
	Intercept	0.577	2.63	10	0.83
	Motorcycle Speed	0.004	0.06	38	0.94
LA	Low-mounted Auxiliary lamps (plus low beam headlamp)	0.208	0.42	38	0.62
HA	High-mounted Auxiliary lamps (plus low beam headlamp)	-0.051	0.46	38	0.91
LHA	Low and High Auxiliary lamps (plus low beam headlamp)	1.435	0.44	38	0.002
LED	LED lamps (plus low beam headlamp)	0.326	0.42	38	0.45
MHB	Modulated High Beam headlamp	0.577	0.42	38	0.18
LB	Baseline condition (Low Beam headlamp only)	0			

Total time spent gazing at the motorcycle per trial for landmark and non-landmark participants

Separate analyses were conducted for landmark and non-landmark participants to examine the total duration of motorcycle gazes on each trial. For each participant, the sum of all motorcycle gaze durations was computed for each trial. The 87 motorcycle gaze duration sums for landmark participants were analyzed as described above. A negative estimate was obtained for the effect of motorcycle speed suggesting a tendency for higher motorcycle speeds to be associated with shorter total time spent looking at the motorcycle, however this effect was not statistically significance ($p = 0.13$). None of the effects for lighting treatments were statistically significant.

Only 55 motorcycle gaze duration sums were available to be analyzed for non-landmark participants. For these data, the effect of motorcycle speed did not approach statistical significance ($p = 0.84$). As was the case for results from the analysis of mean gaze durations, the total time spent gazing at the motorcycle was significantly longer for the LHA lighting treatment as compared to the baseline condition. Based on the least square means generated by the analysis, non-landmark participants spent 4.62 seconds gazing at the motorcycle per trial with the LHA lighting treatment as compared to 2.53 seconds in the baseline condition. None of the other effects for experimental lighting treatments reached our criterion for statistical significance, although the MHB condition (4.08 seconds) came close (p = .10).

Figure 16 shows the total time spent gazing at the motorcycle per trial for landmark participants and non-landmark participants for each lighting condition based on the least squares means from the two statistical models. Error bars represent +/- 1 standard error of the mean. The results suggest the landmark participants were less influenced by the motorcycle's lighting treatment as compared to the non-landmark participants (although some of the increased variability in non-landmark data may be due to the smaller sample size for this group).

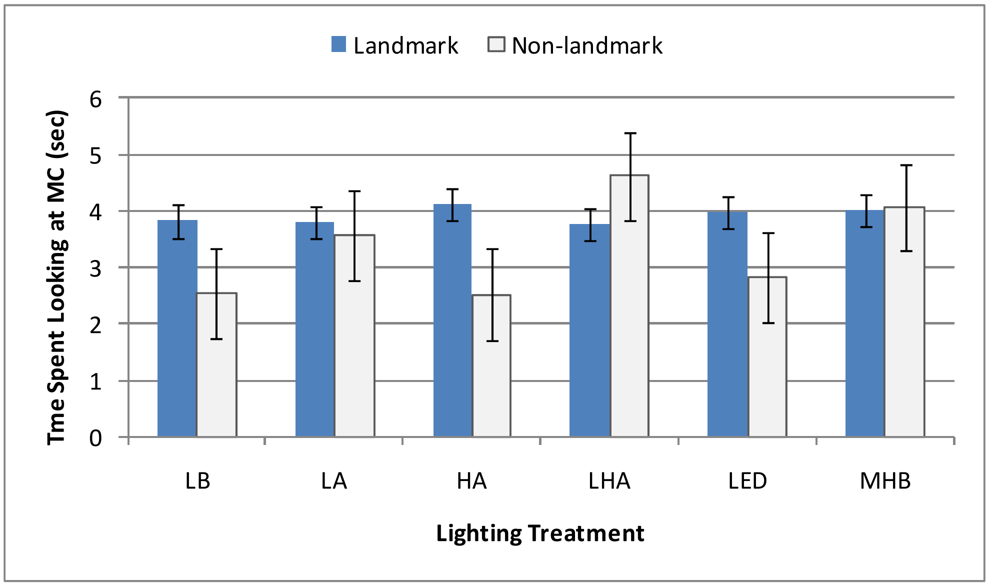

Figure 16. Total Time Gazing at Motorcycle for Landmark and Non-Landmark Participants by Lighting Treatment

<u>Duration of landmark and non-landmark participants' first motorcycle gaze events</u>
Two separate analyses were conducted for landmark and non-landmark participants to examine the duration of each participant's first motorcycle gaze event per trial. These statistical models were similar to those described above and included effects of lighting treatment and motorcycle speed as predictors. For the 15 landmark participants with valid data, motorcycle speed was not a statistically significant predictor of first motorcycle gaze duration, and neither were the effects of the experimental lighting treatments.

For the non-landmark participants, motorcycle speed was not a statistically significant predictor of first motorcycle gaze duration. None of the effects for lighting treatments reached statistical significance with only 11 participants in this group, although the LHA treatment effect was nearly statistically significant (p = 0.06). The least squares mean motorcycle gaze duration for LHA was 2.16 seconds as compared to 1.03 seconds for the baseline condition.

Time when landmark and non-landmark participants' first glances at the motorcycle occurred

Two separate analyses were conducted for landmark and non-landmark participants to examine the time when each participant first glanced at the approaching motorcycle on each trial. The analyses were similar to those described above. Results from the analyses showed that neither the data for the landmark group nor the data for the non-landmark group depended significantly on motorcycle speed or lighting treatments.

4. Discussion

4.1 Summary and interpretation of results

A key research question was to determine whether participants provided a greater safety margin to an approaching motorcycle with various enhanced forward lighting treatments as compared to the baseline condition where the motorcycle had only the low beam headlamp illuminated (LB). The results did not indicate that mean safety margins given by the "left-turning" participants to approaching motorcycles were significantly different for experimental lighting treatments as compared to the baseline treatment. This result is consistent with the previous NHTSA-sponsored study on motorcycle conspicuity (Pierowicz, Gawron, Wilson, & Bisantz, 2011). As predicted, safety margins for participants who said that they used a landmark strategy were associated with the motorcycle's speed. Faster motorcycle speeds were associated with shorter safety margins. Non-landmark participants who did not use fixed roadside objects to judge when it would be safe to turn seemed to compensate for variability in approaching vehicles' speed because motorcycle speed was not a significant predictor of their safety margins.

The mean safety margins observed in this study may be considered as consensus judgments of 32 participants about the last moments that it would be safe to turn. Therefore, those individual safety margin measurements which fell within the bottom quartile of the distribution (< 3.44 seconds) would be considered unsafe by a majority of the participants. Short, unsafe safety margins occur occasionally in natural traffic flows when a turning driver initiates a turn in front of an approaching motorcycle and the approaching motorcycle is too close in terms of its arrival at the intersection. From a safety perspective, it would be desirable if enhanced lighting treatments on the motorcycle could help to reduce the frequency of these unsafe turning maneuvers.

The present results showed that some of the experimental lighting treatments may provide a safety benefit for motorcycles because they were less likely to be associated with short safety margins as compared to the baseline lighting condition. Having either illuminated lower auxiliary lamps (LA) or modulated high beam headlamp (MHB) on the motorcycle significantly reduced the probability of obtaining a short safety margin as compared to the baseline condition with an illuminated low beam headlamp (LB). There was also an indication that the four-lamp enhanced lighting treatment (LHA) reduced the probability of obtaining a short safety margin as compared to the baseline condition but this result was not quite statistically significant (p = 0.06). These results indicate that enhancing the forward lighting on motorcycles during the daytime may be a promising countermeasure for reducing "left turn across path" crashes.

The perceptual mechanisms by which the experimental lighting treatments affected participants' tendency to give short safety margins are not clear, although they may not be related to speed perception. It was hypothesized that landmark participants who based their judgments of when it was no longer safe to turn on the juxtaposition of an approaching vehicle with some feature of the roadway scene would not pay much attention to the approaching vehicle's speed and therefore would not be influenced by the experimental lighting treatments to the extent that these treatments enhanced or biased speed perception. As predicted, mean safety margins given by landmark participants were related to motorcycle speed and these results indicated that landmark participants did not fully compensate for the speed of the approaching motorcycle. For landmark participants (but not for non-landmark participants) the probability of obtaining a short safety margin was also significantly related to motorcycle speed. Although in this case, higher motorcycle speeds were associated with lower probability of obtaining a short safety margin.

Participants who did not rely on a simple landmark strategy were expected to be more strongly influenced by the experimental lighting treatments if these treatments affected perception of speed and/or perception of approaching vehicles' arrival times. Results from separate analyses for landmark and non-landmark participants showed that landmark participants were more strongly influenced by the lighting treatments than non-landmark participants. In fact, data from non-landmark participants, when analyzed separately, did not show any statistically significant effects of lighting treatments for predicting the occurrence of short safety margins. Taken together, these results suggest that the perceptual mechanism by which the experimental lighting treatments reduced the probability of obtaining short safety margins is not related to speed perception.

It is possible that the different proportions of short safety margins observed for different lighting treatments are due to differences in conspicuity (tendency to capture and hold participants' attention) rather than to perceptual mechanisms necessary for judging time to arrival. Lighting treatments with less conspicuity may occasionally fail to capture the participant's attention or may result in a slower response from the participant. There was some evidence that the experimental lighting treatments enhanced the conspicuity of the motorcycle as defined by measures of participants' looking behavior. However, only a few of the differences observed between the experimental treatments and the baseline condition were statistically significant. The frequency of gazes directed toward the motorcycle and the total time spent looking at the motorcycle per trial did not vary significantly between treatment and baseline conditions, but the mean duration of gazes at the motorcycle was significantly longer for the LHA treatment as compared to the baseline condition. Also, the very first gaze toward the motorcycle in each trial was significantly longer for the LHA treatment as compared to the baseline condition. Another measure of conspicuity, the time when the first gaze at the motorcycle occurred, did not show any significant differences between the experimental lighting treatments and the baseline condition. Apparently, the experimental lighting treatments did not prompt participants to look at the motorcycle any earlier during its approach than the baseline treatment.

When landmark and non-landmark participants' data were analyzed separately, none of the lighting treatment effects on gaze measures were statistically significant for landmark participants, but for non-landmark participants the LHA treatment was associated with significantly longer motorcycle gazes, longer initial gazes at the motorcycle, and longer total time looking at the motorcycle as compared to the baseline condition. Perhaps the landmark participants tended to cognitively process information from approaching vehicles systematically but narrowly, considering only the approaching vehicle's instantaneous position in relation to a landmark. Non-landmark participants, whose strategies for the primary task may have included comparing time to arrival estimates for approaching vehicles with estimates of their own vehicle's time to complete a turn maneuver, may have performed a deeper analysis of the approaching vehicle's features including lighting.

It is interesting to note that most of the landmark participants said that they began using that strategy early on in the session. Perhaps the secondary task used in this study was sufficiently difficult that it prompted participants to manage their workload by finding a “shortcut” for performing the primary task. This hypothesis would predict that landmark participants may have been able to devote more of their looking time to Task 2. In fact, when controlling for motorcycle speed and lighting treatments, there was no statistically significant difference between landmark and non-landmark participants in the amount of time spent looking in the direction of the Task 2 light. It is not known whether these participants ever use a landmark strategy when they are actually driving, but the fact that most reported using the strategy early on in the session suggests that they may have used it before. We speculate that at least some left turning drivers who are faced with a long wait for an adequate gap in approaching traffic or those who have a high workload due to secondary tasks (or impairment) may sometimes rely on a landmark strategy. For those drivers, enhanced motorcycle lighting treatments may help to prevent them from making left turns that violate motorcycles’ right-of-way.

4.2 Study limitations

Several limitations to the present study were noted.

- For safety reasons, research participants never made any real turning maneuvers in this study, and therefore, the results obtained may not apply to actual driving behavior. In particular it is not known whether the length of the session and the repeated nature of the tasks encouraged participants to make their turn/no turn decisions using strategies that that they would not have used if they were actually driving.

- The lighting treatments and mounting locations selected for inclusion in the study may not be optimal choices for enhancing motorcycle conspicuity. In particular, the LED lamps were mounted vertically to follow the contours of the front forks. These lamps were designed to be mounted horizontally as daytime running lights on passenger vehicles. By mounting them vertically the light was not efficiently distributed across very wide angles horizontally. Perhaps this reduced its effectiveness as a conspicuity enhancement for viewers who were looking at the approaching motorcycle from an oblique angle.

- In retrospect, a larger sample of participants would have improved the reliability of the results especially with regard to the eye tracking data. Several participants’ eye tracking results could not be used due to calibration problems with the eye tracker and due to excessive glare in the outdoor environment. Also, a larger sample size would have provided more reliable comparisons between subsets of participants (i.e. comparing those who used landmark versus non-landmark strategies).

5. Conclusions

Although the results of this study did not provide any evidence that the experimental lighting treatments on the motorcycle influenced the mean safety margin (judgment of the last safe moment to turn in front of an approaching motorcycle), there was evidence that the experimental lighting treatments significantly reduced the occurrence of short safety margins. This suggests that enhancing the forward lighting on motorcycles during the daytime may be effective at reducing the probability that drivers will turn in front of the motorcycle with an unsafe short safety margin. Potentially, this would reduce crash rates. In particular, the low-mounted set of auxiliary lamps (LA), the modulated high beam headlamp (MHB) and the four-lamp auxiliary treatment (LHA) were most effective at reducing short safety margins. Also, the results suggest that the conspicuity of the motorcycle as measured by participants' looking behavior was increased, at least for a subset of the participants, by the LHA and MHB treatments.

These results should be interpreted cautiously in light of the differences observed between subsets of participants in the study. In a post-study interview, some participants reported using a landmark strategy to judge when it was safe to turn by comparing the position of approaching vehicles to fixed roadside landmarks. Other participants focused on the approaching vehicles speed, the time until its arrival at the conflict point, or used other strategies. Differences were observed between landmark participants and non-landmark participants in the effects of the experimental lighting treatments. For participants who used a landmark strategy, the influence of the experimental lighting treatments was to reduce the probability of giving a short safety margin, while for non-landmark participants the influence of the experimental lighting treatments was to increase the time spent looking toward the motorcycle.

Future research on motorcycle conspicuity and crashes resulting from right-of-way violations may benefit from an expansion in experimental paradigms from an emphasis on time/distance perception and perceptual biases revealed by measures of central tendency to the study of rare events including failures or delays in detection, lapses in attending to detected objects, individual differences in drivers' perceptual strategies, and countermeasures for inattention blindness.

Overall, the results from this study indicate that enhancing the forward lighting on motorcycles during the daytime may be a promising countermeasure for reducing "left turn across path" crashes.

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APPENDIX A: Recruitment Screening Questions for Interested Callers

[Screening Responses to ads for Study of Drivers' Eye Movements]

Initial telephone contact date: ____

How did you hear about the study?: ____________________________________

"The Drivers' Eye Movements Study takes about 90 minutes and participants will be paid $60 for their time. If you are selected to participate, we will schedule an appointment for you to come to Westat's office in Rockville. The study will be conducted inside an automobile. A researcher will drive you to a nearby study site and park next to the roadway. From inside the car you will watch traffic go by and push a button whenever you think that it would be safe to make a turn in front of oncoming traffic, but you will never actually drive. While you are watching the traffic, you will wear an eye tracker which is like a pair of large glasses that has two very small cameras mounted on it. One of the cameras is focused on your eye and the other camera is focused on the scene ahead of you. The eye tracker device does not come in contact with your eyes, but it records where you are looking."

Do you have a valid driver's license? Is your driver's license a special license that allows you to drive any of the follow vehicle types? Commercial vehicles? Heavy trucks? Motorcycles? Buses?	
How old were you when you first obtained a driver's license?	
How old are you now?	
Gender?	Male Female
How many days a week do you typically drive?	
Now I'd like to ask you about your experience driving different types of vehicles. Please tell me if you or anyone in your immediate family has ever driven any of the following types of vehicles: (NOTE: FOR EACH "YES" RESPONSE PROBE FOR EXPERIENCE) - When? How often? Pickup trucks? A heavy truck such as a box truck? Motorcycles? Scooters or mopeds? Buses?	
Would you be available to participate sometime during the week? Monday-Friday? Best Days?	
Would you be available to participate sometime during the weekend? Saturday -Sunday? Best Days?	

Contact information:

Name:	
Home Phone:	
Cell Phone:	
Work Phone:	
E-mail:	

Mailing address:

Address :	
City/State/ZIP	

APPENDIX B: Luminous Intensity of Auxiliary Lamps

The following figures display the luminous intensity of the auxiliary motorcycle lamps used in the study when viewed from various angles. Horizontal angle relative to the lamp is plotted on the x-axis, vertical angle relative to the lamp is plotted on the z-axis, and luminous intensity in candelas (cd) is plotted on the y axis. Note that the luminous intensity scale differs for each lamp, depending upon its maximum luminous intensity. This was done to emphasize the pattern of luminous intensity for each lamp rather than the relative intensities of the various lamps. Each figure's caption states the peak luminous intensity of the lamp. Luminous intensity values were calculated based on measurements made with a Minolta T-1 Illuminance Meter at a distance of 25 feet. The lamps were measured in place on the motorcycle. Measurements were made with lamps mounted on the motorcycle with the motorcycle engine off. The lamps were powered at 12.8 volts (regulated). Figures B-1 to B-8 show the detailed intensity patterns for lamps near their peak and Figures B-9 to B-10 show examples of how the luminous intensity from an LED lamp and a conventional auxiliary lamp decreases at more extreme angles. Left/right asymmetries in the extent of the measurements shown for the LED lamp in Figure B-10 are due to the front tire blocking the beam at angles greater than 10 degrees from the mounting position toward the opposite side of the bike.

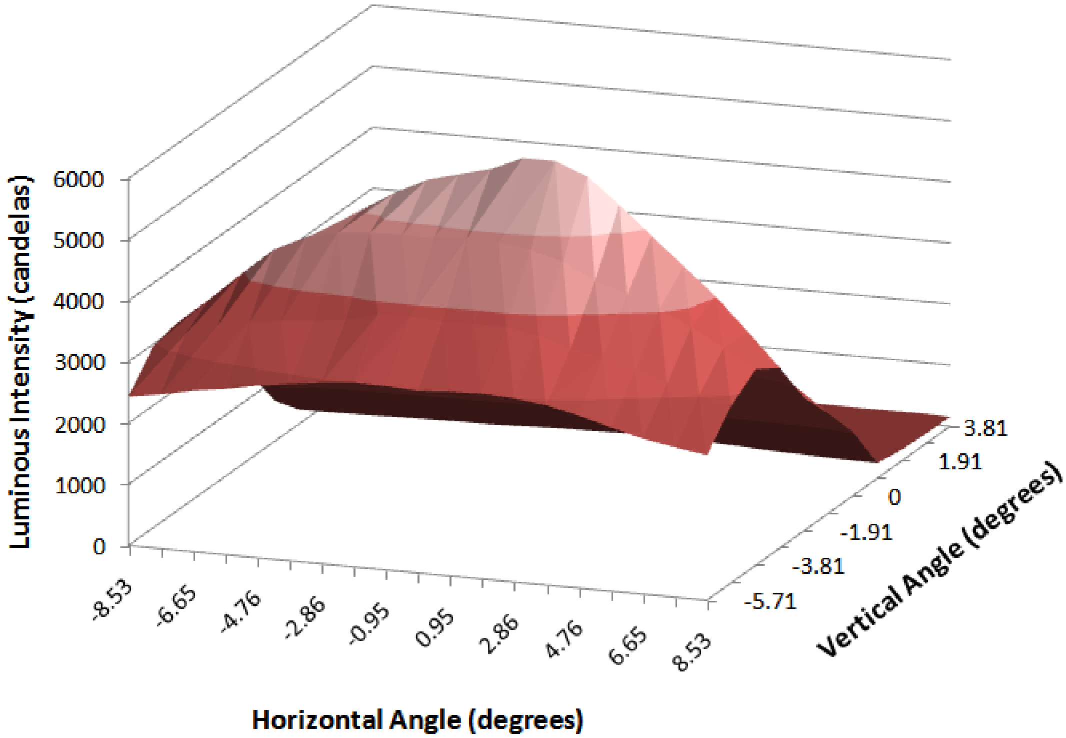

Figure B-1. Luminous intensity of low beam headlamp (peak = 5,981 cd)

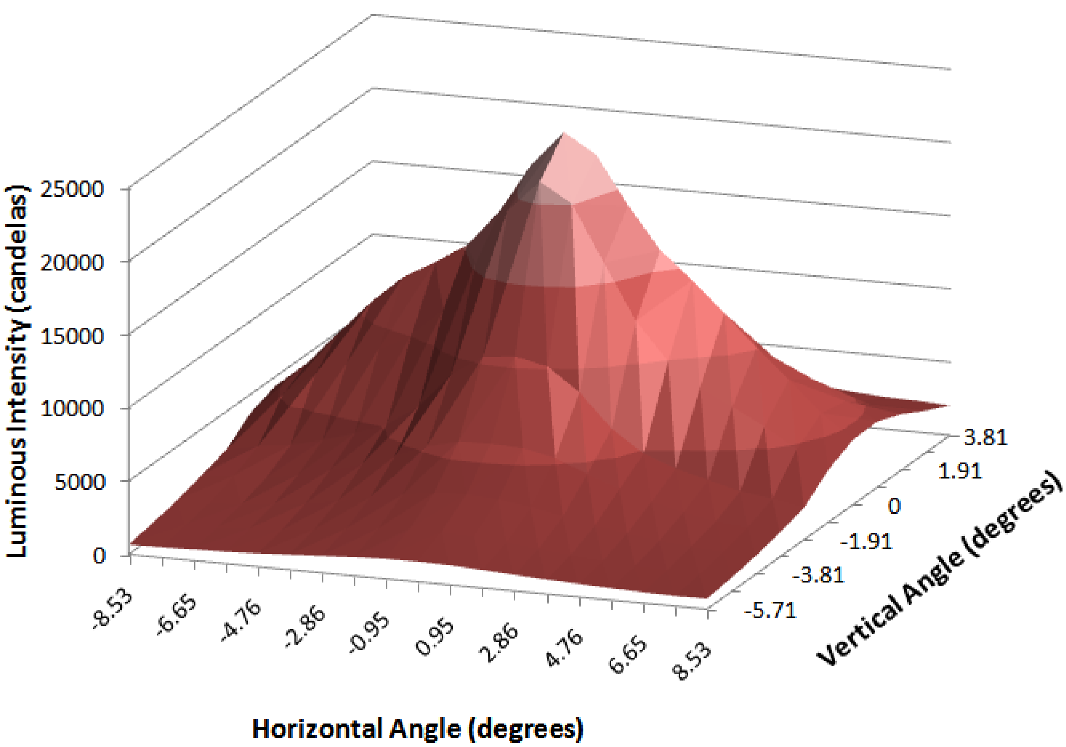

Figure B-2. Luminous intensity of high beam headlamp (peak = 23,574 cd)

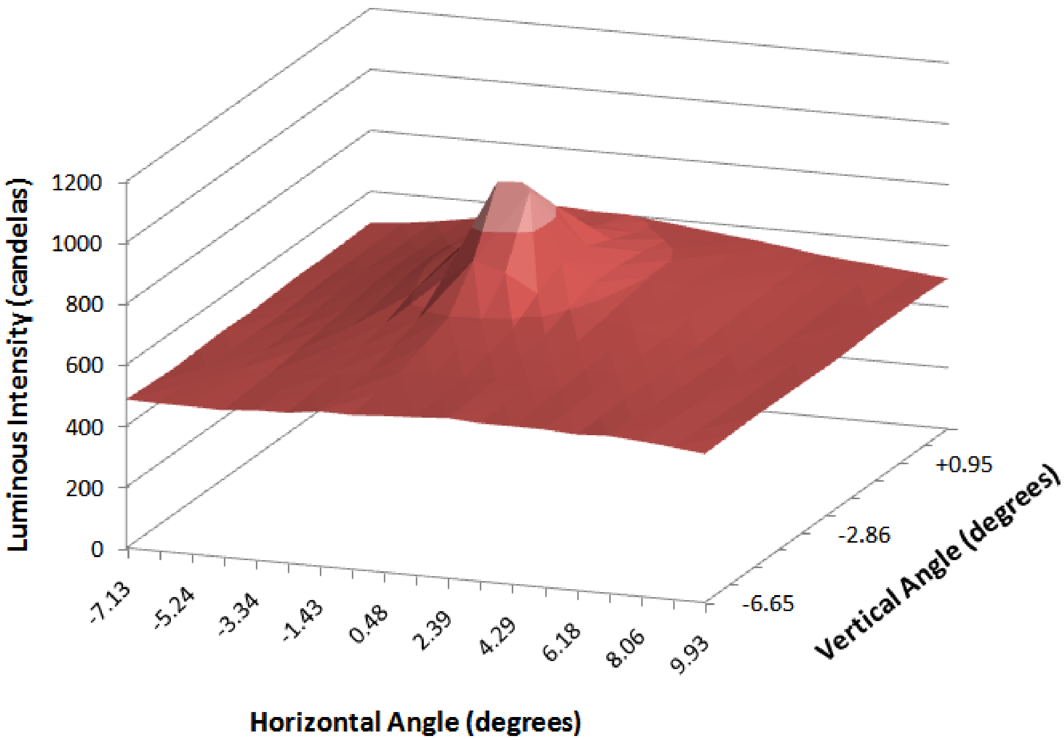

Figure B-3. Luminous intensity of upper left bullet lamp (peak = 929 cd)

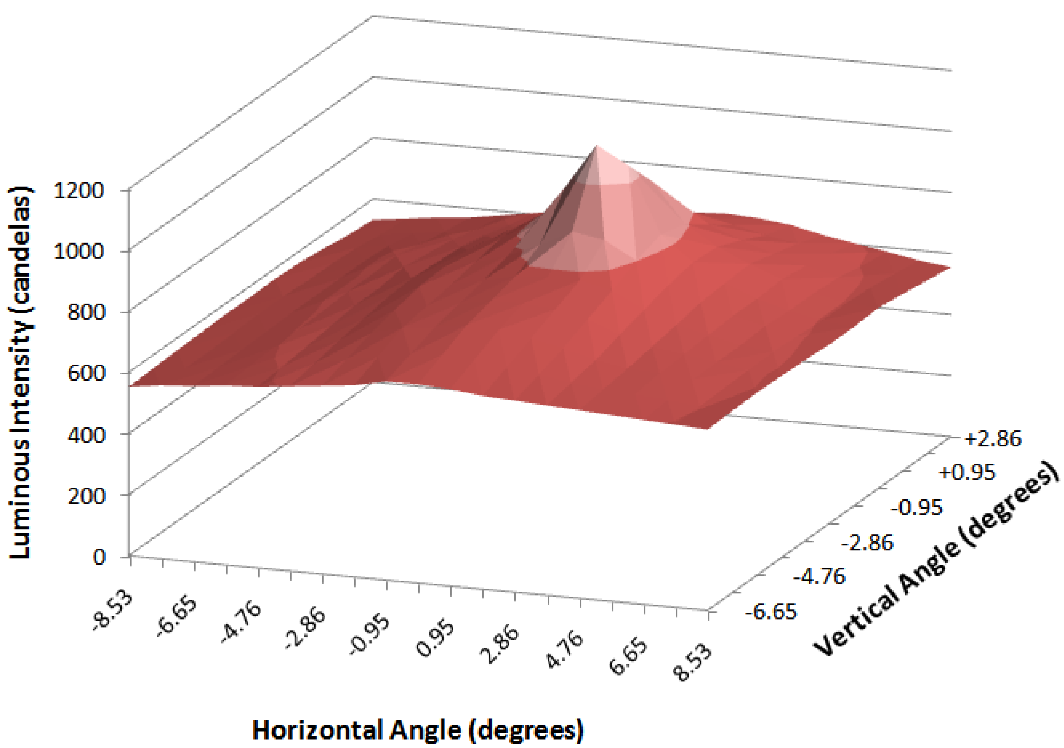

Figure B-4. Luminous intensity of upper right bullet lamp (peak = 1103 cd)

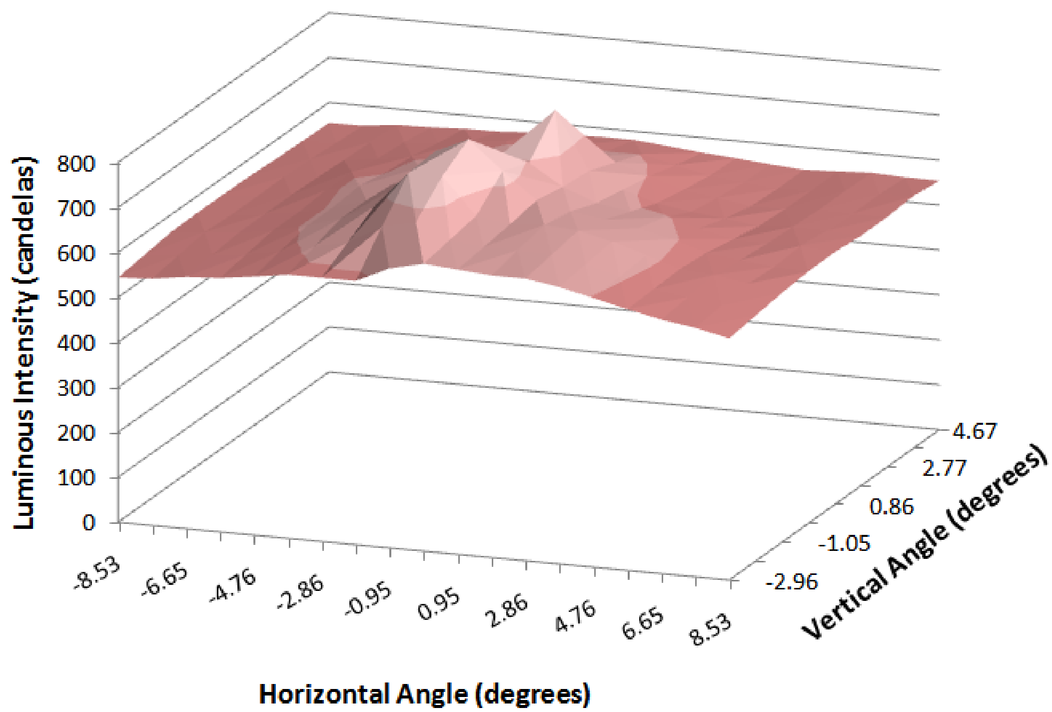

Figure B-5. Luminous intensity of lower left bullet lamp (peak = 784 cd)

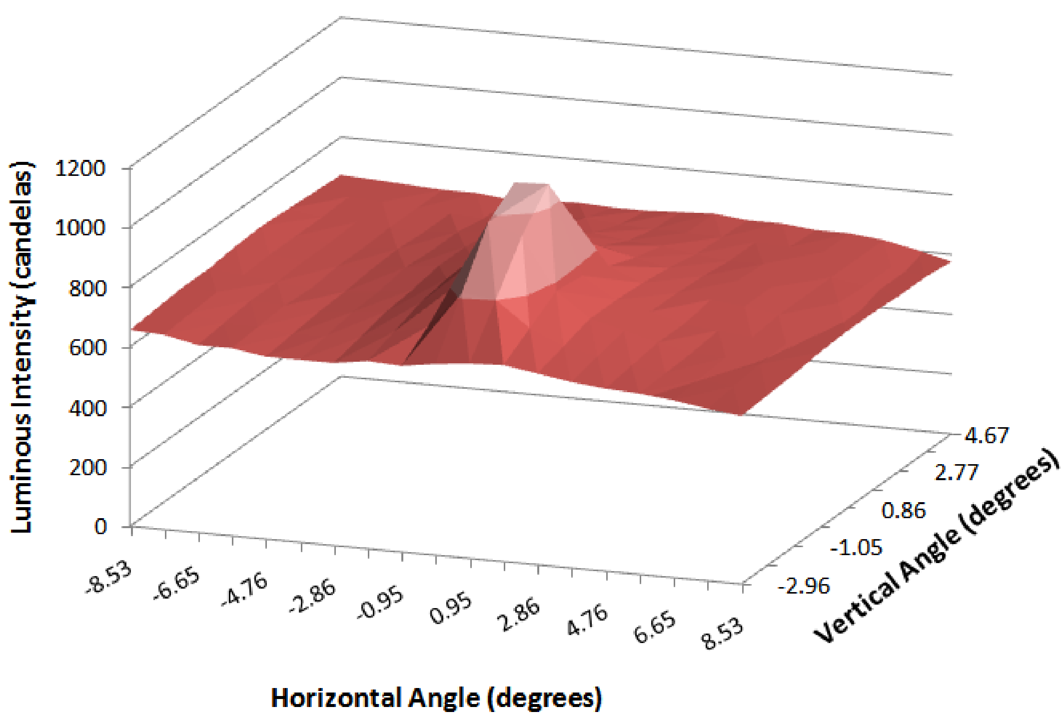

Figure B-6. Luminous intensity of lower right bullet lamp (peak = 1063 cd)

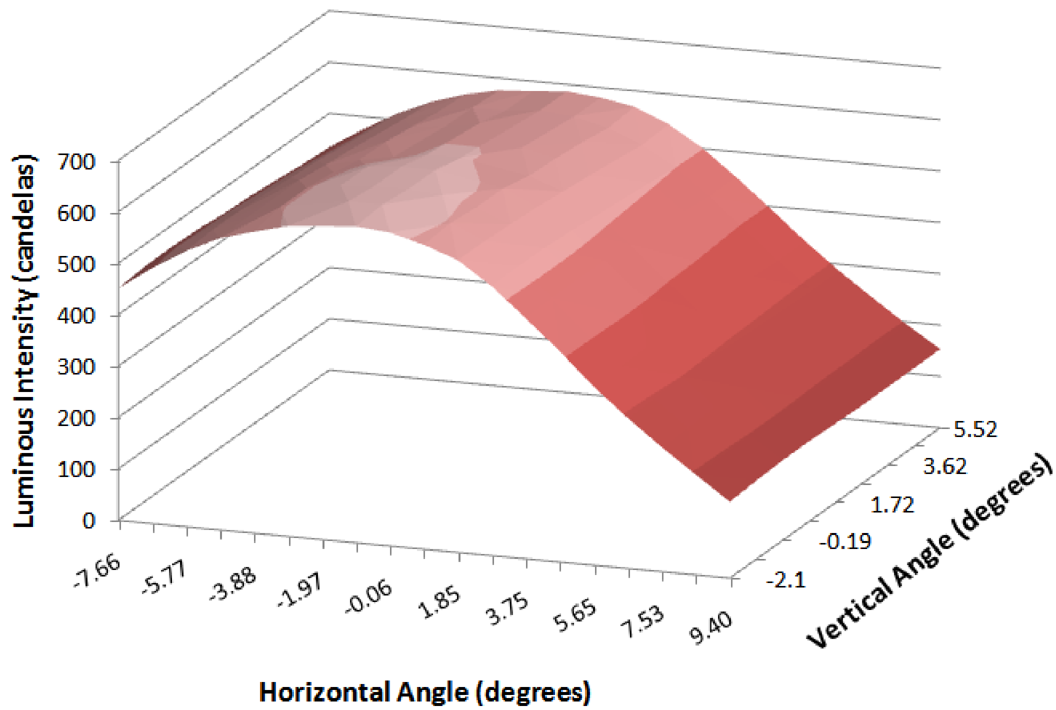

Figure B-7. Luminous intensity of left LED lamp (peak = 621 cd)

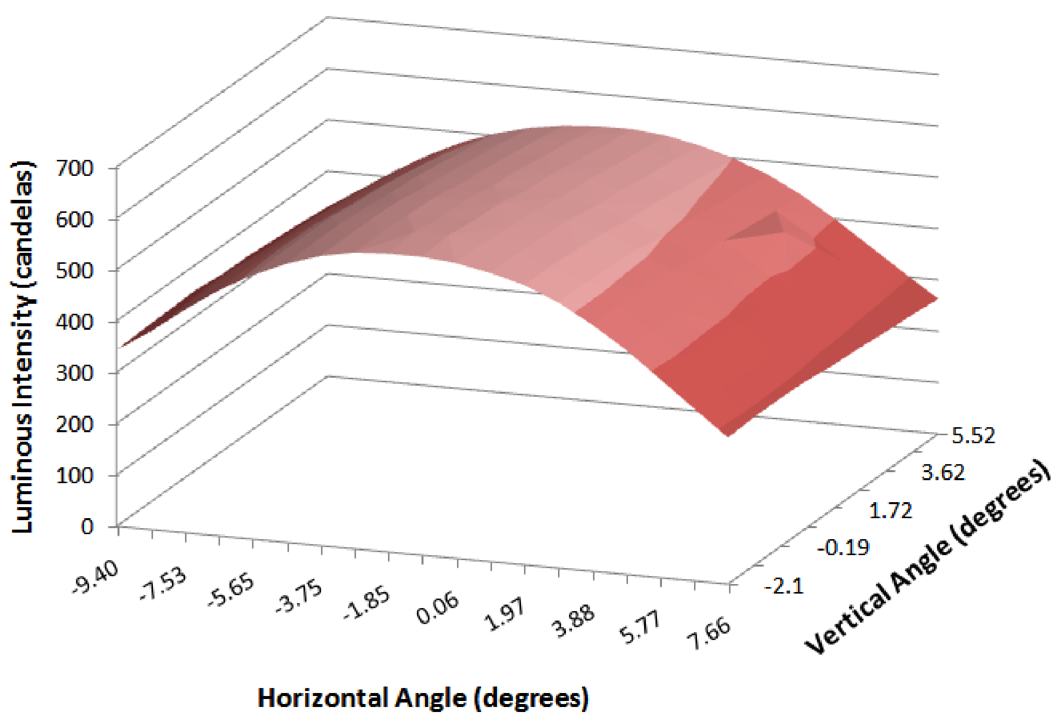

Figure B-8. Luminous intensity of right LED lamp (peak = 586 cd)

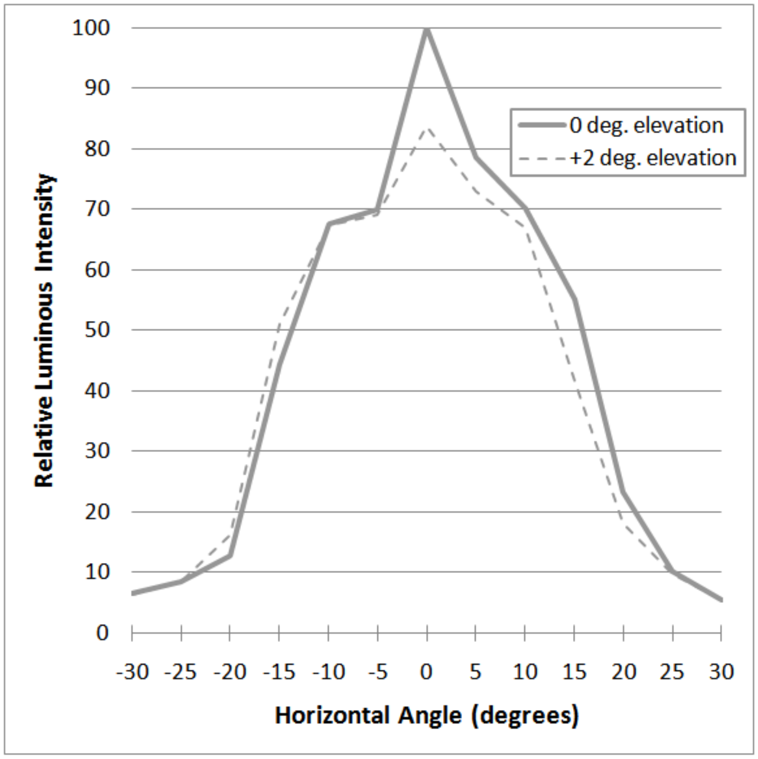

Figure B-9. Relative luminous intensity of upper left bullet lamp

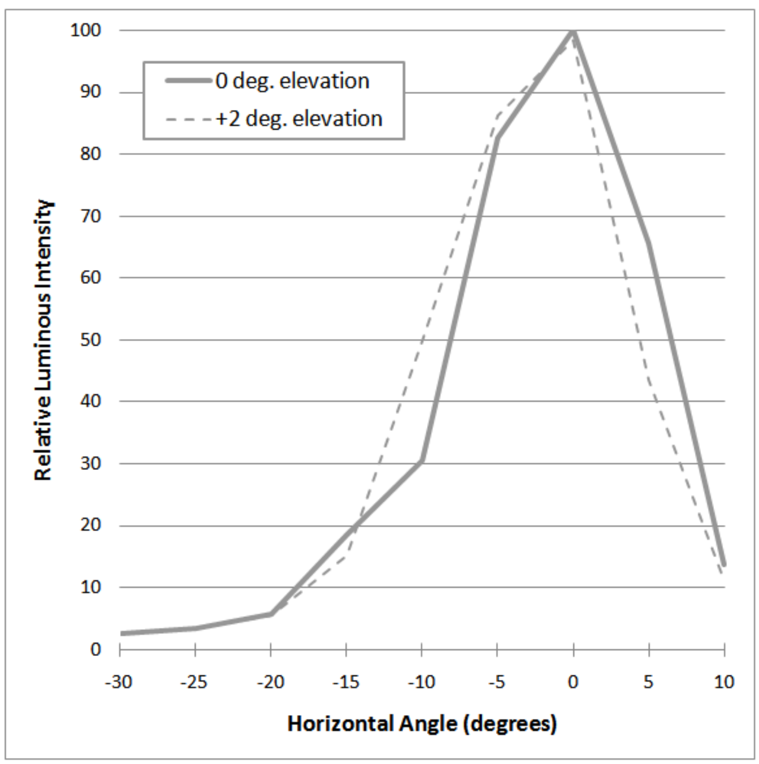

Figure B-10. Relative luminous intensity of left LED lamp

APPENDIX C: Informed Consent

Purpose of research. You are being invited to volunteer as a participant in a research study of how drivers observe approaching traffic. This study is being conducted by Westat for the National Highway Traffic Safety Administration. The purpose of the study is to collect information about the patterns of where drivers typically look while they are waiting to turn across the path of oncoming traffic.

Research procedure. As a participant you will be a passenger in a research vehicle driven by a Westat researcher. You will not drive the vehicle yourself. During the data collection period, the research vehicle will be parked outdoors next to the roadway at a local study site. You will be asked to sit in the drivers' seat and watch the approaching traffic. You will be asked to push a button to indicate when you believe that it would be safe to make a left turn across the path of oncoming traffic. In order to measure what you are looking at to make that decision, you will be asked to wear an eye tracking device. This device resembles a large pair of glasses, and has two very small cameras attached. One of the cameras records the scene in front of you and the other camera records a view of your eye. No part of the eye tracking device touches your eyes. The entire data collection period will last for approximately 90 minutes including travel to and from the study site. You will be paid $60 for your time.

Foreseeable risk. As a research participant, you will encounter the normal risks of being a passenger in a vehicle on local roadways. While the research vehicle is parked near the roadway at the study site, there is a small risk that the research vehicle could be struck by another vehicle causing injury or death to you. When you arrive at the research site you will be asked to move from the passenger's seat to the driver's seat for data collection. When data collection is complete, you will be asked to move back to the passenger seat for the drive back to Westat's office. There is a small risk that you may be struck by another vehicle when you walk around the research vehicle to change seats. The Westat researcher with you will watch traffic and assist you to help minimize the risk.

The eye tracking device poses a very small risk of injury. There are no sharp surfaces on the eye tracking device and the device operates at a low voltage so the risk of an electrical shock is very small.

Benefits of the research. The findings of this study may improve safety for drivers by gaining a greater understanding of the causes of left-turn crashes caused by drivers turning in front of approaching vehicles. There are no immediate benefits of this research for study participants.

Confidentiality. The fact that you are participating in this study will remain confidential. All personally identifying data collected will be kept in confidence by Westat. That is, we will not provide your personally identifiable data to anyone including government agencies, insurers, or anyone else outside of Westat. To protect your confidentiality, each participant in the study will be assigned a unique ID number and all the data collected will be kept in a secured file identified by that number, without any personal identifiers. Your personal identifiers and link to your study data will be kept in a separate secure file. Only Westat will have access to the list that links your identity to your data. Your personal information will be destroyed within 3 months after the study is complete. The final report of the research will contain data without any personal identifiers or information that would lead to the identification of a participant.

Contact person. If you have any questions about the research project please contact Dr. James Jenness, Principal Investigator, at Westat, 1650 Research Blvd., Rockville, MD 20850; (240) 314-2424.

For questions about research participants' rights and protections, please contact Sharon Zack at 1-800-937-8281 ext. 8828. She can be reached at Westat, 1650 Research Blvd., Rockville, MD 20850.

Voluntary withdrawal from the study. Your participation in this study is entirely voluntary. Refusal to participate will involve no loss of benefits to which you are otherwise entitled. You may choose to stop participating at any time. If you choose to stop before the end of the data collection period you will be paid on a pro-rated basis for the amount of time that you participated.

Duration of the study. Data will be collected for approximately 90 minutes. It is possible that the study could be terminated early or that your participation could be terminated if you fail to cooperate with the study or if technical difficulties with the research equipment arise. If you fail to cooperate with the study you will not be paid. If the study is ended early for technical difficulties or other reasons deemed necessary by Westat staff, you will be paid for the entire session.

I have read the above and recognize the risks of this study. I agree to participate as a participant in the research. I understand that participation is voluntary and I may withdraw from the study at any time. I have received a copy of this consent for my records.

Printed name of participant	Date
Signature of participant	Date
Signature of researcher	Date

APPENDIX D: Participant Instructions Script

<Researcher introduces self and [other researcher].> He will be in the back seat making sure the computer is recording correctly. I'll be up front with you. First, go ahead and make yourself comfortable. You can adjust the seat so you're sitting in a comfortable driving position.

During this session, you will watch oncoming traffic and decide when you would be willing to make a left turn. We're in the median of the road, but I want you to imagine that we're actually in a left turn lane and that you're trying to turn left. Since there is no actual road to turn left on, we set up those orange cones to your left. Imagine that there is a road between those cones that you want to turn into. Also imagine that we are on a paved, flat road and not this hilly grass.

<show blue button> You'll use this button to indicate when you would be willing to start turning. So when you would be willing to start turning, hold the button down. When an oncoming car gets close and you are no longer able to start a turn, let go of the button. So hold the button down when you can start to turn, and let go of it when you can't. Give it a try for a minute to see what it's like. *<let participant try; give feedback>* You can ignore pedestrians and bicyclists on the sidewalk; we're only interested in traffic on the road. Also, please make sure to press the blue button every time that you have an opportunity to turn, even if you see a bigger gap in traffic coming up. We want to know every time that you could turn.

To make this more challenging, you will have a second task to do. Since you are trying to turn left, you should also be glancing where you are trying to go. Look at the traffic cones to your left. In the top of the one on the left, there is a light. I'll turn it on now so you can see it. *<turn on light>* During the session, this light will occasionally turn on. While you're watching oncoming traffic, you will also have to keep an eye on this light and press the big Easy button when you see it on. When you press the button, the light will turn off. Go ahead and rest the button on your left leg. You don't have to clip it around your leg.

Let's practice doing both tasks at once. Remember – hold the blue button down when you can start turning, and release it when you can't start turning. At the same time, keep an eye on the light in the cone to the left and press the Easy button when you see it lit. Make sense? You can practice for a minute or so starting now. *<give feedback as necessary>*

OK, good. While you're doing these tasks, you'll be wearing this eye tracker. These glasses have two small cameras – one is looking at your right eye using this round reflector and another is looking straight ahead at whatever you're looking at. We'll take a few minutes to get it adjusted for you, then it will be able to show us exactly where you are looking. I'll go ahead and put the glasses on you now. … Is that comfortable? Please try not to touch the glasses at all during this session. If you adjust or bump the glasses during the session, we might have to stop to recalibrate it. Please try to avoid touching your face or hair during the session. If the headset is getting uncomfortable or you need a break, just let me know and we can pause. *<calibrate>*

We're all set. Once we start, [the researchers] will sit here quietly and make sure everything is going smoothly. I may need to step out of the car occasionally to call back to the office. If you accidentally bump the headset or feel it move, let me know so I can make sure it's still aligned correctly. And if you have any questions or comments, feel free to ask. You'll be doing this for up to 40 minutes, so let me know if you want to take a break or rest your eyes. One last thing before we start: you have your choice of no music or the Eagles Greatest Hits.

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