2004-01-2258

Target Detection Distances and Driver Performance with Swiveling HID Headlamps

Shane McLaughlin and Jon Hankey
Virginia Tech Transportation Institute

Charles A. Green and Michael Larsen
General Motors

ABSTRACT

Twent-two participants of varying ages detected roadside targets in two consecutive dynamic evaluations of a horizontally swiveling headlamp vehicle and a vehicle with the same headlamps that did not swivel. Participants detected targets as they drove unlighted low-speed public roads. Scenarios encountered were intersection turns, and curves with approximate radii of 70-90m, 120-140m, 170-190m, and 215-220m. Results from the first study found improved detection distances from the swiveling headlamps in left curves, but unexpectedly decreased detection distances in larger radius right hand curves. The swiveling algorithm was altered for the second study, and the headlamps used did not have the same beam pattern as in the first study. Results from the second study again found improved detection distances from the swiveling headlamps while in the larger radius right hand curves fixed and swivel were not statistically different. No practically significant results were found as regards driving performance measures taken in these studies. These study results suggest that horizontally swiveling headlamps can provide for increased detection distances in many curve and turn scenarios; however, care must be taken in the execution of a swiveling algorithm and beam pattern.

INTRODUCTION

Since before the release of the Tucker in 1948 with its center mounted swiveling lamp, there has been interest in aiming headlamps to provide greater illumination when turning. As one type of Adaptive Frontlighting System (AFS), commonly referred to as bending light, the beam pattern of these headlamps can be directed horizontally based on information such as steering-wheel position, yaw rate, navigational databases, and other types of input. While vertical swivel is also considered, this report focuses on horizontally swiveling headlamps. Several different approaches have been taken to investigate possible methods of implementation and the possible benefits of swiveling headlamp systems.

For example, Sivak, Flannagan, Schoettle, and Nakata (2001) performed an analytical study investigating seeing performance with U.S. and European beam patterns in 80m radius and 240m radius curves in both directions. In the smaller radii turn, the beam was shifted horizontally 15deg and in the larger radii turn, 10deg. Using simulation, the authors predicted seeing performance would be improved on curves for both European and U.S. beam low beam patterns. Some benefit was also found with the U.S. beam pattern over the European.

A subjective evaluation of AFS technologies was conducted by Hamm (2002), who reports on a drive review in which 43 individuals drove an AFS vehicle which was capable of three different modes of headlamp horizontal swivel: (1) both lights swivel together equally, (2) one side only swivels, (3) or each light can swivel a different angle. 27 of the drivers were between 25 years and 45 years of age. Six were under 25 years and 10 were over 45 years of age. Participants rated headlamps on dimensions such as homogeneity and range in curves, using a scale from unsatisfactory to optimal. Participants drove on a route of their choosing while responses were recorded by a second individual. Subjective evaluation of range in curves indicated one lamp turning was evaluated as having shorter range. Lamps turning different angles were evaluated as having the longest range. Scores for both lamps swiveling equally fell between the other two options.

Newman (2004) reports on a comparison of fixed halogen lamps to an asymmetrically (i.e., not parallel) swiveling halogen system based on speed and steering wheel angle. Participants drove approximately 25 minutes on a curved course with AFS both enabled at times and disabled at times. Participants were unaware of the system type. Their age ranged from 26 years of age to 55 years of age. Obstacles were placed on curves of different radii, and participants were instructed to report when they saw the obstacle. The authors report 55% visibility improvement with swivel over fixed halogen, with greater benefit found where targets were on the inside of tighter curves. In a pedestrian detection task, participants with AFS detected and stopped 1.8m shorter from 50km/h when using AFS.

The objective of AFS systems is to provide earlier detection of targets or objects in curves without being detrimental or disturbing to oncoming drivers. The purpose of the research reported here is to support the design of a headlamp-control algorithm that would achieve these objectives. This report describes two similar studies. The first study was conducted to test the performance of an initial swiveling algorithm. The algorithm was then tuned according to the results of the first study. The second study was conducted to evaluate the performance of the updated swiveling algorithm.

In each of these studies, participants drove two vehicles: one with the swiveling headlamps and one without. They drove each of the vehicles on public roads and identified targets that had been placed along the road. The distance at which targets were recognized was measured and compared between the swiveling and fixed headlamps.

APPARATUS

For each study, high intensity discharge (HID) visual/optically aimed right D2S projector headlamps with the same beam pattern were installed on two Cadillac Sevilles like those shown in Figure 1. One of the vehicles had the swiveling headlamp capability, and the second vehicle had fixed headlamps.

Figure 1. Fixed and swiveling headlamp test vehicles with targets.

The beam pattern used within each study was the same on both vehicles. The beam pattern used on the vehicles in the second study was somewhat different than the beam pattern used in Study 1. This is described in more detail in the Study 2 Specifics section and in the Results and Discussion sections.

Each night before testing, the windshields and headlamps of the vehicles were cleaned, and the aim of the headlamps was checked and adjusted, if necessary.

The swiveling and fixed headlamp vehicles were instrumented with video cameras that recorded four views into a quad split to include the participant's face, the forward road scene, and the road to the left and right near the vehicle. Audio was also recorded in the interior of the vehicle. The four video views and the audio recording were multiplexed and synchronized with vehicle data being collected at 10Hz on an experimenter's laptop. The laptop was also used by the experimenter to record detection distances during the study. Vehicle measures were also collected, including speed, longitudinal acceleration, lateral acceleration, steering angle, and yaw rate.

METHODS

PARTICIPANTS - In each study, 22 participants were divided approximately equally into two age groups: younger (25yrs – 35yrs) and older (55yrs – 65yrs) and by gender. For more detail see the Study 1 Specifics and Study 2 Specifics sections.

EXPERIMENTAL DESIGN - <u>Independent Variables</u> The experimental design for the studies was a mixed-factor design. Age Group was the between-subjects factor, with two levels (younger, older). The within-subjects factors were the two types of headlamps and ten curve groups. The curves used in the study were grouped into intersection turns, and small, medium, large, and extra-large curves, with approximate radii for these groups of ~20-50m, 70-90m, 120-140m, 170-190m, and 215-220m, respectively. All of the intersections and curves were driven in both directions during the session to achieve left and right curves. The experimental design and participant numbers (e.g., s5 = participant number 5) are presented in Table 1.

Table 1. Target Detection experimental design.

		Younger				Older			
		Males		Females		Males		Females	
Scenario		Fixed	Swivel	Fixed	Swivel	Fixed	Swivel	Fixed	Swivel
Left turn	Intersection - ~ 20-50m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Small – 70-90m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Medium – 120-140m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Large – 170-190m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Extra Large – 215m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
Right turn	Intersection - ~ 20-50m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Small – 70-90m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Medium – 120-140m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Large – 170-190m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22
	Extra Large – 215m	s1-s5	s1-s5	s6-s10	s6-s10	s11-s16	s11-s16	s17-s22	s17-s22

To avoid effects from the presentation order of the two types of headlamps, half the participants were exposed to the swiveling headlamps first, and half were exposed to the fixed headlamps first. The test route was divided into three segments that formed loops. To avoid effects from the order in which a participant traversed the loops, three different orders were developed. The order of loops was also balanced across headlamp type so that each headlamp type was presented on each loop order an equal number of times.

<u>Dependent Variables</u> - Target Detection Distances - The primary dependent variable of the study was target detection distance. The target used was an 18cm by 18cm square with a 6cm by 6cm tab extending to the left or right of the larger 12% Lambertian reflective gray

square area (See Figure 2). This type of target has been used elsewhere when measuring headlamp beam patterns (Mortimer, 1974) and small target visibility (Janoff, 1993). The tab was surrounded by a black background. The targets were placed with the edge of the 18cm by 18cm area located at the edge of the pavement. The figure below shows a target placed on the right side of the road with a right-facing (outside) tab. The participant notified the experimenter as soon as he/she could see a target and then told the experimenter what direction the tab faced when he/she was able to see it. Distances were recorded through synchronized audio, video, and experimenter button presses.

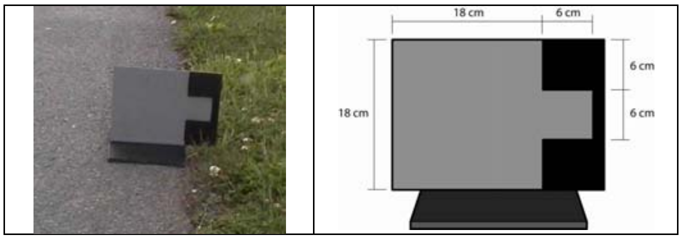

Figure 2. Target.

Targets were placed on the inside edge of curves, placing them on the right edge of the driving lane on right-hand curves and on the left side of the road in left-hand curves (see Figure 4).

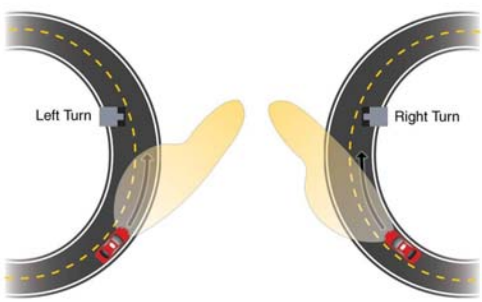

Figure 3. Target placement in curves.

In intersection turns, the targets were placed nearest the lane into which the vehicle would be turning. Therefore, in right turns, the target was placed on the right side of the road after the turn (see Figure 4). In left turns, the target was also placed on the right side of the road after the turns (see Figure 5).

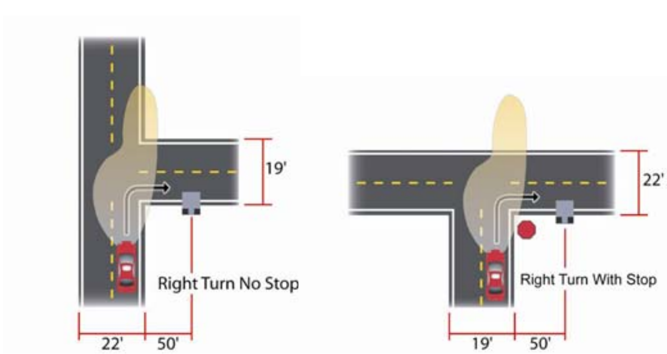

Figure 4. Target placement in right intersection turns.

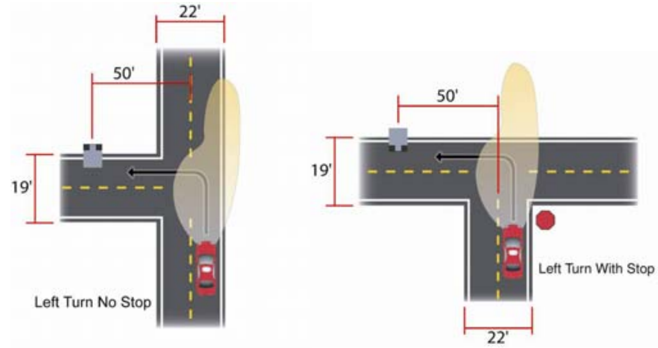

Figure 5. Target placement in left intersection turns.

It should be noted that targets were placed on public roads which included typical visual clutter to the side of the road from objects such as mailboxes, drainage pipes, litter, etc, and even sometimes in the road. Participants tended to call out a target when they clearly recognized it as one of the experimental targets. There were very few situations where a participant called "target" for something other than a target. For consistency with other target detection and recognition research, we will refer to this first participant response as "detection" throughout. Analysis was not performed on the step where participants identified the direction of the tab.

Driving Performance - Driving performance measures were also collected to investigate longitudinal and lateral control while using the two types of headlamps. The measures of longitudinal control were the average speed (mph), maximum speed (mph), speed variance, and hard braking (g). The measures of lateral control were the average steering angle (deg), steering variance, average lateral acceleration (g), maximum lateral acceleration (g), and average yaw rate (deg/s). The average, maximum, and variance of these measures were taken within the following road segments:

- Intersections - data from 60ft (18m) to the target location
- Curves (70m – 215m) - data from 165ft (50m) to the target location
- Straight - data from 165ft (50m) to target location

Post-drive Questionnaires - In addition to measuring detection distances and driving performance, experimenters administered post-drive questionnaires to investigate participants' perception of differences between the swiveling and fixed headlamps. The three areas investigated in the questionnaire were the participant's impression of how the headlamps (1) helped him/her see possible targets or obstacles in the road, (2) helped him/her see the road ahead, and (3) compared to his/her personal headlamps. Participants responded to all the questions on a five-point Likert -type scale with anchors of Strongly Disagree, Disagree, Neither Disagree nor Agree, Agree, and Strongly Agree. A final question asked if the participant noticed anything unusual about the headlamps after both cars had been driven.

TEST ROADWAY - The study was conducted along public roads found in Southwestern Virginia. The road generally passed through rural areas and some neighborhoods. The road segments were unlighted and contained numerous curves and hills. Specific curves, with constant grade and radii within the previously identified groupings, were used for the placement of experimental targets. Curves were selected that provided consistent curve radii in both directions and were traversed in opposite directions to achieve right and left curves of the same radii. Targets were also placed in some straight segments and in segments with vertical curvature to avoid clues as to the purpose of the study. Several factors including the different loop order (discussed in the Independent Variables section) assigned to the second vehicle and the winding and dark roads appeared to prevent participants from anticipating targets. This was reported frequently by participants and in fact, experimenters required several nights of training before they could begin to anticipate target locations. The speed limit was 25mph for all of the route segments except where one of the 215m curves and one of the extra targets were located. For these the speed limit was 35mph. In places, the road geometry required the participant to go at speeds slower than 25mph, such as in small radii curves and intersections. Two turns were used for the intersection group, four curves were used for the small radii group, three for the medium radii group, two for the large radii group, and two for the extra large radii group (see the Independent Variables section for curve dimensions). Figure 6 provides a map of the route with the turns or curves used for target placement identified.

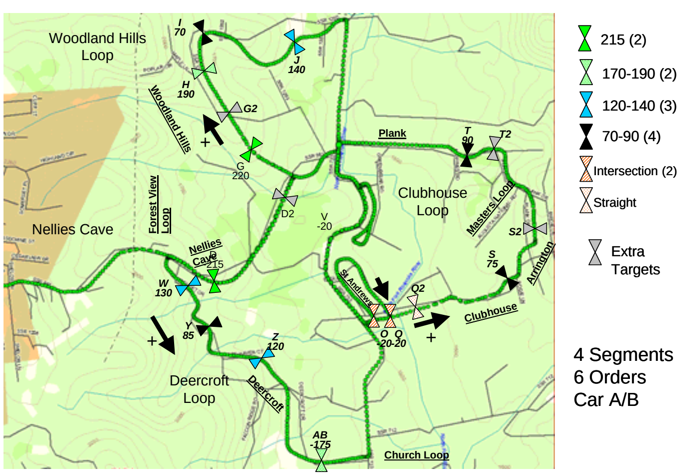

Figure 6. Route map and target locations.

Turns or curves are identified by letter, with the measured radii shown below the letter. Locations denoted with a letter followed by the number 2 (for example G2) were added to include targets roughly on straight sections or sections of vertical curvature. One target (Q2) was located on a straight segment of road and is used to compare the two headlamps on a straight road.

PROCEDURE - Participants were initially screened over the phone to ensure that they did not have any health conditions that would make operating the experimental vehicles a risk and that they were not familiar with the test routes. Upon arriving at the Virginia Tech Transportation Institute's (VTTI) research facility, the participant completed the initial paperwork required for experiments at VTTI and a pre-drive questionnaire. The participant was then tested for visual acuity using the Snellen Chart. Visual acuity of 20/40 or greater was required to participate. Contrast sensitivity and colorblindness were also measured but are not included in this analysis. After these tests were complete, the participant was introduced to the study and given initial training in the experimental procedure. The participant was then accompanied by the experimenter to the first test vehicle.

Once in the vehicle, the experimenter oriented the participant by pointing out the seat and steering-wheel adjustments, and the gear shift. The experimenter then got into the passenger seat and instructed the participant to drive a practice segment to rehearse identifying targets and to review the experimental procedures and post-drive questionnaires. After any questions were answered, the experimenter instructed the participant to drive to the test course. While on the test course, drivers were instructed of the speeds to maintain, for example "On this road we would like you to maintain 25 mph or less." Upon reaching the course, the actual test drive began. When the participant saw a target, he or she would say "TARGET." Once the participant was able to identify which way the tab was facing, he or she would say "IN" or "OUT," indicating whether the tab faced into the road or away from the road. If a participant did not call out a target, a detection and recognition distance of zero was used in the analysis. Missed targets were infrequent (e.g., 9 in Study 1) and so not analyzed separately. During the drive, the front-seat experimenter provided route guidance at turns according to the vehicle location and order of route loop presentation (see Independent Variables section). These route instructions were timed to not to occur near targets. This procedure continued until the participant had passed each of the curves in both directions, according to the assigned loop order. The participant then drove to a rendezvous point to complete a post-drive questionnaire, to stretch, and to switch to the second vehicle. The participant then drove the second vehicle on a route consisting of a different order of the same loops. After each of the curves were again passed in both directions, the participant and experimenter left the test course and completed the post-drive questionnaires (see Appendices B and C) for the second vehicle. Driving time in each vehicle was approximately one hour and fifteen minutes.

STUDY 1 SPECIFICS

In Study 1, the two vehicles used were a 2000 Cadillac Seville, which had swiveling headlamp capability and a 2001 Cadillac Seville, which had fixed headlamps.

Study 1 included 22 participants, with ten participants in the 25yrs – 35yrs age group and 12 participants in the 55yrs – 65yrs age group. Equal numbers of males and females were present in each group. One participant often initiated conversation with the experimenter during the drive, which the experimenter was unable to effectively discourage. The measurements of target identifications for most of the targets for this participant were outliers from those of the other participants and so were removed from the analysis.

STUDY 2 SPECIFICS

In Study 2, the two vehicles used were a 2002 Cadillac Seville, which had swiveling headlamp capability and a 2003 Cadillac Seville, which had fixed headlamps. The beam pattern on the Study 2 vehicles provided less illumination to the left side of the road than the beam pattern used on the Study 1 vehicles. It should be noted however that the beam pattern was the same for both vehicles (i.e., Fixed and Swivel). For a comparison of the difference between the beam pattern used in Study 1 and Study 2 review the Straight Road Comparison section in the Results section. Study 2 included 22 participants, with eleven in the 25yrs – 35yrs age group and eleven in the 55yrs – 65yrs age group. Of the 22 participants, there were six females and five males in the younger age group, and five females and six males in the older age group. A 220m radius curve was added in Study 2 to provide two separate curves in largest turn group. In Study 2, the performance measures based on lateral and longitudinal acceleration were not used.

A pilot test of an in-vehicle warning system was also conducted with the same participants used in Study 2. This pilot test involved the following changes to the Study 1 protocol for use in Study 2. Prior to the Study 2 drive, while familiarizing the participant with the vehicle controls, the experimenter stated, "Above the radio there is a [type of warning] light on the dash board. It may illuminate at times during the study, but you can just ignore it." For a few of the participants, the light illuminated briefly during the drive. After the AFS portion of Study 2 was complete and all objective and subjective data collected, a staged scenario was executed to test the effectiveness of the warning light.

PRE-DRIVE QUESTIONNAIRE – BOTH STUDIES

In each study, in the pre-drive questionnaire that was administered at the beginning of each session, the participant was asked to approximate how frequently he or she drove at night. Figure 7 illustrates the typical night driving done for each study. In the first study, six out of the 22 participants (32%) indicated that they drive every night, and eight out of 22 (36%) indicated that they drive at night three times per week. Five out of 22 participants (23%) indicated that they drive at night once a week, and two out of 22 (9%) indicated that they drive at night less than once per week.

In the second study, eight out of the 22 participants (36%) indicated that they drive every night, and 13 out of 22 participants (59%) indicated that they drive at night three times per week. One of the 22 participants (5%) indicated driving once per week.

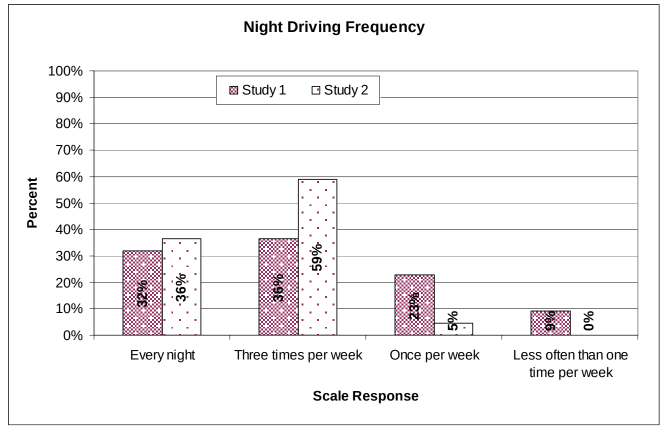

Figure 7. Night driving frequency.

Figure 8 presents the distribution and types of vision correction in the participants. With respect to the type of corrective lenses most often worn while driving at night, in the first study, six out of the 22 participants (27%) indicated that they do not wear any type of corrective lenses. Five out of 22 (23%) indicated that they wear bifocals, and five out of 22 (23%) indicated that they wear single-vision eyeglasses. Four out of the 22 participants (18%) wear trifocal lenses, and two out of 22 (9%) indicated that they wear contact lenses while driving at night.

In Study 2, five out of the 22 participants (23%) indicated that they do not wear any type of corrective lenses. Eight out of 22 (36%) indicated that they wear bifocals, and five out of 22 (23%) indicated that they wear single-vision eyeglasses. Four out of 22 (18%) indicated that they wear contact lenses while driving at night. None of the participants indicated that they wear trifocal lenses while driving at night.

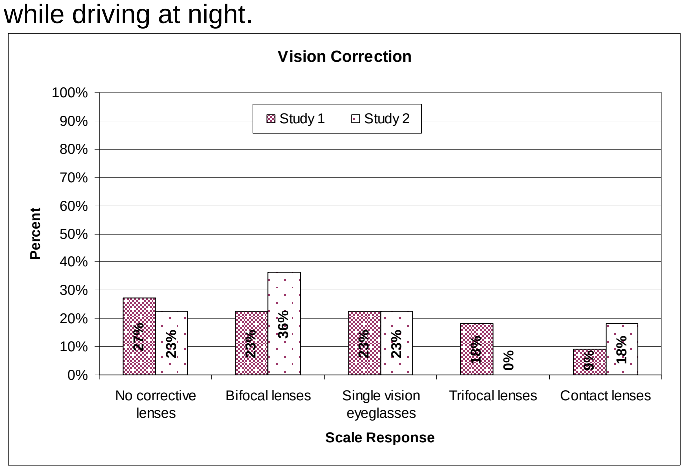

Figure 8. Types of glasses or lenses.

When asked about the difficulty caused by oncoming headlights and streetlights while driving at night, nine out of 22 (41%) of the participants in Study 1 indicated that such lights cause no difficulty. Eleven out of 22 (50%) of the participants indicated that oncoming headlights and streetlights cause little difficulty, and two out of 22 (9%) indicated that such lights cause moderate difficulty. None of the participants in this study felt that oncoming headlights and streetlights cause extreme difficulty while driving at night.

In Study 2, five out of 22 (23%) of the participants indicated that such lights cause no difficulty. Thirteen out of 22 (59%) of the participants indicated that oncoming headlights and streetlights cause little difficulty, and four out of 22 (18%) indicated that such lights cause moderate difficulty. None of the participants in this study felt that oncoming headlights and streetlights cause extreme difficulty while driving at night. Figure 9 shows the distribution of responses related to difficulty with oncoming traffic or streetlights.

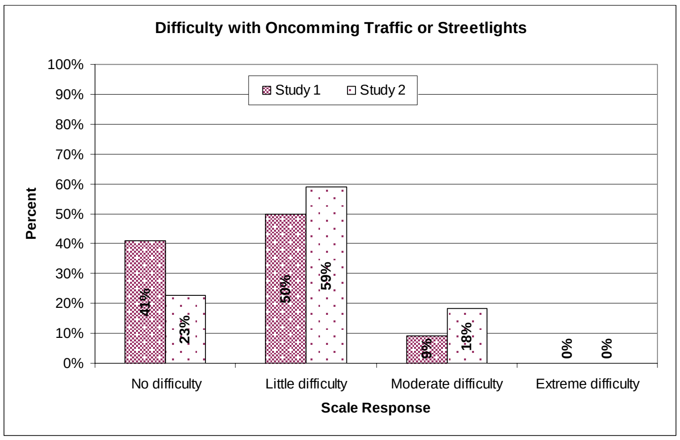

Figure 9. Difficulty with oncoming traffic or streetlights.

In the first study, 13 out of the 22 participants (59%) indicated that they drive at night with no difficulty. Eight out of 22 participants (36%) indicated that they experience little difficulty while driving at night, one out of 22 (5%) indicated moderate difficulty. None of the participants in this study indicated that they experience extreme difficulty while driving at night.

Eight out of the 22 participants (36%) in Study 2 indicated that they drive at night with no difficulty. Twelve out of 22 (55%) indicated that they experience little difficulty while driving at night, 2 out of 22 (9%) indicated moderate difficulty. None of the participants in this study indicated that they experience extreme difficulty while driving at night. Figure 10 portrays these responses.

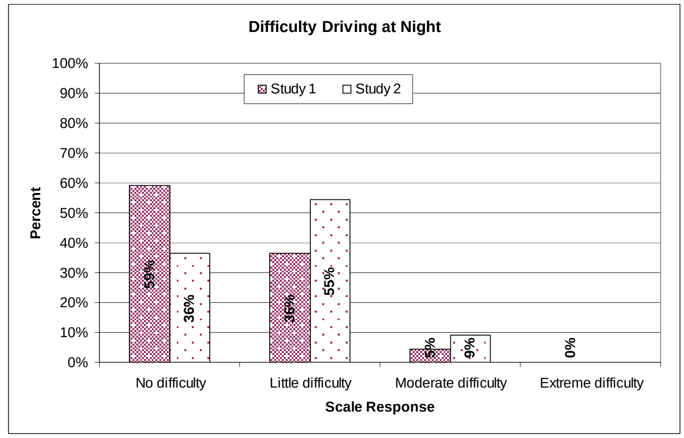

Figure 10. Night time driving difficulty.

In Study 1, when asked to indicate their major concern while driving at night, 10 out of the 22 participants (45%) indicated that they were most concerned about animals. Eight out of 22 (36%) indicated that they were most concerned with glare, two out of 22 (9%) answered that they were most concerned about weather. Four out of 22 (19%) gave other responses to the question.

In Study 2, when asked to indicate their major concern while driving at night, 6 out of the 22 participants (27%) indicated that they were most concerned about animals. The same number of participants (27%) indicated that they were most concerned about glare. Three out of 22 (14%) answered that they were most concerned about weather. Another 3 out of 22 (14%) answered that they were concerned about other drivers. Four out of 22 (19%) gave other responses to the question. Types of concerns and frequencies are presented in Figure 11.

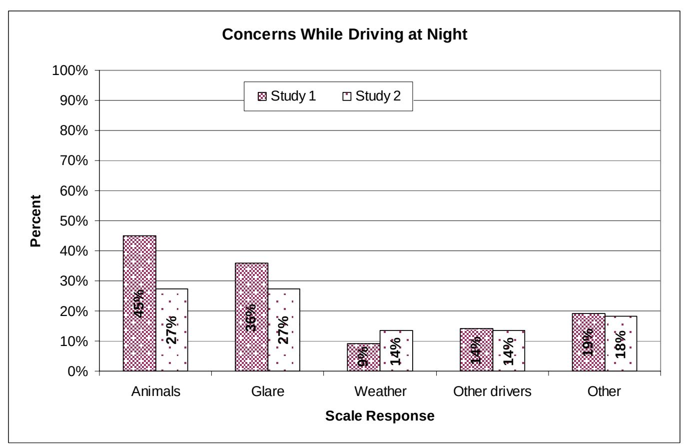

Figure 11. Night time driving concerns.

STUDY 1 RESULTS

DETECTION DISTANCES - A 2 (Age Group) x 2 (Curve Direction) x 2 (Headlamp Type) mixed-factorial Analysis of Variance (ANOVA) was conducted for each Curve Radius to investigate differences in target detection distances. Curve Direction and Headlamp Type were analyzed as within-subjects variables and Age was treated as a between subjects variable. Table 2 identifies ANOVA p-values where $p<0.01$ or which were statistically significant at an α=0.05 level (marked with an asterisk).

Table 2. Results ANOVA.

AFS I	Curve Radius				
	Intersection	70-90m	120-140m	170-190m	215m
Curve Direction			0.0001*	0.0007*	0.0001*
Headlamp Type	0.0064*			0.0782	0.0158*
Curve Direction X Headlamp Type			0.0039*	0.0958	0.0056*
Age Group					
Headlamp Type X Age Group					
Curve Direction X Age Group	0.0417*			0.0805	
Curve Direction X Headlamp Type X Age Group					

* significant at a <0.05

HEADLAMP TYPE - Headlamp Type by Curve Direction interactions were found for 120-140m curves (p=0.0039) and the 215m curve (p=0.0056) (see Figure 12). The 170-190m curve also indicated a similar interaction though not statistically significant at the α=0.05 level (p=0.0956). Both the 120-140 meter and the 170-190 meter curves indicate that the tested swiveling headlamps tended to be more effective than the fixed headlamps when making a left turn or in a left curve, but they were not as effective as fixed headlamps when making a right turn or in a right curve. The 215m curve also indicated that the fixed beam pattern performed better in right-hand curves but indicated no difference between headlamps in a left hand curve. This performance of the 215 meter curve to the right also caused a significant main effect for headlamp type for the 215 meter curve (p=0.0158).

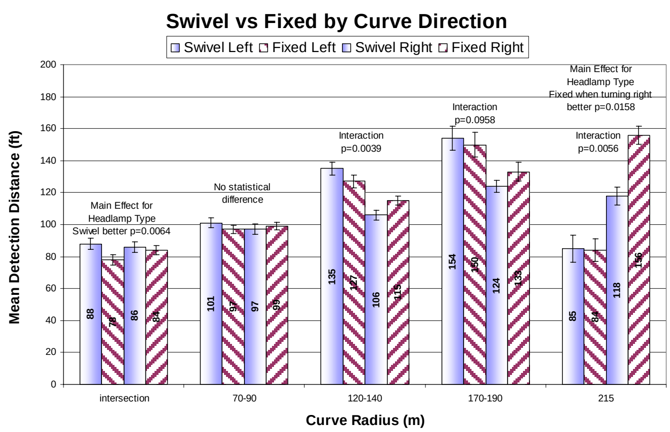

Figure 12. Study 1 – Means and standard error by turn or curve direction and radius.

The intersections (see Figure 13) also showed a statistically significant main effect for Headlamp Type (p=0.006). When turning left at intersections, participants detected targets further away with swiveling headlamps than with fixed headlamps. The mean target detection distance in left turns without a stop sign was 76ft with swiveling headlamps and 64ft with fixed headlamps (p=0.046). In left turns with a stop sign, the mean target detection distance was 100ft with swiveling headlamps and 93ft with fixed headlamps (p=0.040). In right turns at intersections, no statistical difference was found between the headlamp types.

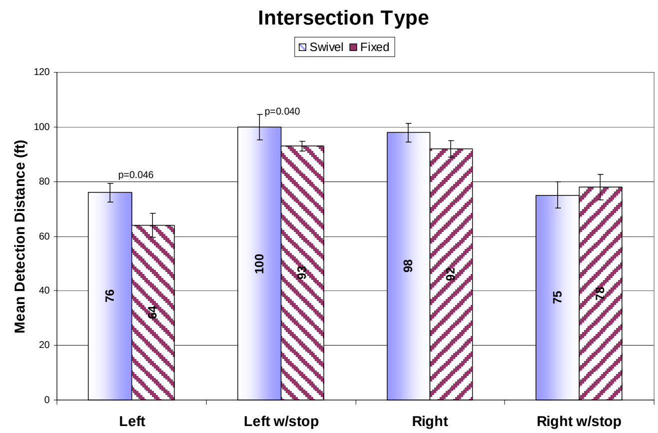

Figure 13. Study 1 - Intersection means and standard error results.

<u>Curve Direction</u> - Main effects of Curve Direction, left or right, were found for the 120-140m (p=0.0001), 170-190m (p=0.0007), and the 215m (p=0.0001) curves. When turning left longer detection distances were found for curves between 120m and 190m. The opposite effect was found for the 215m curve, with longer detection distances when turning right. In the left-hand 120-140m curves, the mean detection distance was 132ft, while in right curves of the same size, the mean target detection distance was 111ft. In 170-190m curves to the left, the mean target detection distance was 153ft. For the same size right-hand curve, mean target detection distance was 129ft. In the 215m curve to the left, the mean target detection distance was 85ft, while in the same curve to the right, it was 132ft. No significant differences were found for the intersection curves (left 83ft, right 86ft) or the 70-90m curves (left 100ft, right 98ft).

<u>Age Group</u> - The results indicated no Age Group main effect. However, there was an Age Group by Curve Direction interaction for intersections (p=0.0417). In left-turn intersections, the younger and older groups had mean target detection distances that were close to each other (84ft and 83ft, respectively). In right-turn intersections, however, the younger group's mean target detection distance of 92ft was 11ft longer than the older group's mean target detection distance of 81ft. In the 170-190m curves, a p-value of 0.0805 was found for the interaction of Curve Direction and Age Group. This is not statistically significant at the α=0.05 level and does not appear to be supported by a similar trend among the other curve groups.

DRIVING PERFORMANCE MEASURES - When comparing measures of driving performance, the data was analyzed for each participant and each target. Across the road segments prior to targets (see Dependent Variables section), the average value, maximum value, and variance in the longitudinal and lateral control measures were compared. No differences in these values could be found between the swiveling and fixed headlamps on the two vehicles.

POST-DRIVE QUESTIONNAIRES - Paired t-tests were used to investigate differences between the swiveling and fixed headlamps in each question on the post-drive questionnaires. No significant differences were found between the headlamps for this subjective data. Nine of 22 participants (41%) noticed that the headlamps moved on the swiveling headlamp car. Twenty of 22 participants (91%) commented on difficulty with the headlamps in hills (8 participants) or the distance the headlamps illuminated was short (12 participants). These comments occurred with both types of headlamps.

STUDY 2 RESULTS

Detection Distances - A 2 (Age Group) x 2 (Curve Direction) x 2 (Headlamp Type) mixed-factorial ANOVA was conducted for each Curve Radius to investigate differences in target detection distances. Curve Direction and Headlamp Type were analyzed as within-subjects variables and Age was treated as a between subjects variable. Table 3 identifies ANOVA p-values where $p<0.01$ or which were statistically significant at an $\alpha=0.05$ level (marked with an asterisk).

Table 3. Results ANOVA.

AFS II	Curve Radius				
	Intersection	70-90m	120-140m	170-190m	215-220m
Curve Direction	<.0001*	0.0002*	<.0001*	<.0001*	<.0001*
Headlamp Type		0.0004*	0.0107*	0.0595	
Curve Direction X Headlamp Type		0.0002*		0.0012*	0.0167*
Age Group		0.0314*	0.0455	0.0147*	0.0003*
Headlamp Type X Age Group	0.0275*				
Curve Direction X Age Group					0.0082*
Curve Direction X Headlamp Type X Age Group				0.0159*	

* significant at a <0.05

<u>Headlamp Type</u> - Statistically significant interactions between Curve Direction and Headlamp Type were found for curve radii between 70m and 220m (see Figure 14). In left curves, the swiveling headlamps performed better than the fixed headlamps. In right curves of the same radii, swiveling headlamps appear to perform similarly to fixed headlamps. In the 120-140m curves, swiveling did better in either curve direction. The interactions indicate that the tested swiveling headlamps tended to be more effective than the fixed headlamps when making a left turn or in a left curve and were approximately the same as fixed headlamps when making a right turn or in a right curve when following the 70-90m curves or the 170-190m curves. Swiveling also did better on left or right curves of 120-140m radii. The largest radius curve showed a 10ft greater mean detection distance when the curve was to the right for the fixed headlamps than the swivel headlamps. A simple effects model indicated that this 10 ft difference was not significant at an $\alpha=0.05$ level.

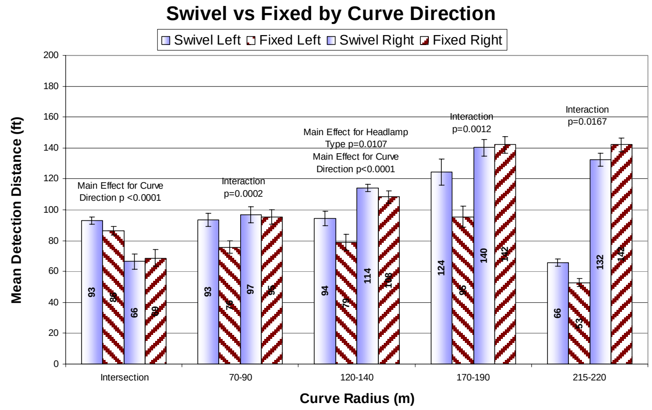

Figure 14. Study 2 – Means and standard error by turn or curve direction and radius.

<u>Curve Direction</u> - Main effects of Curve Direction, left or right, were found for all of the curves (see Figure 15). This indicates differences in target detection distance from Curve Direction, regardless of the use of fixed or swiveling headlamps.

Detection distances in the left-hand curves were shorter for all of the curve radii except the intersections. In the 70-90m curves, the mean detection distance was 85ft in the left-hand curves and 96ft in right-hand curves. In 120-140m curves to the left, the mean detection distance was 86ft, while in right curves of the same size, the mean target detection distance was 112ft. In 170-190m curves to the left, the mean target detection distance was 110ft. For the same radius right-hand curve, the mean target detection distance was 141ft. In the 215-220m curves to the left, the mean target detection distance was 59ft, while in the same curve to the right, it was 137ft.

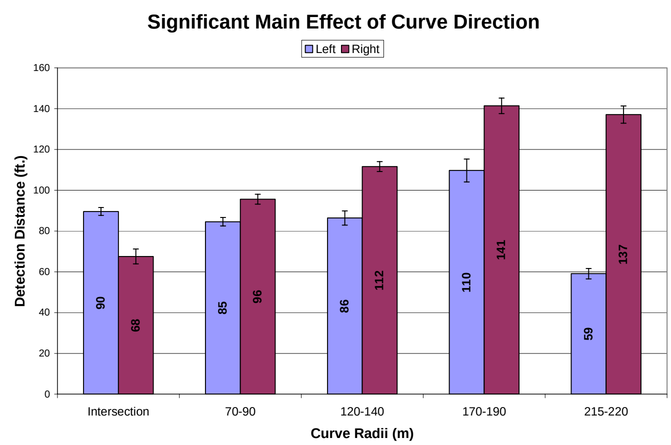

Figure 15. Study 2 –Curve Direction means and standard errors.

<u>Intersections</u> - Where participants were turning right at an intersection with a stop sign, the mean detection distances with both systems were much shorter than for the other types of intersection turns. Mean detection distances in these right turn with a stop situations were 36ft for swiveling headlamps and 37ft for fixed headlamps. For the right turn without a stop and both

left turn intersection situations, mean detection distances ranged from 86ft to 97ft. Because of this difference, each intersection type was investigated separately for swiveling headlamps versus the fixed headlamps (See Figure 16). Only the left turn with a stop scenario indicated a significant difference between the two types of headlamps (p=0.0167). Where the participants turned left after a stop sign and a target was on the far side of the turn, the swiveling headlamps had a mean detection distance of 97ft, compared to the mean detection distance for the fixed headlamps of 86ft.

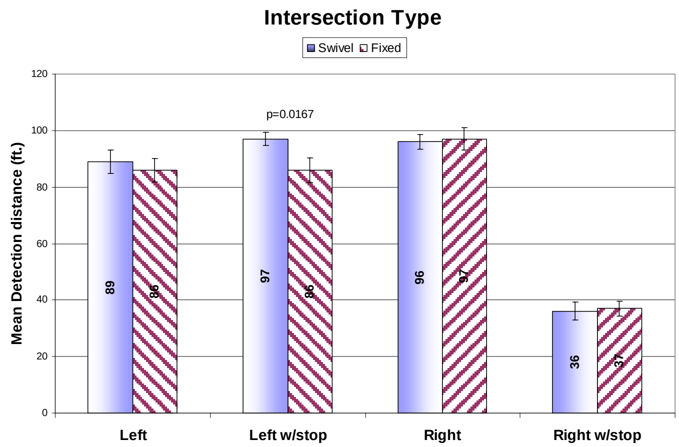

Figure 16. Study 2 - Intersection results.

Age Group - The younger group outperformed the older group in each of the curve groups. There was an interaction found for Age Group X Curve Direction X Headlamp Type (p=0.0159) for the 170-190m curve radii. In left turns of this radius, the mean detection distance for the younger group with swiveling headlamps was longer than for the older group. In turns to the right, no differences were observed between the performance of the older and younger groups. Figure 17 presents this interaction.

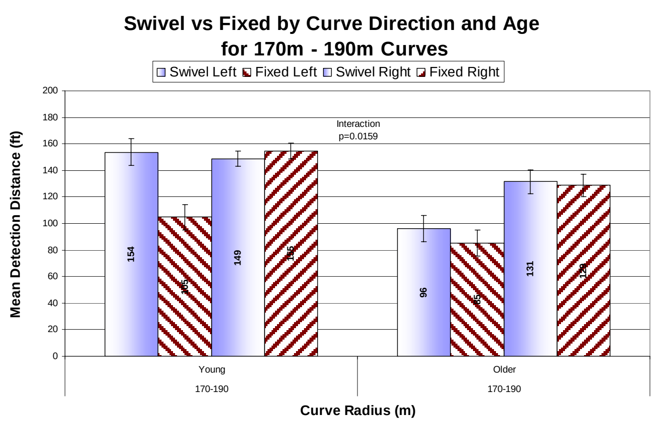

Figure 17. Study 2 – 170-190m Direction X Age interaction.

There was also an interaction found for Age X Headlamp Type for intersections (p=0.0275). Analysis of this interaction indicates that older participants did better in intersections using swivel headlamps than with fixed headlamps (see Figure 18). No statistically significant difference was found between swivel and fixed in intersection turns for the younger group.

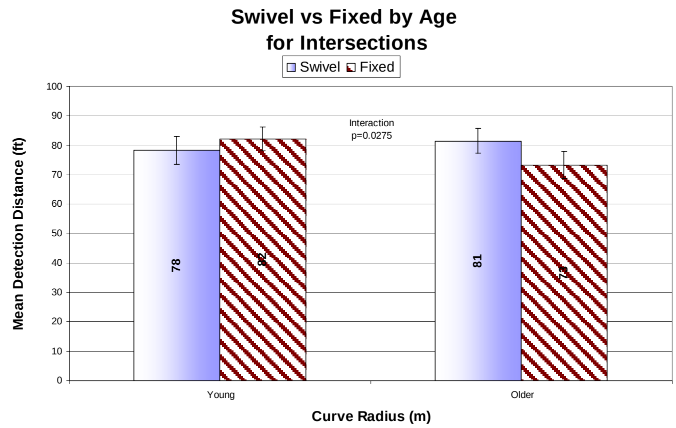

Figure 18. Study 2 – Age effect at intersections.

DRIVING PERFORMANCE MEASURES - When comparing measures of driving performance, the data was analyzed for each participant and each target. Across the road segments prior to targets (see Dependent Variables section), the average value, maximum value, and variance in the steering angle and yaw were compared. No practically significant differences in these values could be found between the swiveling and fixed headlamps on the two vehicles.

Study 1 and 2 Straight Road Comparison - When making direct comparisons between the absolute performance on detection distance between study 1 and study 2 it is important to remember that the beam patterns between the two studies were different. To gain a further understanding of this difference that would not be influenced by swiveling lights a target presented on a straight section was selected. This target could be approached from each direction, thereby providing a measure of detection distance for a right side of the road target as well as a left side of the road target. The mean detection distance for the target when on the left side of the road decreased from 128ft in the first study to 98ft in the second study. On the right side of the road in the straight segment, the mean detection distances were similar between the two studies. Figure 19 presents the differences in the detection distances on the left and right side of the road from the first and second studies.

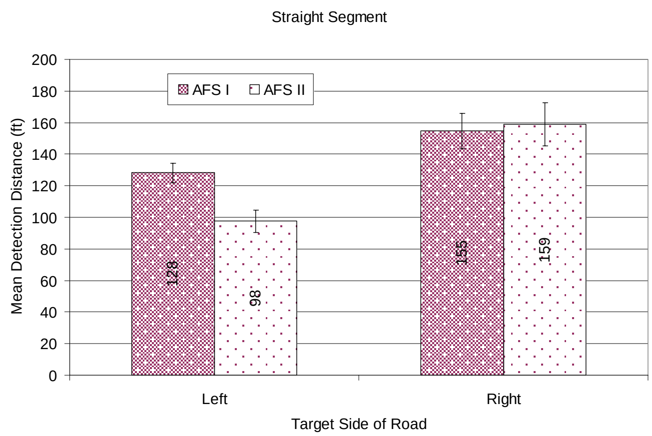

Figure 19. Study 1 and Study 2 Straight road means and standard errors.

POST-DRIVE QUESTIONNAIRES - Paired t-tests were used to investigate differences between the swiveling and fixed headlamps in each question on the post-drive questionnaires. No significant differences were found between the headlamps for this subjective data.

Nineteen out of 22 participants (86%) commented on the movement of the swiveling headlamps, and of these, 9 commented that the headlamps moved in accordance with the steering wheel. Fifteen of 22 participants (68%) commented on difficulty with the headlamps in hills (6 participants) or the distance of the headlamps being short (9 participants). These comments occurred with both types of headlamps.

In the final question, 8 out of 22 (36%) participants stated that the swiveling headlamps did not meet their needs, and 11 out of 22 participants (50%) stated that the fixed headlamps did not meet their needs.

DISCUSSION

In the first study, participants' target detection distances while driving the vehicle with headlamps employing the first swiveling algorithm were equal or longer in left-hand curves than those reported for the fixed lamps. In right curves however, shorter target detection distances resulted when participants drove the vehicle with the swiveling headlamps as compared to the fixed headlamps, particularly in the largest radius curve. The algorithm modifications undertaken prior to Study 2 had the goal of improving target detection distances by participants driving the vehicle with swiveling headlamps through right-hand curves to be comparable or better than those measured when driving the vehicle with fixed headlamps through right hand curves.

With the modified algorithm tested in Study 2, in left-hand curves, participants' measured target detection distances with the swiveling headlamps continued to be larger than those measured with the fixed headlamps, with greater differences than shown in Study 1. In right-hand curves ranging in size from the small radii turns in intersections to the approximately 190m radius curves, participants' measured target detection distances while driving the vehicle with the swiveling headlamps were not significantly different than those measured when driving the vehicle with the fixed headlamps. This suggests that the swiveling algorithm utilized in Study 2 is an improvement over that used in Study 1, because it indicates that the swiveling headlamps are comparable to fixed headlamps in terms of participants' target detection distances in right-hand curves of these radii. It is important to note here that the beam pattern also changed from Study 1 to Study 2.

Comparison of the straight road segment indicated a difference in detection distances between the first study and the second study. Additionally, in the first study, measured target detection distances were generally greater for curves to the left than for curves to the right for curves between 120-190m radius, regardless of Headlamp Type. In the second study, the measured target detection distance for targets placed on the left side of the road was reduced for both swiveling and fixed headlamps, while for targets placed on the right side of the road, measured target detection distances remained approximately the same from Study 1 to Study 2. Measured target detection distances in intersections present an exception to this finding. In intersections, turning right at a stop sign in Study 2 had mean detection distances of approximately half the distances that were measured in Study 1. Detection distances in turns to the left without a stop may also have been slightly less in Study 2. Turning left at a stop sign, and turning right without a stop sign were similar between Study 1 and Study 2. The shorter participant target detection distances for targets placed on the left side of the road found in Study 2 are in accordance with luminance measurements taken on the targets, which indicated that for a given distance, more light was reaching the targets placed on the right side of the road than was reaching targets placed on the left side of the road.

The differences in detection distances on the left side of a straight road from Study 1 to Study 2 are due to differences in the headlamp beam pattern which was used between the two studies. The differences in curves between Study 1 and Study 2 are due to both the beam pattern and algorithm. The set of headlamps used in Study 2 had generally less illumination on the left side of the road. From this research, it is apparent that successful implementation of a swiveling headlamp system depends on the algorithm design and that the beam pattern of a headlamp must also be considered.

In the intersections tested, in right turns, no significant differences in participants' measured target detection distances were found between fixed and swiveling headlamps in either the first or second study. In left turns at intersections, the first study found swiveling headlamps to provide for longer target detection distances whether the participant was turning left at a stop sign or turning left without stopping. In the second study however, swiveling headlamps provided for longer target detection distances than fixed headlamps when turning left at a stop sign, but they did not provide significantly different results when participants turned left without stopping.

When investigating age differences, the first study indicated differences between the age groups participating during right turns at intersections. In these turns, the younger group recognized the targets earlier (~11ft) than the older group. In Study 2, participants' measured target detection distances while negotiating curves in the largest curve group indicated the younger group recognized the targets at greater distances than the older group regardless of Curve Direction, but that there was a greater difference (~36ft) when negotiating the right-hand curves. Study 2 also indicated an Age Group X Curve Direction X Headlamp Type interaction for the 170-190m curves in which the younger group recognized the targets at greater distances in left turns of this size when they were driving the vehicle equipped with swiveling headlamps as compared to cases when they were driving the vehicle equipped with fixed headlamps. This difference in measured target detection distances was not seen with the older group.

In Study 2, measured target detection distances in the intersections for both Headlamp Types were greater when the participant was negotiating a left- hand turn. This difference can be attributed to the larger radius curve in a left-hand turn at an intersection than in a right-hand turn. Whether with swiveling or fixed headlamps, the larger radius allows the light from the headlamps to reach the target at a greater distance along the path of the turn and generates longer detection distances.

No significant driver performance differences were identified based on the methods used in this study. Further research in this area might pursue testing a fixed and swiveling headlamps on one vehicle to achieve the maximum control over vehicle and instrumentation differences.

Participants did not indicate any differences in their perception of headlamp performance between the two Headlamp Types. A large number of participants indicated difficulty from both Headlamp Types in both studies due to the discrete beam pattern cut-off line both headlamps employed.

CONCLUSIONS

Algorithm changes incorporated into Study 2 involved reducing the amount of swivel in larger radii turns. It is believed that too much swivel to the right in Study 1 caused excess near field illumination, which reduced the target detection distances. Possible hypotheses to explain this include: 1) the driver's eyes may be being drawn to this location, or 2) the light adaptation of the eyes may be raised, therefore reducing the ability of the participants to detect targets beyond the near field.

These studies suggest that for the tested beam pattern and targets, swiveling low beam headlamps can provide for increased detection distances, and by extension increased time to react, in left-hand curves. The swiveling headlamps tested provided for a detection distance increase ranging from 8 to 30 percent depending on the curve radius, with the largest improvements measured in mid-sized curves between 120m and 190m in radius. At the same time, no significant decreases were found in detection distances in right-hand curves or at intersections; in fact, swiveling beams may provide for increased detection distances in certain intersection left-hand turn scenarios. Thus swiveling low beam headlamps may be able to provide seeing benefits in many driving scenarios without observed disbenefits.

However, our initial experience with this swiveling low beam headlamp system revealed that small differences in the execution of the system algorithm made significant differences in driver's detection performance. Our initial swiveling system algorithm unexpectedly significantly reduced target detection distances in large radius right-hand curves. This initial algorithm was not predicted to have such a performance decrement from photometric analysis. Therefore we recommend careful design combined with on-road driver performance testing of swiveling low beam headlamp algorithms to ensure desired system benefits under the largest range of driving scenarios.

REFERENCES

Hamm, M. (2002). Adaptive lighting functions history and future – performance investigations and field test for user's acceptance. Society of Automotive Engineers. SAE 2002-01-0526

Janoff, M. (1993). The relationship between small target visibility and a dynamic measure of driver visual performance. Journal of the Illuminating Engineering Society, v22 (1) 104-112.

Mortimer, R. (1974). Field and computer-simulated evaluation of head lamp beams. Driver Visual Needs in Night Driving – TRB Special Report 156. Transportation Research Board, September 4-6, 1974.

Neumann, R. (2004). AFS halogen headlamp system – Experimental study and first field results. Society of Automotive Engineers. SAE 2004-01-0439.

Sivak, M., Flannagan, M., Schoettle, B., and Nakata, Y. (2001). Benefits of applying adaptive lighting to the U.S. and European low-beam patterns. Ann Arbor, MI: University of Michigan Transportation Research Institute. Report No. UMTRI-2001-20.

Theeuwes J, Alferdinck J. (1996). The relation between discomfort glare and driving behavior, Soesterberg, Netherlands: TNO Human Factors Research Institute. Report DOT HS 808 45