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Older Driver Detection of a Roadway Obstacle at Night

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This paper represents an extension of a 2007 HFES Annual Meeting paper (Curry et al, 2007). The original paper focused on the nighttime detection of obstacles stopped along the sides of active roadways by drivers between 20 and 60 years of age. The current paper focuses on a similar detection task, but utilizes a considerably older driver sample. It has been well-recognized for a number of years that driver visual capabilities begin to decline rapidly as the age of the motorist increases. This study was designed to quantify the relative detection distances of a variety of target vehicle characteristics by older, aware motorists on a darkened roadway.

INTRODUCTION

The nighttime detection of obstacles stopped on a roadway has been an issue of concern amongst safety professionals for almost as many years as there have been automobiles. Past research has focused largely on such data as target reflectivity, headlamp luminosity, atmospheric attenuation and other variables. While such information can be of great value to the accident investigator, it is often too obtuse or theoretical to be intrinsically meaningful to members of the average jury in litigation matters.

Further, much of the existing work has focused on the portion of the driving public represented by those less than 60 years of age. While this group represents over 80% of the population, it must be born in mind that approximately 10% of the driving public is between 60 and 69 years of age, 7% are between 70 and 79 years of age, and almost 3% are over 80 years of age according to 2011 Department of Transportation statistics (the most recent available at the time of this writing.)

As the eye ages it undergoes gradual optical changes, including a thickening of the aqueous humor that fills the eye, a thickening and yellowing of the lens itself, and dark pupil diameter decrease, all of which result in a reduction in retinal illuminance (see Figure 1). Light sensitivity under scotopic conditions decreases with age, and rod photoreceptors selectively dropout. Additionally, photopigment regeneration is slowed in the older retina, manifesting as prolonged dark adaptation times. These effects taken together, result in an approximately linear reduction in the amount of light reaching the retina as one gets older. Until the age of about 70 years, these optical changes are almost exclusive in explaining reductions in visibility exhibited by older adults when compared to younger adults (Bullough & Rea, 2010.) Spatial vision also declines with age (especially for high spatial frequency objects under dim illumination) and contrast sensitivity declines (Jackson and Owsley, 1999).

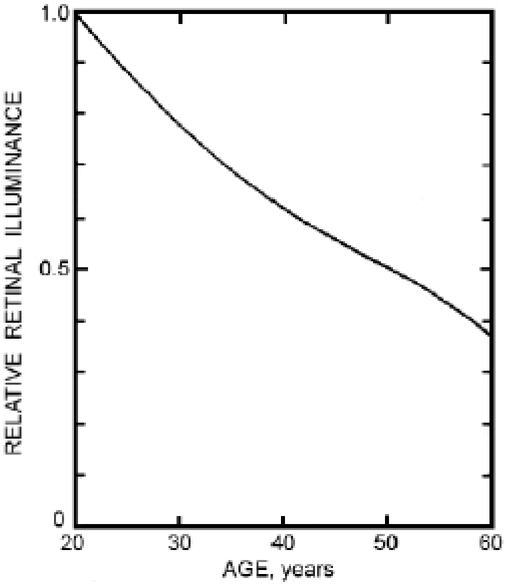

Figure 1 Age-related reduction in retinal illuminance caused by lens thickening and yellowing and by pupil size reductions (Rea and Ouellette, 1991)

As mentioned earlier, the question of how far away a roadway object can be detected is often of critical interest to those investigating accidents. Our earlier study (Curry, 2007) attempted to quantify the distances at which various obstacles could first be recognized by alerted motorists ranging from 20 to 60 years of age (the average age of our test sample was approximately 39 years.) This study will contrast detection distances found in our earlier study with those found for an older group of subjects to determine how the detection distances are affected by increased age.

METHOD

Both this study and that reported in our prior paper were conducted to support cases that were involved in litigation at those times. Since the issues involved in the cases were somewhat different, an identical methodology could not be utilized for the second study as was used in the first. The original study focused on obstacles located at a position equivalent to the right shoulder of the roadway, while the current study was focused on obstacles directly ahead of the motorist. This likely affected the results to some degree, but the data from both studies still lends itself to comparison.

Subjects

A total of seven test participants were selected as drivers for the test vehicle. These test participants ranged from 61 to 82 years in age (average 68.9 years old, standard deviation of 8.3 years), including four males and three females. All test participants possessed current driver's licenses. It was confirmed that each driver had passed the vision requirements for holding a valid Illinois drivers license and that their eye sight had been relatively unchanged since their last vision exam. Requirements for holding an unrestricted Illinois license include minimum visual acuity of 20/40 with or without corrective lenses and at least 140 degree of peripheral vision (the ability to see to the side) with or without corrective lenses. Thus, each driver's eyesight was assumed to be 'road-worthy' at the time of the subject study. The number of test participants was limited by a variety of factors including difficulty obtaining volunteers in the appropriate age group who were willing to participate in a late night study, the substantial amount of time necessary to conduct the study, and the limited availability of the airport runway used as a test facility.

Procedure

The selected test location was a non-operational runway at a general aviation airport located approximately 70 kilometers west of Chicago. The location was selected in order to provide an extended, level, flat travel surface. This was done in order to eliminate any potential obstructions of the target and to minimize any sources of artificial illumination other than the test vehicle's headlights. All testing was performed under low beam illumination. Testing was performed at least two hours after local sunset in order to minimize potential differences in ambient illumination between successive subjects. The amount of illumination provided by the moon itself was obviously beyond experimental control, but there was negligible difference in horizontal and vertical illumination levels over the course of testing (~0.01 lux).

In the subject study, two vehicles (the target and the bullet vehicle) were placed on an unilluminated concrete surface, approximately 1200 meters apart. Research participants were directed to drive the first (i.e. bullet) vehicle towards the second (i.e. target) vehicle, while indicating the first point at which they were able to detect several specified characteristics/features of the target vehicle. The bullet vehicle was an unmodified 2010 Dodge Caravan minivan with the low beam headlights (H13 halogen) illuminated. The target vehicle consisted of a white 2005 Kenworth tractor unit attached to a white 53' box trailer unit. Both units were equipped with all FMVSS 108 required markings, reflectors, etc. and were in a relatively clean condition, as would be observed on a typical vehicle after a normal period of operation. The target vehicle was positioned perpendicular to the bullet vehicle's path of travel, in a jackknifed configuration, as shown in Figure 2 at the end of this paper.

Prior to the initiation of testing, subjects were shown the target vehicle close-up, and each of the following target characteristics/features were clearly identified to them:

- Tractor headlights
- Trailer side-marker/parking lights
- Trailer retro-reflective striping located on the sides of the trailer body
- Trailer body outline
- Tractor body outline
- Distinguishing between the trailer company logo and the side of the trailer body

Participants were instructed to drive the bullet vehicle at a slow speed (8-16 kph) in a straight line towards the target vehicle while looking for the aforementioned characteristics/features on the target vehicle. When the driver detected any of the target features, they were instructed to immediately stop the vehicle, at which point an experimenter got out of the vehicle, measured the distance between the bullet and target vehicles, and returned to the bullet vehicle to resume testing. In practice, measurement was accomplished by placing markers on the runway every 30 meters from the target and measuring the distance between the bullet vehicle at the time of notification and the nearest marker. After each measurement, the driver was instructed to continue driving forward at a slow speed until each of the target features were detected and the corresponding distances were measured.

Each research participant completed the study tasks with the target vehicle in three different lighting configurations:

1. Fully lighted – Tractor headlights and trailer parking/marker lights fully illuminated
2. Semi-lighted – Tractor headlights extinguished, but trailer parking/marker lights illuminated
3. Dark – Tractor headlights and trailer parking/marker lights completely extinguished

Some of the target features were assessed only under the applicable lighting conditions (i.e., headlight and side marker light detection distance was only collected when those lights were activated.) The configuration of the test site provided for a maximum starting distance between the subject and the target vehicles of approximately 1200 meters. During testing, the runway lighting on all runways was completely extinguished.

Due to the certainty factor and reaction time delay in reporting detection to the experimenter, the detection distance data presented here is marginally shorter than the distance at which the subjects actually detected the target. This measurement "error" is likely less than 6 meters based on a probable 0.5 second reaction time (Green, 2000).

RESULTS

Means and standard deviations were calculated for each target under each visibility condition. These results are presented in Tables 1 through 3 below.

Target	Mean Detection Distance (m)	Std Dev of Detection Distance
Tractor headlights & marker lights	1060	10
Trailer side marker & parking	1022	32
Trailer retro-reflective tape	511	317
Trailer body	355	164
Tractor cab	115	74
Trailer company logo	92	85

Table 1 Detection Distances, Condition #1
(Fully lighted – All lights active on target vehicle)

Target	Mean Detection Distance (m)	Std Dev of Detection Distance (m)
Tractor headlights & marker	N/A	N/A
Trailer side marker & parking	1033	48
Trailer retro-reflective tape	488	204
Trailer body	358	133
Tractor cab	180	95
Trailer company logo	89	40

Table 2 Detection Distances, Condition #2
(Semi-lighted - Only parking and marker lights active on target vehicle)

Target	Mean Detection Distance (m)	Std Dev of Detection Distance (m)
Tractor headlights & marker	N/A	N/A
Trailer side marker & parking	N/A	N/A
Trailer retro-reflective tape	558	235
Trailer body	280	79
Tractor cab	178	67
Trailer company logo	64	4

Table 3 Detection Distances, Condition #3
(Dark - All lights on target vehicle extinguished)

DISCUSSION

For comparison purposes, the detection distances for comparable targets from our 2007 study are presented in Table 4.

Target	Mean Detection Distance (m)	Std Dev of Detection Distance (m)
Flashers & Taillights	1100+	N/A
Retro-reflective Striping	924	38
Car body (light-colored)	113	40

Table 4: Data from 2007 Study

As can readily be seen by simple comparison of the data, the average detection distances for the most-readily detectable features, the vehicle marker lights, were comparable and exceeded one kilometer across the two studies. The next most-readily detectable, common feature, the retro-reflective striping, however, was not visible to the older group of test subjects until the bullet vehicle was considerably closer than was found for the younger subjects. In the unlit condition, the retroreflective striping could not be detected by the older group until it was at roughly 50 – 60% of the detection distance of the younger group.

When attempting to detect an unlighted vehicle body, the older group was able to detect the non-self-illuminated white truck cab at a much longer distance than the younger group was able to pick out the non-self-illuminated light-colored automobile body (178 vs. 113 m). This was somewhat surprising. To some degree this was a reflection of the relative size difference between the two targets. The semi-truck cab used in the current study, at its average detection distance, was approximately 41 arc-minutes in width and 76 arc-minutes in height, while the automobile used in the prior testing, at its average detection distance, was approximately 56 arc-minutes in width and 44 arc-minutes in height. This suggests that a 26% larger target in the second study resulted in a 57% greater detection distance for the older group. Both vehicles were white in color. It is doubtful that the greater detection distance could have been a function of a greater reflectivity of the grill of the truck, since this aspect of the target was a relatively small portion of the target face (and examination of the vehicle photos suggests that its reflectivity was actually lower than the painted surface of the vehicle.) The difference in detection distance could be simply a function of the truck trailer leading the eye to the position of its cab in the second study, while the car in the first study was a stand-alone target.

Another factor of interest is that the car target used in the original study was parked in a position approximating that of the *right* shoulder of a roadway, while the truck cab used in the second study was positioned to the *left* of the aimpoint of the bullet vehicle (approximating that of a vehicle in an opposing lane.) Since automobile headlights are oriented slightly to the right to avoid producing unacceptable glare levels for oncoming motorists, this suggests that the target truck cab in the second study should have received commensurately *less* illumination from the bullet vehicle than did the car target in the first study.

A noteworthy difference between the two studies lies in the variability of some of the measurements. For the original study, the standard deviation of the detection distance for the retroreflective striping was approximately 4% of the detection distance for the younger group under non-self-illuminated conditions. In our follow-on study, the standard deviation for the retroreflective striping was more than 40% of the mean detection distance under similar lighting conditions. For the vehicle body detection distance under non-self-illuminated conditions, the standard deviation for the younger group was approximately 35% of the mean, while the standard deviation was 30-35% of the mean for the older group, depending on whether the target was the truck or the trailer.

The data suggests that for the older group there was a much greater degree of variability in target detection distance for narrow targets (the 5-cm wide retroreflective striping) compared to larger targets (the vehicles themselves). Unsurprisingly, there appears to have been a considerable glare effect from the headlights of the vehicle for the older subjects with regard to detecting the cab of the truck itself when the lights were illuminated. The same glare effect did not manifest itself with only the parking/marker lights illuminated. Overall, the results of this study were in general agreement with those found in our earlier paper.

Unlike drivers in a typical roadway scenario, the subjects in this study were aware of the targets in the "roadway" in their path of travel and were conducting an active search. It has been suggested that unalerted motorists typically do not detect objects until they are at roughly half the distance they are detected at by alerted motorists (Olson et al, 2009.) This heuristic is based upon daylight viewing, and may be inappropriate for nighttime testing using headlight illumination, since light falling onto a target is a function of the square of the distance, rather than being a linear function of it (i.e., the light falling onto a target doubles when the distance from the source is reduced by 30%.)

If one were to assume both that unalerted motorists did indeed have to be at half the distance from the target to have a detection likelihood equal to that of alerted motorists and that the data could be represented by a standard normal distribution, then the values for Table 5 would represent the likely 85th percentile detection distances for unalerted older motorists based on the data collected in this study (Minium, 1978).

Target	**Estimated Average Unalerted Detection Distance (m)**	**Estimated 85th Percentile Unalerted Detection Distance (m)**
Retro-reflective tape	279	162
Trailer body	140	101
Cab of truck	89	55

Table 5 Estimated Unexpected Target Detection Distance for Unlighted Targets by Older Motorists (Based on standard normal distribution and 50% reduction of detection distance of alerted subjects)

Based on past studies of human visual detection functions, it is more likely however that the distribution would be lognormal, rather than normally distributed (Holst, 1992; Selvitelle, 1974). Table 6 presents data similar to that in Table 5 regarding the likely 85th percentile detection distance assuming a lognormal distribution.

Target	**Estimated Average Unalerted Detection Distance (m)**	**Estimated 85th Percentile Unalerted Detection Distance (m)**
Retro-reflective tape	279	181
Trailer body	140	105
Cab of truck	89	56

Table 6 Estimated Unexpected Target Detection Distance for Unlighted Targets by Older Motorists (Based on lognormal distribution and 50% reduction in detection distance of alerted subjects)

Given a highway travel speed of 105 kph (29 m/s) and an average perception reaction time of 1.5 seconds for an unexpected event (Green, 2008), an approaching vehicle operator would cover almost 44 meters prior to the first onset of braking after detecting a target in the road ahead. A braking level of 0.3*g* (2.9 m/s^2) would result in a total stopping distance of 187 meters. Using a braking level of 0.5*g* (4.9 m/s^2) would result in a total stopping distance of 130 meters, while 0.7*g* (6.9 m/s^2) braking would result in a stopping distance of 105 meters. This suggests that even an unaware 85th percentile older driver should be able to avoid striking an unlit, retro-reflectorized obstacle by completely stopping the vehicle through a relatively moderate brake application after detecting the object ahead, and should also be able to avoid striking an unlighted, unreflectorized target by completely stopping the vehicle through more aggressive braking. Additionally, the ability to steer a vehicle would further increase the impact avoidability in these situations. This analysis is based on the unalerted driver detecting the obstacle at half the distance of an alerted driver.

Tables 7 and 8 represent data similar to that shown in Tables 5 and 6, but are based on the premise that the detection distance for unalerted observers is a function of a doubling of the level of illumination of the target by the bullet vehicle, rather than a halving of the distance to the target.

Target	Estimated Average Unalerted Detection Distance (m)	Estimated 85th Percentile Unalerted Detection Distance (m)
Retro-reflective tape	391	227
Trailer body	196	141
Cab of truck	125	77

Table 7 Estimated Unexpected Target Detection Distance for Unlighted Targets by Older Drivers (Based on standard normal distribution and 30% reduction of detection distance of alerted subjects)

Target	Estimated Average Unalerted Detection Distance (m)	Estimated 85th Percentile Unalerted Detection Distance (m)
Retro-reflective tape	391	253
Trailer body	196	147
Cab of truck	125	78

Table 8 Estimated Unexpected Target Detection Distance for Unlighted Targets by Older Drivers (Based on lognormal distribution and 30% reduction in detection distance of alerted subjects)

Since the estimated target detection distances in Tables 7 and 8 are demonstrably longer than those in Tables 5 and 6, the similar conclusions with regard to ability of an unalerted motorist to be able to bring their vehicle to a halt prior to striking the stopped object apply, with the exception that the unalerted driver should be readily able to avoid the potential accident with more moderate levels of braking.

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Figure 2 Target Obstacle in Tested Configuration