Driver Detection of Roadside Obstacles at Night

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Oftentimes vehicular accidents involve collisions, not between two vehicles on the roadway, but between a vehicle which departs from the roadway and a vehicle parked on the shoulder. In many such cases, the striking party will maintain that they were in control of their vehicle at all times, but were simply unable to detect the parked vehicle due to lack of illumination or inadequate warning of its presence. A search of the available literature has produced no data which quantifies the relative detectability of such warning devices compared to reflections from such surfaces as vehicle bodies, non-illuminated taillight lenses, or retroreflective striping such as that required on transport trailers and trucks. This study was designed to quantify the relative detection ranges of each of these surfaces for a vehicle parked alongside a darkened roadway by an aware motorist.

INTRODUCTION

The detection of obstacles both in the roadway and along its shoulders has been a concern of researchers for many years. Much of the research that has been performed to date has focused on issues such as target reflectivity, headlamp illumination and atmospheric attenuation. 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. Further, the reflectivity of surfaces often varies greatly with the angle of incidence of the illumination falling upon them.

An additional complicating factor is that low-beam automotive headlights represent a compromise between several competing factors. High-beam headlights are designed to project directly along the roadway itself, while low-beam headlights are designed to reduce glare for oncoming drivers to a reasonable level. This results in low-beam headlights being aimed downward and slightly to the right of the vehicle's path of travel (Dewar and Olson, 2002). Fortunately or not, drivers typically use their low beam, rather than high beam headlights while driving (Olson and Farber, 2003).

A number of studies (e.g., Olson and Sivak, 1983) have investigated the visibility of pedestrians located to the sides of the road, wearing either low or high reflectivity clothing. The Olson and Sivak study found a 50th percentile detection distance of approximately 46 meters (150 feet) for dark-clad pedestrians located to the right of the vehicles path of travel, while that of those wearing white clothing was almost twice that distance. In those cases, the clothing reflectivity of the dark clad pedestrian was below 5%, while that of the white clad pedestrian was approximately 70%. This type of data is extremely valuable when investigating vehicle-pedestrian accidents, but sheds little light on surfaces which have been purposefully designed to provide enhanced reflectivity.

According to Federal Motor Vehicle Safety Standard (FMVSS) No. 108, all heavy trailers (those with a Gross Vehicle Weight Rating over 4536 kg [10,000 pounds]) manufactured on or after December 1, 1993 must be equipped with red-and-white retroreflective tape, sheeting and/or reflex reflectors around the sides and rear to make them more visible. In March 1999, the Federal Highway Administration extended this requirement to the entire on-road trailer fleet, directing motor carriers engaged in interstate commerce to retrofit heavy trailers manufactured before December 1993 with tape or reflectors. Since June 2001, almost all heavy trailers on the road have been equipped with some form of reflective treatment.

As mentioned earlier, the question of how far away a roadside object can be detected is often of critical interest to those investigating accidents. It is obvious that increasing the reflectivity of targets in the visual environment will make them more detectable under most nighttime driving scenarios, but the issue of how much is often not quantified. For example, even the red surfaces of stop signs are typically 100 to 1000 times more reflective than the typical pedestrian at similar distances (Olson and Farber, 2003), but obviously, such signs are not visible at 100 to 1000 times the distance, due to size and attenuation issues. The important question in many legal venues is at what distance are similarly highly reflective targets such as taillight lenses, reflectorized safety triangles, and retroreflective striping, visible to oncoming motorists? This study attempts to provide some experimental evidence with regard to the comparative detection distance of such objects when positioned on the shoulder of the roadway.

METHOD

Subjects

Thirty subjects (20 male and 10 female) between the ages of 20 and 60, of which approximately half wore corrective lenses, were asked to drive a test vehicle (a 2004 Pontiac Grand Prix) at approximately 16 kilometers per hour (10 mph) along a straight, flat section of pavement. Targets which might commonly be found alongside a roadway were placed according to the experimental schedule. Only one target per test run was visible in order to avoid confusion among multiple targets. The subjects were aware of the type of targets being employed and the purpose of the testing.

Procedure

The selected test location was on a non-operational runway at a general aviation airport located approximately 70 kilometers from Chicago. The location was selected in order to provide an extended, level, flat travel surface 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). All testing was performed at least two hours after local sunset in order to minimize differences in ambient illumination between subjects. The amount of illumination provided by the moon itself was obviously beyond experimental control, but the selected test nights encompassed a negligible difference in illumination level of 0.01 lux (range from .02 to .03 lux). The experimental setup involved a total of 10 different targets: 1-4) a dull matte-grey wooden target approximating the rear dimensions of a semi-trailer, equipped with retroreflective striping as required in FMVSS 108, taillights and flashers positioned appropriately for such a vehicle (test conditions involved the target with taillights on, flashers on, both taillights and flashers on, and retroreflective striping only with all lights turned off); 5) a reflectorized warning triangle with an overall height of 46 cm and sides of 43 cm which was designed as a warning device compliant with FMVSS 125.571.125; 6) a non-reflectorized safety orange triangle of identical size; 7) the non-illuminated taillights of a light silver-white 2000 Chevrolet Impala (taillight size approximately 32 cm x 23.5 cm); 8) the vehicle body of the same 2000 Chevrolet Impala; 9) the non-illuminated taillights of a black 2004 Infinity G35X (taillight size approximately 24 x 23.5 cm), and 10) the vehicle body of the same 2004 Infinity G35X. Since license plates vary in terms of color and relectivity across designs and states, the license plates were removed from the vehicles during testing.

The configuration of the test location provided for a maximum starting distance between the subject and the test targets of approximately 1100 meters (a 150 meter safety margin from the airport's crossing runway [semi-active] was maintained in case of an aircraft being forced to make an emergency landing at the facility.) During testing, the runway lighting was not illuminated on either runway.

During each of the data collection runs, subjects were instructed to drive the test vehicle while maintaining "lane position" based on a highly visible longitudinal seam that ran the length of the runway surface. Targets were placed to the outside of the seam at a distance corresponding to the likely position of such targets if parked alongside of an operational roadway (approximately 0.6 m outside the seam.) Subjects were instructed to proceed down the runway towards the targets at a speed of no more than 16 kph. They were asked to notify an experimenter seated in the passenger seat and bring the vehicle to a stop as quickly as possible once they were certain that they had detected the target for a particular data collection run. At that point, an experimenter would depart the vehicle, return to the location at which the subject had notified them of the sighting, and measure the distance from that position to the target. In practice, this was accomplished by placing markers on the runway every 30 meters from the target and measuring the distance between the car at the time of notification and the nearest marker. Only one target was visible during each data collection run, in order to eliminate the possibility of misidentification of alternate targets.

Independent variables which were examined included: 1) subject age (blocked into two groups---20 to 40 years of age and over 40); 2) gender; 3) seated eye-height above the ground (blocked into two groups---less than 117 cm and more than 117 cm); 4) whether or not the subject wore eye correction, and 5) ambient illumination on the test night. The sole dependent measure in this study was distance between the driver's position when they detected the target and the target itself. Subjects were requested to be certain that they had actually detected a target before notifying the experimenter and stopping the vehicle, though they did not necessarily have to identify the nature of the target. For example, the reflectorized triangle could be seen as a bright object before it could be identified as a triangle. Due to the certainty factor and reaction time delay in reporting detection to the experimenter, the detection distance data presented here is undoubtedly at least somewhat 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).

Data Analysis

The data was initially examined using one-way analysis of variance (ANOVA). No significant ($\alpha < 0.05$) differences between any of the independent variables were found. Since tests for equality of variance showed no significant differences between independent variables, the data was aggregated for subsequent analysis. Paired samples t-tests were utilized to detect significant differences between the targets.

RESULTS

Significant differences at the 0.05 level were found between all of the targets, with the exception of the non-illuminated car taillights and that between either of the two car bodies and the non-reflectorized triangle. Table1 shows the mean detection range and standard deviation for each target.

Target	Mean Detection Range (m)	Std Dev of Detection Range (m)
Flashers & taillights	1100*	N/A
Flashers only	1100*	N/A
Taillights only	1100*	N/A
Retro-reflective tape	924	38
Retro-reflective triangle	720	163
Light-colored car taillights	324	62
Dark-colored car taillights	329	79
Light-colored car body	113	40
Dark-colored car body	87	33
Non-retro-reflective triangle	86	26

*All subjects were able to see these targets at the maximum range of the test facility. As such, no mean or standard deviations could be computed.

Table 1: Detection Ranges

DISCUSSION

On the whole, the results were unsurprising in terms of the relative detectability of the different targets. One comparison of particular interest to the authors was that between the retroreflective tape and that of the reflectorized safety triangles. Federal Motor Carrier Safety Regulations require that commercial carriers place a warning device (e.g., a safety triangle) 30.5 meters (100 feet) ahead and 30.5 meters behind vehicles stopped on the shoulders of two-way roads, or 30.5 meters and 61 meters to the rear of vehicles stopped on divided highways or one-way streets. Based on the data from this study, the retroreflective tape could be detected at a significantly greater distance than the reflectorized triangles. Even allowing for the 61 meters behind the vehicle that such warning devices are to be placed, the retroreflective tape on the rear of commercial vehicles would be visible from almost 150 meters farther away that the rearmost of the warning triangles.

This difference may be a function of the greater surface area of the reflective striping (the standard tape was greater in width than the sides of the standard warning triangle), the difference in color between the two (red for the surface of the triangle vs red and white for the tape), the greater elevation from the roadway surface of the tape (the height of the rear deck of the trailer surface vs a height of 46 cm for the triangle), or some combination of the three factors.

The superior detection distance for the retroreflective tape is supported by other research. In 2001, the results of an analysis of the benefits of adding retroreflective striping to heavy trailers were published by the National

Highway Safety Administration (Morgan, 2001). That study, examining almost 11,000 accidents, found that under “dark-not-lighted conditions” (similar to the test conditions in the current study) accidents were reduced by 41% when the striping was present. Reduction in accidents under “dark-lighted”, “dawn” and “dusk” conditions were non-significant. Assuming that the majority of the drivers of commercial vehicles involved in the accidents in the NHTSA study would have had safety triangles deployed in compliance with the Federal Motor Carrier Safety Regulations, the reduction in accidents must have stemmed from the addition of the retroreflective tape providing enhanced detectability. This strongly suggests that, in terms of simple detection, the use of reflective markings on trailers provides significant benefit beyond that provided by the deployment of safety triangles.

The study detailed here was performed using newly applied retroreflective tape that was in clean condition. It is probable that the benefits of the tape would be degraded under conditions of wear or were it to be covered by substantial amounts of dirt or other materials. The above mentioned NHTSA study confirms these facts, noting that clean tape reduces rear impacts by 53 percent, while dirty tape resulted in a reduction of only 27 percent (60 percent of the trailers examined had clean tape, while about 30 percent of the trailers had some dirt, and less than 5 percent had "very dirty" tape.) The NHTSA study also noted that between 96 and 99 percent of the retroreflective tape on the sides of trailers was intact, while values for the rear of the trailers ranged from 92 to 95 percent. Again, the significant reduction in accidents suggests that even under conditions of degraded tape, the presence of the tape itself provides benefit over that of warning triangle deployment alone.

One issue that remains unclear is the possibility that identification of the presence of the warning triangles provides potentially valuable information regarding the status (i.e., stopped rather than moving) of the target vehicle. At longer distances this may be true. However, it is likely that the simple increase in target size as an oncoming motorist approached the stopped target would provide this same information. Studies have shown that motorists are immediately able to detect closing velocities between themselves and other objects as long as the apparent size of the approaching object is changing at above a value of 0.003 rad/sec (0.17 deg/sec) (Hoffman and Mortimer, 1996). Assuming a closure rate between a vehicle proceeding at 105 kph (65 mph) and a stopped commercial vehicle with retroreflective striping across the rear, this level of size change would be reached at a distance of slightly over 150 meters or five seconds travel time. The oncoming motorist could, of course, detect that they were closing on the stopped vehicle through successive observations of it over time at a much longer distance.

Nothing in the current study should suggest that standard reflectorized safety triangles are of no benefit however; under conditions where direct view of the stopped vehicle is obstructed by either intervening obstacles or road geometry they can provide valuable information depending on their placement.

An interesting point is that there is no national requirement of which the authors are aware that mandates the use of safety triangles for non-commercial vehicles. Detection ranges for the more visible of the two passenger vehicles employed in the study were less than 13% of that for the appropriately marked commercial vehicle analog, providing approximately 4 seconds of response time for an oncoming motorist (3 seconds for the darker vehicle.) Given that the detection ranges for unaware drivers would be expected to be lower than that for the alerted subjects in this study, this may or may not provide adequate time to respond appropriately. That said, it should also be noted that reflections from the taillights of both vehicles were detectable at more than three times the distance that the vehicles themselves could be detected.

CONCLUSIONS

The data from this study indicates that deployment of warning triangles behind stopped commercial vehicles may offer no additional benefit beyond that already provided by the retroreflective striping mandated on such vehicles by federal law on straight flat roadways (though there may potentially still be benefit in areas with obstructed view). The retroreflective striping under dark conditions with no additional illumination beyond minimal ambient light and the test vehicle’s low-beam headlights provided over 900 meters of detection distance (over 30 seconds, assuming a vehicle speed of 105 kph), while the warning triangles provided approximately 700 meters (almost 24 seconds, assuming the same 105 kph vehicle speed.) Either of these two indicators allow for more than adequate time for an oncoming vehicle operator to detect, identify, and (if necessary) respond to vehicles stopped beside the roadway.

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