Comparing A Timed Exposure Methodology to the Nighttime Recognition Responses from SHRP-2 Naturalistic Drivers

2017-01-1366
Published 03/28/2017

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CITATION: Muttart, J., Dinakar, S., Suway, J., Kuzel, M. et al., "Comparing A Timed Exposure Methodology to the Nighttime Recognition Responses from SHRP-2 Naturalistic Drivers," SAE Technical Paper 2017-01-1366, 2017, doi:10.4271/2017-01-1366.

Abstract

Collision statistics show that more than half of all pedestrian fatalities caused by vehicles occur at night. The recognition of objects at night is a crucial component in driver responses and in preventing nighttime pedestrian accidents. To investigate the root cause of this fact pattern, Richard Blackwell conducted a series of experiments in the 1950s through 1970s to evaluate whether restricted viewing time can be used as a surrogate for the imperfect information available to drivers at night. The authors build on these findings and incorporate the responses of drivers to objects in the road at night found in the SHRP-2 naturalistic database. A closed road outdoor study and an indoor study were conducted using an automatic shutter system to limit observation time to approximately ¼ of a second. Results from these limited exposure time studies showed a positive correlation to naturalistic responses, providing a validation of the time-limited exposure technique. This technique is safe and simple to conduct and was not subject to observer hypersensitivity as were other nighttime recognition techniques.

Introduction

The goal of this research is to evaluate a time limited nighttime recognition protocol that accurately accounts for driver expectancies. The purpose of such a protocol is to allow researchers to safely and efficiently test the factors that affect recognition for various object properties including location, pattern, material, motion, etc.

A query of the Fatal Accident Reporting Service [1], showed that more than half (69.8%) of all fatal crashes involving a pedestrian death in 2014 occurred between 6 pm and 6 am. The crash statistics were even more alarming on weekends, with 86.4% of pedestrian crashes occurring between 6 pm and 6 am. Of the 4735 pedestrian deaths in the U.S. in 2014, 733 were coded as “Not visible (dark clothing, no lighting, etc.)”. Numerous parties including researchers, governments, manufacturers, police investigators, drivers and vulnerable road user advocates have all struggled to understand driver responses to obstacles encountered at night. All these parties may benefit from the proposed evaluation method for nighttime object recognition.

The SHRP-2 Naturalistic Driving database [2] illuminates many of the issues that drivers face at night. These data are an ideal control for the evaluation and validation of other experimental methodologies like the presented timed exposure method. As an example, the

SHRP-2 data contains a relatively large set of driver responses to deer, and small animals. Naturalistic data like SHRP-2 by its nature is very expensive and difficult to collect. The data also tends to contain relatively few occurrences of pedestrians in the roadway and certain other rare or specific events of interest. This led the authors to develop the presented timed exposure method using high occurrence events like deer and small animals, once validated, can be applied to risky, rare and novel nighttime events for which there is little or no naturalistic response data available. Ultimately, the goal is to find a method with the least risk exposure to drivers, pedestrians, and experimenters that best evaluates the abilities of drivers to recognize obstacles at night.

Other Nighttime Recognition Research Methodologies

A fundamental goal of any study intended to measure the "visibility" of objects at night is to do so in a safe setting. However, this can result in a trade-off with creating a realistic test environment. A review of the stated methods of many studies does not indicate an attempt to account for the differences between real life drivers' *recognition* and the *visibility* of drivers in the research. There is a distinct difference between when an object, or part of an object, becomes visible and when a driver will recognize and respond [3]. The conundrum for researchers is that, a priori knowledge of conditions will limit risk to the participant, but the trade-off of this knowledge is that their expectation will increase their recognition distance. For example, in one study, researchers suspended retroreflective balls in the travel path of drivers. When drivers knew the ball was present, 100% identified the ball from an average distance of 193 m (632 feet), yet without this knowledge, more than 70% failed to respond. For the few who responded the average recognition distance was less than 15 m (50 feet) [3]. The light from the retroreflective ball was there to be seen, but not recognizable despite being directly ahead of the driver in some instances. The reason for the failure to respond is that the light did not offer the driver enough information to understand what it was. This is evidenced by the fact that two-thirds of those who failed to respond indicated they had seen the ball before failing to respond. The difference between visibility and recognition is highlighted by conditions such as a pedestrian standing sideways with an inadequate safety vest, or a car parked sideways across the road. In these cases, a driver might only recognize a floating light and not what the light is actually attached to. This demonstrates the importance of identifying the differences between the absolute visibility of objects and the real-world recognition distance. The presented timed exposure method accounts for real world recognition distance and not the static nighttime visibility of objects at night often measured in past research.

For a nighttime recognition study to be generalizable to real-world performance, the method must account for driver recognition ability and realistic driver expectancies while maintaining the safety of participants. Previous research on driver nighttime recognition utilized one of four different experiment types:

1. Laboratory studies, one involving observers with limited time exposures [4]; and others that showed video recordings of pedestrians or vehicles to participants [5, 6];
2. Field studies on a closed test track, usually an airport runway [7, 8, 9, 10] or closed road, with experimenters asking participants to drive slowly until they detected or recognized a defined target [7, 11] or to make observations from the passenger's seat while an experimenter drove slowly [12, 13]. Other researchers asked participants to report when they recognized the pedestrian or target while driving a more normal speed [8, 9, 10, 14, 15];
3. Field studies on an open road with traffic, with targets placed along the roadside [16, 17, 18]. In one instance, Kledus et al., [19] fitted drivers with eye tracking glasses and asked them to be a participant in a "fatigue study". These drivers traveled past 16 pedestrians during the drive. Kledus, et al used driver fixation on the pedestrian as a surrogate for recognition;
4. Naturalistic studies [20, 2], used vehicle installed instrumentation to capture real world driving performances. This data is by far the highest quality and should be used if possible. However, it has the limitation that conditions of interest occur rarely if they are present at all. This data collection method is also extremely complicated and expensive to conduct.

Each of these methodologies has different strengths and limitations. Laboratory studies offer the greatest controls and safety, yet the weakest ecological validity when measuring the response of an unsuspecting driver in a real-life driving scenario. Field studies on a closed course allow experimenters to control the testing, but the drivers are aware they are being tested, and the environment (e.g., airport runway) usually lacks the visual noise that was present on many roads. Field studies on open roads provide the most natural test environment, however, drivers are still aware of the purpose of the testing, and thus their expectancy for conditions cannot be ignored. Although Kledus et al [19] was able to create more realistic test conditions by developing a ruse for participants. Drivers eye glances toward roadside pedestrians were recorded as part of measuring recognition distances, yet the drivers believed they were participating in a fatigue study. This methodology could not safely be employed to test responses to an obstacle in the road that the vehicle might strike, such as an unilluminated and unmarked trailer or car. The two issues that must be accounted for when conducting nighttime recognition research are driver safety and expectancies. The current research presents a methodology that attempts to account for both issues, by maximizing the former and minimizing the latter.

Accounting for Factors and Experimental Design

The results of studies are frequently reported as the percent of drivers that recognized an object, considered a hazard by the researchers, or the average recognition distance of an object. However, very few report the discrimination (hypersensitivity) of the drivers, specifically, the percentage of drivers that had a false positive (found a target that was not there). Without accounting for both the correct detections and the incorrect responses, readers are unable to gauge the true abilities of drivers to recognize the targets at night.

The table below shows the four possible detection outcomes based upon Signal Detection Theory [21].

Table 1. The four possible outcomes of Signal Detection Theory

	Responds	**Does not respond**
Hazard present	Correct response	Miss
No hazard present	False alarm	Correct rejection

Some studies have asked prepared observers to respond (typically by braking) when they first see something, and then again when they can describe the object [9, 10]. However, the realism of these test results is questionable in the context of signal detection theory. In the real-world hazards are rare and false positives are almost unheard of. Consider the condition where a driver skids their vehicle only to realize there was no dangerous condition. Since drivers rarely see hazards, they tend to delay their response to ensure a hazard is present (i.e., a correct response). In some studies, the drivers are expecting hazards and the cost of a false positive response is low or non-existent. Participants know that they can brake safely since it is part of the instructions. Thus, in these studies drivers recognize and respond to the hazards at a greater distance. This makes the results less generalizable to the real-world, where drivers know from experience that a hazard is rarely present.

To be able to compare research findings to real-world performance, we must be able to determine how study responses compare to likely responses of a driver on the open road. Night recognition studies conducted on open roadways were compared to those conducted on a closed course. The latter was found to over-estimate recognition distances by an average of 27.4 m (89.9 ft.) [16]. Light colored and illuminated objects were especially over-estimated on recognition distance compared to dark objects. Consequently, the trends in performance of drivers in closed course studies were not consistent with their counterparts in open-road studies (See Figure 1). The extremely long recognition distances for light colored objects in closed course studies suggests that these participants may have been hypersensitive.

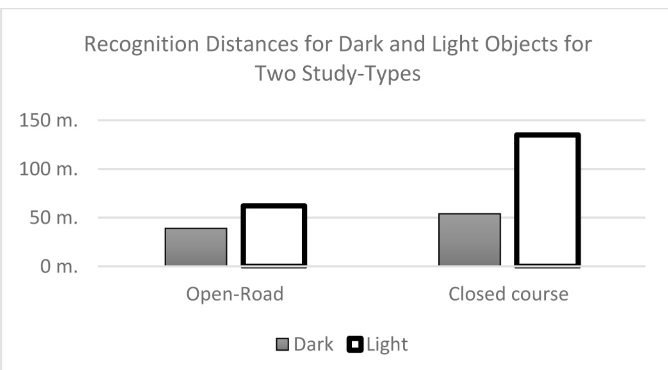

Figure 1. Results from Muttart and Romoser, 2009 showing the recognition distances for light and dark colored targets in open-road and closed course studies

The factors that have been cited in research as those that are most associated with driver recognition and driver expectancies can be recalled by the acronym CAPLETS [3]. Each term in the acronym is listed in Table 2, along with the research that cited each term as being a factor in nighttime response. Each of the terms listed in CAPLETS is a measure of information available to the driver. Consider a driver who must respond to a small child pedestrian, dressed in low contrast clothing, on an unlit highway at 1 AM. Clearly, that driver would have less information than a driver who was confronted on that same road by a traffic signal ahead that changed from a yellow ball to a red ball. In the latter instance, the signal contrasts well from the background, and the driver knows the meaning of the light and the appropriate response.

Table 2. The factors in the acronym CAPLETS that are associated with nighttime recognition and driver expectancies

Expectancy Factors	References
Contrast	22, 23, 24, 25
Anticipation	
Driver Experience	26, 27, 28
Predisposition: (relevance, value, previous information, or priority)	3, 12, 23, 30, 31, 32
Pattern (**Shape, edges, movement**)	12, 17, 23, 33
Lighting	3, 22, 24
Eccentricity	24, 29, 34
Time of exposure	4, 22
Size	3, 22, 24

Of the expectancy terms listed in Table 2, Blackwell [4] and Adrian [22] cited time-of-exposure as a factor associated with nighttime recognition, i.e., consider the information available to a typical driver with no expectation of a pedestrian compared to an experimental driver on a test track who knows there will be a pedestrian. Real world drivers almost always make decisions based on much less information. Blackwell [4] controlled the information to the observer by limiting the time of exposure to the time necessary for one eye glance.

The timed exposure technique limits the information and therefore, the expectancy of the observers. As a driver moves they make periodic visual fixations toward different locations due to the movement of the vehicle and their focus. Suppose a driver glances ahead when 60 m (200 ft.) from an obstacle in the road. If the obstacle is not detected or recognized during that glance (glance "i"), the driver will not likely recognize the obstacle until they make a subsequent glance at a later time (glance i + n).

Therefore, as proposed by Blackwell, a timed exposure technique accounts for the probability of detection in one glance, which we hypothesize is similar to the limitations of real-life drivers. The presented timed exposure technique can be conducted in controlled situations with repeated samples. Although a tested observer is aware of the test, the limited exposure time controls for their expectation. Since participants do not know the exact location or type of target the presenter can control for correct recognition as well as correct misses and false positive responses (i.e., claiming to see obstacles that are not there), while providing a very safe test environment.

Control and Experimental Conditions: The Hypotheses

The 2nd Strategic Highway Research Program (SHRP-2) [2] naturalistic driving study recently released data that includes information from nearly 3,100 drivers. Participants throughout the country allowed researchers to install video cameras and data collection equipment in their personal vehicles. The video recordings include detailed environmental conditions as well as eye glance location and durations including external objects. The participants drove as they normally would for one to three years and were not given any instructions on where to look, what to look for, or how to respond. At the end of the experiment, the researchers collected data on more than 1000 crashes (mostly very minor) and over 3000 near crashes. Included among these responses were drivers' responses to obstacles in the road at night, including deer, small animals, and tree branches across the road.

The naturalistic responses in the SHRP-2 data were used as an experimental control. A deer was included in the current timed-exposure study because three closed course studies and the SHRP-2 data reported driver responses to deer. In considering the results of these studies, the reader should remain cognizant of the specific differences between detection distance (when something was visible) and recognition distance (when an object is recognizable). Much of this research focused on responses to deer and animals. Clearly, many more fatalities involve pedestrians. However, the primary purpose of this research is to evaluate a nighttime recognition methodology. There were several drivers' responses to deer and smaller animals in the naturalistic data from the SHRP-2 study. The SHRP-2 naturalistic data offers insight to how real life drivers recognized objects at night and were utilized as the experimental control in the current research. Also, there were four closed course that measured drivers' recognition distances when responding to deer or moose.

Fambro et al. [9] and Gibbons et al. (35) each presented field studies performed on a closed test track. Fambro et al. at Texas A&M University used a former airport and Gibbons et al. used the Virginia Smart Road facility, a closed course track. Fambro et al. asked drivers to travel toward the target and report when they detected (first saw) the target, and again when they recognized the target. The deer had a 0.17 reflectance and was recognized an average distance of 65 m (213 ft.) The 15th percentile recognition distance was 33 m (108 ft.). Gibbons et al. did not provide results for detection or recognition distances or information related to reflective qualities of the deer, rather they reported an odds ratio of 0.97 for the probability drivers recognized a deer target.

A study by Bhagavathula and Gibbons [36] also used a deer target, in a closed track field study. The results, which did not account for differences in lighting conditions by target object, indicate that the deer target was "recognized" at an average of 49.02 m; SD = 33.53 (160 ft.; SD = 109.98) and "detected" at 61.49 m; SD = 39.79 (201 ft.; SD = 130.51). The authors indicated that the targets were recognized earlier in the lighted areas when compared to the unlighted areas.

Bhagavathula et al. [36] did not follow most other research that used detection as the threshold for visibility (associated with responses from farther away) and recognition as the threshold for when the participant knew the true character of the obstacle [9]. Usually, drivers recognize the object after detecting it, not before. However, the purpose in this research was to show the effects of additional expectancies. The findings suggest that additional trials where drivers responded to the same targets offered more information to the drivers and that telling the drivers to look for a secondary target did not distract them from finding a common and repeatedly shown target such as the deer.

In a fourth study where drivers responded to a moose decoy with moose hide [11]. Drivers were asked to drive at 10 to 15 km/h toward the moose until the moose was first visible and to then stop. The authors wrote "*The test subjects in this study knew what to expect; they knew that they would encounter a moose and they knew exactly how to react to it.*" [p. 80, 11]. Median detection distances with low beam were 75 m (SD = 29 m) and 147 m (SD = 51 m) for high beam. The median detection distances for the moose when in the left shoulder was 64 m (SD = 55 m), when on the right the median detection distance was 84 m (SD = 37 m) and detection distance was 124 m (SD = 54 m) when ahead.

Deer targets account for information related to the *pattern* term seen in Table 2 and the CAPLETS acronym. However, the other variables must also be considered. Adrian [22] developed a Small Target Visibility model based upon the responses of drivers to small targets, primarily from the Blackwell studies [4]. Since the SHRP-2 data included several responses to smaller animals, a small rabbit was included in the timed exposure research [2].

The Small Target Visibility model proposed by Adrian should also account for these CAPLETS factors. As previously stated, the Small Target Visibility model is based on contrast recognition. Additionally, this model accounts for lighting, time of exposure, and viewing distance. Also, recognition distance for objects that were both dark and light colored were uniformly worse (black) or better (white) than the responses to deer. Which is unlike previous closed course research that over-reports recognition distance performances for light colored and retroreflective targets.

The ability to recognize bright objects with higher calculated visibility levels has been strongly dependent upon the methodology of the study. Shinar [12] showed that when observers knew a pedestrian would be wearing retroreflective materials, recognition distances increased at a greater than linear rate. However, when a driver was not informed beforehand, the ability of a driver to detect a pedestrian wearing retroreflective clothing was comparatively poor [3, 12, 17]. Therefore, a retroreflective license plate was included in this research. The reason for including a license plate was to determine if the timed exposure technique accounted for the typical hypersensitivity bias associated with light colored and retroreflective targets in closed course testing.

The hypotheses in this experiment include the following:

- Hypothesis 1. Drivers in the timed exposure study will be equally likely (as a percentage) to recognize or fail to recognize a deer or small animal when compared to the SHRP-2 data at 60 m (200 feet) from impact.
- Hypothesis 2. Factors such as size (the rabbit), non-uniform color (the deer), and unrecognizable pattern (the license plate) will have significant effects on observers' abilities to recognize targets in low illumination conditions (when presented for limited duration).
- Hypothesis 3. The timed exposure technique will better predict the recognition distances obtained from the SHRP-2 data than other closed course recognition methodologies.

Methodology

Participants

Testing was conducted in an indoor facility in Orlando, FL and at a closed airport runway in State College, PA. A total of 40 participants were run in Florida (9 female), but data from 4 participants was excluded due to equipment malfunctions making the final number 36. The average recorded age was 44.6 (SD = 9.7). In Pennsylvania, there were 12 participants, all males, with an average age of 43.2 (SD = 8.6). All participants had good visual acuity with or without the use of some form of corrective lens.

Equipment

A specialized acetate sheeting, referred to as Smart Tint ™, was placed in front of the windshield. The Electrical Department at Three Rivers Community Technical College developed a control system that activated the Smart Tint to allow a defined time for participants to view the forward scene. The timing on the system was accurate, repeatable and had negligible transition times between clear and opaque states.

Deer targets (See Figure 2), a small stuffed rabbit, a license plate, and two pedestrians were used as targets. The pedestrians were dressed in hospital scrubs, either all black or all white in color. The deer targets were covered with Deer hides (shown in Figures 2 and 3), which did not cause the reflectance measurements to change but were found to be more camouflaged as compared to the painted surface.

Figure 2. Deer target with hide depicted on the right roadside

Two vehicles were utilized for testing: 1) a 2006 Subaru Tribeca B9 with H11 headlight bulbs, which were replaced before both tests 2) a 2013 Ford Explorer with 9005 headlight bulbs, not replaced. The Subaru was used in both Florida and Pennsylvania. The Ford was only utilized in the testing at Pennsylvania. Readers should be aware that the 2006 Subaru Tribeca B9's headlight housing was tinted with regular automotive window tint for the indoor testing in Florida. This allowed for objects presented indoors, at closer distances, to experience similar illuminance values as the objects presented outdoors at further distances. The actual change in object angular size was accounted for in all visibility level (VL) calculations and did not result in a significant difference in the response of participants.

Figure 3. Photograph showing the five targets utilized in the experimentation (Deer, black clothing, white clothing, small rabbit, and license plate)

Procedure

In Florida, the Subaru was placed at one end in an indoor ballroom, with a "roadway" created across the diagonal length of the room with dimensions 30m x 55m. Tape lines representing the lane edge were placed left and right of the experiment vehicle to create a 3.6m (12 ft.) wide lane. The targets were placed either to the left edge or right edge of the 3.6m (12 ft.) lane and at distances of 30 or 50 m. The Pennsylvania testing was conducted on a closed airport runway, with the two experiment vehicles placed back-to-back.

The purpose of the two tests was to verify that the testing procedure was effective with different vehicles and locations. In Pennsylvania, different vehicles were used on a paved test track and when faced with different road markings.

On the runway, temporary retroreflective road markings were placed in front of the vehicles. The markings were set to mimic a rural environment for the Subaru and a two-lane highway environment for the Ford. The experimental vehicles were placed in the right lane. Retroreflective delineators and cones were placed along the prepared roadside. The Ford had newer headlights and was placed at the scene with newer headlights and more visual noise. Again, lane widths were 3.6m (12 ft.). The targets, when present, were placed at either 50 or 70 m in front of the Subaru, and 60 and 80 m in front of the Ford. These distances were selected to obtain a range of distances and visibility levels.

A series of experiments were conducted where licensed drivers were asked to be seated in a stationary vehicle at an unlit location. The vehicle was powered throughout the testing to ensure that the illumination from the headlights would be constant. Two participants were tested in each vehicle simultaneously, one seated in the driver's seat and another in the passenger's seat. At the Pennsylvania site, in the second half of the study, the drivers exchanged sides. The test method was approved by an Institutional Review Board and participants signed an informed consent prior to testing. Experimenters explained the procedure to each participant prior to initiating the test procedure.

Each participant was given two practice views through the sheeting. The participants were told that the roadway and background would remain as seen during these trials. After these practice trials, testing was performed by activation of the electronic shutter by an experimenter standing next to the vehicle. That experimenter would give the participants a ready countdown prior to activation. The opening of the shutter allowed observers to view the road ahead for 0.285 seconds (nominally 0.3 seconds with rise-up and shut-down transitioning time resulting in the fully clear time). The participant was given an answer sheet and asked to write one of three responses after each trial: 1) Describe what they saw, if they could recognize the object in the road; 2) State that they detected something in the road, but that the object was unrecognizable; 3) Report that they did not detect anything in the road during that trial.

During the testing, illuminance measurements were taken at each target. Also, luminance readings were taken of each target, through the Smart Tint™ and vehicle's windshield. The targets were placed at distances of 30 to 80 m from the front of the vehicle. A counterbalancing matrix was used to present the six targets including dark and light pedestrians, deer, rabbit, license plate and no target with an equal likelihood. The distance of and side of the road where the targets appeared were also balanced. The participants were informed that there would be one or more trials where no target was present.

Data Processing

Recognition distance for deer, animal and tree targets was calculated from the SHRP-2 database. The speed when once drivers slowed at a rate of 0.4 g was averaged with the speed when the vehicle reached the target. The time when the vehicle reached the target was subtracted from the 0.4 g time. This elapsed time and the average speed were used to compute the response distance.

As mentioned earlier, the closed course experimental results from Fambro et al.; Gibbons et al.; Rogers et al.; and Bhagavathula et al. were compared to the recognition distances obtained from the SHRP-2 data. Another comparison was made for those who avoided the deer or animal in the SHRP-2 data and those who struck the deer or animal. Recognition distances and probability of recognition in the closed studies, the SHRP-2 data, and the results from this research were also compared. Luminance and illuminance measurements were reported for comparison purposes. Recognition distances from each study type were compared using Mann-Whitney U non-parametric ranking with a decision criteria of a z-score of plus or minus 1.96 ($P < .05$).

Results

The results from the SHRP-2 data included: 1) the distance from impact (or near impact) at which drivers slowed at least 0.4 g (Recognition distance in meters) was recorded as was the speed loss (km/h) from recognition to impact; 2) the percent who responded; and 3) the average age group of each driver. These data were further separated due to environmental factors such as the presence of an oncoming vehicle, the hazard emerging from left or right, whether the driver was engaged in a secondary task, the type of lighting that was present, and whether the driver crashed or not. The drivers' responses to deer and related statistics are listed in Table 3 and the responses to small animals and related statistics are listed in Table 4.

There were 7 instances involving deer and 4 instances involving small animals where there was uncertainty (in some way) in the SHRP-2 data. This uncertainty was from several sources including the manner the animal emerged into the road and reporting of the data.

Secondary tasks were divided into three categories: 1) No secondary task; 2) A secondary task that involved only a passenger in the car, or a glance away, or singing; 3) A visual and manual secondary task that involved an act being done with a driver's hands such as reaching, texting, handheld cell phone use, eating, or personal hygiene.

Table 3. Driver responses to deer in the SHRP-2 Naturalistic data

SHRP-2 Recognition of Deer	Age	N	Percent Recogn.	Speed Loss (km/h)	Recognition Dist. (m)	Z-Score	P
Total Averages	38.3	45	82%	18.3	25.0		
No Oncoming vehicle	37.1	34	83%	18.7	26.1		
Oncoming vehicle	44.5	11	60%	14.8	18.0	-2.45	**0.014**
Left	41.5	25	92%	18.8	27.5		
Right	34.5	20	70%	17.7	17.0	-2.71	**0.007**
No Secondary Task	38.6	14	79%	19.5	30.8		
Visual or Auditory Secondary Task	36.3	23	87%	19.8	24.6	-0.92	0.357
Visual and Manual Secondary Task	43.4	8	75%	11.8	15.7	0.08	0.936
Unlit Dark	39.5	19.0	68%	20.1	34.5		
Dusk / Dawn	37.0	6.0	100%	20.6	11.9	4.30	**.000**
Lighted Dark	37.4	20.0	90%	15.8	19.0	3.85	**.000**
Crash	36.5	11	73%	6.5	10.6		
Near Crash	38.9	34	85%	22.1	29.6	-5.32	**.000**
Age <20	19.0	12	83%	16.0	27.3	-0.64	0.522
Ages 20 - 50	33.5	20	79%	20.8	27.4		
Age >50	65.7	12	83%	15.5	19.3	-1.21	0.226

Table 4. Drivers responses to small animals in the SHRP-2 Naturalistic data

SHRP-2 Recognition of Deer	Age	N	Percent Recogn.	Speed Loss (km/h)	Recognition Dist. (m)	Z-Score	P
Total Averages	33.6	58	81%	10.8	13.2		
Oncoming veh	25.9	8	88%	14.8	16.6		
No Oncom. Veh.	34.6	51	80%	10.0	13.1	-1.39	0.164
Left	31.8	18	83%	9.4	13.8		
Right	37.0	28	86%	10.1	14.3		.
Ahead	25.4	11	64%	11.0	11.7	-0.09	0.928
No Secondary Task	33.1	29	76%	10.9	15.4		
Visual or Auditory Secondary Task	36.9	12	75%	10.5	11.9	-1.21	0.226
Visual and Manual Secondary Task	30.3	16	94%	11.0	13.9	-0.48	0.631
Dark unlit	35.0	24	83%	12.7	16.8		
Dusk/dawn	20.3	4	100%	20.1	22.8	-1.30	0.193
Dark lighted	34.3	30	77%	8.0	9.6	4.17	**.000**
Crash	29.6	18	56%	8.3	14.7		
Near-Crash	35.5	40	93%	11.9	10.9	-3.58	**.000**
Small Slow Animal	31.9	19	84%	12.0	13.1	Slow / fast	
Small Fast Animal	32.3	25	80%	7.3	11.5	-6.16	**.000**
Medium Slow Animal	24.0	4	75%	28.6	21.2	Small/Med.	
Medium Fast Animal	62.8	4	100%	8.8	18.4	1.10	0.271
Undetermined Animal	31.5	6	67%	11.0	11.6		
Age <20	19.0	16	88%	11.8	13.3	-1.80	0.072
Age 20 - 50	28.8	29	83%	11.4	14.3		
Age >50	69.0	11	82%	8.5	12.0	-1.80	0.072

The data show that the average recognition distance of deer was approximately 25 meters (SD = 22.6 m), medium sized animals were recognized at 19.8 m from impact, and small animals were recognized approximately 12.2 m (SD = 12.8 m) from impact. These results suggest that the size of the object was a factor associated with recognition. However, the difference between small and medium sized animals (Table 4) did not reach significance (P = .271). And small differences in visual angle of animals at different distances did not influence the results when the size was considered in the VL calculations mentioned later.

The presence of an on-coming vehicle was a significant factor when responding to deer. With oncoming traffic, drivers recognized deer at 69% of the distance when compared to situations where no oncoming vehicle was present. Though, when responding to smaller animals, oncoming traffic was not a significant factor.

The initial position from which the animal emerged was not a factor at all when responding to small animals, and was contrary to what would be expected when responding to deer. Low beam headlights cast more light to the right than left, yet drivers responded earlier to deer on the left. When a deer emerged from the right, the time to contact was usually shorter, which might explain this result.

When drivers were engaged in secondary tasks, primarily secondary tasks involving reaching, and manual manipulation, such as texting, reaching, or manipulating something, recognition distances decreased. Yet secondary tasks failed to reach significance. The primary reason that visual manual secondary tasks were not a significant influence on recognition was that there were only 8 drivers with no secondary task.

Confounding findings were seen when evaluating the influence of street lighting. Drivers recognized deer and small animals earlier on unlit roads than on lighted roads.

Related to age, those who were 20 to 50 recognized the animals earlier than did drivers in younger or older age groups, but these differences were not significant.

Lastly, those who crashed and those who avoided were compared. Those who crashed responded later than those who avoided a deer. Conversely, when responding to small animals, those who crashed responded earlier than those who did not crash.

A very notable finding is that when the SHRP-2 data is compared to closed course studies where time of exposure was not controlled, the recognition distances were considerably longer than those by the real-world drivers in SHRP-2.

Table 5. Comparison of the SHRP-2 results to other published research

Target	Study	Left	Ahead	Right
Sm. Animal	SHRP-2	9.3 m	11.7 m	14.5 m
Deer	Gibbons		61.0 m	
Deer	Fambro	65.0 m		
Deer	Bhagavathula (detected)		61:5 m	
Deer	Bhagavathula (recognized)		49.0 m	
Deer	SHRP-2	26.7 m		22.8 m
Moose	Rogers & Robbins	89.0 m	133.0 m	93.0 m

SHRP-2 data would not report the response of a driver who did not have to respond in an emergency manner. Yet, the SHRP-2 recognition distances appear consistent with prior research. Open-road recognition distances of near 32 m for dark objects and approximately 51 m for gray targets [29]. The SHRP-2 data suggests that slightly more than half the drivers should recognize a deer at 30 m and many fewer should recognize the deer when 50 m from the car.

Next, the results from the timed exposure testing were consistent with the SHRP-2 data. When the rabbit was 50 m from the observer, very few recognized the rabbit. Conversely, more than half recognized the rabbit when 30 m from the vehicle.

Table 6 (indoor) and Table 7 (outdoor) show results from the timed exposure testing conducted at the indoor site in Florida and outdoors in Pennsylvania. During the testing observers responded to the five targets as well as trials where no target was present. When indoor, drivers were presented targets at 30 and 50 m and on both sides of the simulated roadway.

Of the 40 instances in the timed exposure study when no target was present 5 drivers in the rural outdoor environment responded with a false positive (detected a target that was not there). In the highway environment, there were 8 false positives.

For comparison purposes, the cumulative distribution of responses from the SHRP-2 data was plotted and is shown in Figure 4. A comparison of the proportion of observers who correctly identified the target in the timed exposures were compared to the SHRP-2 results. The reader should consider that the SHRP-2 data mentioned here includes the time necessary to brake or steer 0.4 g while the timed exposures are the distance at recognition. Thus, the recognition distance during the timed exposures should be a constant amount greater than the distance where the vehicle is being slowed at 0.4 g.

The average speed of the drivers that responded or failed to respond to a deer or smaller animal was 56.8 km/h (35.3 mph). Should a driver need 0.75 seconds to move his or her foot from the accelerator pedal to the brake and then to brake up to 0.4 g, the average distance traveled during that time was approximately 11.8 m (38.8 ft.). Thus, we would expect the SHRP-2 results, without leg movement and braking, to be an average of 11.8 m later (shorter distances to impact) than the timed shutter results. Figure 4 shows the SHRP-2 results compared to the timed shutter results with 11.8 m added. The timed shutter results from the Subaru indoor and outdoor were strongly correlated with the SHRP-2 results for recognition of deer (r^2 = 0.996) and recognition of smaller animals (r^2 = 0.975). The linear relationship between distance and probability of recognition was also strongly correlated (See Figures 4 and 5).

While there will always be a correlation between probability of recognition and distance, these data show a linear trend. With a linear trend, the ability to find the optimal match can be found by manipulating the time of exposure. For example, if these drivers had a shorter exposure time, we would expect the red line in Figure 4 and 5 to be lower, but with a greater timed exposure, the red line would be higher, and would also likely start bending (be non-linear), particularly for lighted targets as discussed earlier.

Table 6. Results from the indoor timed exposure testing

	30L	30R	50L	50R
DEER				
Hit	39%	89%	17%	44%
Miss	6%	0%	61%	6%
Not Recognized	56%	11%	22%	50%
Avg VL	8.7	36.5	-7.7	4.1
WHITE				
Hit	100%	100%	67%	89%
Miss	0%	0%	0%	0%
Not Recognized	0%	0%	33%	11%
Avg VLFeet	74.5	191.1	9.3	27.8
Avg VL Feet + Chest	49.2	112.3	4.6	15.5
BLACK				
Hit	6%	39%	0%	0%
Miss	78%	22%	83%	94%
Not Recognized	17%	39%	17%	6%
Avg VL				
RABBIT				
Hit	44%	61%	6%	0%
Miss	56%	28%	89%	100%
Not Recognized	0%	11%	6%	0%
Avg VL	-2.8	-2.0	0.0	0.0
LIC. PLATE				
Hit	17%	22%	22%	22%
Miss	6%	6%	0%	0%
Not Recognized	78%	72%	78%	78%
Avg VL	53.9	141.3	34.9	138.0
NO TARGET	0	0	0	0
Hit	0	0	0	0
Miss	100%	100%	100%	100%
Not Recognized	0	0	0	0

Table 7. Results from the outdoor timed exposure tests

	Rural 1 Lane				Marked Divided 4 Lane			
	50L	50R	70L	70R	60L	60R	80L	80R
DEER								
Hit	3	2	0	1	8	3	6	7
Miss	5	5	6	8	1	4	2	1
Not Recognized	2	3	4	1	1	3	2	2
Avg. VL Vert.	6.9	-1.1	6.9	24		39.1	6.6	2.7
WHITE								
Hit	7	6	6	7	7	8	6	9
Miss	2	3	3	3	2	2	2	0
Not Recognized	1	1	1	0	1	0	2	1
	34.3	27.9	15	10.5	25.4		18.3	
BLACK								
Hit	0	2	2	0	6	5	4	5
Miss	9	7	7	8	4	5	5	5
Not Recognized	1	1	1	1	0	0	1	0
	-6.3	-24.2			-36	-28.1	-29.5	-20
RABBIT								
Hit	0	0	0	0	0	0	0	0
Miss	10	8	10	7	9	9	9	9
Not Recognized	0	2	0	3	1	1	1	1
	18.6				-8.9	-7.3		

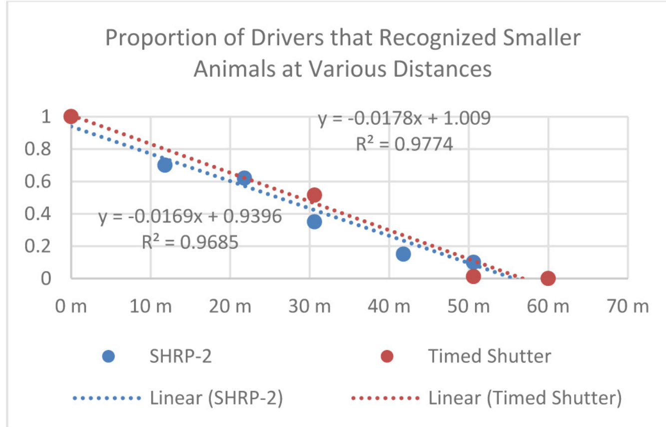

Figure 4. Proportion of drivers that recognized deer at increasing distances in the SHRP-2 data (blue) and the timed shutter studies (red)

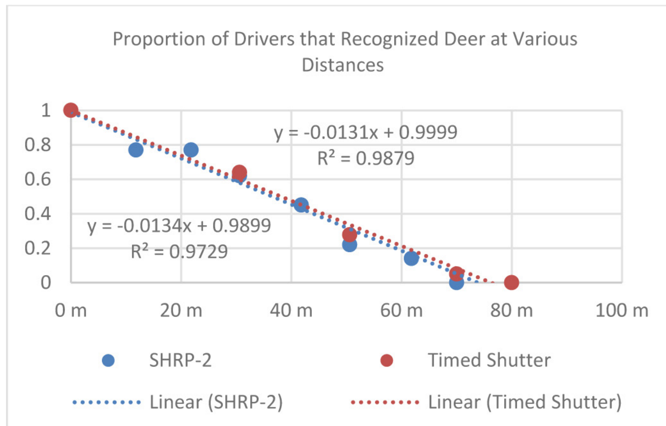

Figure 5. Proportion of drivers that recognized smaller animals at increasing distances in the SHRP-2 data (blue) and the timed shutter studies (red)

Recognition rate was compared to average visibility level (VL) for both the indoor and outdoor timed exposure tests. Figure 6 shows a noticeable trend that as VL increased by more than 20, the probability of detection increased to over 50% for positive contrasts.

However, these results demonstrate that VL, as an independent metric, does not result in high recognition rates. The R squared value was only 0.27. While VL is an obvious factor in nighttime recognition, other factors must be considered. As an example, consider the results when the license plate was the target. The license plate had a very high VL, but only 20% of the participants were able to recognize the target as being a license plate and similarly few were able to identify the license plate as being in the road.

The timed exposure results were compared to other on-road research [17, 19]. The average recognition distance of darkly clad pedestrians who were along the near side of the road were recognized (fixated upon) at an average distance of 45.5 m [19]. These results suggest that driver recognition might occur at some time after a driver fixates upon a target. The road study results from Balk et al. [17] were consistent with these results. Balk et al. reported an average recognition distance of less than 20 m for a pedestrian with black clothing. The SHRP-2 results show that deer were recognized at an average distance of 25 m and we would expect a pedestrian wearing all black to be recognized at a similar distance (approximately 32 m). The timed exposure testing procedure showed that approximately 20 to 22% (with a range of 6 to 39%) of drivers were able to recognize the pedestrian dressed in all black when 30 m away indoor or 50 m away outdoor. These results suggest that Blackwell's recommendation of 0.2 second exposure, rather than the 0.3 second exposure time used here, might be optimal for outdoor testing.

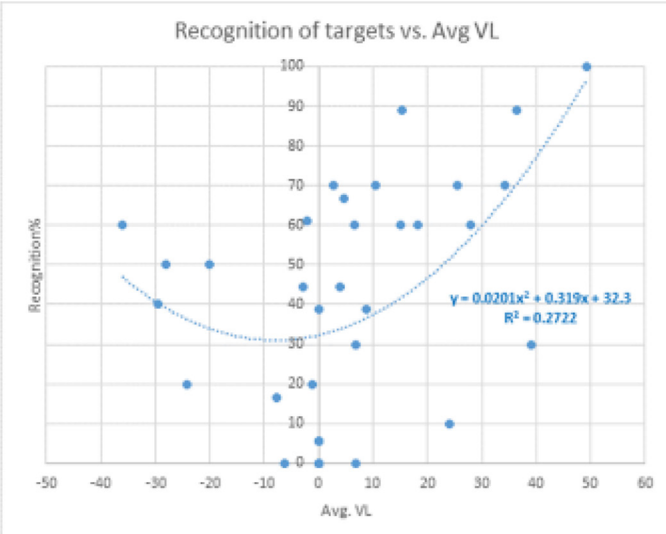

Figure 6. Probability of recognition related to visibility level

Conclusions

Results from these limited exposure time studies showed an agreement between naturalistic responses, providing a validation of the time-limited exposure technique. This technique is safe and simple to conduct and is not subject to oversensitivity as are other nighttime recognition techniques.

As hypothesized, the timed exposure technique offered recognition distances that were consistent with road studies and the naturalistic data. While a correlation between distance and probability of recognition is expected, drivers in the timed exposure study were also equally likely (as a percentage) to recognize or fail to recognize a deer or small animal as was in the case of the SHRP-2 data when 60 m (200 feet) from impact.

As hypothesis 2 suggested, factors such as size (the small animals versus the deer) resulted in differences recognition distances. Also, non-recognizable patterns, such as the hide of the deer and more specifically, the non-descript information offered by a retroreflective license plate did not offer observers sufficient information to recognize the plate as being something that was in the road, or identifiable. Some participants reported the object to appear off the road, particularly when placed at a location (visual angle) other than directly ahead. While VL offers a general gauge to estimate how recognizable an object might be, pattern, visual eccentricity, and size of objects other than a small square target must also be considered. The Small Target Visibility model was based upon the same size target at different distances, not different size objects. Therefore, the Small Target Visibility model as proposed by Adrian does not account for these factors. More research is planned related to the Small Target Visibility model.

The presented timed exposure technique was better able to estimate on-road drivers' abilities to recognize objects at night than other closed course study methodologies. The timed exposure techniques offered better estimates of recognition distance and failures to recognize than did other closed course methodologies and did not exhibit the large overestimation of recognition distances typically common when measuring the recognition of light colored targets and retroreflective targets. For instance, only 20% of the participants recognized the retroreflective license plate which is also consistent with the results by Balk et al (17) or Muttart et al (3). Balk et al. showed that drivers still performed poorly when responding to a pedestrian wearing retroreflective clothing, if the pattern of retroreflection did not offer drivers a clear pattern. Muttart et al (3) showed that a bright object without a corresponding pattern or meaning offered drivers inadequate information to respond.

In general, drivers were more likely to respond with a false positive (response when a target was not present) in the outdoor studies than when indoor or in the SHRP-2 dataset. In trials when no targets were presented, in 13 of 80 trials, observers claimed to have seen a target, when no target was present in the outdoor testing. A response when no target is present is referred to as a false positive response. There were no false positives in the indoor timed exposure tests Clearly, the outdoor drivers were more biased toward responding than were the drivers in the SHRP-2 dataset or during the indoor timed study. This resulted in a greater recognition distance to be calculated for the outdoor studies than the indoor or the SHRP-2 dataset. However, the timed exposure technique reports both hits and misses and these differences can be accounted for by calculating the discrimination bias of the observers (21).

Essentially, the SHRP-2 results show anecdotally that recognition distance decreased when drivers were engaged in a secondary task, but that result was not significant. Similar weak relationship existed with age in that drivers over 50 and younger than 20 recognized as only slightly shorter distances. Given the several variables that influence nighttime recognition that have been discussed, samples of greater than 12 might be necessary.

Many of the SHRP-2 result leave us wanting more samples. However, when examining the responses to deer with oncoming traffic present, we can see a significantly lower recognition distance as well as far fewer percent who responded (no oncoming vehicle = 83%, oncoming vehicle 60%). Also, while the recognition distance results may have been contradictory, we can see than only 68% of drivers responded before reaching the location of a deer on unlit roads.

Prior researchers claim that unexpected drivers will recognize objects at half the distance of expected drivers [37, 38, 39]. This research shows that the one-size-fits-all claims by Roper and Howard [37] and Hyzer and Hyzer [38, 39] is not supported by this research. Clearly, each of the factors in the acronym CAPLETS, as well as the methodology are factors that influence the information to, and expectancy of drivers. When we compare the SHRP-2 results to those from Rogers et al. [11], Fambro et al. [9] Bhagavathula [36] and Gibbons et al. [35], we can see that results from closed course studies overestimated real-world recognition distances. Each of the closed course studies that measured the response to deer or moose used a slightly different methodology. Hence, the closed course studies reported recognition distances that were 1.7 to 4.9 times greater than the recognition distance of deer in SHRP-2. Rogers and Robbins [11] overestimate the SHRP-2 results by a magnitude of 4.9 times. Rogers and Robbins allowed the driver to drive very slowly, respond when they first detect something (without having to identify the object) and they conducted the study on a closed course. Each of these methods are associated with increased recognition distances that make the results more difficult to extrapolate to real world drivers (M = 105 m compared to 25 m SHRP-2). The acronym CAPLETS offers a better comparison of varying expectancies by comparing the information available to the driver.

The results of the relationship between VL and recognition is consistent with previously published work [40]. Menard and Cariou [40] showed that VL value linearly correlated with the observer's description of visibility. Mayeur et al. [41] also determined that recognition distance increased as VL increased. However, there is some degree of scatter in these results which can be explained by the current methodology. The current research intentionally selected targets that a VL focused recognition model (like the STV model by Adrian) might have difficulty with, including a very small target, a retroreflective target, a light-colored pedestrian, a dark colored pedestrian, and a target with fur (natural camouflage). As expected, these targets exposed some of the weaknesses in the use of VL as a sole measure of a driver's ability to recognize a target. However, these results support the premise that VL is a factor that should be included in any model.

One reason that a VL-based model might have had difficulty with these results may be due to the lack of pattern [42] as a factor in the VL calculation. Mayeur et al. pointed out that the Small Target Visibility (STV) model focuses on visibility level and that the Adrian model offers a simplification of the recognition task. Bremond et al. [43] suggested that VL cannot fully explain the detection performance of drivers. The authors suggest that VL is related to detection distances, but pattern and all of the CAPLETS must be accounted for appropriately.

The timed exposure technique has been the foundation for the PC Detect (24) and The STV (22) visibility models. This research took the timed exposure technique from the laboratory (4) to the field. The timed exposure technique generated results that were closely related with similar targets in naturalistic research. These results suggest that a timed exposure can be utilized as a surrogate for drivers' expectancy, or more precisely, the information available to the driver. Restricting observation times limits driver information and information is a measure of expectancy. Additional research is planned to expand upon the influence of target size, anticipation, pattern, visual angle, lighting (including glare), and other exposure times. Also, responses with visual clutter, and secondary targets might influence the ability of drivers to recognize objects at night (5, 25, 44, 45) and should be explored further.

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Acknowledgments

The findings and conclusions of this paper are those of the author(s) and do not necessarily represent the views of the VTTI, SHRP 2, the Transportation Research Board, or the National Academies.

This research has been reviewed by WIRB and deemed to be exempt from human subject testing requirements.

Special thanks should go to Suntasy Gerhard for her hard work and analysis of much of the data in this study. Also, the following assisted in this research; Steve Mawhinney, Chris Forbes, Frank Gauss, Steve Schmit, Chuck Veppert, and Lynn Carangelo. Also, we would like to thank Michael Flannagan for his advice.

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

http://papers.sae.org/2017-01-1366