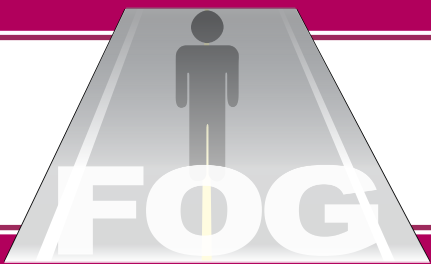

ENV

Volume VI

Enhanced Night Visibility Series: Phase II–Study 4: Visual Performance During Nighttime Driving in Fog

PUBLICATION NO. FHWA-HRT-04-137

DECEMBER 2005

U.S. Department of Transportation

Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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McLean, VA 22101-2296

FOREWORD

The overall goal of the Federal Highway Administration's (FHWA) Visibility Research Program is to enhance the safety of road users through near-term improvements of the visibility on and along the roadway. The program also promotes the advancement of new practices and technologies to improve visibility on a cost-effective basis.

The following document summarizes the results of a study on the visual performance of drivers during nighttime driving in fog. The study was conducted under Phase II of the Enhanced Night Visibility (ENV) project, a comprehensive evaluation of evolving and proposed headlamp technologies under various weather conditions. The individual studies within the overall project are documented in an 18-volume series of FHWA reports, of which this is volume VI. It is anticipated that the reader will select those volumes that provide information of specific interest.

This report will be of interest to headlamp designers, automobile manufacturers and consumers, third-party headlamp manufacturers, human factors engineers, and people involved in headlamp and roadway specifications.

Michael F. Trentacoste
Director, Office of Safety
Research and Development

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16. Abstract

Phase II—Study 4 was part of the Enhanced Night Visibility project, a larger research effort investigating drivers' visual performance during nighttime driving. Study 4 helped expand the knowledge of how current vision enhancement systems can affect detection and recognition of different types of objects during adverse weather, specifically for fog conditions. Thirty participants were involved in the study. A 6 by 3 mixed factorial design was used to investigate the effects of different types of vision enhancement systems and driver's age on detection and recognition of a pedestrian on the roadway. Subjective evaluations also were obtained for the different vision enhancement systems.

The analysis based on objective and subjective results revealed that the infrared thermal imaging system is the best configuration for detecting pedestrians in fog conditions. Halogen headlamps supplemented with ultraviolet A (UV–A) was a better configuration for detecting pedestrians than the halogen and high intensity discharge (HID) headlamps alone; however, the UV–A technology does not represent a dramatic improvement over the halogen and HID headlamps used in this research.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ENHANCED NIGHT VISIBILITY PROJECT REPORT SERIES

This volume is the sixth of 18 volumes in this research report series. Each volume is a different study or summary, and any reference to a report volume in this series will be referenced in the text as "ENV Volume I," "ENV Volume II," and so forth. A list of the report volumes follows:

Volume	Title	Report Number
I	Enhanced Night Visibility Series: Executive Summary	FHWA-HRT-04-132
II	Enhanced Night Visibility Series: Overview of Phase I and Development of Phase II Experimental Plan	FHWA-HRT-04-133
III	Enhanced Night Visibility Series: Phase II—Study 1: Visual Performance During Nighttime Driving in Clear Weather	FHWA-HRT-04-134
IV	Enhanced Night Visibility Series: Phase II—Study 2: Visual Performance During Nighttime Driving in Rain	FHWA-HRT-04-135
V	Enhanced Night Visibility Series: Phase II—Study 3: Visual Performance During Nighttime Driving in Snow	FHWA-HRT-04-136
VI	Enhanced Night Visibility Series: Phase II—Study 4: Visual Performance During Nighttime Driving in Fog	FHWA-HRT-04-137
VII	Enhanced Night Visibility Series: Phase II—Study 5: Evaluation of Discomfort Glare During Nighttime Driving in Clear Weather	FHWA-HRT-04-138
VIII	Enhanced Night Visibility Series: Phase II—Study 6: Detection of Pavement Markings During Nighttime Driving in Clear Weather	FHWA-HRT-04-139
IX	Enhanced Night Visibility Series: Phase II—Characterization of Experimental Objects	FHWA-HRT-04-140
X	Enhanced Night Visibility Series: Phase II—Visual Performance Simulation Software for Objects and Traffic Control Devices	FHWA-HRT-04-141
XI	Enhanced Night Visibility Series: Phase II—Cost-Benefit Analysis	FHWA-HRT-04-142
XII	Enhanced Night Visibility Series: Overview of Phase II and Development of Phase III Experimental Plan	FHWA-HRT-04-143
XIII	Enhanced Night Visibility Series: Phase III—Study 1: Comparison of Near Infrared, Far Infrared, High Intensity Discharge, and Halogen Headlamps on Object Detection in Nighttime Clear Weather	FHWA-HRT-04-144
XIV	Enhanced Night Visibility Series: Phase III—Study 2: Comparison of Near Infrared, Far Infrared, and Halogen Headlamps on Object Detection in Nighttime Rain	FHWA-HRT-04-145
XV	Enhanced Night Visibility Series: Phase III—Study 3: Influence of Beam Characteristics on Discomfort and Disability Glare	FHWA-HRT-04-146
XVI	Enhanced Night Visibility Series: Phase III—Characterization of Experimental Objects	FHWA-HRT-04-147
XVII	Enhanced Night Visibility Series: Phases II and III—Characterization of Experimental Vision Enhancement Systems	FHWA-HRT-04-148
XVIII	Enhanced Night Visibility Series: Overview of Phase III	FHWA-HRT-04-149

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

General Terms

AASHTO .... American Association of State Highway and Transportation Officials
ENV .... Enhanced Night Visibility
FHWA............................... Federal Highway Administration
GPS .... Global Positioning System
ITS.................................... Intelligent Transportation Systems
SUV.................................. sport utility vehicle
UV.................................... ultraviolet
UV–A .... ultraviolet A (wavelength 315 to 400 nanometers)
VDOT .... Virginia Department of Transportation
VES .... vision enhancement system
VTRC................................ Virginia Transportation Research Council

Vision Enhancement Systems

HLB.................................. halogen (i.e., tungsten-halogen) low beam
hybrid UV–A + HLB .... hybrid UV–A/visible output together with halogen low beam
five UV–A + HLB .... five UV–A headlamps together with halogen low beam
HLB–LP .... halogen low beam at a lower profile
HID .... high intensity discharge
IR–TIS............................... infrared thermal imaging system

Statistical Terms

ANCOVA .... analysis of covariance
ANOVA .... analysis of variance
DF .... degrees of freedom
F value............................... F-ratio
lsmean .... least-squares mean
MS..................................... mean square
P value............................... statistical significance
SE...................................... standard error
SS .... sum of squares

Measurements

ft .... feet
h... hours
km/h .... kilometers per hour
lx .... lux
m .... meters
mi/h .... miles per hour
s .... seconds
W/cm^2 .... watts per square centimeter
$\mu W/cm^2$ .... microwatts per square centimeter

Stopping Distance

a..deceleration rate
BRT...................................braking reaction time
V..velocity
d..distance
g..acceleration
f...friction
G..gradient

Contrast Sensitivity

cpd.....................................cycles per degree
PCLA ....percentage of contrast left eye line A (line A represents 1.5 cpd)
PCRA ....percentage of contrast right eye line A (line A represents 1.5 cpd)
PCLB.................................percentage of contrast left eye line B (line B represents 3.0 cpd)
PCRB ....percentage of contrast right eye line B (line B represents 3.0 cpd)
PCLC.................................percentage of contrast left eye line C (line C represents 6.0 cpd)
PCRC ....percentage of contrast right eye line C (line C represents 6.0 cpd)
PCLD ....percentage of contrast left eye line D (line D represents 12.0 cpd)
PCRD ....percentage of contrast right eye line D (line D represents 12.0 cpd)
PCLE.................................percentage of contrast left eye line E (line E represents 18.0 cpd)
PCRE.................................percentage of contrast right eye line E (line E represents 18.0 cpd)

CHAPTER 1—INTRODUCTION

Phase II—Study 4 of the Enhanced Night Visibility (ENV) project was the last in a series of studies conducted on the Virginia Smart Road testing facility that focused on drivers' visual performances during adverse weather conditions (i.e., rain, snow, and fog). The tasks in this experiment consisted of driving at night in fog conditions testing six different vision enhancement system (VES) configurations (a subset of the configurations used for Phase II, Studies 1 and 2; see ENV Volumes III and IV). This study evaluates drivers' ability to detect and recognize pedestrians while using the different VESs. Study participants also were asked to make subjective performance ratings following their use of each VES.

The driving portion of the study at the Virginia Smart Road testing facility was conducted with the road closed to all traffic except the experimental vehicles. No more than two vehicles were on the road at any time. A training session familiarized participants before the onroad study.

The next chapter discusses the methodology in this study.

CHAPTER 2—METHODS

PARTICIPANTS

Thirty individuals participated in this study. They had not participated in any other studies for the ENV project (i.e., clear, rain, snow, glare, or pavement marking studies). Participants were divided into three age categories: 10 drivers were between the ages of 18 and 25 (younger category), 10 were between the ages of 40 and 50 (middle-aged category), and 10 were over 65 (older category). There were five males and five females in each age category. Candidates for the study had to meet the conditions of a screening questionnaire (appendix A). Participants also had to sign an informed consent form (appendix B), present a valid driver's license, pass the visual acuity test (appendix C) with a score of 20/40 or better (as required by Virginia State law), and have no health conditions that made operating the research vehicles a risk.

Participants were told they could withdraw freely from the research program at any time without penalty and that no one would try to make them participate if they did not want to continue. If they chose at any time not to participate further, they were instructed that they would be paid for the amount of actual participation time. Participants received $20 per hour for their participation. All data gathered as part of this experiment were treated with complete anonymity.

EXPERIMENTAL DESIGN

A mixed-factor design was used to collect data during the onroad portion of the study (i.e., detection and recognition tasks). There were two independent variables:

- VES configuration.
- Age.

The between-subjects variable of the experiment was age. The within-subject variable was VES configuration. Unlike the three previous studies (i.e., clear, rain, and snow), this study used just one object type, a pedestrian in white clothing. The reason for limiting the number of objects was the variability of the fog-making conditions. (See Smart Road section for more details.) Table 1 shows a representation of the experimental design including the object presented to participants. A detailed explanation of each of the independent variables follows the table.

Table 1. Experimental design: 6 by 3 mixed-factor design (6 VES configurations, 3 age groups).

VES Configuration	Younger Age Group	Middle Age Group	Older Age Group
HLB	Pedestrian	Pedestrian	Pedestrian
Hybrid UV–A + HLB	Pedestrian	Pedestrian	Pedestrian
IR–TIS	Pedestrian	Pedestrian	Pedestrian
Five UV–A + HLB	Pedestrian	Pedestrian	Pedestrian
HLB–LP	Pedestrian	Pedestrian	Pedestrian
HID	Pedestrian	Pedestrian	Pedestrian

HLB = halogen low beam
UV–A = ultraviolet A
IR–TIS = infrared thermal imaging system
HLB–LP = halogen low beam at a lower profile
HID = high intensity discharge

Object

The one object selected for this study was a pedestrian (table 2) mainly because of the high crash-fatality rates pedestrians represent.[1,2] This study used real pedestrians. Although pedestrian mockups have been used in previous research of this type, using mockups in this study would have restricted the performance capabilities of the infrared thermal imaging system (IR–TIS) and limited the external validity of the study.[3]

In the experiment, the pedestrian was presented at the following contrast level: white clothing against the fog background at night. The pedestrian walked perpendicular to the vehicle path, representing a pedestrian crossing the road (figure 1). Because of the variability of the fog-making conditions, each participant saw a single object multiple times with each VES. This provided a more precise assessment of object visibility independent of slight fluctuations in fog density. A pedestrian dressed in white was selected because it represents the type of object that would benefit the most from the ultraviolet A (UV–A) headlamps based on the results from the other weather condition studies and the expected fluorescence of the clothing material. The assumption was that the detection and recognition levels with the UV–A configurations for a pedestrian dressed in white would be better than for a pedestrian dressed in black because the white clothing would fluoresce more. In addition, a pedestrian crossing in front of vehicles has the greatest potential to affect safety. Detailed object characterization information is provided in ENV Volume IX.

Table 2. Description of the object.

Object	Reflectance at 61 m (200 ft) (%)	Location	Special Instructions
Perpendicular Pedestrian, White Clothing	50	Walk in a straight line (perpendicular) from right edgeline to centerline.	Wear white clothing. Walk to centerline; then walk backward to right edgeline. Repeat.

Figure 1. Photo. Perpendicular pedestrian in white clothing.

INDEPENDENT VARIABLES

Age

The age factor had three levels: younger participants (18 to 25), middle-aged participants (40 to 50), and older participants (65 or older). These age groups were created based on literature review findings (refer to ENV Volume II) that suggest changes in vision during certain ages. (See references 4, 5, 6, 7, and 8.) Each age group comprised five males and five females. Gender was used as a control but not as a factor of interest.

VES

Following is a list of the VES configurations:

- Halogen (i.e., tungsten-halogen) low beam (HLB).
- Hybrid UV–A with visible output together with HLB (hybrid UV–A + HLB).
- Five UV–A headlamps together with HLB (five UV–A + HLB).
- HLB at a lower profile (HLB–LP).
- High intensity discharge (HID).
- Infrared thermal imaging system (IR–TIS).

For an indepth look at the technical specifications of each headlamp, refer to ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*.

The presentation orders for each VES configuration were counterbalanced. Table 3 provides an example of the VES configuration order for a pair of participants. The first column, “Order,” indicates the order in which the VESs were presented. The second column, “VES,” presents the VES configuration that was used. The third column, “Vehicle,” indicates whether a sport utility vehicle (SUV) or a sedan was used for the VESs.

Table 3. Example of the VES configuration order for a pair of participants.

Participant	Order	VES	Vehicle
1	Practice	HLB	SUV 1
	1	HLB	SUV 1
	2	Hybrid UV–A + HLB	SUV 1
	3	IR–TIS	Sedan
	4	Five UV–A + HLB	SUV 2
	5	HLB–LP	Sedan
	6	HID	SUV 3
2	Practice	HLB	SUV 2
	1	Five UV–A + HLB	SUV 2
	2	HID	SUV 3
	3	Hybrid UV–A + HLB	SUV 1
	4	HLB–LP	Sedan
	5	HLB	SUV 1
	6	IR–TIS	Sedan

The six VES configurations tested were selected based on several considerations. The HLB and the HID headlamps are currently available on the market, and they reflect the most commonly used headlamps (HLB) and the headlamp type with a growing section of the market (HID). They were included as two of the configurations to allow comparison of new VES alternatives to what is readily available.

There was also some concern about possible changes in the detection and recognition distances resulting from the use of high-profile headlamps, such as halogens on an SUV, versus lower-profile headlamps, such as halogens on a sedan. This is important to consider because of the growing number of higher-profile vehicles on the Nation’s roadways; therefore, two halogen-based VESs of different heights were included, one at a low profile (i.e., HLB–LP) and one at a high profile (i.e., HLB) on a sedan and SUV, respectively.

The configurations that used the UV–A headlamps had to be paired with HLB headlamps because UV–A headlamps provide minimal visible light. These UV–A headlamps stimulate the fluorescent properties of objects irradiated by the UV radiation, producing visible light. Their purpose is to supplement, not eliminate, regular headlamps. Two different UV–A headlamp configurations were used in this study: hybrid UV–A and five UV–A. The hybrid UV–A headlamp is an experimental prototype that produces a significant amount of visible light, although not enough light to allow driving without standard headlamps. The UV–A headlamps used in the five UV–A configuration produce far less visible light. The UV–A and HLB pairings resulted in two different VES configurations: hybrid UV–A + HLB and five UV–A + HLB.

The IR–TIS was included because of its ability to present the driver with images of the environment based on the temperature differential of objects. This approach has the potential to allow very early detection of pedestrians, cyclists, and animals (i.e., objects generating heat) as well as roadway infrastructure objects that shed heat (e.g., guardrails, light posts).

There are several reasons for the decrease in the number of VES configurations from the clear and rain conditions (ENV Volumes III and IV). The need to limit participation to one night became apparent during pilot testing. The fog-making environment changed from night to night; therefore, all the VESs that needed to be tested were run in the same night to avoid the potential for confounding environmental changes and the within-subject variable, VES. To account for potential changes within the same night, fog density measurements were taken. (See Covariate section under Objective Dependent Variables.) Based on the results from the clear and rain conditions, the tested high output halogen (HOH) configuration was either no different or worse than the HLB, so it was decided that no further testing for this configuration was necessary. Similarly, the UV–A and HID pairings also were found to provide little improvement in clear and rain conditions, and therefore, were not included in this study. Halogen high beam was not included because this configuration is known for its potential to hinder driver’s visibility during fog at night because of increased backscatter.

OBJECTIVE DEPENDENT VARIABLES

Detection and recognition distances were obtained to analyze the degree to which the different VES configurations enhanced nighttime visibility while driving. These two variables were selected because of their common use and acceptance in the human factors transportation literature. (See references 9, 10, 11, 12, and 13.) Both terms, detection and recognition, were explained to the participants during the training session. Detection was explained as follows: "Detection is when you can just tell that something is on the road in front of you. You cannot tell what the object is, but you know something is there." Recognition was explained as follows: "Recognition is when you not only know something is there, but you also know what it is."

During training and practice, the participants were instructed on the use of a hand-held pushbutton wand used to mark the moments when they detected and recognized objects. The participants were instructed to press a button on the wand when they detected an object on the road, then press it again when they recognized the object. The front-seat experimenter flagged the data collection the moment the participant drove past the object. Detection and recognition distances were calculated from distance data collected at these three points in time.

Backscatter

The light reflected back to the driver from the fog, or backscatter, was used as a potential covariate for the detection and recognition distances. The fog movement behavior varied from night to night. Confounds resulting from this movement were mitigated by running all VES conditions in the same night; however, variations in fog density within the same night were still possible, which could have changed the amount of backscatter. For example, a less dense fog will result in a lower value of illuminance at the eye of the driver than will a denser fog because less light is reflected back from the fog (i.e., less backscatter). To account for this variation, the backscatter from the fog was recorded at the point of detection. An illuminance meter was positioned between the rearview mirror and the windshield. The meter was connected to a laptop that continuously read the illuminance measurements from the meter. The back-seat experimenter recorded the illuminance measurement obtained with the meter when the participant pressed the button for detection (appendix G). Backscatter was evaluated to determine if variations in fog density were enough to have a significant effect in the detection and recognition distances. If the illuminance due to backscatter affected the results, the values recorded at the point of detection (lux) could be used as a covariate to adjust the mean detection and recognition distances before evaluating the main effects and interactions for statistical significance.

SUBJECTIVE RATINGS

Subjective ratings also were collected as dependent variables. Participants were asked to evaluate seven statements for each VES using a seven-point Likert-type scale. The two anchor points of the scale were one (indicating "Strongly Agree") and seven (indicating "Strongly Disagree"). The statements addressed each participant's perception of improved vision, safety, and comfort after experiencing a particular VES. Participants were asked to compare each experimental VES to their regular headlamps (i.e., the headlamps on their own vehicle). Researchers assumed that participants' own vehicles represented what they knew best, and therefore, were most comfortable using. Following is the list of statements on the questionnaire:

- This vision enhancement system allowed me to detect objects sooner than my regular headlights.
- This vision enhancement system allowed me to recognize objects sooner than my regular headlights.
- This vision enhancement system helped me to stay on the road (not go over the lines) better than my regular headlights.
- This vision enhancement system allowed me to see which direction the road was heading (i.e., left, right, or straight) beyond my regular headlights.
- This vision enhancement system did not cause me any more visual discomfort than my regular headlights.
- This vision enhancement system makes me feel safer when driving on the roadways at night than my regular headlights.
- This is a better vision enhancement system than my regular headlights.

SAFETY PROCEDURES

Safety procedures were implemented as part of the experiment. These procedures were used to minimize possible risks to participants during the experiment. The safety measures included the following requirements:

- All data collection equipment was mounted so that, to the greatest extent possible, it did not pose a foreseeable hazard to the driver and did not interfere with any part of the driver's normal field of view.
- Participants wore the seatbelt restraint system anytime the car was on the road.
- Two trained experimenters were in the vehicle at all times.
- An emergency protocol was established before testing.

The onroad pedestrians were trained when to clear the road, based on a preset safety-envelope mark. In addition, they were provided with radios in case the front-seat experimenter needed to communicate with them.

APPARATUS AND MATERIALS

Onroad driving was conducted using four vehicles. The experimental vehicles included three SUVs and a sedan. All vehicles were equipped with laptops for data collection. Software was developed to link the data collection system to the vehicle to obtain distances traveled (i.e., electronic odometer) and speed. The distances from the points of detection and recognition to the pedestrian were obtained from the electronic odometer data. The software program on the laptop allowed the front-seat experimenter to change between VES configurations and pedestrian orders (figure 2). After all the pedestrians had been presented for a VES condition, the program went directly into the subjective questions asked by the experimenter. In addition, the software also gathered information such as the participant's age, gender, and assigned identification number.

```
--------------------------- PARTICIPANT INFORMATION ----------------------------
DRIVER:       (Z/X)Participant ID 000    (A)Age: Y    (G)Gender M
PASSENGER:    (C/V)Participant ID 000    (E)Age: Y    (R)Gender M
-------------------------------- CURRENT SETUP --------------------------------
 (H)VES [PRACTICE]             (O)Target Order [01]       (D)Day [1]
 (N)Number of Participants [1]    (B)Beep [ON]
 OUTPUT FILENAME: N0000010.dat    (P)EXPERIMENT[0]: Fog
------------------------------------------------------- ----------------------
  ==>SETUP MODE                                  DRIVER:
     [1  ](3520)  White Perp Pedestrian            Detection Dist.: ---.--
     [2  ](4530)  White Perp Pedestrian            Recognize Dist.: ---.--
     [4  ](2204)  White Perp Pedestrian            Success:        YES
     [5  ](3115)  White Perp Pedestrian
                                                   PASSENGER:
                                                   Last Dist.: ---.--
                                                   Recognize Dist.: ---.--
                                                   Success:        YES

                                                     CALIBRATION VAL:  4294967295
                                                     CURRENT DISTANCE:  0.00
                                                     NEXT TARGET AT:  0.00

                                              B1  B2
  Hit key in () to change option.    'S' to start program.      'Q' to quit.
```

Figure 2. Diagram. Data collection display screen.

The software used by the back-seat experimenter was developed to link the data collection system to the illuminance meter to obtain the backscatter reading at the point where the participant detected the pedestrian (appendix G).

The VESs were distributed among the four vehicles (figure 3 through figure 6). The three SUVs had light bars installed, allowing experimenters to aim the test headlamps by adjusting its horizontal and vertical position. The HLB–LP and IR–TIS were the only exceptions; these were factory installed on the sedan. Note that either of the two SUVs equipped with the UV–A headlamps could also be used for the HLB-only configuration.

Figure 3. Photo. Five UV–A + HLB.

Figure 4. Photo. Hybrid UV–A + HLB.

Figure 5. Photo. HID.

Figure 6. Photo. HLB–LP with IR–TIS.

Smart Road

The all-weather testing facility on the Smart Road was used in this study (figure 7 and appendix H). The pedestrian was presented at four different locations on the Smart Road (figure 8). Each participant changed vehicles on the second turnaround of the Smart Road. One onroad experimenter was assigned to each participant; this experimenter was responsible for escorting the participant to the next vehicle, showing him or her where the controls were, and verifying that the correct VES configuration was being tested. Two other onroad experimenters were positioned at the various locations. One onroad experimenter was assigned to locations 1 and 5, and another onroad experimenter was assigned to locations 2 and 4. See appendix J for details on the protocol for the onroad experimenters. A total of four onroad and four in-vehicle experimenters (one in the front seat to monitor distance data collection and one in the back seat to monitor the illuminance meter software) were part of the study each night.

Figure 7. Photo. Smart Road.

The all-weather testing facility on the Smart Road generated the fog (figure 9 and figure 10; overhead lighting was turned off for the study). Data were not collected during heavy wind conditions. Fog generation was the weather condition that varied the most from night to night. Operation of the fog generation system required continuous monitoring during each night of data collection to ensure the fog density was constant. The system used water and compressed air mixed at nozzles mounted over the center of the road to produce fog. The pressure ratio of the air and water was controlled to provide a consistent fog density. A visibility meter was positioned on the roadside to assist in this system control.

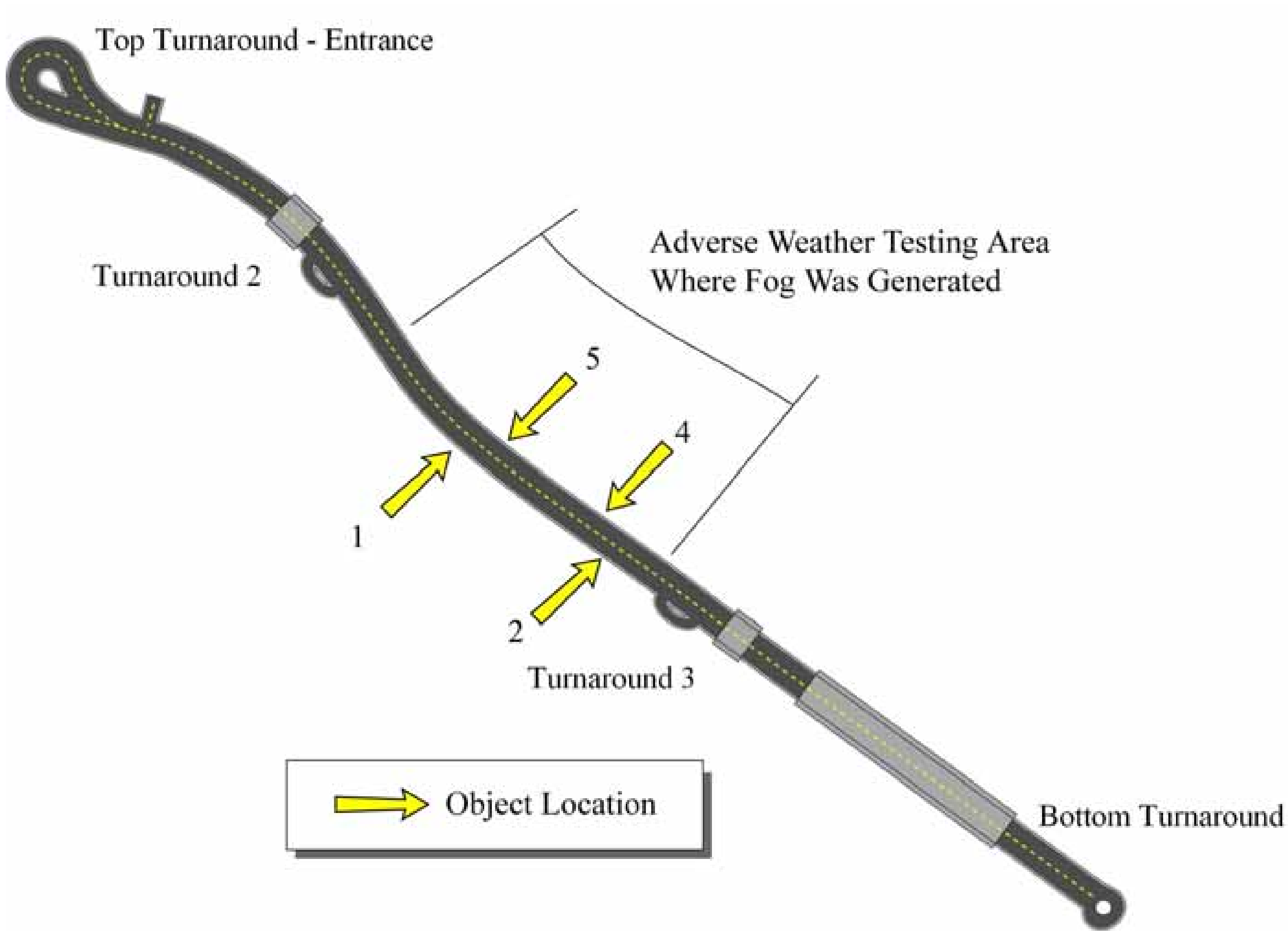


Figure 8. Diagram. Locations where pedestrians were presented for the adverse weather condition (note the area where fog was generated).

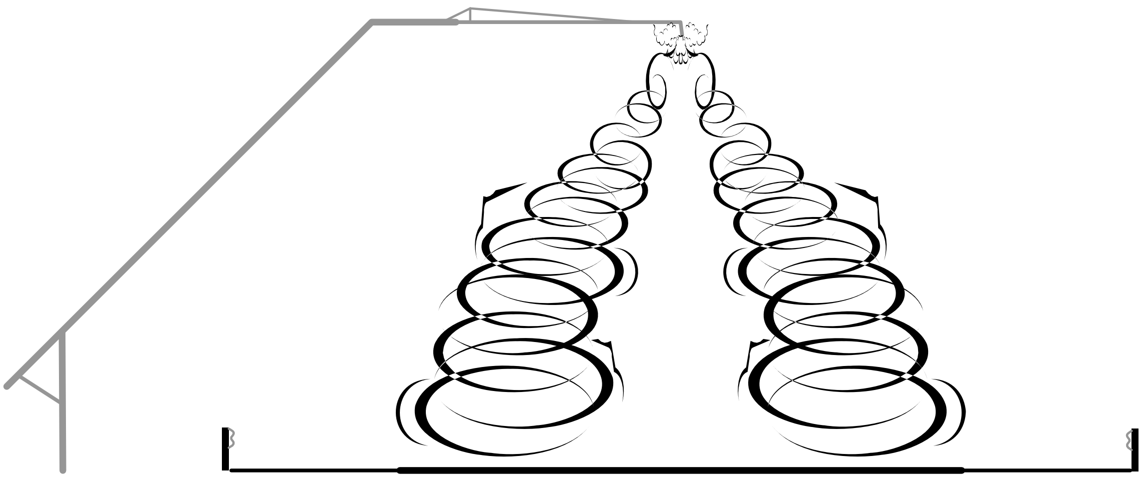


Figure 9. Diagram. Fog tower generating fog.

Note: lights were turned off for study

Figure 10. Photo. Smart Road overhead lighting system and fog towers starting to make fog.

Headlamp Aiming

The headlamps used for the HLB, HID, and UV–A configurations were located on external light bars. Each light assembly required a re-aiming process, which took place before the experimental session began. At the beginning of the Phase II studies, a headlamp aimer was not available to the contractor, so an aiming protocol was developed with the help of experts in the field. (See references 14, 15, 16, and 17.) The details of the aiming protocol used for this specific study are described in appendix K. During the photometric characterization of the headlamps, it was discovered that the position of the maximum intensity location of the HLB configuration was aimed higher and more toward the left than typically specified. The effect of this aiming deviation on detection and recognition distances is undetermined. The aiming could have resulted in more illumination on pedestrians leading to increased detection and recognition distances. The aiming could also have led to increased backscatter from the fog, resulting in decreased detection and recognition distances. Details about the aiming procedure and the maximum intensity location are discussed in ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*.

EXPERIMENTAL PROCEDURE

Two participants performed the experiment simultaneously. The experiment, which consisted of two sessions, was performed in one night for each pair of participants. The first session included vision screening, laboratory training, and IR–TIS training. The second session involved the experiment on the Smart Road. The entire experiment lasted approximately 3.5 h. During the onroad session, participants were familiarized with the Smart Road and the experimental object before starting the experiment. Six VES configurations were presented to the participants; the order of VES presentation was counterbalanced. A discussion of the details follows.

Participant Screening

Candidates initially were screened over the telephone (appendix A). If a candidate qualified for the study, a time was scheduled for testing. After the candidate arrived at the contractor facility, he or she received an overview of the study and then was asked to complete the informed consent form (appendix B) and to take an informal vision test for acuity using a Snellen chart, a contrast sensitivity test, and a color vision test (appendix C). The vision tests were performed to ensure that all participants had at least 20/40 vision and identify any type of vision disparity that might have influenced the results. A detailed experimenter protocol for vision testing appears in appendix D. If no problems were identified, the participant was trained on the tasks in the experiment to be performed during the drive.

Training

Each participant was taught how to perform the tasks associated with object detection and recognition and told how the questionnaires would be used. The study protocol and the picture of the objects were presented at this point (appendixes D and E). The participants for this study received training similar to the training participants from the previous ENV studies received (i.e., clear, rain, and snow conditions). Even though only one type of object, the perpendicular pedestrian dressed in white, was used, participants were shown all the objects used in the other studies to maintain their multiple-object visual scanning behavior. Participants also were instructed in the detection and recognition definitions, use of the pushbutton wand, and the Likert-type scales for the subjective questionnaire. The purpose of this lab training and practice was to allow all participants to begin the experiment with a standard knowledge base. After the lab training, each participant practiced detecting an example of the experimental object using the IR–TIS.

Vehicle Familiarization

Because the participants drove multiple vehicles as part of the study, each participant was familiarized as soon as he or she reached the next experimental vehicle. While the vehicle was parked, the onroad experimenter reviewed general information concerning the vehicle's operation (appendix L). The participant was asked to adjust the seat and steering wheel positions for his or her driving comfort. When the participant felt comfortable with the controls of the vehicle, the experiment was ready to begin.

Driving Instructions

The participant was instructed to place the vehicle in park when he or she reached turnarounds 2 and 3 (figure 8) while the onroad experimenters prepared for the next lap. The participant also was instructed to drive at 16 km/h (10 mi/h) during the experimental sessions and to follow instructions from the in-vehicle experimenter at all times.

Driving and Practice Lap

Each participant conducted a practice drive down the road to become familiar with the road and the vehicle. No object was presented during the practice drive. At the turnaround, the front-seat experimenter gave the pushbutton wand to the participant and instructed him or her that this portion of the session was a practice run to familiarize him or her with the protocol. The participant then drove back up the road for a practice run of detection and recognition tasks, obtaining feedback from the front-seat experimenter as needed. After the practice tasks, the participant began the tasks of the experiment, driving with each of the six VESs in the assigned order.

General Onroad Procedure

Distance data were collected while the participant drove with each VES. The front-seat experimenter provided the participant with a pushbutton wand to flag the data collection program when the participant detected and recognized the object. The participant performed no tasks while driving other than detection, recognition, and maintaining a speed of 16 km/h (10 mi/h). The front-seat experimenter sat in the passenger seat and told the participant when he or she could begin driving and where to park. The front seat experimenter also administered the subjective questionnaires after each VES configuration and controlled the data collection program. Details on the front-seat experimenter protocol appear in appendix F. The back-seat experimenter recorded the following information for each run: windshield wiper speed (low, medium, or high), illuminance reading at the detection point, and any additional information about the fog. Details on the back-seat experimenter protocol appear in appendix G.

Sequence of Data Collection

Every participant followed the same sequence of events when collecting the data for each of the VES configurations:

1. One object (the pedestrian) was presented at each of the four locations for the fog condition for each VES.
2. The participant pressed the pushbutton when he or she was able to detect the pedestrian.
3. The back-seat experimenter recorded the illuminance reading the moment the participant detected the pedestrian.
4. The participant pressed the pushbutton again when he or she could recognize the object as a pedestrian and identified the pedestrian aloud.
5. The front-seat experimenter flagged the data collection system the moment the participant passed the pedestrian.
6. The participant drove one lap, which completed a run for that VES. Then the participant answered a subjective rating questionnaire for that VES. The participant changed vehicles (if necessary) and started the next VES run.
7. After all VES configurations were completed, the participant was instructed to return to be debriefed (appendix I).

The study was performed once every night from 7:30 p.m. to 11 p.m. until all pairs of participants had completed the experiment. Each participant was paid for the total number of hours (training and experimental session) at the end of the experimental session.

DATA ANALYSIS

Data for this research were contained in one data file per VES configuration per participant. A separate data file contained illuminance data per VES per participant. All the data collected for the 30 participants were merged into a single database that included objective, subjective, and illuminance data. The illuminance measures were evaluated to determine how the fog varied for each VES. An analysis of variance (ANOVA) was performed to evaluate drivers' visual performance under each of the different treatments. PROC GLM was used in SAS® statistical software to compute the ANOVA. The full experimental design model was used in the data analysis (table 4).

Table 4. Model for the experimental design.

SOURCE
<u>*BETWEEN*</u>
Age
Subject (Age)
<u>*WITHIN*</u>
VES
Age by VES
VES by Subject (Age)

A Bonferroni post hoc analysis was performed for the significant main effects ($p < 0.05$). For the significant interaction, the means and standard errors were graphed and discussed. Post hoc analyses assisted in identifying experimental levels that were responsible for the statistical significance of the main effects. Note that the significance of a main effect or interaction does not make all interior levels significantly different. For a detailed discussion of post hoc tests and ANOVA, see Winer, Brown, and Michels.(18)

CHAPTER 3—RESULTS

Results included in this report are based on statistically significant effects at an $\alpha = 0.05$ level except where otherwise stated. In main effect graphs, means with the same letter are not significantly different based on the Bonferroni post hoc test. Bars above and below the means indicate standard error.

FOG DENSITY CONSISTENCY

Maintaining a consistent fog density over multiple testing sessions is difficult even with artificial fog, but doing so was important to allow unbiased comparisons between the VESs. One available metric to test fog density is the amount of backscatter, light reflected back from the fog to the driver's eye point. Not surprisingly, different headlamp designs elicit different amounts of backscatter in the same fog condition. The consistency of fog density can be inferred by comparing these backscatter differences from multiple fog sessions to backscatter differences in a baseline clear condition; if the differences between VESs are similar in both conditions, the fog density can be considered consistent.

A baseline backscatter estimate in a no-fog, clear condition was conducted as part of the fog model development discussed in ENV Volume IX. To measure backscatter in the fog condition, an illuminance meter was positioned in the experimental vehicles to collect backscatter data during the object detection and recognition trials as discussed in the Apparatus section. This backscatter data was analyzed to determine any potential bias or potential confounding differences that existed in fog for the different VESs. Comparison of this data to the baseline estimates of each VES showed that VESs with low backscatter in the clear condition had low backscatter in fog conditions, and VESs with high backscatter in the clear condition had high backscatter in fog conditions. Therefore, when controlling for the differences in the baseline backscatter for each VES, on average, the fog provided fairly consistent levels of backscatter for each VES. As shown in table 5, the variation in fog was also similar across the VESs. This suggests that although there were variations in the fog, there was no VES that consistently had thicker or thinner fog than the other VESs. Also, the three age groups had similar backscatter ranges, with means between 0.24 lux (lx) and 0.26 lx. Given that no consistent bias in fog density could be ascertained, the variations in fog were considered random and were not analyzed further in the following objective measures. ENV Volume IX gives more information on the fog and the fog model.

Table 5. Backscatter from fog by VES.

VES	Range (lx)	Mean (lx)	Standard Deviation (lx)
IR–TIS	0.09–0.55	0.25	0.10
Five UV–A + HLB	0.05–0.50	0.16	0.10
Hybrid UV–A + HLB	0.09–0.59	0.26	0.11
HLB	0.06–0.65	0.21	0.12
HID	0.10–0.74	0.35	0.14
HLB–LP	0.11–0.79	0.28	0.11

OBJECTIVE MEASUREMENTS

An ANOVA was performed on the objective measurements taken during the Smart Road portion of the study. The model for this portion of the study was a 6 (VES) by 3 (Age) mixed factorial design. ANOVA summary tables were obtained for both objective dependent measurements (table 6 and table 7). A total of 626 observations resulted from the experiment for each objective measurement. When drivers were not able to detect and recognize a pedestrian, a value of 0 was assigned.

Table 6. ANOVA summary table for the dependent measurement: detection distance.

Source	DF	SS	MS	F value	P value	
Between						
Age	2	63640.7	31820.3	5.8	0.0082	*
Subject/Age	27	148825.7	5512.1	1.8		
Within						
VES	5	252796.0	50559.2	8.4	0.0001	*
VES by Age	10	35704.9	3570.5	0.6	0.8173	
VES by Subject/Age	134	806586.5	6019.3	2.0		
TOTAL	625	1307553.8				

* $p < 0.05$ (significant)

Table 7. ANOVA summary table for the dependent measurement: recognition distance.

Source	DF	SS	MS	F value	P value	
Between						
Age	2	62778.5	31389.3	7.0	0.0036	*
Subject/Age	27	121401.0	4496.3	1.6		
Within						
VES	5	212611.7	42522.3	7.3	0.0001	*
VES by Age	10	46333.6	4633.4	0.8	0.6335	
VES by Subject/Age	134	780796.2	5826.8	2.1		
TOTAL	625	1223921.0				

* $p < 0.05$ (significant)

Both main effects were significant ($p < 0.05$) for detection and recognition distances, but not their interaction (table 8). The results for the main effects VES and age are shown in figure 11 and figure 12.

The HLB headlamp is the most commonly available VES, making its experimental results a baseline measure. It is important to compare the results of other VESs to results obtained for the HLB in the following descriptions of the significant results. Note that this is only one halogen headlamp type and beam pattern; it does not necessarily represent all halogen headlamps currently on the market.

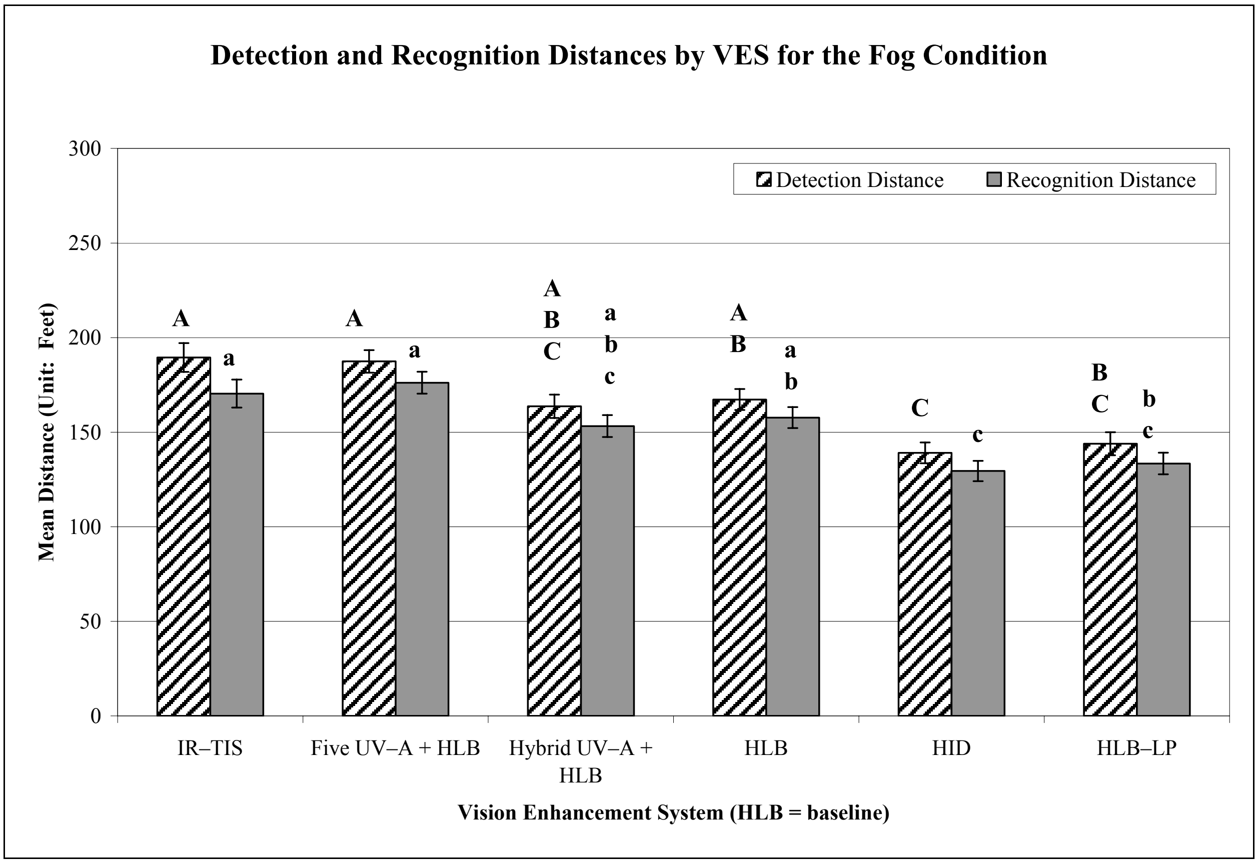
Table 8. Summary of significant main effects and interactions.

Source	Significant Detection	Significant Recognition
Between		
Age	x	x
Subject/Age		
Within		
VES	x	x
VES by Age		
VES by Subject/Age		

x = $p < 0.05$ (significant)

VES Main Effect

VESs were significantly different from each other ($p < 0.05$) in terms of the detection and recognition distances (figure 11). Post hoc analyses showed that HLB provided detection and recognition distances that were significantly longer than the HID VES by approximately 8.5 m (28 ft). HLB was not statistically different from the other four VESs in terms of detection or recognition distances.

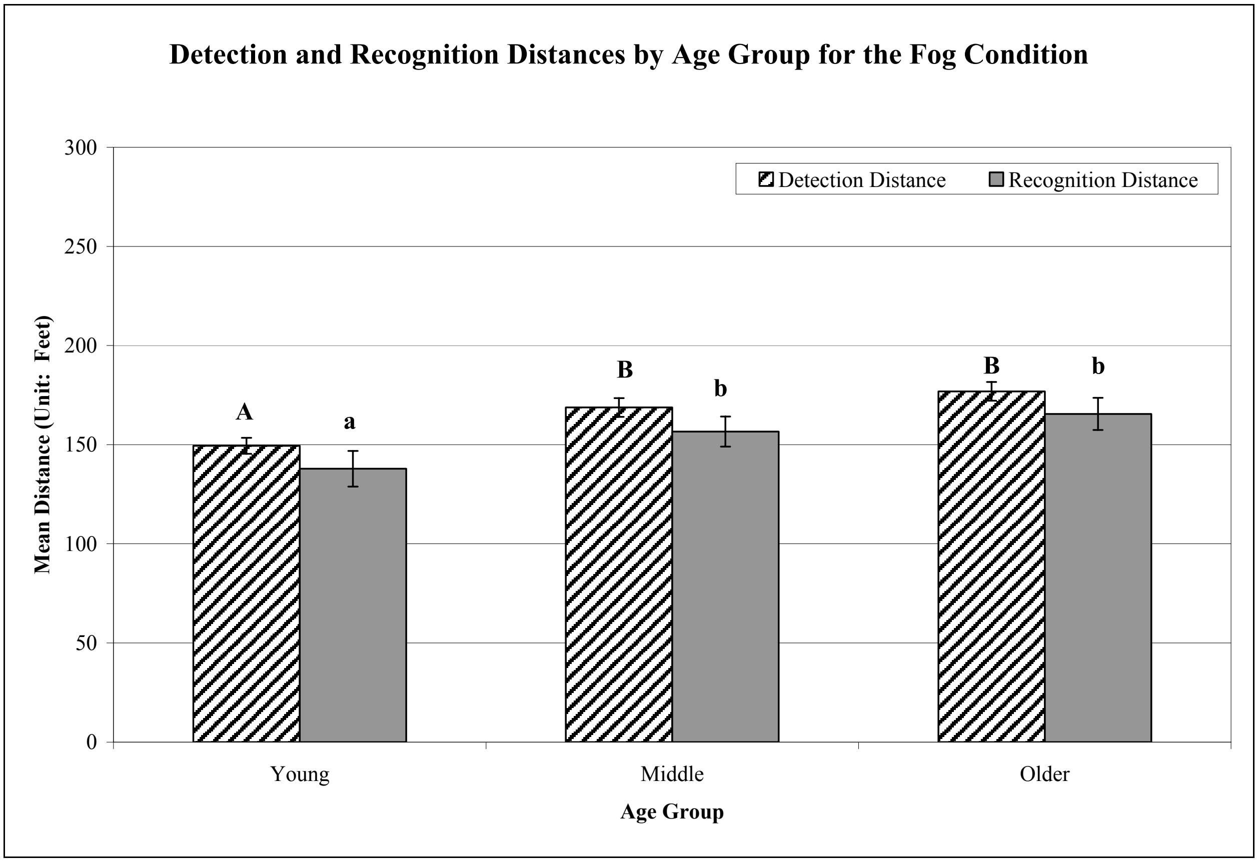


Means with the same letter are not significantly different.
1 ft = 0.305 m

Figure 11. Bar graph. Bonferroni post hoc results for the main effect: VES.

Age Main Effect

The results from the ANOVA showed a significant difference ($p < 0.05$) among the three age groups in terms of detection and recognition distances (figure 12). Both detection and recognition follow the same pattern with respect to age: distances were not significantly different between older and middle-aged drivers, but they were significantly different between these two age groups and the younger drivers. The detection and recognition distances for the two older age groups were longer than those of the younger drivers by approximately 8.5 m (28 ft).



Means with the same letter are not significantly different.
1 ft = 0.305 m

Figure 12. Bar graph. Bonferroni post hoc results for the main effect: age.

SUBJECTIVE MEASUREMENTS

An analysis of variance (ANOVA) was performed to analyze the subjective measurements taken on the Smart Road. The model for this portion of the study is a 6 (VES) by 3 (Age) factorial design. Table 9 through table 15 present the ANOVA summaries for each of the seven subjective statements, and table 16 summarizes significant main effects and interactions.

Table 9. ANOVA summary table for the Likert-type rating for detection.

Statement 1: Detection						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	8.6	4.3	1.4	0.2747	
Subject/Age	27	85.7	3.2			
Within						
VES	5	56.2	11.23	11.2	<.0001	*
VES by Age	10	18.8	1.9	1.9	0.0539	
VES by Subject/Age	134	134.7	1.0			
TOTAL	178	303.9				

* = $p < 0.05$ (significant)

Table 10. ANOVA summary table for the Likert-type rating for recognition.

Statement 2: Recognition						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	14.0	7.0	2.1	0.1433	
Subject/Age	27	90.7	3.4			
Within						
VES	5	51.3	10.3	10.0	<.0001	*
VES by Age	10	16.1	1.6	1.6	0.1229	
VES by Subject/Age	134	137.5	1.0			
TOTAL	178	309.6				

* = $p < 0.05$ (significant)

Table 11. ANOVA summary table for the Likert-type rating for lane-keeping assistance.

Statement 3: Lane-keeping assistance					
Source	**DF**	**SS**	**MS**	**F value**	**P value**
Between					
Age	2	18.4	9.2	2.0	0.1500
Subject/Age	27	121.8	4.5		
Within					
VES	5	7.1	1.4	1.2	0.3002
VES by Age	10	16.1	1.6	1.4	0.1927
VES by Subject/Age	134	155.6	1.2		
TOTAL	178	319.0			

Table 12. ANOVA summary table for the Likert-type rating for roadway direction.

Statement 4: Roadway direction					
Source	**DF**	**SS**	**MS**	**F value**	**P value**
Between					
Age	2	13.3	6.7	1.9	0.1713
Subject/Age	27	95.6	3.5		
Within					
VES	5	9.2	1.8	1.7	0.1482
VES by Age	10	15.7	1.6	1.4	0.1793
VES by Subject/Age	134	148.8	1.1		
TOTAL	178	282.6			

Table 13. ANOVA summary table for the Likert-type rating for visual discomfort.

Statement 5: Visual discomfort					
Source	**DF**	**SS**	**MS**	**F value**	**P value**
Between					
Age	2	13.6	6.8	1.9	0.1770
Subject/Age	27	99.1	3.7		
Within					
VES	5	6.9	1.4	1.0	0.4080
VES by Age	10	8.2	0.8	0.6	0.8060
VES by Subject/Age	134	181.7	1.4		
TOTAL	178	309.5			

Table 14. ANOVA summary table for the Likert-type rating for overall safety rating.

Statement 6: Overall safety rating					
Source	**DF**	**SS**	**MS**	**F value**	**P value**
Between					
Age	2	24.9	12.5	2.4	0.1128
Subject/Age	27	142.2	5.3		
Within					
VES	5	11.2	2.2	1.6	0.1693
VES by Age	10	12.2	1.2	0.9	0.5700
VES by Subject/Age	134	189.0	1.4		
TOTAL	178	379.5			

Table 15. ANOVA summary table for the Likert-type rating for overall VES evaluation.

Statement 7: Overall VES evaluation						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	13.7	6.9	1.5	0.2432	
Subject/Age	27	124.2	4.6			
Within						
VES	5	22.8	4.6	3.4	0.0065	*
VES by Age	10	11.5	1.2	0.9	0.5779	
VES by Subject/Age	134	180.5	1.3			
TOTAL	178	352.7				

* = $p < 0.05$ (significant)

Table 16. Summary of significant main effects and interactions for the Likert-type rating scales.

Source	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Between							
Age							
Subject/Age							
Within							
VES	x	x					x
VES by Age							
VES by Subject/Age							

x = $p < 0.05$ (significant)

To understand drivers' ratings of the various VESs in terms of safety and comfort, the results of all seven statements for every VES were sorted by ascending mean rating. Drivers rated the IR−TIS as the most likely to help them detect and recognize pedestrians sooner. In general, HIDs received better rankings than did HLBs on statements relating to farther detection, effectiveness in lane-keeping assistance, less visual discomfort, and overall perception of safety. A list of all statements and mean ratings for each VES is presented next.

- ***Statement 1:*** This vision enhancement system allowed me to detect objects sooner than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	Mean Rating
IR–TIS	1.33
Hybrid UV–A + HLB	2.20
Five UV–A + HLB	2.38
HID	2.47
HLB	2.50
HLB–LP	3.23

- ***Statement 2:*** This vision enhancement system allowed me to recognize objects sooner than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	Mean Rating
IR–TIS	1.47
Hybrid UV–A + HLB	2.20
Five UV–A + HLB	2.55
HLB	2.57
HID	2.67
HLB–LP	3.23

- ***Statement 3:*** This vision enhancement system helped me to stay on the road (not go over the lines) better than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	Mean Rating
HID	2.47
HLB	2.50
Hybrid UV–A + HLB	2.60
HLB–LP	2.83
IR–TIS	2.93
Five UV–A + HLB	3.00

- ***Statement 4:*** This vision enhancement system allowed me to see which direction the road was heading (i.e., left, right, or straight) beyond my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	Mean Rating
HID	2.30
Hybrid UV–A + HLB	2.60
IR–TIS	2.67
HLB	2.67
Five UV–A + HLB	2.97
HLB–LP	3.00

- ***Statement 5:*** This vision enhancement system did not cause me any more visual discomfort than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	**Mean Rating**
HLB–LP	1.73
HLB	1.77
Hybrid UV–A + HLB	1.97
HID	1.97
Five UV–A + HLB	2.03
IR–TIS	2.33

- ***Statement 6:*** This vision enhancement system makes me feel safer when driving on the roadways at night than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

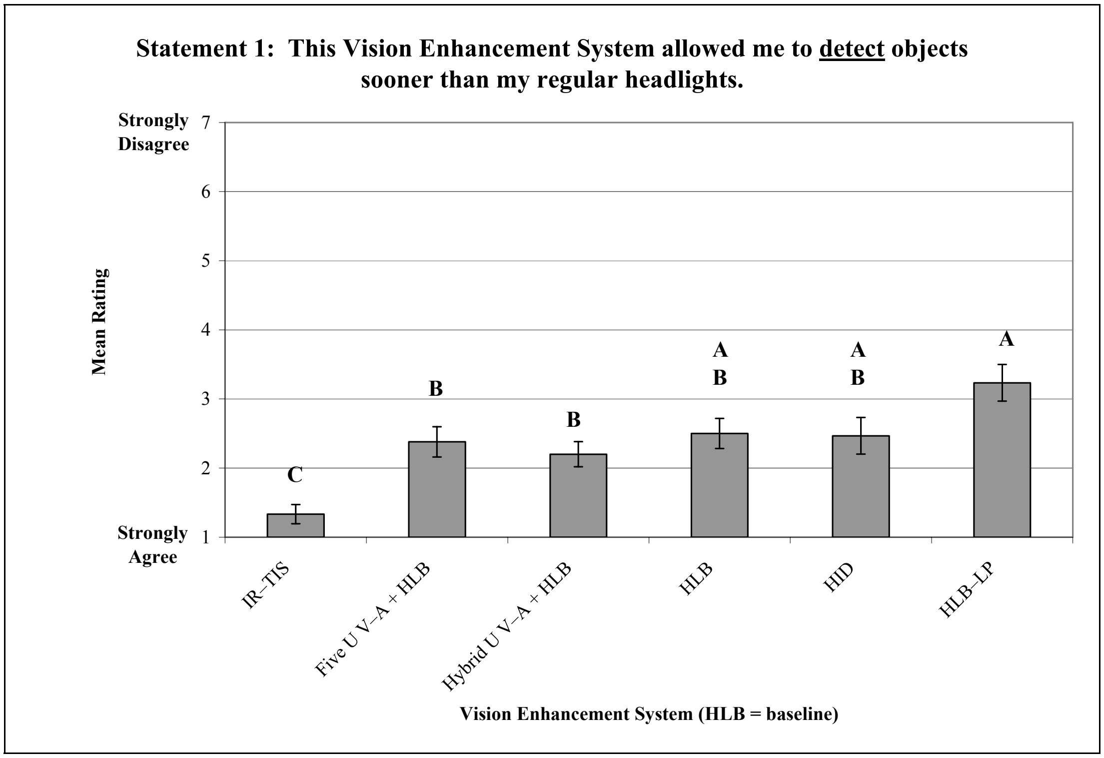
VES	**Mean Rating**
IR–TIS	2.00
Hybrid UV–A + HLB	2.17
HID	2.50
HLB	2.53
Five UV–A + HLB	2.59
HLB–LP	2.73

- ***Statement 7:*** This is a better vision enhancement system than my regular headlights (1 = Strongly Agree; 7 = Strongly Disagree).

VES	**Mean Rating**
IR–TIS	1.53
Hybrid UV–A + HLB	2.10
HID	2.37
HLB	2.40
Five UV–A + HLB	2.48
HLB–LP	2.63

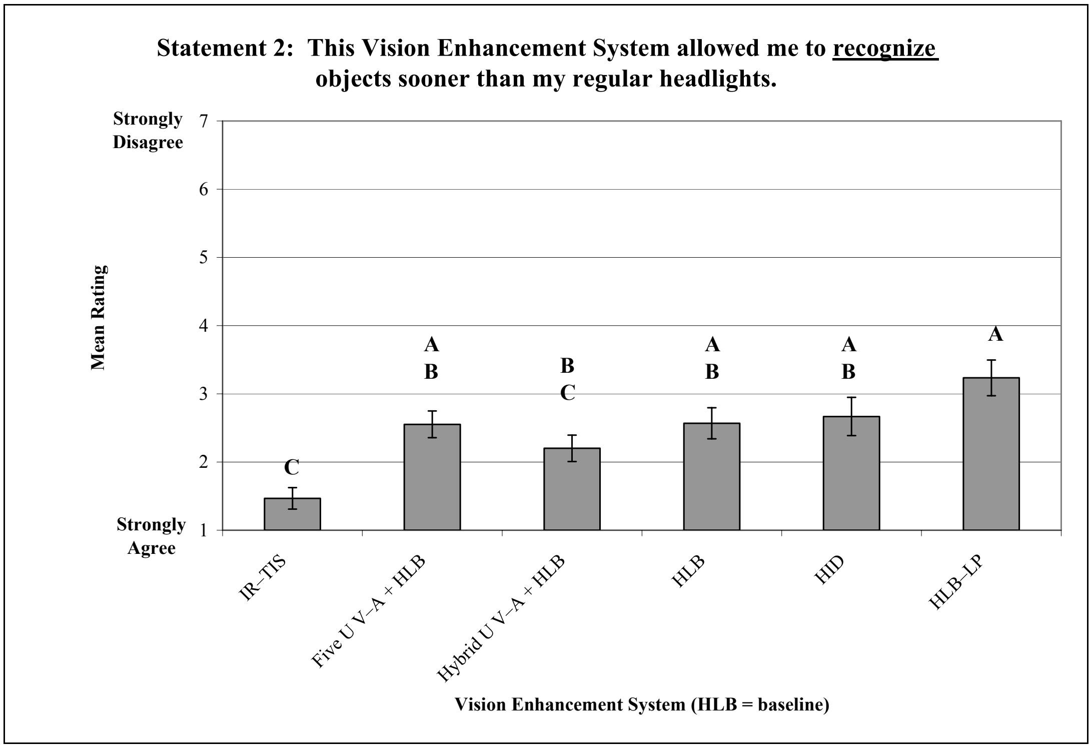
Statistically significant post hoc test results were graphed for ease of interpretation (figure 13 through figure 15). There were no significant differences in terms of age. VES type was significant ($p < 0.05$) for statements 1, 2, and 7. In statement 1, "This vision enhancement system allowed me to detect objects sooner than my regular headlights," a significant difference ($p < 0.05$) was observed between the IR–TIS configuration and all other configurations. IR–TIS received a mean rating of 1.33 (i.e., "Strongly Agree"), while the HLB baseline received a mean rating of 2.50 (figure 13). HLB and HID were not statistically different from the other headlamp configurations or from each other. Statements 2 and 7 show that HLB and HID were not statistically different from the other headlamp configurations or from each other (figure 14 and figure 15). Results for the subjective evaluation of ease of recognition of objects (statement 2) show that the HLB and HID are statistically different from the IR–TIS configuration, where the

IR–TIS has a lower rating (i.e., closer to "Strongly Agree"). The overall subjective evaluation (statement 7) shows no statistical differences among HLB, HID, and IR–TIS.



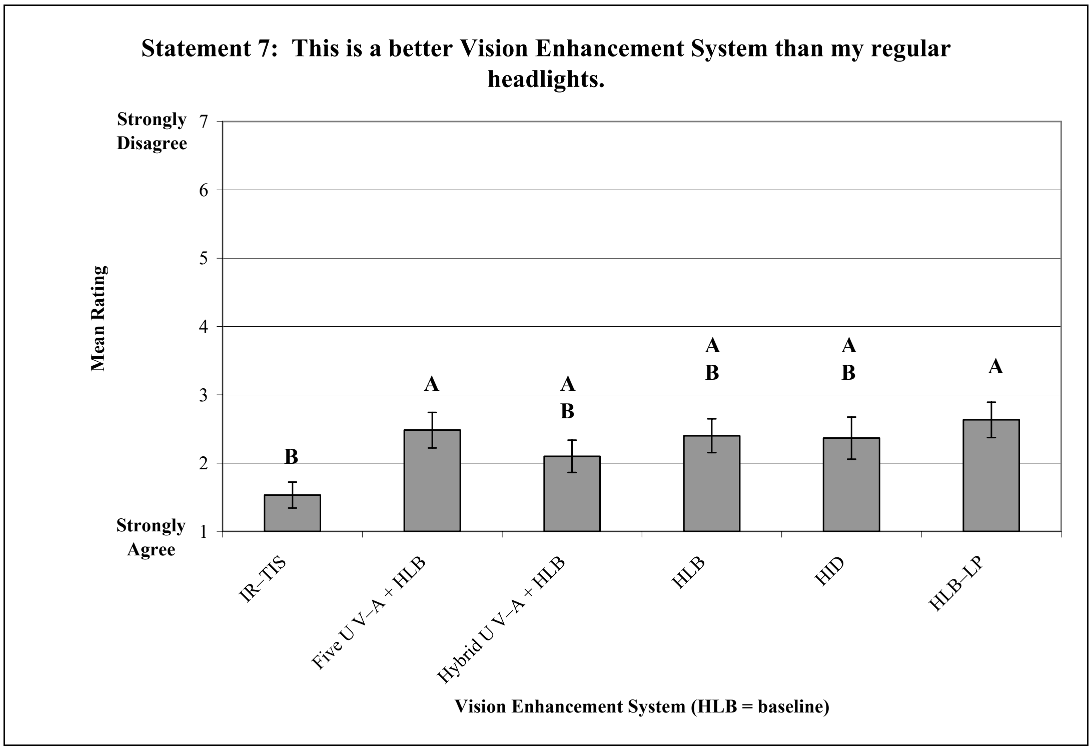
Means with the same letter are not significantly different.

Figure 13. Bar graph. Bonferroni post hoc results on the ratings evaluating detection for the main effect: VES.



Means with the same letter are not significantly different.

Figure 14. Bar graph. Bonferroni post hoc results on the ratings evaluating recognition for the main effect: VES.



Means with the same letter are not significantly different.

Figure 15. Bar graph. Bonferroni post hoc results on the overall rating for the main effect: VES.

CHAPTER 4—DICUSSION AND CONCLUSIONS

VES EFFECTS ON DETECTION AND RECOGNITION DISTANCES

As discussed in ENV Volume III, the literature review suggested that new VES technologies, including HID, configurations supplemented by UV–A headlamps, and IR–TIS, would outperform HLB in the experimental conditions for this study. Although some of these technologies indeed outperformed HLB, even IR–TIS, which had the largest detection distance increase over HLB of 6.7 m (22 ft), was not statistically different. On the other side of the spectrum, the worst-performing VES, HID, fell short of the detection distance for the HLB by about 8.5 m (28 ft). Similar to the other ENV studies where HLB outperformed the HID, the means indicate that HLB provided significantly greater detection and recognition distances than did HID. This result was expected; backscatter impairs the detection and recognition of objects because of decreased dark adaptation and a greater white wall effect, and the HID headlamps had greater backscatter than did the other headlamps in the fog condition. This increase in backscatter for HID was also observed in the baseline estimate from a no-fog condition.

The pedestrian dressed in white crossing the road was selected as the object for this experiment in part because it was the object with the greatest opportunity to perform well with UV–A. UV−A headlamps improved detection and recognition distance of this pedestrian when they were used together with HLB; however, the 6.1-m (20-ft) improvements suggested by this study are not of the magnitude of the ones reported by Mahach et al. and Nitzburg et al., nor are they statistically significant or meaningful for implementation purposes.[19,20]

AGE EFFECTS ON DETECTION AND RECOGNITION DISTANCES

Two previous studies in the ENV project (ENV Volumes IV and V) showed that visibility in adverse weather is severely restricted for all age groups and that there are no significant differences for detection and recognition distances among them. This effect is partially repeated during the fog condition. All age groups showed shorter detection and recognition distances in fog when compared to the detection and recognition distances obtained in the clear condition study (ENV Volume III); however, fog seems to negatively affect detection and recognition even more for the younger group than for the other two groups. It should be noted that the 8.4-m

(27-ft) difference in detection and recognition between younger drivers and older drivers is relatively small. To explain the statistical difference between the two older groups and the younger group, additional data checks were performed. As mentioned previously, the range of fog density was similar for all age groups. In addition, the average travel speed was approximately 14 km/h (9 mi/h) for all age groups, eliminating the possibility of a difference in the time available to detect the pedestrian.

The instances where the pedestrian was not detected were reviewed. It was found that only younger drivers failed to detect the pedestrian crossing the road. Younger drivers missed the pedestrian a total of six times under visibility conditions similar to those of middle-aged and older drivers, who all detected the pedestrian.

Potential outliers (denoted with a circle in figure 16 through figure 18) were also examined. The middle-aged group had two potential outliers, and the older group had one (figure 17 and figure 18). All three cases were reviewed. Speed, fog density, and experimenter notes reflect no abnormalities; therefore, the data points were kept in the original analysis (results reported in this volume). To determine if these three data points caused the significant difference, the full analysis was performed again without them; the same results were obtained. The mean distances for older and middle-aged drivers decreased negligibly by 0.3 m (1 ft) and 0.6 m (2 ft), respectively, not affecting the results previously obtained.

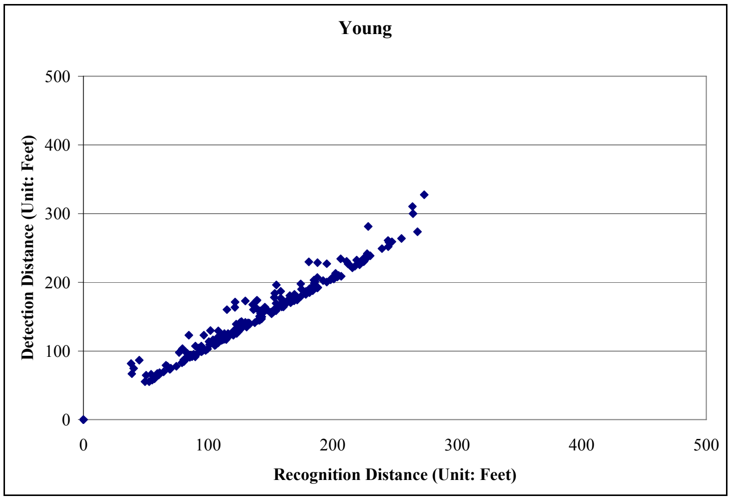


Figure 16. Scatter plot. Young drivers' detection versus recognition distances.

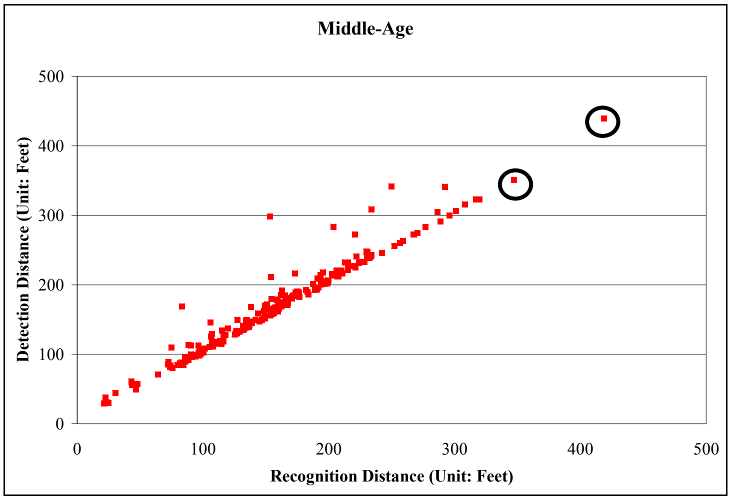


Figure 17. Scatter plot. Middle-aged drivers' detection versus recognition distances.

Figure 18. Scatter plot. Older drivers' detection versus recognition distances.

Participants' vision was also reviewed. The literature suggests that the decline in vision generally begins slowly after 40, followed by an accelerated decline after 60.[5,6,8] The same age-dependent trends of decreased visual acuity and contrast sensitivity mentioned in ENV Volumes III, IV, and V are evident for the participants in this investigation. Figure 19 shows participants' visual acuity, and figure 20 through figure 24 show participants' percentage of contrast for the left eye (PCL) and right eye (PCR) for test lines A through E, which represent 1.5, 3.0, 6.0, 12.0, and 18.0 cycles per degree (cpd), respectively.

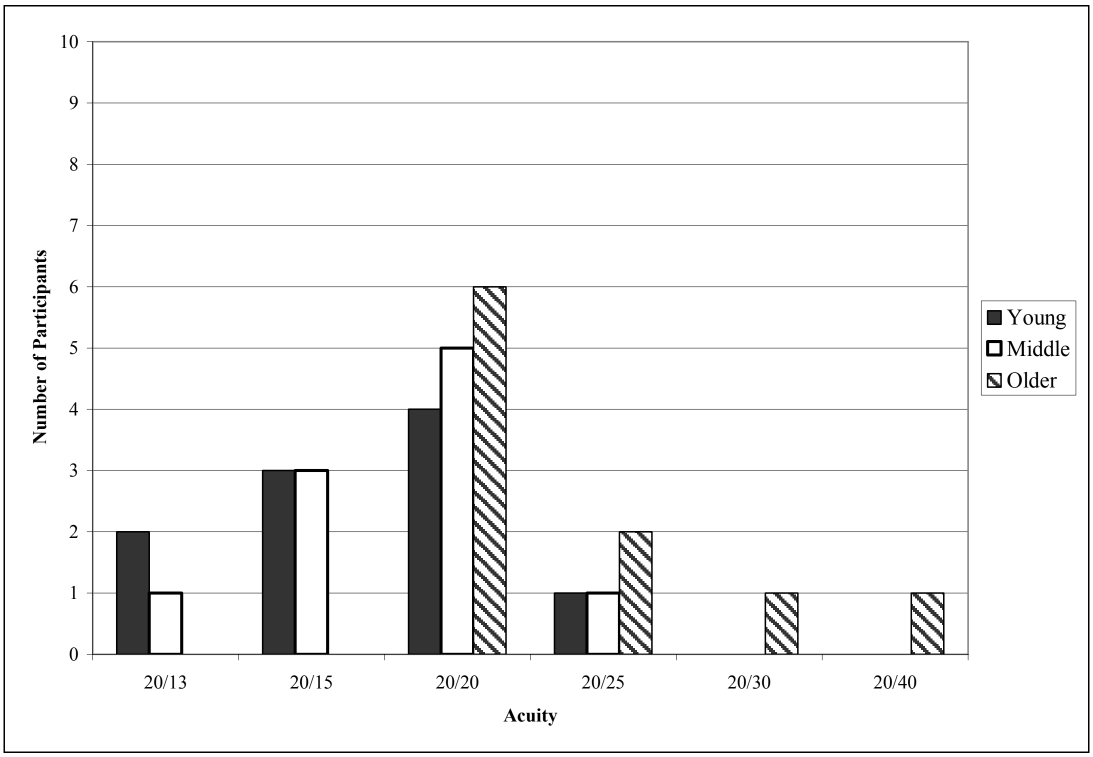


Figure 19. Bar graph. Participants' visual acuity divided by age group.

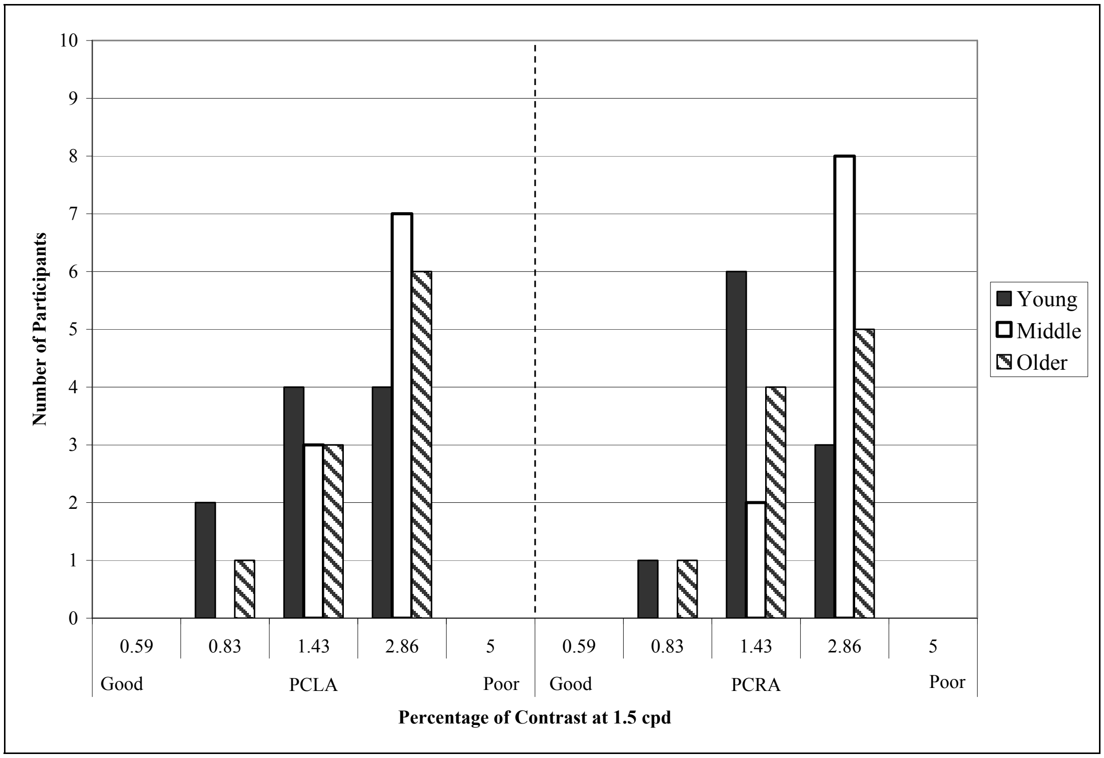


Figure 20. Bar graph. Participants' contrast sensitivity at 1.5 cpd (cycles per degree) divided by age group.

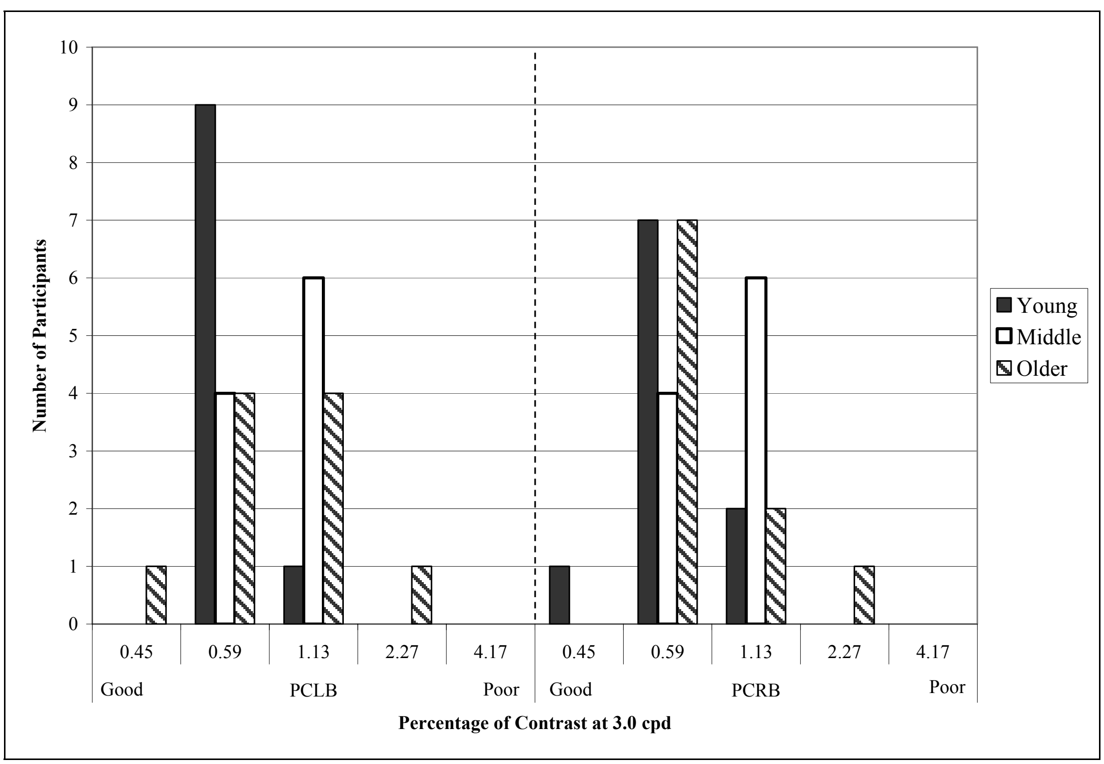


Figure 21. Bar graph. Participants' contrast sensitivity at 3.0 cpd divided by age group.

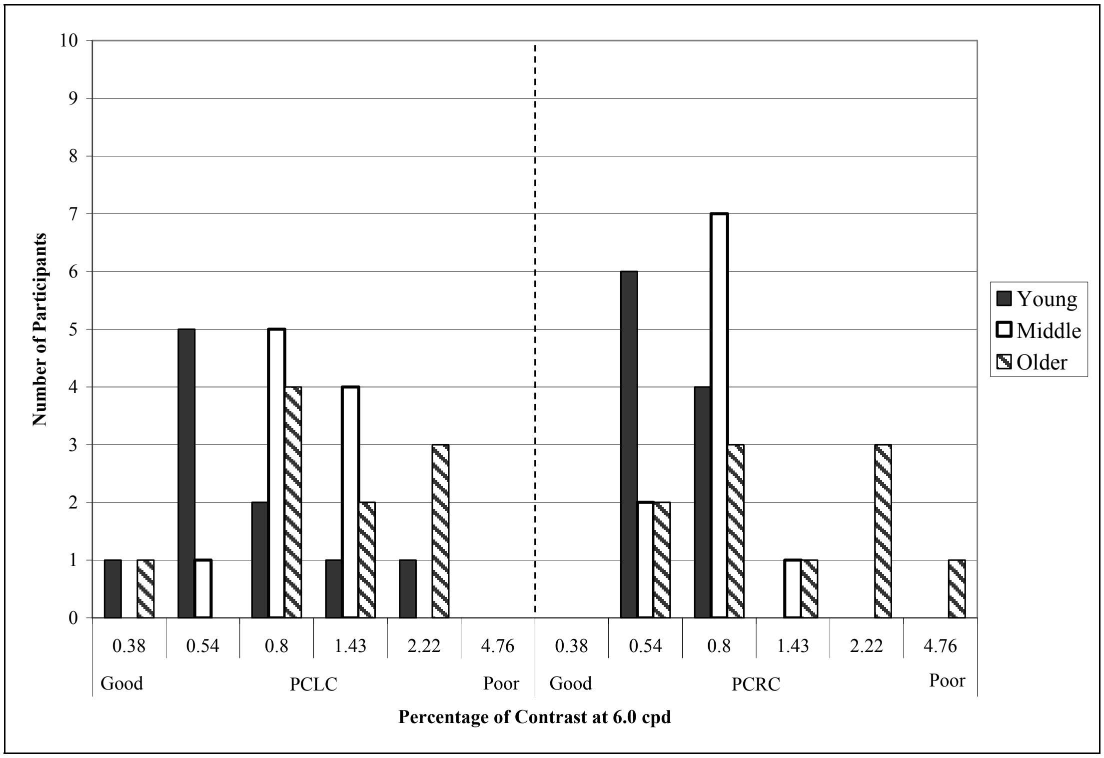


Figure 22. Bar graph. Participants' contrast sensitivity at 6.0 cpd divided by age group.

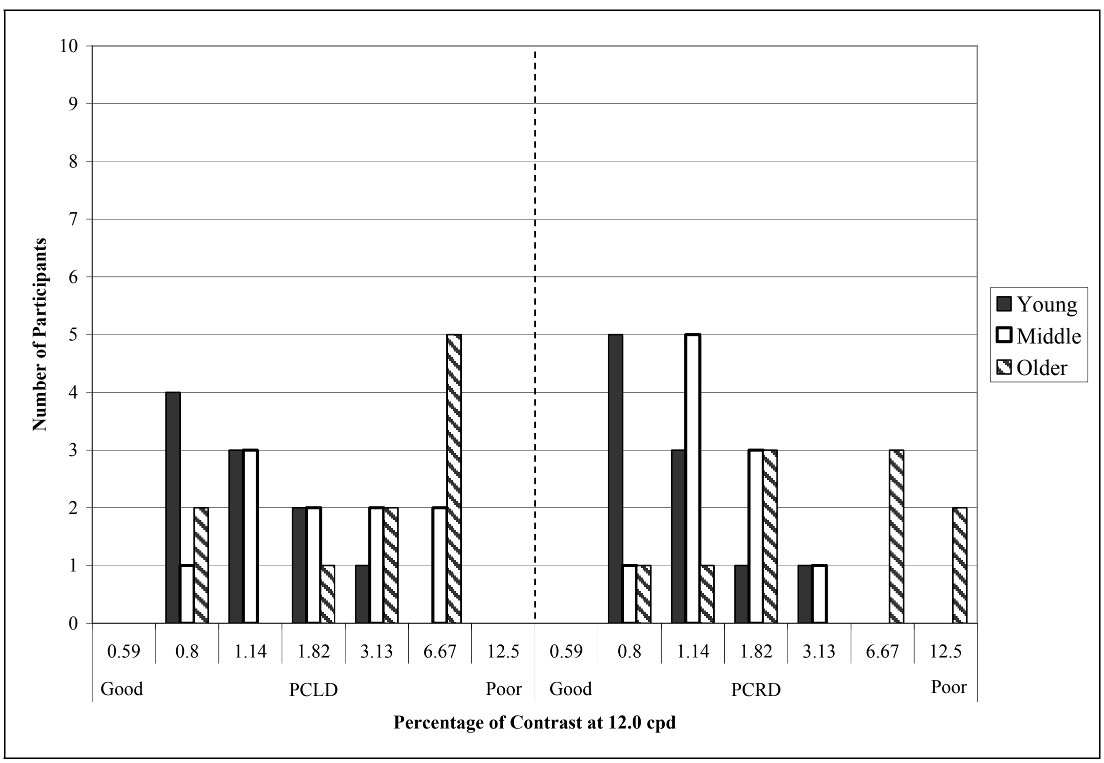


Figure 23. Bar graph. Participants' contrast sensitivity at 12.0 cpd divided by age group.

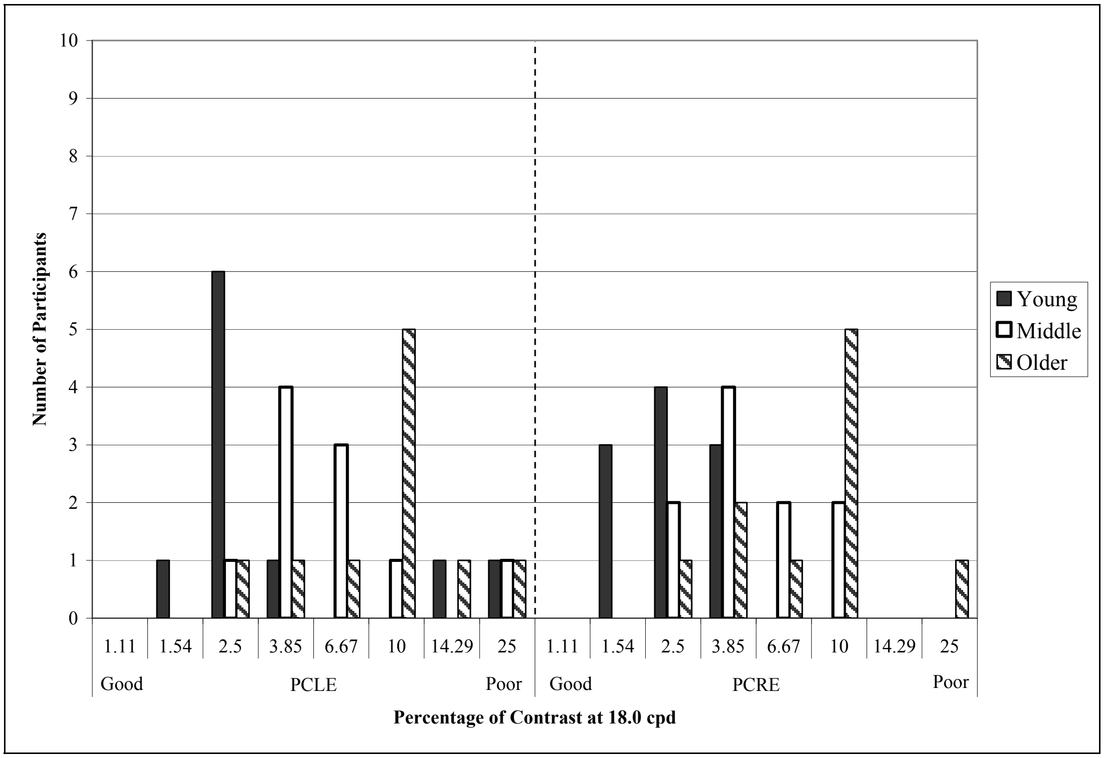


Figure 24. Bar graph. Participants' contrast sensitivity at 18.0 cpd divided by age group.

None of the measurements obtained for this study justify why younger drivers were not able to detect pedestrians as far away as the other two age groups. One potential hypothesis is that young drivers have less experience driving in fog conditions, so they have more difficulties in detecting hazards. Skill acquisition and risk-taking analysis are two potential factors that might help explain this issue.(21) For younger drivers, the skill to detect hazards when their vision capabilities are impaired might not be fully acquired at the stage at which the participants of this study were recruited (mean age for younger drivers was 21 years old). As mentioned, this is a skill, and therefore, it is not dependent on knowledge or physical capabilities. If the younger drivers have not been exposed to fog repeatedly, they might have a more difficult time acquiring that skill. Fog is a weather condition that is not as common as other weather conditions. To put it in perspective, rain occurs in the United States an average of 29 percent of the time during a year, while fog occurs only 6 percent of the time; however, fog's fatality rate is higher, indicating that more problems are encountered during this weather condition.(22) As shown in previous research, experience contributes to effective negotiation of different driving scenarios.(23)

In addition, risk perception of different driving scenarios increases with age.[24] Previous research has shown that older drivers with vision deficiencies tend to unconsciously be more alert of their surroundings. It has been suggested that older drivers compensate for impairments not only by adapting their driving behavior, but also by using the compensatory potential still available to them.[25] Therefore, smaller perceivable cues (e.g., just noticeable changes in contrast) might trigger the awareness of a potential roadway hazard quicker in an older driver than in a younger counterpart when visibility is as restricted as it is in fog. Additional research should be conducted to determine if this age finding is due to experience or an experimental artifact.

VES CAPABILITIES COMPARED ACROSS WEATHER CONDITIONS

When compared to the clear weather condition, fog (producing 0.05 to 0.79 lx of backscatter) severely decreased visibility for all VESs (table 17). Overall, the decrease in detection distance in fog is the largest among all the adverse weather conditions tested. The detection distances of all VESs were reduced by more than 70 percent.

The IR–TIS had the longest detection distance in fog. This was different from the rain condition, where it was severely restricted, and the snow condition, where it was not evaluated because snow covered the lens of the IR camera. The rank order of the VESs in fog by detection distance stayed fairly similar to the clear condition and the other adverse weather conditions (table 17). As suggested in the other adverse weather studies, this result might lead to a hypothesis that the rank order would remain constant under any level of adverse weather. While a definitive finding would require testing at varying levels of fog for different objects, there is nothing in the data to suggest that UV–A augmentation would significantly improve detection or recognition distances under different fog densities.

Table 17. Differences in detection distances between clear, rain, and snow conditions and the fog condition.

VES	Clear Detection (ft)	Rain Detection (ft)	Snow Detection (ft)	Fog Detection (ft)	Detection Difference (Clear − Fog) (ft)	Reduction from Clear to Fog (%)	Detection Difference (Rain − Fog) (ft)	Reduction from Rain to Fog (%)	Detection Difference (Snow − Fog) (ft)	Reduction from Rain to Fog (%)
IR–TIS	686	178	NA	189	497	72	−11	−6	NA	NA
Five UV–A + HLB	625	221	217	187	438	70	34	15	30	14
Hybrid UV–A + HLB	617	210	204	164	453	73	46	22	40	20
HLB	564	198	195	167	397	70	31	16	28	14
HID	506	179	168	139	367	73	40	22	29	17
HLB–LP	527	179	NA	144	383	73	35	20	NA	NA

NA = data not available
1 ft = 0.305 m

STOPPING DISTANCES IN FOG

While there were some significant differences in the detection and recognition distances among different VESs during nighttime driving in the fog condition, these differences would result in minimal improvements to driver reaction times for the object tested (pedestrian in white clothing). Table 18 shows the mean detection distances for all the VESs in comparison to the HLB system, which was used as a baseline because of its widespread availability.

Table 18. Mean detection and recognition distances during nighttime driving in fog.

VES	Mean Detection (ft)	Mean Recognition (ft)	Comparison to HLB: Detection (ft)	Comparison to HLB: Recognition (ft)
IR–TIS	189	170	22	13
Five UV–A + HLB	187	176	20	18
Hybrid UV–A + HLB	164	153	−4	−5
HLB	167	158	0	0
HID	139	129	−28	−28
HLB–LP	144	133	−23	−24

1 ft = 0.305 m

These differences in distance can be translated to gains or losses in reaction time (table 19). In previous research, reaction time has been used to evaluate time margins for crash avoidance behavior when encountering obstacles in the driving path.[26] Significant differences between the HLB and other VESs were less than 7.6 m (25 ft), which translates to less than 1 additional second of reaction time, even at relatively low speeds (i.e., 40 km/h or 25 mi/h; see table 19). Overall, use of the IR–TIS resulted in a detection improvement over other systems; however, this difference was not statistically significant for most of them. On average, the HID configuration, provided the lowest detection and recognition distances.

Table 19. Difference in reaction time available depending on vehicle speed; based on the difference of detection time from HLB.

VES	Detection Distance Difference (ft)	25 mi/h (s)	35 mi/h (s)	45 mi/h (s)	55 mi/h (s)	65 mi/h (s)
IR–TIS	22	0.6	0.4	0.3	0.3	0.2
Five UV–A + HLB	20	0.6	0.4	0.3	0.3	0.2
Hybrid UV–A + HLB	−4	−0.1	−0.1	−0.1	0.0	0.0
HLB	0	0.0	0.0	0.0	0.0	0.0
HID	−28	−0.8	−0.5	−0.4	−0.3	−0.3
HLB–LP	−23	−0.6	−0.5	−0.4	−0.3	−0.2

1 ft = 0.305 m
1 mi/h = 1.6 km/h

While these distances and reaction times provide an indication of the advantages of one system over another, they fail to describe completely any potential safety benefits or concerns based on VES use; however, with a limited number of assumptions, the VES-specific detection distances in fog can be compared against various speed-dependent stopping distances. Collision avoidance research dealing with different aspects of visibility suggests that time-to-collision is an important parameter in the enhancement of driving safety.(27) For consistency, time-to-collision is presented as "stopping distance" (distance to collision) for direct comparisons to the detection distances from the current study. Stopping distance is the sum of two components: (1) the distance needed for the braking reaction time (BRT) and (2) braking distance (table 20). Braking distance is the distance that a vehicle travels while slowing to a complete stop.(28)

For a vehicle that uniformly decelerates to a stop, the braking distance (d_{BD}) is dependent upon initial velocity (V), gravitational acceleration (g), coefficient of friction (f) between the vehicle tires and the pavement, and the gradient (G) of the road surface, with the gradient measured as a percent of slope. The equation in figure 25 provides the calculation of the braking distance (d_{BD}) under these conditions:

$$d_{BD} = V^2/[2g(f+G)]$$

Figure 25. Equation. Braking distance.

The total stopping distance (d) is the sum of the braking distance (d_{BD}) and the distance traveled during the brake reaction time. The results from driver braking performance studies suggest that the 95th percentile BRT to an unexpected object scenario in open road conditions is about 2.5 s. (See references 29, 30, 31, and 32.) For a vehicle traveling at a uniform velocity, the distance traveled during BRT is the product of the reaction time and the velocity. Assuming a straight, level road with a gradient of zero percent ($G = 0$), the equation for the total stopping distance is as shown in figure 26:

$$d = 2.5V + V^2/2gf$$

Figure 26. Equation. Total stopping distance for brake reaction time plus braking distance.

The equation in figure 26 may be used with either metric or English units, with distance (d) in meters or feet, velocity (V) in m/s or ft/s, and a value for the acceleration due to gravity (g) of 9.8 m/s^2 or 32.2 ft/s^2.

The American Association of State Highway and Transportation Officials (AASHTO) provides separate equations for stopping distance with metric and English units, in which the acceleration due to gravity (g) and the coefficient of friction (f) are combined into a deceleration rate, and the velocity (V) is in units of km/h or mi/h, respectively.[(29)] The equation in figure 26 was used in this report because it does not require conversion factors and allows for a more direct comparison of the effect of varying the coefficient of friction (f).

To calculate total stopping distance, AASHTO suggests using a deceleration rate (a) of 11.2 ft/s^2 (3.4 m/s^2), resulting in a friction coefficient of 0.35 as seen in the equation in figure 27.[(29)]

$$f = a/g = 11.2\ ft/s^2 / 32.2\ ft/s^2 = 0.35$$

Figure 27. Equation. AASHTO calculation of coefficient of friction for wet pavement.

Depending upon the density and type of fog, the driving surface may be dry or wet. To provide the greatest sensitivity in calculation of the differences between the VESs used in this study, the coefficient of friction used for these calculations is based on Lindeburg data for dry surface conditions.[(33)] The data obtained from Lindeburg is comprehensive in terms of type of surface, tire condition, and speed. A mean value of 0.65 was obtained for the coefficient of friction for dry surfaces (across all dry conditions). To accommodate most types of vehicles' braking capabilities, a conservative approach was taken for the calculations, and 0.60 was used as the coefficient of friction. Using this approach, stopping distances were calculated as shown in table 20.

Table 20. Stopping distances needed for a dry roadway.

	25 mi/h	35 mi/h	45 mi/h	55 mi/h	65 mi/h	70 mi/h
Speed (ft/s)	37	51	66	81	95	103
BRT in terms of Distance (ft)	92	128	165	202	238	257
Braking Distance (ft)	35	68	113	168	235	273
Stopping Distance (ft)	**126**	**197**	**278**	**370**	**474**	**529**

1 ft = 0.305 m
1 mi = 1.6 km

The previous calculations represent a simple and ideal condition, but it allows for some visualization of the VESs' capabilities. Based on these calculations, the average detection distances for all VESs, with the exception of HID and HLB–LP, provide enough time for the driver to react and brake at speeds of up to approximately 40 km/h (25 mi/h) for a pedestrian crossing the street dressed in white clothing (table 21; in this table, an "X" means the stopping distance might be compromised). Above 40 km/h (25 mi/h), the stopping distances might be compromised for all the evaluated VESs; however, some caveats apply. First, these distances were obtained while drivers were moving at approximately 16 km/h (10 mi/h), and their ability to detect objects will not necessarily remain the same as speed increases. Second, VESs that are currently close to the stopping distance or that need a longer stopping distance might quickly become less effective when conditions worsen (e.g., wet pavement, worn tires, down hill condition, different object than the one tested).

Table 21. Detection distances of white-clothed perpendicular pedestrian and potential detection inadequacy when compared to stopping distance at various speeds.

VES	Detection (ft)	151 ft at 25 mi/h	245 ft at 35 mi/h	358 ft at 45 mi/h	490 ft at 55 mi/h	642 ft at 65 mi/h	724 ft at 70 mi/h
IR–TIS	189		X	X	X	X	X
Five UV–A + HLB	187		X	X	X	X	X
Hybrid UV–A + HLB	164		X	X	X	X	X
HLB	167		X	X	X	X	X
HID	139	X	X	X	X	X	X
HLB–LP	144	X	X	X	X	X	X

X = stopping distance might be compromised
1 ft = 0.305 m
1 mi/h =1.6 km/h

SUMMARY

Most of the findings for the fog condition are consistent with the findings obtained for the clear condition (ENV Volume III). The following conclusions can be made regarding the VESs tested during the fog condition:

- IR–TIS is the best configuration for detecting pedestrians based on objective and subjective results.
- Halogen headlamps supplemented with UV–A is a better configuration for pedestrian detection than the halogen and HID headlamps alone.
- UV–A technology does not represent a dramatic improvement over the halogen and HID headlamps used in this research.
- The HLB showed the least degradation in object detection when compared to the results of the clear condition study (ENV Volume III).
- For the VESs evaluated, the fog condition resulted in reductions in detection distances ranging from 70 to 73 percent of the detection distances obtained under clear conditions.
- With the exception of the IR–TIS, the fog condition resulted in the shortest detection distances for all of the VES configurations tested under the various weather conditions (clear, rain, snow, and fog).

APPENDIX A—SCREENING QUESTIONNAIRE

Driver Screening and Demographic Questionnaire: ENV-Fog

Note to Screening Personnel:

Initial contact with the potential participants will take place over the phone. Read the following Introductory Statement, followed by the questionnaire (if they agree to participate). Regardless of how contact is made, this questionnaire must be administered before a decision is made regarding suitability for this study.

Introductory Statement (Use the following script in italics as a guideline in the screening interview):

Good morning/afternoon! My name is _____ and I work at the Smart Road. I'm recruiting drivers for a study to evaluate new night vision enhancement systems for vehicles.

This study will involve you driving different vehicles on the Smart Road at night. The Smart Road is a test facility equipped with advanced data recording systems here in Blacksburg, VA. It is equipped with technology that will allow us to create snow, fog, and rain. You will be driving in man-made fog. The session will take approximately 4 hours. We will pay you $20 per hour. The total amount will be given to you at the end of the night. Would you like to participate in this study?

If they agree:

Next, I would like to ask you several questions to see if you are eligible to participate.

If they do not agree:

Thanks for your time.
****

Questions

1. Do you have a valid driver's license?
   Yes _____ No _____

2. How often do you drive each week?
   Every day ____ At least 2 times a week____ Less than 2 times a week_____

3. How old are you? ______

4. Have you previously participated in any experiments at the [contractor facility]? If so, can you briefly describe the study?
   Yes _____ Description:____
   No _____

5. How long have you held your drivers' license? ____________________________________

6. What type of vehicle do you currently drive? _____________________________________

7. Are you able to drive an automatic transmission without assistive devices or special equipment?
Yes _____ No _____

8. Have you had any moving violations in the past 3 years? If so, please explain.
Yes _____ ____
No _____

9. Have you been involved in any accidents within the past 3 years? If so, please explain.
Yes _____ ____
No _____

10. Do you have a history of any of the following? If yes, please explain.

Heart condition	No____	Yes________________________________
Heart attack	No____	Yes________________________________
Stroke	No____	Yes________________________________
Brain tumor	No____	Yes________________________________
Head injury	No____	Yes________________________________
Epileptic seizures	No____	Yes________________________________
Respiratory disorders	No____	Yes________________________________
Motion sickness	No____	Yes________________________________
Inner ear problems	No____	Yes________________________________
Dizziness, vertigo, or other balance problems	No____	Yes________________________________
Diabetes	No____	Yes________________________________
Migraine, tension headaches	No____	Yes________________________________

11. Have you ever had radial keratotomy, [laser eye surgery], or other eye surgeries? If so, please specify.
Yes _____ ____
No _____

12. (Females only, of course) Are you currently pregnant?
Yes _____ No _____

13. Are you currently taking any medications on a regular basis? If yes, please list them.
Yes _____ ____
No _____

14. Do you have normal or corrected to normal hearing and vision? If no, please explain.
Yes _____
No _____ ____

I would like to confirm your full name, phone number(s) (home/work) where you can be reached, hours/days when it's best to reach you, and preferred days to participate.

Name ____ Male / Female

Phone Numbers (Home)__________________________(Work)__________________________

Best Time to Call ____

Best Days to Participate_____________________
****

Criteria For Participation:

1. Must hold a valid driver's license.
2. Must be 18-25, 40-50, or 65+ years of age.
3. Must drive at least two times a week.
4. Must have normal (or corrected to normal) hearing and vision.
5. Must be able to drive an automatic transmission without special equipment.
6. Must not have more than two driving violations in the past 3 years.
7. Must not have caused an injurious accident in the past 2 years.
8. Cannot have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures within 12 months, respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.
9. Must not be pregnant.
10. Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).
11. No history of radial keratotomy, [laser] eye surgery, or any other ophthalmic surgeries.

****

Accepted: ________ Days that will attend study: (T):_________(N1):_________

Rejected: ________ Reason:____

Screening Personnel (print name):_______________________ (Date):________

APPENDIX B—INFORMED CONSENT FORM

[Contractor Facility]
Informed Consent for Participants of Investigative Projects

Title of Project: Detection and Recognition of Nonmotorists, Objects, and Traffic Control Devices under Various Weather Conditions and Different Vision Enhancement Systems

Investigators: ________________________________

THE PURPOSE OF THIS RESEARCH/PROJECT

THE PURPOSE OF THE PROJECT IS TO DETERMINE THE DEGREE OF ENHANCED VISIBILITY OF THE ROADWAY ENVIRONMENT WITH VARIOUS TYPES OF VISION ENHANCEMENT SYSTEMS WHILE DRIVING AT NIGHT.

I. PROCEDURES

Show a current valid driver's license.
Read and sign this Informed Consent Form (if you agree to participate).
Participate in three vision tests.
Perform one or more of the following portions of the study (you will be performing the studies that are marked with a checkmark):

- ❑ Study 1: Drive a vehicle on the Smart Road at no more than 25 miles per hour and report when you see the first and the last pavement markings on a given portion of the road.

- ❑ Study 2: Drive a vehicle on the Smart Road at no more than 25 miles per hour and evaluate the level of discomfort caused by glare from headlamps of vehicles coming in the opposite direction.

- ❑ Study 3: Drive a vehicle along the Smart Road at no more than 10 miles per hour and respond when you see objects in and along the roadway.

II. RISKS

The primary risks that you may come into contact with are the obstacles on the road for the study or sliding on the roadway during the "Rain" or "Snow" conditions (if this applies to the study that you will be performing). It is for this reason that you are to maintain a speed of not more than 10 miles per hour and to maintain a 50-foot area between the vehicle and the obstacles (only applies to Study 3). For your safety, the following precautions are taken:

- The Smart Road is equipped with guardrails in the All-Weather Testing section. Therefore, if you do lose control of the vehicle, the guardrails will prevent you from sliding off the road.

- You are required to wear a seatbelt at all times in the vehicle, and the vehicle is equipped with antilock brakes.

- You do not have any medical condition that would put you at a greater risk, including but not restricted to heart conditions, head injuries, epilepsy, and balance disorders.

- In addition, you have not had radial keratotomy, (laser) eye surgery, or any other ophthalmic surgeries.

- The only other risk that your may be exposed to is fatigue after sitting in the driver's seat for a prolonged period of time. However, if you would like to take a break at any time, please inform the experimenter.

III. BENEFITS OF THIS PROJECT

While there are no direct benefits to you from this research (other than payment), you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Your participation will help to improve the body of knowledge regarding various vision enhancement systems.

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this experiment will be treated with confidentiality. Shortly after you have participated, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 3). After the experiment, the data will be kept in a locked safe.

V. COMPENSATION

You will be paid $20 per hour for participating in this study. You will be paid in cash at the end of your voluntary participation in this study.

VI. FREEDOM TO WITHDRAW

As a participant in this research, you are free to withdraw at any time without penalty. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

VII. APPROVAL OF RESEARCH

Before data can be collected, the research must be approved, as required, by the (name of review board). You should know that this approval has been obtained.

VIII. SUBJECT'S RESPONSIBILITIES

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.

2. To inform the experimenter if you incur difficulties of any type.

3. Wear your seatbelt.

4. Abide by the 10 miles per hour speed limit.

IX. SUBJECT'S PERMISSION

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Signature   Date

Should I have any questions about this research or its conduct, I may contact:

(Names of researchers and review board)   (Phone number)

APPENDIX C—VISION TEST FORM

PARTICIPANT NUMBER: __________

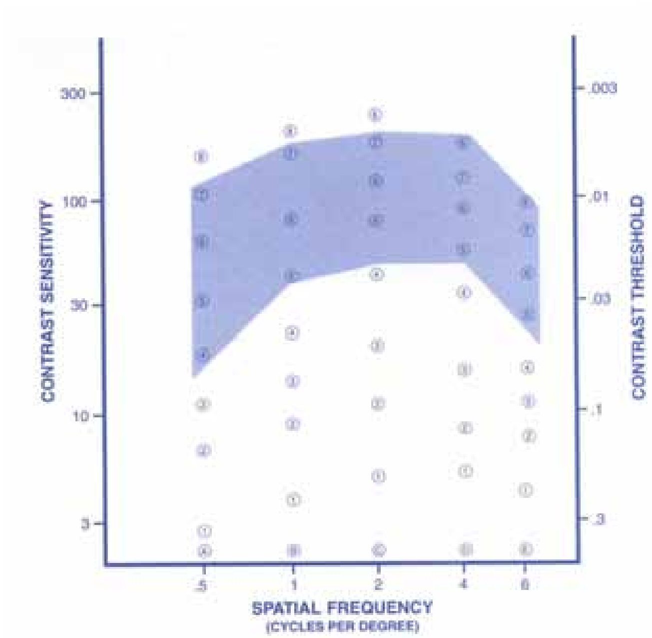
VISION TESTS

Acuity Test

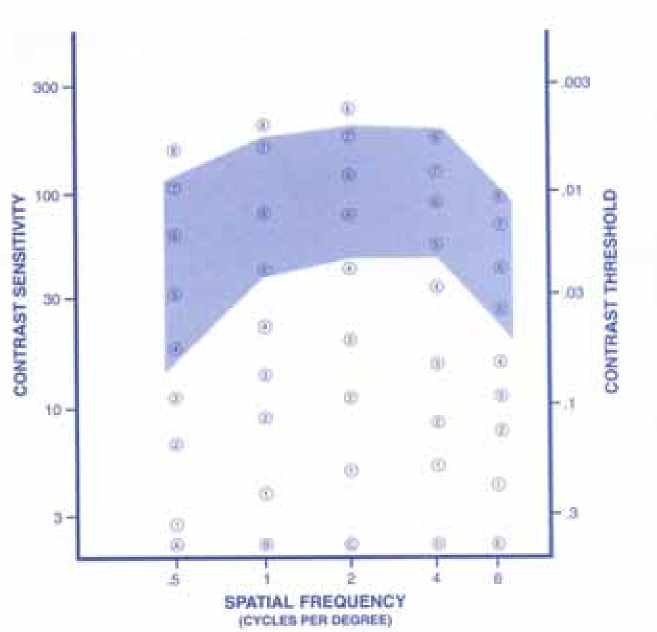
- Acuity Score:_________

Contrast Sensitivity Test

Left



Right



Ishihara Test for Color Blindness

1._____ 4._____ 7.____

2._____ 5._____

3._____ 6._____

APPENDIX D—TRAINING PROTOCOL

Protocol for ENV-Objects

Front Seat Experimenters—Training

1. Prior to the participant's arrival, make sure that all the needed forms are available.

2. Set up the conference room.
   - Close all the shades.
   - Turn on all overhead lights.
   - Turn off halogen lamps.
   - Position work light for vision contrast by placing it within the tape on the floor. Get color vision test, eye occluder, alcohol, and cotton balls.

3. Greet participant.

4. Record the time that the participant arrived on the debriefing form.

5. Ask to see driver's license.
   - Must be a valid Class A driver's license to proceed with the study. Out of state is fine.

Experimenter reads all text in italics aloud to each participant.

This research is sponsored by the Federal Highway Administration. The purpose is to gather information that will be available to the public, including car manufacturers. The goal is to determine the best vision enhancement systems to help drivers see objects and pavement markings at night.

This study will involve you driving different vehicles on the Smart Road, after you have completed a training session. We will pay you $20 per hour at the end of the evening.

The study will take place on the Smart Road testing facility. The road will be closed off to all traffic except for experimental vehicles. There will be at most two experimental vehicles on the road at one time including the vehicle you will be in.

During the study, two experimenters will be in the vehicle with you at all times. The front seat experimenter will be responsible for asking you questions during the drive, recording some data, and monitoring the equipment. In addition, he or she will be able to answer any questions you have. You will be exposed to six different vision enhancement systems. You will make one lap on the Smart Road for each vision enhancement system. On these laps you will be exposed to several objects. Your job will be to tell me when you are able to detect the object, and when you are able to recognize what the object is.

Do you have any questions at this time?
(Answer questions if needed).

6. Informed consent.
    - Give the participant the form-encourage them to read it.
    - Answer questions.
    - Have participant sign and date both forms.
    - Give the participant a copy of the informed consent.

7. Tax Forms.
    - To complete the W-9, the participant must fill out the following in the box:
        - Name,
        - Address,
        - Tax ID number (social security number),
        - Sign and date at the bottom.

The other side of the form is a University Voucher stating they are not being "permanently" employed by our project. Have them print their name on the top of the form.

8. Vision tests.

Follow me and I will go through the vision tests with you.

The results for all three parts must be recorded on the Vision Test Form.

The first test is the Snellen eye chart test.

- Take the participant over to the eye chart test area.
- Line up their toes to the line on the floor (20 feet).
- Participants can leave on their glasses if they wear them for driving.

Procedure*: Look at the wall and read aloud the smallest line you can comfortably read.*
- If the participant gets every letter on the first line they try correct have them try the next smaller line. Continue until they miss a letter. At that time, record the one that they were able to read in full (line above).
- If they get the first line they attempt incorrect, have them read the previous line. Repeat as needed until they get one line completely correct. Record this acuity.
- Participant must have 20/40 or better vision using both eyes to participate in the study.

The next vision test is the Contrast Sensitivity test. Take the participant over to the eye chart test area.

- Line up their toes to the line on the floor (10 feet).
- Participants can leave on their glasses if they wear them for driving.

Procedure: *We are going to test how well you see bars at different levels of contrast. Your ability to see these bars relates to how well you see everyday objects. It is VERY IMPORTANT you do not squint or lean forward while you are taking the test.*

- Point out the sample patches at the bottom of the chart with the three possible responses (left, right, or straight).
- Cover one eye with an occluder. (DO NOT let the participant use his/her hand to cover the eye since pressure on the eye may cause erroneous contrast sensitivity test results).
- Instruct the participant to begin with Row A and look across from left to right. Ask the participant to identify the last patch in which lines can be seen and tell you which direction they tilt. If the response is incorrect, have the participant describe the preceding patch.
- Use the table in the ENV binder to determine if subjects' answers are correct.
- Each vertical column of numbers on the second part of the Vision Test form corresponds to a horizontal row on the chart. Record the last patch the participant correctly identifies in each row by marking the corresponding dot on the form.
- To form the participant's contrast sensitivity curve, connect the points marked.
- Cover the other eye and repeat all the steps above.

The last vision test is the Test for Color Blindness.

Procedure:

- Take the participant back to his/her desk.
- Place the book containing the plates on the testing apparatus.

Please hold the red end of this handle to your nose and read the number on the following plates.

- Record the participants answers on the Vision Tests Form.

9. ENV Training.

After the eye tests, have the participant sit at the table. Explain the following:

The following presentation will provide instructions, definitions, and examples of the objects we will be using. You can ask me questions at any time. There will be some pages I will place extra emphasis on. Any questions before we begin the presentation?

Answer questions as needed. Once there are no more questions, begin the instructions. Stress the following points:

- Definition of **detection** versus **recognition**.
- Stress safety (i.e. 10 mph, drive safely, etc).
- Again, answer questions.

Slide 1: *This study is called Enhanced Night Visibility given that its purpose is to evaluate Vision Enhancement Systems. Tonight I will be one of the experimenters that will be riding with you.*
Slide 2: *This is a timeline of how the night will break down. We are in the Laboratory Training portion right now. Once we are done with the lab training we will familiarize you with the Thermal Imaging System and the procedure for the experiment.*

Slide 3: *The enhanced night visibility project is an extensive research project to determine what vision enhancement system configuration will best help people see objects on the road at night.*

We needed people to give us information on visibility and preference of the different vision enhancement systems. That is why you were asked to come here tonight. The information you give us will be compiled with other people's data so we can determine the best configuration.

We will be using four different vehicles on the road. One car with a Thermal Imaging System, and three sport utility vehicles. You will be performing the study in the "fog" condition.

Slide 4: *We are going through this training to make you more comfortable with the study before we begin driving. We will cover the items mentioned on this slide. I want to stress that if you have any questions, please stop and ask at any time.*

Slide 5: *The Smart Road is perfect for testing of this type. It is completely closed off, making it safe for both drivers and experimenters.*

Slide 6: *This is a picture of part of the Smart Road during daytime.*

Slide 7: *You will drive a total of four vehicles tonight. Each vehicle might include more than one configuration of Vision Enhancement Systems for a total of 6 different configurations. Five of those configurations are headlamps and the 6th configuration is an Infrared-Thermal Imaging System. This last one is a Heads Up Display positioned over the steering wheel. You will have the opportunity to practice with this system tonight.*

Slide 8: *Your primary responsibility is to drive safely. We are also interested in how far away drivers can detect and recognize objects along the road with these Vision Enhancement Systems. We will explain what we mean by detection and recognition shortly. However, I would like to show you this.*

Show them the button

I will ask you to hold a button like this during the study in your hand while driving. You will press the button like this.

Press the button

When you press this in the car, you will hear a beep.

Slide 9: *Detection is when you can just tell that something is on the road in front of you. You cannot tell what the object is but you know something is there. Detection is important while driving since it prepares you to possibly make an evasive action.*
As soon as you detect an object, please press the push button.

Slide 10: *Recognition is when you not only know something is there but you also know what it is. This is important to help you decide how best to avoid the object. For instance, if you see an* *object in the road and then realize it is a dog, you know that the object can move unpredictably and you need to slow down greatly and likely swerve to avoid it. If however you see an object and it is a box you know the object is not likely to move and slowing down a little and swerving will likely be sufficient.*

When you can accurately recognize an object, I would like you to press the push button and identify the object verbally at the same time. You will need to be specific when you identify. If you see an object, you will need to tell me what the object is.

For example,
"I see a Person"
"I see a Cyclist"

If you perform an Unsuccessful Recognition, you can press the push button again.

Slide 11: *Dynamic objects include pedestrians and cyclists. The pedestrians will be people walking either along the road or across the road; the cyclists will be riding a bicycle across the road. We will see pictures of these objects shortly.*

Slide 12: *Here are pictures of the objects. They will not look exactly like this in the road since these were taken during the day. However, this should give you a good idea of what they will look like.*

Slide 13: *We will also have some questions for you to answer. As soon as you are done with a Vision Enhancement System, you will evaluate it. Therefore, after you see the objects with each VES, I will ask you this series of questions (*show questionnaire*). We want you to rank your answer on a scale from 1 to 7. One means you strongly agree with the statement. Seven means you strongly disagree with the statement. You can give me any number between one and seven. Your answers may or may not be different for each VES, we just want your opinion on the one you just saw.*

*Here is the questionnaire that you will be answering for each VES. Let's go over each of the statements. Please, feel free to stop me at anytime, and ask as many questions as you want. (*Read and explain each statement.*)*

Slide 14: Go over main points.

Slide 15: *Do you have any questions?*
Answer any questions.

Shortly we will have you drive one of the experimental vehicles to help familiarize you with the Thermal Imaging System. This uses a heads up display that is projected onto the windshield just below your field of view. The Thermal Imaging System is not intended to be used alone instead it is supposed to accompany your normal driving. Be sure to view the road as your normally do while also using the heads up display.

Show them diagram.

This is a diagram of the course for tonight's training.

While reading the following section, point out the path that the participant is supposed to follow for the training.

First drive to the road section. The speed limit for this portion is 25 mph. On this section you will be able to see how things like pavement markings show up in the heads up display. At the turnaround of the road section you need to pull to the far right-hand side of the shoulder and stop the car just past the cone. Then turn the steering wheel fully to the left before beginning the U-turn. Be sure to look for traffic approaching from both directions.

We will now proceed to the gravel lot. When entering the gravel lot, between the two cones, watch for traffic coming from the right. Once on the gravel lot the speed limit is 15 mph. You will then drive through two more cones driving parallel to the white line on your left. Here you will see one of the objects involved in the experiment and how it appears in the heads up display. Then make a U-turn around the cone at the end of the white line and leave the gravel lot and proceed to the road section.

You will repeat this process seeing different object two more times. This will conclude the training for today.

Any questions?

10. Take the participant to the IR–TIS vehicle. Orient them to the vehicle.
    - You need to have them start the vehicle before orienting them because the seat and wheel move when you start it. Be sure to warn the participants of that before you start the car.
    - Button on left side of seat moves seat up and down, back and forth (show button).
    - Button for the steering wheel moves the wheel up and down, in and out.
    - There are many lights. The only ones they need to worry about are the speedometers-analog and digital (point each out). The subject is free to use whichever they feel most comfortable with.
    - Turn on the headlights all the way (two clicks). Make sure they are on before you get in the passenger seat.
    - Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.

11. Turn on the HUD and adjust brightness.
    - There are two controls used to power and adjust the HUD, located to the left of the steering wheel and under the dash board. The right control, an up/down sliding switch, is used to power the display. The display is powered "on" when the sliding switch is pulled into the top position and is powered "off" when the sliding switch is pushed down into the lowest position. The position of this sliding switch will change the brightness of the HUD.

12. Adjust position of the HUD.

- The left control is used to adjust the vertical position of the display. Press the top or bottom of the switch to move the display up or down in the driver's field of view, but make sure that the driver can see the display over the top of the steering wheel.

13. Describe the HUD to the driver.

The thermal imaging system is composed of infrared technology that "lights up" the road ahead. The idea is to provide the driver with an enhanced view of the roadway ahead when traveling at night. In this vehicle, in addition to your normal tasks of detecting and recognizing, we will ask you to tell us whether your recognition was made using the IR system or through the windshield using only the headlights. For example, you may make a detection (I see something), and when you are able to recognize the object (I see a person) include 'using the IR system' or 'using the headlights' at the end of the statement (i.e. 'I see a person using the IR system'). This additional task will only occur in this vehicle when the IR system is in use.

14. Instruct/assist the driver through 3 laps of the training course.
    - Ask driver periodically to describe what they can see using the HUD.

15. Take Eye Height Measurements on all vehicles that are available.
    - To do this, first explain to the participant that you are going to make a mark on the window as to where their eye level is located. Instruct them to adjust their seat to where they think they will be comfortable. Once they are situated, tell them to look ahead, relax, and stay as still as possible. Close the door and take the measurements.
    - Use the level (located in valet box) to assess participant's eye position. Once you have found their eye position mark a "+" on the glass (using a dry-erase marker).
    - Using the "+" as a reference point, take measurements (horizontal and vertical).
    - Take vertical measurement with metal end of tape measure down where the glass intersects with the black plastic.
    - Take horizontal measurement with metal end of tape measure to the right where glass intersects with black plastic.

APPENDIX E—TRAINING SLIDES

Enhanced Night Visibility

Schedule and Training

Experimenters:

Schedule

Training

- Driver's License Verification
- Informed Consent
- Forms and Questionnaires
- Vision Tests
- Laboratory Training
- In-vehicle Familiarization

What is the Enhanced Night Visibility study?

- What is enhanced night visibility?
- Why is your help important?
- Vehicles:
  - Car
  - SUV
- Scenario:
  - Smart Road test facility
  - Nighttime
  - Weather: Clear, Rain, Snow, or Fog

Lab Training

- This training will help orient you to:
  - the Thermal Imaging System
  - the definition of terms we will use
  - the procedures
  - the objects
  - what we will ask from you

The Smart Road

- For this research effort, you will be driving on the Smart Road test facility.
- The Smart Road will be closed off to all traffic other than research vehicles. As a result, there will be at most two vehicles moving on the road, including the one you are driving.

The Smart Road

Experimental Vehicles

- Vision Enhancement Systems
  - The Night Vision System
  - Prototype Headlamps

Detection and Recognition

- Your primary task is to drive safely
  - Training; 15 mph in gravel lot, 25 mph on paved road
  - 10 mph on Smart Road
- Your job will be to detect and recognize different objects on the Smart Road
- You will be required to press a button when you both detect and recognize objects

Detection of Objects

- Detection is when you can just tell that something is on the road in front of you.
  - Detection is important while driving in that it prepares you to possibly make an evasive action
- When you detect an object, push the button as soon as you know something is in the road.

Recognition of Objects

- Recognition is when you can say for sure *what* the object is.
  - This provides you with more information so you can adequately react to the object
- When you can recognize the object, you must push the button and, at the same time, identify the object to the experimenter by saying, "I see a _____."
- In case of an Unsuccessful Recognition press the push button again as soon as you notice what the right object is and tell the experimenter.

Types of objects

- Dynamic Objects
  - Pedestrians: People will be walking along side or across the road.
  - Cyclists: People will be riding bicycles across the road.

Dynamic Objects

Pedestrian

Bicyclist

Note that a cyclist and a pedestrian in black clothing were included in the training slides to avoid automatic assumption of object type upon detection.

Questionnaires

- You will be asked to respond to a list of questions after each VES
  - Headlamp configuration questionnaire: You will provide a numbered rating of each headlight on a scale from 1 to 7.
    - Show questionnaires and different rating scales.

What we need from you

- Driving is the primary task, so use safe driving practices
- Maintain the specified speed limit
- Immediately push the button when you **Detect** and/or **Recognize** an object
- Verbally identify all objects as you press the button for the **Recognition** portion
- Respond to the questionnaires
- Ask questions whenever you need to

QUESTIONS?

APPENDIX F—FRONT SEAT EXPERIMENTER'S PROTOCOL

Front Seat Experimenter's Protocol - Fog

Data Collection

Orient participant to the vehicle.
Take participant to the SUV 1 & 2 parked outside the front door.
Check which vehicle they will do their first VES in and have them drive that vehicle if it is available.
Show them how to adjust their seat, interior display lights, the windshield wipers and the steering wheel.
Explain to them how to turn on and off the parking lights.
Make sure they are wearing their seatbelt.
Say,

You will notice that your side and rearview mirrors have been covered. This is to reduce the glare that you might get from other vehicles.

Turn on the baseline (HLB) VES for the drive to the road and practice run. Do NOT turn on the UV lights.
Turn on the power button to the power supply/converter unit. This is the lower of the two units located behind the driver's seat in each vehicle. The On/Off switch is a small switch button. There are several red and green lights located near the On/Off switch, and these lights will cycle on when the unit is switched on. The red lights will go dark if there are no problems on power-up.
Turn the toggle switch on the upper unit ON.
To turn on power to each individual headlamp:
Locate the blue and cream colored On/Off button box (with voltage output display) that controls the individual lights. This box is attached to the power supply/converter in the SUV 1 & 2. Simply depress the appropriate red button corresponding to the desired light. The button will remain in the depressed position and will light up red until depressed a second time to release the button and turn the light off.

Make sure that you are both wearing your seatbelt.
Instruct the driver to drive to the Smart Road.
Radio the control room, ask for the gate to be opened and tell them the number of cars entering the road.
The first vehicle will drive down to T3.
Radio the relay station to let them know that you are driving down.
The second vehicle will park at the entrance of T2 and wait for the relay station to say that they can come down.

Orient participant to Smart Road.

First we will drive down the road to get you used to the road and the vehicle. Go ahead and drive down the road at a comfortable speed (<30mph). It is very *important for your safety, and the safety of the experimenters on the road, that you slow down to 10 mph or slower when we reach the section of road with fog on it.*

Allow the participant to drive down the road.
The second vehicle can begin once they are notified that the first vehicle is at T3.
Remind them of the speed limit if necessary.
Start slowing down as soon as you can see the fog, so you can do a smooth entrance at 10 mph or less.

First vehicle at T3:
Pull all the way to the farthest parking space.
Put the vehicle in park and have the participant take their foot off the brake.
Have the participant turn off the parking lights.
Radio the relay station that the second vehicle can drive down.

Second vehicle at T3:
Pull into the nearest parking space.
Put the vehicle in park and have the participant take their foot off the brake.

Review instructions with participant (This may be done while waiting at T2 or T3 during the practice drive).

Show them the button.

I will need you to hold this in your hand during the study. When you press this you will hear a beep. Once the study begins I need you to press the button as soon as you detect an object.

***Detection** is when you can just tell that something is on the road in front of you. You cannot tell what the object is but you know something is there.*
When you can accurately recognize an object, I would like you to press the push button again and identify the object verbally at the same time.

***Recognition** is when you not only know something is there but you also know what it is.*

You will need to be specific when you recognize. If you see an object, you will need to tell me what the object is.

For example,
"I see a Person" or "I see a cyclist"
If you perform an Unsuccessful Recognition, you can press the push button again and then verbally identify the object.

Hand them the button.

Once both vehicles are at T3 radio the onroad experimenters that you are ready to begin.

Let drivers do a practice run up the Smart Road.

We will now practice while you drive up the hill to help you get used to driving the vehicle on the Smart Road and using the push button. I would like you to drive up the road at 10 miles per hour or less (we don't want the speed dial to go over the 10 mph at any point) .

On the way up we will practice how to detect and recognize objects. You will see 2 objects. Please remember to say:

"I see a person" or "I see a cyclist."

If you perform an Unsuccessful Recognition, you can press the push button again and then verbally identify the object.

Set up the computer at the second turnaround if you haven't already.
Enter in participant number, age, gender, and condition.

It is VERY important that you do not talk to the drivers when you are collecting data. EMERGENCIES EXCLUDED!!!!

Monitor the computer while going up the hill:
Make sure that the value in the "Current Distance" field is increasing. This ensures the program is working.

Perform the following tasks:
Press the computer space bar again when your body is in line with the object. After space bar is pressed, the arrow will scroll down to the next object.

During the practice run, you may need to assist the participant. For example, if they do not indicate the Detection or Recognition points and the object is close to 40 feet, you need to say,

We are very close to the first object please press the push button as soon as you can detect it and then once again when you can recognize it.

Monitor the safety of the pedestrians on the road.
Use the computer program to determine when you are approaching a pedestrian.
Say **"**Station X, Clear" as soon as the participant recognizes the pedestrian.
If driver does not see pedestrian, use the computer read out to determine when the vehicle is within 40 feet of pedestrian. Tell the pedestrian to clear at that time.
Make sure the participant is not driving over 10 mph. They should be driving under 10 mph. This can be verified using the computer read out.

The screen is going to start flashing when the vehicle is 40 feet away from the station. If there is a pedestrian on the station say “Station X, Clear” as soon as the screen starts flashing.
If you forget to press the “Spacebar” the program will go to the next station 50 feet after it passes the station. Please make a note on the error sheet, so the person working with the data can subtract the 50 feet from the station location recorded in the program.

<u>First vehicle at T2:</u>
Pull in to the turnaround and keep to the right hand side of the road. Park at the cone so that you are on the road side of the turnaround, facing up the hill, and parallel to the road.
As soon as the first car reaches the turnaround, they need to let the second vehicle know that they can proceed up.

<u>Second vehicle at T2:</u>
Pull up to the cone on the left hand side of the turnaround.
Wait until the first car is out of sight before you go down the road.

Ask participant questions about the VES.
You may begin to ask the questions when the driver is past the fog, if you are comfortable doing so. If not, wait until they are parked.
Remind subjects of the scale, where 1 is strongly agree, and 7 is strongly disagree.
After station 5 the screen will change to a new screen where the questions for each VES will appear. In order for the first question to appear you can press “s.” If you need to quit at this point to redo some of the tasks press “Shift+Q.”

Document any unexpected events that occurred during the previous run on the “In-Vehicle Notes Sheet”.

Show participant to their next vehicle as per the order sheet.
Ask the participant to leave the vehicle running and make sure it is in park.
Turn off the HID or HLB lights.
Assist driver in getting out of the vehicle if necessary.
Use the stepstools if necessary.
Lead/guide participant from one vehicle to the next-if there are vehicles with lights on, take the participant around the back of the vehicle.
Open the door for the participant and move the seat back before they get in.

Orient participant to next vehicle and turn on the lights.
If they have been in the vehicle before, ask them if they remember the controls. Be sure to offer to answer questions.
See each vehicle’s orientation instructions below.
Be sure to turn on the lights yourself and show them where to turn off the parking lights.
UV lights need to be turned on as soon as you get in the vehicle to give them time to warm up, prior to data collection.
Explain to the participant where the dimmer switch is.
Remind the participant to keep their seatbelt on at all times.
Ask them if they have any questions.

SUVs
Button on left side of seat moves seat up and down, back and forth (show button).
Lever on steering column moves the wheel up and down.
Hand the participant the keys and have them start the car (if not on).
Turn on the parking lights (one click only).
Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.

Sedan
You need to have them start the vehicle before orienting them because the seat and wheel move when you start it. Be sure to warn the participants of that before you start the car.
Button on left side of seat moves seat up and down, back and forth (show button).
Button for the steering wheel moves the wheel up and down, in and out.
There are many lights. The only ones they need to worry about are the speedometers- analog and digital (point each out). The subject is free to use whichever they feel most comfortable with.
Turn on the headlights all the way (two clicks). Make sure they are on before you leave the vehicle.
Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.
Show the participant how to turn on and adjust the windshield wipers.

Prepare for the first VES.
Make sure you are in the correct vehicle, using your VES order.
Once back to the data collection screen you can edit the Experimental Setup and the Target Order for the next condition.
Let the valet check the headlamps and radio that everything is ok.
Radio the onroad experimenters when you are ready to go down.
Continue down the road.

Start data collection for first VES when you are parallel with the guardrail.

Monitor the safety of the pedestrians on the road.
Use the computer program to determine when you are approaching a pedestrian.
Say **"**Station X, Clear**"** as soon as the participant recognizes the pedestrian.
If driver does not see pedestrian, use the computer read out to determine when the vehicle is within 40 feet of pedestrian. Tell the pedestrian to clear at that time.
Make sure the participant is not driving over 10 mph. This can be verified using the computer program.

Continue the same procedure for the rest of the VES.
Using the IR push button in the Sedan.
Make sure IR is cleared to "0" (press push button until it reads "0").
Each time the participant recognizes an object with the IR, press the button once.
Make sure to clear back to "0" before pressing the spacebar.
Make a note on the notes sheet for each IR.

Bring Participant Back to the Building.
Participant should drive the vehicle they did their last VES in, back to the building.
Leave the vehicle running and turn off the laptop so the back seat experimenter can return all computers to the lab.

Document Time on Participant's Debriefing Sheet.
Ask driver to fill out the payment receipt log.
Pay the driver, and thank them for their participation.

APPENDIX G—BACK SEAT EXPERIMENTER'S PROTOCOL

Back Seat Experimenter's Protocol Fog

<u>Set Up</u>

Setting up the computers.
One back seat experimenter should set up the Sedan first since they need it for training.
The other back seat experimenter should set up the SUV 3 first since they need it on the road.
Put a computer in appropriate car and plug in power supply and serial cable (may need to use small screwdriver for some).
Turn on each computer (leave at C:\Fog).
Retrieve all four visibility computers and set up as follows:

Visibility computer setup.
Ensure that the computer is plugged into the electrical adapter and that the serial cable from the [Konica] Minolta Meter is plugged into the 9 pin serial port on the computer.
Turn on the computer.
Turn on the [Konica] Minolta Meter. In all vehicles but the SUV 3, the switch for the meter is on the top of the meter which is mounted on the windshield of the vehicle. In the SUV 3, the meter is on the floor behind the driver's seat. After turning on the meter, make sure that the instrument is working by viewing it through the windshield. The number should change if you place your hand over the detector on the outside. If the instrument does not turn on, the batteries are likely dead and need to be replaced (See "Changing the meter batteries" at the bottom of the protocol). If the numbers do not change, the measurement hold button is likely pressed and needs to be released. The hold button is on the top of the meter and needs to be pushed to release it.
On the computer, start the [Konica] Minolta software using START\Programs\T-A30\dmsta30 (or use the shortcut on the desktop to "dmsta30").
The software will start and will start looking for the meter. If an error occurs and the software asks if the software should be run in offline mode then the communications to the meter have failed and you should check the cable and that the meter is turned on.
If the connection is working, the software should show a list of numbers 1 through 32 with boxes beside them. In all vehicles but the SUV 3, make sure that box zero says OK. In the SUV 3, Box 1 should say OK. If it does not, check the cabling again.

Changing the meter batteries.
There are spare batteries in an envelope in the glove box of each vehicle.
The meter is attached to the mounting plate using Velcro and a thumb screw. Loosen the thumb screw and then pull the instrument from the Velcro.
You might have to remove the cable from the instrument.
Remove the battery cover and replace with 2 AA batteries. You might have to pull the Velcro back from the edge to release the battery cover.
Remount the battery cover, smoothing out the Velcro if required.
Reattach with the thumbscrew first and then with the Velcro.
Tighten the thumbscrew and reattach cable if required

Data Collection

Visibility Computer Operation.

At the start of each run, open a new file in the [Konica] Minolta Software using File\New. The software will ask two questions: 1) Would you like to open a new file? Answer "YES", 2) Measurement type? Answer "OK" to the defaults presented.

Press the green arrow button in the software to start the measurement. The software will ask if you would like to start a measurement and answer "YES".

Record the data number at the start of the run (when the vehicle leaves the turnaround).

During the run, record the data number at the time when the observer detects the object. Also record the lux reading that corresponds with that data number.

Record the data number when the vehicle arrives at the next turnaround.

At the end of the run, press the green box button to stop the measurement, and save the file. Close the file once it has been saved. Then open a new one by clicking on the new file icon (the blank sheet) at the top left on the toolbar.

Repeat procedure for each run.

Taking Notes.

On the "Back Seat Experimenter Notes Sheet" you will need to record the following information for each run:

Data number that corresponds to the time of departure from turnaround (described above).

Windshield wiper speed during run (low, medium or high).

The data number when the subject sees the object (described above).

The lux reading when the participant sees the object (described above).

Any additional information that you can gather about the fog (too thick, too thin, whether you can see the second object from the first station, etc.).

Time of arrival at the next turnaround (described above).

APPENDIX H—SMART ROAD

Figure 28. Photo. Smart Road testing facility.

The Virginia Smart Road (figure 28) is a unique, state-of-the-art, full-scale research facility for pavement research and evaluation of Intelligent Transportation Systems (ITS) concepts, technologies, and products. It is the first facility of its kind to be built from the ground up with its research infrastructure incorporated into a section of public roadway. The Smart Road presently consists of 3.2 km (2 mi) of two lanes of roadway, originating in Blacksburg, VA, which are closed to public traffic and are designated a controlled test facility. When completed, the Smart Road will be a 9.6-km (6-mi) long, four-lane section of the U.S. Interstate system, connecting Blacksburg, VA with U.S. Interstate 81. This connection will serve an important role in the I–81/I–73 transportation corridor. After completion, provisions will be made to route traffic around controlled test zones on the Smart Road to allow for ongoing testing.

Construction of the Smart Road project was made possible through a cooperative effort of several Federal and State organizations, including Virginia's Center for Innovative Technology, the Virginia Department of Transportation (VDOT), the Virginia Transportation Research Council (VTRC), the Federal Highway Administration (FHWA), and Virginia Tech.

The research-supported infrastructure of the Smart Road makes it an ideal location for safety and human factors evaluation. Following is a list of some of the unique research capabilities of the facilities:

- All-weather testing facility.
- Variable lighting test bed.

- Ultraviolet (UV) pavement markings.
- Magnetic tape installed on roadway.
- Onsite data acquisition capabilities.
- In-house differential Global Positioning Systems (GPS).
- Surveillance camera systems.

APPENDIX I—DEBRIEFING FORM

NAME:____________________________

Thanks a lot for your collaboration and interest in this study. The time that you have taken to evaluate these new technologies is greatly appreciated. The results of this evaluation process will help increase the safety of nighttime driving. We will appreciate your cooperation to keep the details of this study as confidential as possible.

If you have any questions please do not hesitate to contact us. __________________will be glad to answer all your questions related to this evaluation process. Have a great day.

Time In: ___________________________________

Time Out: ___________________________________

Total Number of Hours: ___________________________________

Payment: ___________________________________

Experimenter's Signature: ___________________________________

APPENDIX J—ONROAD EXPERIMENTER'S PROTOCOL

ENV-Objects Protocol for Onroad Experimenters—Fog

1. General Policies

The primary goal of this research effort is safety. For that reason, you need to be safe at all times.

- Drive in a safe manner at all times. This means observing the 25 mile-per-hour speed limit on the road, and 10 miles-per-hour if the fog making has started.
- Wear closed-toe shoes at all times.
- Wear dark clothes and dark shoes.
- Always wear your vest on the road during set up and shut down.
- Do not travel with the tailgate open.
- Wear your safety glasses whenever you are exposed to headlights.
- Always drive with your lights on.
- If equipment breaks, tell the PI as soon as possible. Do not leave your shift without notifying the PI or lead experimenter of any damage.
- Attend the nightly meeting.
- Acknowledge all radio messages you receive.

Each night, you will need to arrive to the (testing facility) on time. The nightly meeting will cover topics such as protocol changes, problems from the previous night, and schedule concerns. Make sure you document any problems from the previous night.

Operations of the headlights are outlined with a diagram and description in each vehicle. Failure to follow the procedures will prevent the headlights from working, and therefore leave gaps in the data. For this reason, you are to review the operations each night for your assigned vehicle.

While the study is being conducted, radio communications on Channel 8 need to be minimized (emergencies excluded). Note that the front seat experimenters cannot always respond to questions if they are interacting with the participant at that time. For this reason, you will need to give the front seat experimenters extra time to reply.

2. Pre-Experiment

Attend meeting:

- Review changes in protocol.
- Lead experimenter will distribute the following forms:
    - Vehicle and Road prep sheets-to the valets.
    - VES order sheets with VES diagram- to valet.
    - Object order to onroad experimenters.

Onroad experimenters are responsible for obtaining the following:

- A radio prepared in a plastic bag along with extension if desired.

- Vest.
- Flash light.
- Safety glasses.

Put on vests.
Load the cones in to the SUV 3 to be placed out at the turnarounds when you reach the road. Three will be dropped off at the second turnaround and 4 at the bottom (third) turn around.
Park SUV 1 & 2 at the front of the building for the participants.
Set up parking spaces by putting out the cones at the appropriate locations.
Set up cones at the entrance and exit points of both turnarounds.
Make sure all cones on the road that are not part of the ENV study, are removed from the road.
Each night you will be assigned one of the following locations:
Station 1, 5
Station 2, 4
Before getting to your station double check to make sure you have all of the necessary items. Also make sure one of your radios is set to channel 1, and either hold it or attach it to your clothing. Radios are to be worn at all times. As soon as the participants are on the road, the following rules will begin:

1. Radios are only to be used for communicating information pertaining to the experiment. There is to be no communication about procedure on channel 1 unless there is a deviation from the usual protocol. All onroad experimenters are expected to know the protocol without confirmation from others.
2. There will be a relay at station 1 to repeat any messages not heard by geographically opposite stations.
3. As soon as you receive a message (providing it pertains to you), you must acknowledge that message immediately by saying, "Station X (and Y) copy."
4. If there is an emergency you are to get on the radio IMMEDIATELY and contact the relay station experimenter. The relay station experimenter will make sure the in-vehicle experimenters heard the message.
5. As the trials progress, you will need to make sure that you are ready in the proper position before the experimental vehicle gets to your station and cleared before the vehicle comes back up the road.
6. The experimental vehicle will always drive on the center of the road. If the wind affects where the fog is falling (i.e., towards the tower side or other) please indicate your station and where the fog has the greatest concentration (e.g. Station X – tower, Station Y – Other).

3. Objects Protocol

Drivers will be oriented to the road by driving down the hill. During this time onroad experimenters are to remain hidden. However, on the way up the hill, the following stations will need to present objects:

Station 4	White Perpendicular Pedestrian
Station 5	White Parallel Pedestrian

In-vehicle experimenters will assume that all stations are ready, unless an onroad experimenter radios to say otherwise. Below is a table of the object along with the placement location. This location assumes that the vehicle is driving in the middle of the roadway. If the object needs to be shifted towards the guardrail or towards the other side, move the location accordingly.

OBJECT	LOCATION	SPECIAL INSTRUCTIONS
Perpendicular white pedestrian	Straight (perpendicular) line between center of each lane	Wear white clothing. Walk from the center of the lane on the passenger side of the vehicle to the center of the other lane and back. Repeat.

After the first lap onroad experimenters are to begin as indicated on object order sheets. The front seat experimenters will indicate when the object trials begin.
Put safety glasses on.
SAFETY NOTE: Experimental vehicles are not to come within 40 feet of the object on the roadway. Also, the front seat experimenters will ask you to "clear" once they have detected you, or if they are close to the safety margin. In that case, you can clear as soon as you hear "Station X - Clear." However, if you do not feel safe at any point in time you MUST clear your position. After you step off the road, maintain your position on the shoulder. This will allow the front seat experimenters to record the distances of detection and recognition on the distance measuring devices. This methodology will be repeated for all six VES configurations. The valets will drive around and collect all experimenters and cones after the sixth configuration. If you notice any problems or mistakes occurring during the night record them on the vehicle preparation sheets.

4. Ending Protocol

Gather all experimental equipment and return to the building. At the end of each night there will be a checklist of items for you to complete (see below). After the items are checked, you will be free to leave.

- The onroad people will be picked up by one of the experimental vehicles.
- Valet will collect cones from the turnarounds and carry them in the pickup truck.
- Return the vehicles to the building.
- Note any vehicle problems on the vehicle preparation sheets, and then write them down on the message board.
- Return the radios
- Submit paperwork to front seat experimenter.

APPENDIX K—AIMING PROTOCOL

PROTOCOL SUMMARY
Vehicle/Headlamp Combinations Acronym List:

WH HLB 1	WH HLB 2	SUV # 1 Halogen Low Beam 1 & 2
WH Hybrid UV–A 1	WH Hybrid UV–A 2	SUV #1 Hybrid UV–A 1 & 2
WH HLB 1	WH HLB 2	SUV #2 Halogen Low Beam 1 & 2
WH UV–A 1 thru WH UV–A 5		SUV #2 Five UV–A 1-5
EX HID 1	EX HID 2	SUV #3 High Intensity Discharge

- It is very important to make sure that you have enough time to align all of the headlights prior to the team meeting, and especially prior to the road preparations. Minimum alignment time is 1 hour when no headlamps need to be switched between vehicles, but you should plan on 1 ¼ - 1 ½ hours as a general rule. Alignment times will be greater on days when headlamps must be moved.
- It is important to remember to use the ZERO function on the photometer prior to aligning each light. This is particularly important when recording the photometer values on the Headlamp Alignment form.

Setting up the Non-UV–A headlamps

Applies to the following Vehicle/Headlamp combinations:
SUV #1 HLB (1&2), SUV #2 HLB (1&2)
SUV #3 HID (1 & 2)

- Use the laser to make sure the target board is centered to the vehicle. Each vehicle has a different line on the target board. The lines are labeled directly on the target board. The lines from left to right are: SUV #1 Laser Line, SUV #2 Laser Line, and SUV #3. Locate the appropriate markings on the target board for each VES.
- Turn on the appropriate headlamps, making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.
- Cover up or unplug one headlamp so that you are only taking readings for one light at a time.

<u>Finding the Hotspot:</u>
Align the VES so that the "hotspot" is located within the circle located on the aiming board. The headlamps have both gross and fine adjustments. Typically, only fine adjustments will be required if the headlights are not switched; gross will be required if the headlights are switched.

Using the Photometer:
To determine if the hotspot is in the correct location, you will need to use the International Light, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a "REG" label, and the sensor for the UV light is marked with a "UV–A" label. Use the sensor marked "REG."

Zero the Photometer:
Remember to "ZERO" the photometer prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the photometric sensor. Place the sensor at the alignment location for the headlamp to be aligned. Press the "ZERO" button; this will allow the photometer to measure any undesired background light and remove its effects from the actual light source value. The photometer is ready when the "ZEROING" message has changed back to the "SIGNAL" message. Turn the headlamp on and begin alignment.

Isolating the Hotspot:
Once you find the area you believe has the highest intensity, readings need to be taken in all directions around that location to ensure that is the hotspot. If the hotspot is in the correct location, the light is aligned and you can align the other light(s).

Note that for non-UV lights, the HLBs in particular, the hotspots actually span a large horizontal swath, 2-4 inches wide. It is relatively easy to determine the hotspot vertically, but determining the hotspot horizontally requires more effort and patience given that the horizontal hotspot can be 2-4 inches wide.

Special Instructions for HID alignment in the Blue Box:
Remember that the HIDs require alignment with the photometer for rightmost (no. 2) headlamp and visual alignment based of the left (no. 1) headlamp based on the aligned right headlamp. This is noted on the alignment form.

Setting up the UV–A headlamps

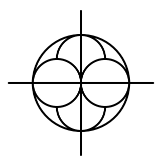
Applies to the following Vehicle/Headlamp combinations:
SUV #2 Five UV–A (1-5)
SUV #1 Hybrid UV–A (1&2)

- Use the laser to make sure the target board is centered to the vehicle. Each vehicle has a different line on the target board. The lines are labeled directly on the target board. The lines from left to right are: SUV #1 Laser Line, SUV #2 Laser Line, SUV #1 UV, and SUV #2 UV. If you are aligning the UV headlamps on SUV number 2, you should use the SUV #2 -UV laser line. All other vehicles require the use of the standard alignment point.
- Turn on the appropriate headlamps, making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.
- Locate the appropriate markings on the target board for that headlamp.
- Cover up the headlamps so that you are only taking readings for one light at a time.

Finding the Hotspot:
Align the headlamps so that the “hotspot” is located on the crosshairs. The hybrid UV–A headlamps have fine adjustments. The five UV–A headlamps require shimming for the vertical location and wrench adjustments for the horizontal adjustment.

Note that it is sufficient to line up the sensor on the crosshairs such that at least the edge of the sensor touches the center of the crosshairs. This means that there is a circular space around the center of the crosshairs, with a radius the size of the sensor in all directions (about 2 inches in diameter), in which the hotspot may be found. This is a larger margin of alignment error than allowed for the non-UV lights and is due to the nature of the mounting of the lights.

HotSpot Location: The large outer circle represents the overall target area. The center of the large circle is the target hotspot location.



Using the Photometer:
To determine if the hotspot is in the correct location, you will need to use the International Light, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a “REG” label, and the sensor for the UV light is marked with a “UV–A” label. For UV–A light, use the photometer sensor marked “UV–A.”

Zero the Photometer:
Remember to “ZERO” the photometer prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the photometric sensor. Place the sensor at the alignment location for the headlamp to be aligned. Press the “ZERO” button; this will allow the photometer to measure any undesired background light and remove its effects from the actual light source value. The photometer is ready when the “ZEROING” message has changed back to the “SIGNAL” message. Turn the headlamp on and begin alignment.

Isolating the Hotspot:
Once you find the area you believe has the highest intensity, readings need to be taken in all directions around that location to ensure that is the hotspot. If the hotspot is in the correct location, the headlamp is aligned and you can align the other light(s).

Reference values for the Various Headlamps:

Note: You look at this table as you look at the *target board* for calibration; it’s backwards when looking directly at the vehicles.

HID		
1 (Left)	*2 (Right)*	
visual alignment based on other light	41.6 W/cm^2	
# 1 HLB & #2 HLB		
1 (Left)	*2 (Right)*	
44.7 W/cm^2	50.1 W/cm^2	
Hybrid UV–A [#1]		
1 (Left)	*2 (Right)*	
100 μW/cm^2	92.0 μW/cm^2	
Five UV–A [#2]		
Top Row lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 μW/cm^2	472 μW/cm^2	484 μW/cm^2
Bottom Row lights		
4 (Bottom Left)	*5 (Bottom Right)*	
486 μW/cm^2	565 μW/cm^2	

Headlamp Alignment Form

Date: _______________
Inits: _______________

HID	
1 (Left)	*2 (Right)*
visual alignment based on other light Actual:	41.6 W/cm^2 Black SUV Actual:

#1 HLB	
1 (Left)	*2 (Right)*
44.7 W/cm^2 Actual:	50.1 W/cm^2 Actual:

#2 HLB	
1 (Left)	*2 (Right)*
44.7 W/cm^2 Actual:	50.1 W/cm^2 Actual:

Hybrid UV–A [#1]	
1 (Left)	*2 (Right)*
100 $\mu W/cm^2$ Actual:	92.0 $\mu W/cm^2$ Actual:

Five UV–A [#2]		
Top Row lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 $\mu W/cm^2$ Actual:	472 $\mu W/cm^2$ Actual:	484 $\mu W/cm^2$ Actual:
Bottom Row lights		
4 (Bottom Left)	*5 (Bottom Right)*	
486 $\mu W/cm^2$ Actual:	565 $\mu W/cm^2$ Actual:	

APPENDIX L—VALET PROTOCOL

Valet Protocol for ENV-Objects—Fog

Pre Experiment Duties:

1. Attend the nightly meeting.
2. Get the following forms from the front seat experimenter:
   - VES order and diagram hand out.
   - Vehicle prep sheets.
   - Participant eye measurement sheet.
   - Ambient light reading (Lux) form.

3. Prep the vehicles according to the vehicle prep sheet.

4. Make sure that you have the following equipment:
   - Flashlight.
   - Radios.
   - Vest.
   - Safety glasses.
   - Eye measurement equipment.
   - Cones.

5. Park SUV 1 and SUV 2 up at the front of the building.

6. With the assistance of the onroad experimenters, perform the road prep according to the road prep sheet.

7. Drop off all onroad staff at their stations.

8. Make sure that your radio is on channel 8.

9. Wait for drivers to arrive at turnaround 2.

Duties during the experiment:

When drivers arrive at T2 – Lead Valet

1. Take eye height measurements for each participant in each vehicle. To do this, first explain to the participant that you are going to make a mark on the window as to where their eye level is located. Instruct them to adjust their seat to where they think they will be comfortable. Once they are situated, tell them to look ahead, relax, and stay as still as possible. Close the door and take the measurements.
    - Use the level (located in valet box) to assess participant's eye position. Once you have found their eye position mark a "+" on the glass (using a dry-erase marker).
    - Using the "+" as a reference point, take measurements (horizontal and vertical).
    - Take vertical measurement with metal end of tape measure down where the glass intersects with the black plastic.
    - Take horizontal measurement with metal end of tape measure to the right where glass intersects with black plastic.
2. The first parking space on each side is termed a "vehicle drop off" and needs to be available at the end of every lap. The valet will move any vehicle that is left in those locations to the parking spots outside the turn around.
3. Whenever possible, the first driver that returns to the middle turnaround should have their next vehicle waiting for them at the foremost parking spot. The valet will need to look at the VES order sheet to determine which vehicle will be used next and which parking spots should be used to ensure that the driver's wait-time is minimized.
4. Before driver goes down the road, ensure the headlights are on and working. USE SAFETY GLASSES.

    <u>SUV 1:</u> If hybrid UV–A is required, make sure they are working. Otherwise, make sure the two HLBs are on.
    <u>SUV 2:</u> If five UV–A is required, all five should be on. Report if one is not working or extremely dull. The HLB lights should be working at all times.
    <u>SUV 3:</u> The two HID headlamps on the front of the vehicle should be on.

Shut down procedures:

1. Pick up all onroad people and all onroad materials.
2. Sign all the radios back in.
3. Submit paperwork to front seat experimenter.

General notes for the valet.

1. Outside of the vehicle discussion should be held with the front seat experimenter whenever problems arise or questions need to be answered. At no point should a discussion about the experiment or the road conditions be held within hearing distance of the participant.
2. While a participant is outside of the vehicle or the vehicle doors are open, the Valet must turn the volume of their radio low so that the participant does not know the nature of the experiment or conditions on the road.

REFERENCES

1. daSilva, M.P., Smith, J.D., & Najm, W.G. (2003). *Analysis of Pedestrian Crashes* (Report No. DOT-VNTSC-NHTSA-02-02). Cambridge, MA: Volpe National Transportation Systems Center.
2. National Highway Traffic Safety Administration. (1999). *Traffic Safety Facts 1998: Overview*. Retrieved from http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSF98/ Overview98.pdf
3. Chrysler, S.T., Danielson, S.M., & Kirby, V.M. (1997). "Age Differences in Visual Abilities in Nighttime Driving Field Conditions." In W.A. Rogers (Ed.), *Designing for an Aging Population: Ten Years of Human Factors/Ergonomics Research* (pp. 310–314). Santa Monica, CA: Human Factors and Ergonomics Society.
4. Mortimer, R.G. (1989). "Older Drivers' Visibility and Comfort in Night Driving: Vehicle Design Factors." In *Proceedings of the Human Factors Society 33rd Annual Meeting*, 154–158.
5. Richards, O.W. (1966). "Vision at Levels of Night Road Illumination: XII Changes of Acuity and Contrast Sensitivity with Age." *American Journal of Optometry/Archives of the American Academy of Optometry*, *43,* 313–319.
6. Richards, O.W. (1972). "Some Seeing Problems: Spectacles, Color Driving and Decline From Age and Poor Lighting." *American Journal of Optometry/Archives of the American Academy of Optometry, 49,* 539–546.
7. Weale, R. (1961). "Retinal Illumination and Age." *Transactions of the Illuminating Engineering Society, 26,* 95–100.
8. Weymouth, F.W. (1960). "Effects of Age on Visual Acuity." In: M.I. Hirsch & R.E. Wick (Eds.), *Vision of the Aging Patient* (pp. 37–62). Chilton: Philadelphia, PA.
9. Barham, P., Oxley, P., & Ayala, B. (1998). "Evaluation of Jaguar's First Prototype Near Infrared Night Vision System and Its Potential Contribution to Road Safety." In A.G. Gale, I.D. Brown, C.M. Haslegrave, & S.P. Taylor (Eds.), *Vision in Vehicles VI* (pp. 203–211). Amsterdam: Elsevier Science.
10. Hodge, A.R., & Rutley, K.S. (1978). *A Comparison of Changeable Message Signals for Motorways* (TRRL Supplementary Report 380). Crowthorne, England: Transport and Road Research Laboratory.

11. Lunenfeld, H., & Stephens, B.W. (1991). “Human Factors Consideration in the Development of an IVHS System: Night Vision Enhancement.” In *Proceedings of the 61st Meeting of the Institute of Transportation Engineers*, 120–124.
12. Nilsson, L., & Alm, H. (1996). “Effect of a Vision Enhancement System on Drivers’ Ability to Drive Safely in Fog.” In A.G. Gale (Ed.) *Vision in Vehicles V* (pp. 263–271). Amsterdam: North-Holland/Elsevier.
13. Stahl, A., Oxley, P., Berntman, M., & Lind, L. (1998). *The Use of Vision Enhancements to Assist Elderly Drivers*. Paper presented at Premier Congres Mondial sur les Application Telematiques aux Transports, Paris.
14. Calderas, J., personal communication, August 22, 2000.
15. Erion, J., personal communication, June 5, 2000.
16. Dutke, F.F., personal communication, June 20, 2000.
17. Schnell, T., personal communication, August 24, 2000.
18. Winer, B.J., Brown, D.R., & Michels, K.M. (1991). *Statistical Principles in Experimental Design*. New York: McGraw-Hill, Inc. pp. 140–197.
19. Mahach, K.R., Knoblauch, R.L., Simmons, C.J., Nitzburg, M., Arens, J.B., & Tignor, S.C. (1997). *A Preliminary Field Evaluation of Ultraviolet-Activated Fluorescent Roadway Delineation* (FHWA-RD-97-082). Washington, DC: U.S. Department of Transportation, Federal Highway Administration.
20. Nitzburg, M., Seifert, R., Knoblauch, R., & Turner, D. (1998). *A Safety Evaluation of UVA Vehicle Headlights* (FHWA-RD-99-079). McLean, VA: U.S. Department of Transportation, Federal Highway Administration.
21. Drummond, A.E. (1989). *An Overview of Novice Driver Performance Issues: A Literature Review* (Report No. 9). Clayton, Victoria: Monash University Accident Research Centre. Retrieved from http://www.monash.edu.au/muarc/reports/muarc009.pdf
22. Blanco, M., Hankey, J.M., Binder, S., & Dingus, T.A. (2001). “Detection and Recognition of Non-Motorists and Objects Using New Technologies to Enhance Night Vision.” In *Proceedings of the Intelligent Transportation Society of America 11th Annual Meeting and Exposition*. Washington, DC: Intelligent Transportation Society of America.
23. Cavallo, V., Brun-Dei, M., Laya, O., & Neboit, M. (1988). “Perception and Anticipation in Negotiating Curves: The Role of Driving Experience.” In A.G. Gale, M.H. Freeman, C.M.

Haslegrave, P. Smith, & S.P. Taylor (Eds.), *Vision in Vehicles II*. Amsterdam: Elsevier Science.

24. Blanco, M. (2002). *Relationship Between Driver Characteristics, Nighttime Driving Risk Perception, and Visual Performance under Adverse and Clear Weather Conditions and Different Vision Enhancement Systems*. Unpublished doctoral dissertation, Virginia Polytechnic Institute and State University. Retrieved from http://scholar.lib.vt.edu/theses/available/etd-05202002-171805/unrestricted/Blanco-Dissertation.pdf
25. Holland, C.A. (2001). *Older Drivers: A Literature Review* (Road Safety Research Report No. 25). UK: Department of Transport, Local Government and the Regions. Retrieved from http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/pdf/dft_rdsafety_pdf_504602.pdf
26. Uno, H., & Hiramatsu, K. (2001). "Collision Avoidance Capabilities of Older Drivers and Improvement by Warning Presentations." In *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles* (CD paper # 185). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.
27. van der Horst, R., & Hogema, J. (1993). "Time-to-Collision and Collision Avoidance Systems." In *Proceedings of the 6th ICTCT Workshop: Safety Evaluation of Traffic Systems: Traffic Conflicts and Other Measures*, 109–121.
28. Jones, E.R., & Childers, R.L. (1993). *Contemporary College Physics* (2nd Edition). New York: Addison-Wesley.
29. American Association of State Highway and Transportation Officials. (2001). *A Policy on Geometric Design of Highways and Streets*. Washington, DC: AASHTO.
30. Chang, M.S., Messer, C.J., & Santiago, A.J. (1985). "Timing Traffic Signal Change Interval Based on Driver Behavior." *Transportation Research Record, 1027,* 20–30.
31. Sivak, M., Olson, P.L., & Farmer, K.M. (1982). "Radar Measured Reaction Time of Unalerted Drivers to Brake Signal." *Perceptual Motor Skills, 55,* 594.
32. Taoka, G.T. (1989). "Brake Reaction Time of Unalerted Drivers." *Institute of Transportation Engineers (ITE) Journal*, *59*(3), 19–21.
33. Lindeburg, M.R. (1992). *Civil Engineering Reference Manual* (6th edition). Belmont, CA: Professional Publications, Inc.

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