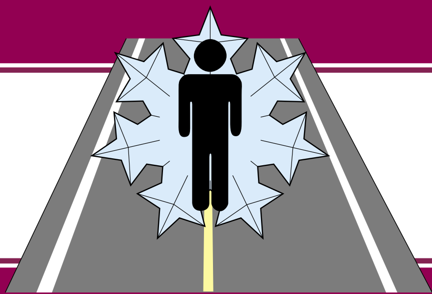

Volume V

Enhanced Night Visibility Series: Phase II—Study 3: Visual Performance During Nighttime Driving in Snow

PUBLICATION NO. FHWA-HRT-04-136

DECEMBER 2005

U.S. Department of Transportation

Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
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 snow. 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 V. 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 3 was part of the Enhanced Night Visibility project, a larger research effort investigating drivers' visual performance during nighttime driving. Study 3 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 snow conditions. A total of 20 participants detected and recognized different roadway objects while driving experimental vehicles equipped with various headlamps in a snow condition. A 4 by 3 by 2 mixed factorial design was used to investigate the effects of the different types of vision enhancement systems, the types of objects on the roadway, and driver's age on detection and recognition distances. Subjective evaluations for the different systems were obtained as well.

The results of the empirical testing suggest that halogen low beam (HLB) configurations combined with an ultraviolet A (UV–A) setup consistently outperform the HLB by itself and the high intensity discharge (HID) configuration with respect to detecting and recognizing pedestrians in a snow environment. All three HLB configurations significantly outperformed the HID configuration for both detection and recognition of the objects presented. The three HLB configurations were not significantly different from each other with respect to recognition distances; however, there was a slight but significant increase in detection distance when the HLB was paired with one of the UV–A systems used. Finally, there were no significant findings for the subjective analysis, although there were some conflicting findings between the subjective and objective data.

17. Key Words
Age, Detection, Halogen, Headlamp, High Intensity Discharge (HID), Infrared, Pedestrian, Night Vision, Nighttime, Recognition, Snow, Ultraviolet, Vision Enhancement System, Weather

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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 fifth 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
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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

five UV–A + HLB .... five UV–A headlamps together with halogen low beam
HID .... high intensity discharge
HLB................................... halogen (i.e., tungsten-halogen) low beam
hybrid UV–A + HLB .... hybrid UV–A/visible output together with halogen low beam

Statistical Terms

ANOVA .... analysis of variance
DF .... degrees of freedom
F value............................... F-ratio
MS..................................... mean square
p value............................... statistical significance
SE...................................... standard error
SS .... sums of squares

Measurements

cm/h................................... centimeters per hour
ft .... feet
h... hours
m .... meters
mi/h .... miles per hour
N/cm^2 .... Newtons per square centimeter
km/h .... kilometers 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
d..distance
d_{BD}....................................braking distance
f..friction
g..acceleration
G..gradient
V..velocity

Contrast Sensitivity

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

CHAPTER 1—INTRODUCTION

Study 3 in Phase II of the Enhanced Night Visibility (ENV) project was the second in a series of three studies tested at the Smart Road testing facility in Virginia that focused on drivers' visual performance during adverse weather conditions such as rain, snow, and fog. The experimental tasks for this study consisted of driving at nighttime in snowfall conditions using 4 different vision enhancement system (VES) configurations taken from the original set of 12 used for Phase II—Studies 1 and 2, ENV Volumes III and IV. Drivers' visual performances were evaluated in terms of detection and recognition distances for different objects while using the different VESs. Subjective performance ratings were garnered from questionnaires administered to participants following the use of each VES.

The driving portion of the study took place at the Smart Road testing facility in Virginia. The road was closed to all traffic except experimental vehicles, and no more than two vehicles were on the road at any time. Participants underwent a training session and participated in the onroad study in one night. The next chapter describes methods used in this study.

CHAPTER 2—METHODS

PARTICIPANTS

Twenty individuals participated in this study. Participants were divided into two age categories. The first group, referred to as "younger drivers," was made up of 10 participants who were between the ages of 18 and 25 years old. The second group, referred to as "middle-aged drivers," was made up of 10 participants who were between the ages of 40 and 50. Each age category had five males and five females. Candidates were allowed to participate only after they met the selection conditions of a screening questionnaire (appendix A). Candidates 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 instructed about their right to withdraw freely from the research program at any time without penalty, and they were told that no one would try to make them participate if they did not want to continue. If at any time they chose 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 for the data collection of the onroad portion of the study (i.e., detection and recognition tasks). There were three independent variables:

- VES configuration.
- Age.
- Object type.

The between-subjects variable of the experiment was age. The within-subject variables were VES configuration and type of object. Table 1 and table 2 show a representation of the experimental design.

Table 1. Experimental design: 4 by 3 by 2 mixed-factor design (four VES configurations, two age groups, three objects).

VES Configuration	Younger Age Group	Middle-Aged Group
HLB		
HID		
Hybrid UV–A + HLB		
Five UV–A + HLB		

Table 2. The three objects presented in each cell of table 1.

	Object
Dynamic	Perpendicular Pedestrian, Black Clothing
	Parallel Pedestrian, White Clothing
	Perpendicular Pedestrian, White Clothing

INDEPENDENT VARIABLES

Age

The age factor had two levels: younger participants (18 to 25 years old) and middle-aged participants (40 to 50 years old). These age groups were created based on literature-review findings (listed in ENV Volume II) that suggest changes in vision during certain ages. (See references 1, 2, 3, 4, and 5). Each age group comprised five males and five females. Gender was used as a control, although it was not a factor of interest. Because of safety concerns, the older age group that was included in the studies on clear and rain conditions was not used in this study. It became apparent during pilot testing that the snow condition presented a risk of older participants slipping in the turnarounds, even though salt was spread throughout the areas where the participants would walk.

VES

Following is a list of the VES configurations used in this study:

- Halogen (i.e., tungsten-halogen) low beam (HLB).
- Hybrid ultraviolet A band and visible output together with HLB (hybrid UV–A + HLB).

- Five UV–A headlamps together with HLB (five UV–A + HLB).
- High intensity discharge (HID).

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

The order of presentation for each VES and object combination was 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 configuration used. The third column, "Vehicle," describes the sport utility vehicle (SUV) used as a platform for the VESs.

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

	Order	VES	Vehicle
Participant 1	0	Practice—HLB	Midsize SUV
	1	HLB	Midsize SUV
	2	Hybrid UV–A + HLB	Midsize SUV
	3	HID	Large SUV
	4	Five UV–A + HLB	Midsize SUV
Participant 2	0	Practice—HLB	Midsize SUV
	1	Hybrid UV–A + HLB	Midsize SUV
	2	Five UV–A + HLB	Midsize SUV
	3	HLB	Midsize SUV
	4	HID	Large SUV

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

Both of the configurations that use the UV–A headlamps were paired with typical headlamps (e.g., HLB) because UV–A headlamps provide minimal visible light. The UV–A headlamps stimulate the fluorescent properties of objects contacted by the UV radiation, producing visible light. Their purpose is to supplement regular headlamps, not to eliminate them. These UV–A and

HLB pairings resulted in two different VES configurations: five UV–A + HLB and hybrid UV−A + HLB. The hybrid UV–A headlamp is an experimental prototype that produces a significant amount of visible light, although not enough light to allow nighttime driving without low-beam headlamps. The spotlight UV–A headlamps used for the five UV–A configuration produce less visible light.

Several factors caused a decrease in the number of VES configurations used in the clear and rain condition studies (ENV Volumes III and IV). Potential changes in the snowmaking environment from night to night and the excessive time required for snowplowing between VES configuration changes resulted in the need to limit the experiment to one night. In addition, pilot testing included the infrared thermal imaging system (IR–TIS) configuration, but the IR camera became packed with snow, so it was not available for use in this study. Because the halogen low beam at a lower profile (HLB–LP) configuration had been used primarily as a comparison to the infrared thermal imaging system (IR–TIS), it also was not included in this study. Based on the results of the studies in clear and rain conditions, the high output halogen (HOH) and halogen high beam (HHB) headlamps tested were either no different or worse than the HLB, so it was unnecessary to further test those two configurations. Similarly, the UV–A and HID pairings also were found not to provide much improvement over HID alone in clear and rain conditions, so they were not included in this study.

Object

Pedestrians were the three objects selected for this study, as noted in table 4 and figure 1 through figure 3. The main reason for using pedestrians was because of the high crash-fatality rates for these nonmotorists.[6,7] This study used real pedestrians to evaluate the effects of object motion on detection and recognition distances; previous research of this type used pedestrian mockups.[8]

Pedestrians were presented to the drivers at two different contrast levels: black clothing against the snow background at night and white clothing against the snow background at night. The pedestrians walked in two different directions: perpendicular to the vehicle path, representing a pedestrian crossing the road; and parallel to the vehicle path, representing a pedestrian walking along the shoulder. The perpendicular pedestrians wore either white (figure 1) or black (figure 3) clothing. The parallel pedestrians wore white clothing only (figure 2). Stations with no objects (blank) were included to keep the study's participants searching for objects and prevent the expectation that they would see two pedestrians while driving downhill and two pedestrians while driving uphill. Table 4 shows the reflectance of each object. Detailed information about the characterization of the different objects is provided in ENV Volume IX.

Table 4. Description of the objects.

Object	Percentage of Reflectance at 61 m (200 ft)	Location	Special Instructions
Parallel Pedestrian, White Clothing	22	In middle of lane on passenger side of vehicle.	Wear white clothing. Walk 10 paces toward the vehicle, then 10 paces back. Be sure you are always facing the vehicle. Repeat.
Perpendicular Pedestrian, Black Clothing	4	Straight (perpendicular) line between center of each lane.	Wear black 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.
Perpendicular Pedestrian, White Clothing	22	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.

Figure 1. Photo. Perpendicular pedestrian in white clothing.

Figure 2. Photo. Parallel pedestrian in white clothing.

Figure 3. Photo. Perpendicular pedestrian in black clothing.

OBJECTIVE DEPENDENT VARIABLES

Detection and recognition distances were obtained to analyze the degree to which the different VES configurations enhanced night visibility while driving during the snow condition. These two variables, detection and recognition, 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 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, participants were instructed on the use of a hand-held wand to indicate when they detected and recognized objects. The participant pressed a button on the wand when he or she detected an object on the road, and then pressed the button again when he or she recognized the object. The in-vehicle experimenter pressed the laptop computer keyboard spacebar when the object of interest was aligned with the driver (i.e., the participant drove past the object). Detection and recognition distances were calculated from distance data collected at these three points in time.

SUBJECTIVE RATINGS

Subjective ratings were also collected. Participants were asked to evaluate a series of seven statements for each VES using a seven-point Likert-type scale. The two anchor points of the scale were "1" (indicating "Strongly Agree") and "7" (indicating "Strongly Disagree"). The statements addressed each participant's perception of improved vision, safety, and comfort after experiencing a particular VES. Each participant was asked to compare the VES he or she was evaluating with his or her own "regular headlights" (i.e., the headlights on the participant's own vehicle). The assumption was made that a participant's own vehicle represented what the participant knew best, and therefore, was most comfortable using. Following is a list of statements used in the questionnaire. The statements on the questionnaire follow. Note that while the word "headlamp" is used throughout the ENV series, the subjective questions posed to the participants used the synonymous word "headlight," as reflected below.

- 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 (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 required that:

- All data collection equipment was mounted such that, to the greatest extent possible, it did not pose a hazard to the driver in any foreseeable instance.
- Participants wore the seatbelt restraint system anytime the car was on the road.
- None of the data collection equipment interfered with any part of the driver's normal field of view.
- A trained experimenter was in the vehicle at all times.
- An emergency protocol was established before testing.
- Salt was placed on the road at the turnaround where participants changed vehicles.
- A snowplow was used to clear the road between VES configurations. This step ensured a constant amount of snow in the driving lanes and prevented excessive accumulation of snow and buildup of ice.

The pedestrians were trained on when to move away from the road based on a preset safety-envelope mark. In addition, they were provided with radios in case the in-vehicle experimenter needed to communicate with them.

APPARATUS AND MATERIALS

Onroad driving was conducted using three SUVs. All vehicles were equipped with laptops for data collection. Software was developed to link the data collection system, such as an electronic odometer, to the vehicle to obtain distances traveled and speed. The distance to the object of interest was obtained from the electronic odometer data. The software program on the laptop allowed the in-vehicle experimenter to change between VES configurations and object orders. After all the objects had been presented for a VES configuration, the program switched to the subjective questions to be asked by the experimenter. In addition, the software gathered information such as the participant’s age, gender, and assigned identification number.

The VESs were distributed among the three vehicles (figure 4 through figure 6). Note that either one of the two SUVs equipped with the UV–A headlamps (figure 4 and figure 5) also could be used for the HLB-only configuration.

Figure 4. Photo. Five UV–A + halogen low beam.

Figure 5. Photo. Hybrid UV–A + halogen low beam.

Figure 6. Photo. High intensity discharge.

Smart Road

This study took place at the all-weather testing facility on the Smart Road in Blacksburg, VA, shown in figure 7 and described in appendix G. Four different locations on the Smart Road were used to present the different objects, as shown in the diagram in figure 8. One onroad experimenter was assigned to each of the two turnarounds used for this study. At the turnaround, where the participant switched vehicles when changing VES configurations, the onroad experimenter was responsible for escorting the participant to the next vehicle, showing him or her where the different controls were, verifying that the correct VES configuration was being tested, and cleaning the windshields and headlamps. At the second turnaround, the other onroad experimenter was responsible for cleaning the windshields and headlamps halfway through the VES run. Appendix K gives a detailed protocol. Four other onroad experimenters were positioned at the predetermined object locations along the road, with two onroad experimenters assigned to cover locations 1 and 5 and two onroad experimenters for locations 2 and 4, as illustrated in figure 8. Appendix I gives details on the protocol for the onroad experimenters. Six onroad experimenters and two in-vehicle experimenters were involved in the study each night.

Figure 7. Photo. Snowmaking on the Virginia Smart Road.

The all-weather testing facility can generate snow by using controlled precipitation to ensure a constant amount of snowfall during the data collection effort. Data were not collected during heavy wind conditions. The selected rate of snowfall, which varied according to wind conditions, was between 5.1 cm/h (2 inches/h) and 12.7 cm/h (5 inches/h), which required most participants to use the vehicle windshield wipers at a high speed. The reason for the range in snowfall resulted from adjustments needed to maintain a similar amount of snowfall throughout the nights the experiment was performed because the environmental conditions for snow development were not consistent across nights. Appendix L gives an indepth description of snowmaking equipment).

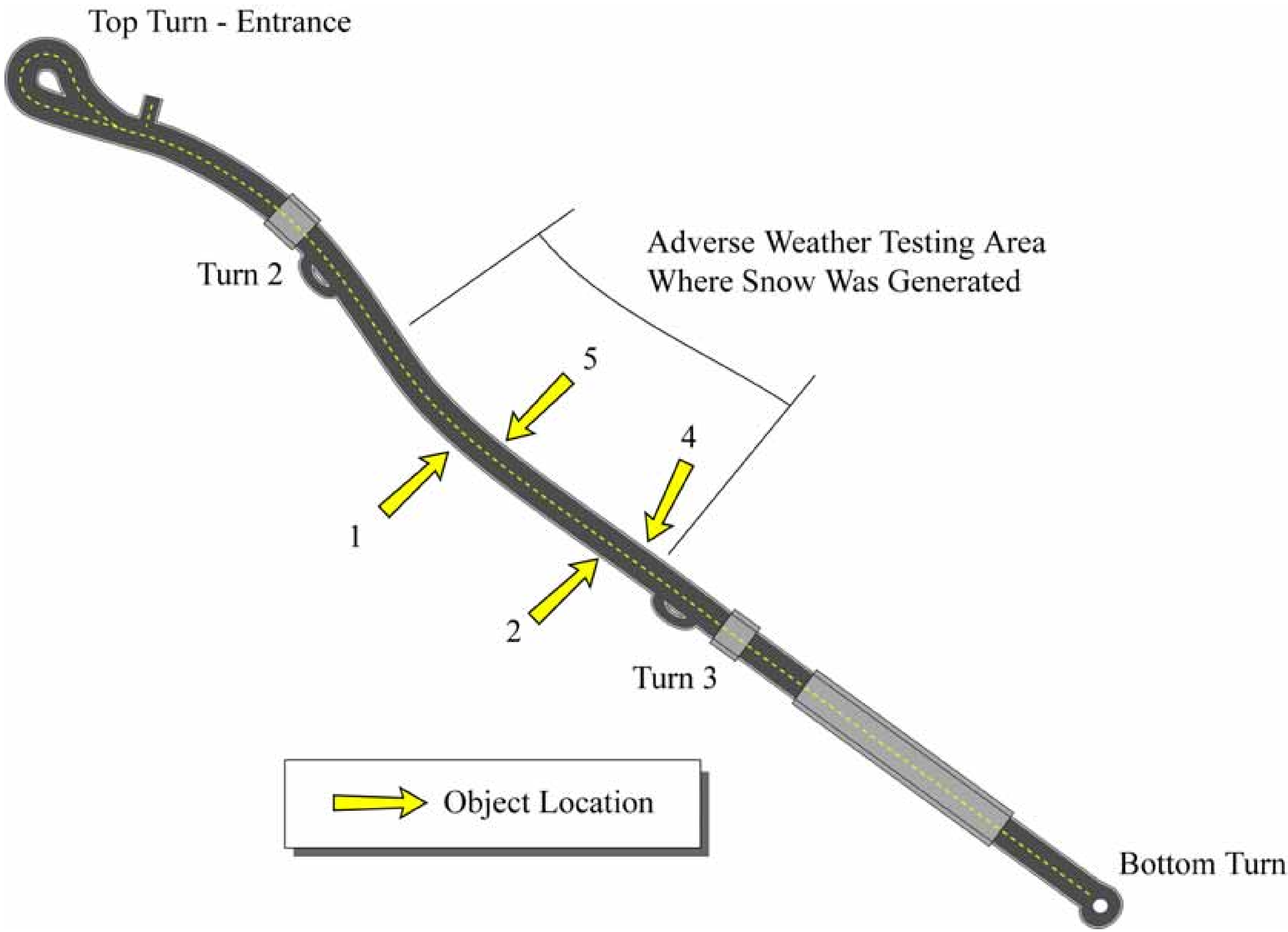


Figure 8. Diagram. Locations where the objects were presented for the adverse weather condition (note the area where snow was generated).

Headlamp Aiming

The headlamps used for several of the VES configurations were on externally mounted light bars. These light bars were used for the HLB, HID, and UV–A configurations. Each light assembly movement required a re-aiming process, which took place each night before the study started. The protocol used for aiming was developed with the help of experts in the field. (See references 14, 15, 16, and 17.) Appendix J gives the details of the aiming protocol used for this specific study. 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 indeterminate. The aiming could have resulted in more illumination on pedestrians, therefore leading to increased detection and recognition distances. The aiming also could have led to increased backscatter from the snow, 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

The experiment was performed in one night, which included the laboratory training and the Smart Road experiment. The entire session lasted approximately 3.5 hours, and two participants performed the experiment simultaneously. The participants were familiarized with the Smart Road and the experimental objects before starting the experiment. During the onroad portion, four VES configurations were presented to the participants; the order of VES presentation was counterbalanced. Details of the procedures are discussed next.

Participant Screening

Initially, candidates were screened over the telephone (appendix A), and if a candidate qualified for the study, a time was scheduled for testing. Qualified candidates were instructed to meet the experimenter at the contractor facility in Blacksburg, VA. After arriving, each candidate was given an overview of the study, then asked to complete the informed consent form (appendix B) and take an informal visual acuity test using a Snellen chart, a contrast sensitivity test, and a color vision test (appendix C). Appendix D describes a detailed experimenter protocol for vision testing. After these steps, and if no problems were identified, the candidate was accepted as a participant and then trained on the experimental tasks to be performed during the drive.

Lab Training

Each participant was instructed on how to perform the tasks associated with object detection and recognition and how the questionnaires would be used. The study protocol and pictures of the objects were presented at this point (appendixes D and E). The detection and recognition definitions, the use of the pushbutton wand, and the Likert-type scales for the questionnaire were also explained. The training presentation outlined the onroad procedures, showed pictures of the objects, and allowed for questions. The purpose of this lab training was to allow all participants to begin the experiment with a standard knowledge base.

Familiarization

Because participants changed vehicles as part of the study, each participant was familiarized as soon as he or she reached an experimental vehicle. While the vehicle was parked, the onroad experimenter reviewed general information concerning its operation (appendix K). Each participant was asked to adjust the seat and steering wheel position for his or her driving comfort. When the participant felt comfortable with the controls of the vehicle, the experiment was ready to start.

Driving Instructions

Participants received instructions to remain in the center of the roadway while driving, which ensured an even snow coverage over the experimental vehicle because the snowmaking towers were extended to be directly centered over the roadway. Participants were also instructed to place the vehicle in park after reaching each of the turnarounds, allowing time for the onroad objects to be changed. Participants were instructed to drive at 16 km/h (10 mi/h) or below on the road where the snow was falling. Participants were required to follow instructions from the in-vehicle experimenters at all times.

Driving and Practice Lap

Each participant drove down the road to become familiar with the road and the vehicle; no objects were presented during this test run. At the bottom turnaround, the experimenter gave the pushbutton wand to the participant and instructed the participant that this portion of the session was a practice to familiarize him or her with the objects. The participant then drove back up the road for a practice run of detection and recognition tasks, obtaining feedback from the experimenter as needed. After the practice tasks, the participant began the experimental tasks, driving with the four VESs corresponding to their assigned order.

General Onroad Procedure

Distance data were collected while each VES was evaluated. The in-vehicle experimenter provided the participant with a pushbutton wand to flag the data collection program when detection and recognition were performed. Other than detection, recognition, and maintaining 16 km/h (10 mi/h) or below, participants performed no other tasks while driving. The experimenter, seated in the passenger seat, let the participant know when to start driving and where to park. The in-vehicle experimenter also administered the questionnaires after each VES configuration and controlled the data collection program. For more details on the in-vehicle experimenter protocol, refer to appendix F.

A snowplow was used between VES reconfigurations to maintain consistent snow coverage on the road. The snowplow usually required about four passes of the road to clear the accumulation, and the in-vehicle experimenter used this time to administer the subjective questions.

Sequence of Data Collection

Each participant followed the same sequence of events for data collection for each of the VES configurations. This sequence was as follows:

1. In the snow condition study, each of the four locations either had an object or was blank in a counterbalanced order for a total of three objects and one blank for each VES configuration.

2. While approaching each location, the participant pressed the button when he or she was able to detect an object.
3. When the participant could recognize the object, he or she pressed the button again and identified the object aloud.
4. The in-vehicle experimenter flagged the data collection system the moment the participant passed the object.
5. The participant performed this detection and recognition sequence for one lap, which completed a run for a given VES. Then the participant answered a subjective rating questionnaire on that VES. The participant changed vehicles (if needed) and started the next VES run after the snowplow informed the experimenter the road was clear to proceed.
6. After all VES configurations were completed, the experimenter instructed the participant to return to the building to be debriefed (appendix H).

The procedures for this study, including training, experimentation, and debriefing, were conducted in two shifts every night (first shift, 7:45 to 11 p.m.; second shift: 11:30 p.m. to 2:30 a.m.). Participants who usually worked and drove late at night ran in the second shift to minimize the possibility of fatigue. Other participants ran during the first shift. Participants received payment for the total number of their participation hours at the end of the experimental session.

DATA ANALYSIS

Data for this research were contained in one data file per VES configuration per participant. All the data collected for the 20 participants were merged into a single database that included objective and subjective data. An analysis of variance (ANOVA) was performed to evaluate drivers' detection and recognition performances with each of the different configurations. PROC ANOVA was used in SAS® statistical software to compute the ANOVA. Table 5 shows the full experimental design model used in the data analysis.

Table 5. Model for the experimental design.

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

The main effects that characterized this study were VES configuration (VES), driver's age (Age), and type of object (Object). A Bonferroni post hoc analysis was performed for the significant main effects ($p < 0.05$). Post hoc analyses assisted in the identification of 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 levels significantly different. A detailed discussion of post hoc tests is referred to Winer, Brown, and Michels.[18]

CHAPTER 3—RESULTS

OBJECTIVE MEASUREMENTS

A total of 240 observations were obtained from the experiment for each of the objective measurements, detection and recognition distances. An ANOVA was performed on both objective measurements using a 4 (VES) by 2 (Age) by 3 (Object) mixed factorial model. The ANOVA summary tables for both detection distance (table 6) and recognition distance (table 7) indicate that only the main effects for VES and object were significant for detection and recognition distances. The interactions and the main age effect were not significant at $p < 0.05$ (table 8).

The mean and standard error (SE) detection distances of the two age groups were as follows:

- Younger age group: Mean = 60.7 m (199 ft), SE = 2.1 m (7 ft).
- Middle-aged group: Mean = 58.8 m (193 ft), SE = 1.8 m (6 ft).

The mean and SE recognition distances were as follows:

- Younger age group: Mean = 56.7 m (186 ft), SE = 2.1 m (7 ft).
- Middle-aged group: Mean = 53.6 m (176 ft), SE = 1.8 m (6 ft).

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

Source	DF	SS	MS	F value	P value	
Between						
Age	1	2462.85	2462.85	0.33	0.5714	
Subject/Age	18	133398.01	7411.00			
Within						
VES	3	78260.57	26086.86	13.51	<.0001	*
VES by Age	3	8128.74	2709.58	1.40	0.2518	
VES by Subject/Age	54	104264.09	1930.82			
Object	2	501349.91	250674.95	71.44	<.0001	*
Object by Age	2	2614.38	1307.19	0.37	0.6916	
Object by Subject/Age	36	126324.28	3509.01			
VES by Object	6	12586.14	2097.69	1.03	0.4085	
VES by Object by Age	6	12746.63	2124.44	1.05	0.4002	
VES by Object by Subject/Age	108	219479.03	2032.21			
TOTAL	239	1201614.61				

* $p < 0.05$ (significant)

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

Source	DF	SS	MS	F value	P value	
Between						
Age	1	5869.12	5869.12	0.61	0.4459	
Subject/Age	18	173962.99	9664.61			
Within						
VES	3	60887.44	20295.81	10.87	<.0001	*
VES by Age	3	10399.35	3466.45	1.86	0.1480	
VES by Subject/Age	54	100852.77	1867.64			
Object	2	481380.77	240690.38	73.94	<.0001	*
Object by Age	2	2787.11	1393.56	0.43	0.6550	
Object by Subject/Age	36	117183.20	3255.09			
VES by Object	6	16970.24	2828.37	1.34	0.2447	
VES by Object by Age	6	17810.23	2968.37	1.41	0.2177	
VES by Object by Subject/Age	108	227513.45	2106.61			
TOTAL	239	1215616.69				

* $p < 0.05$ (significant)

Table 8. Summary of significant main effects and interactions.

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

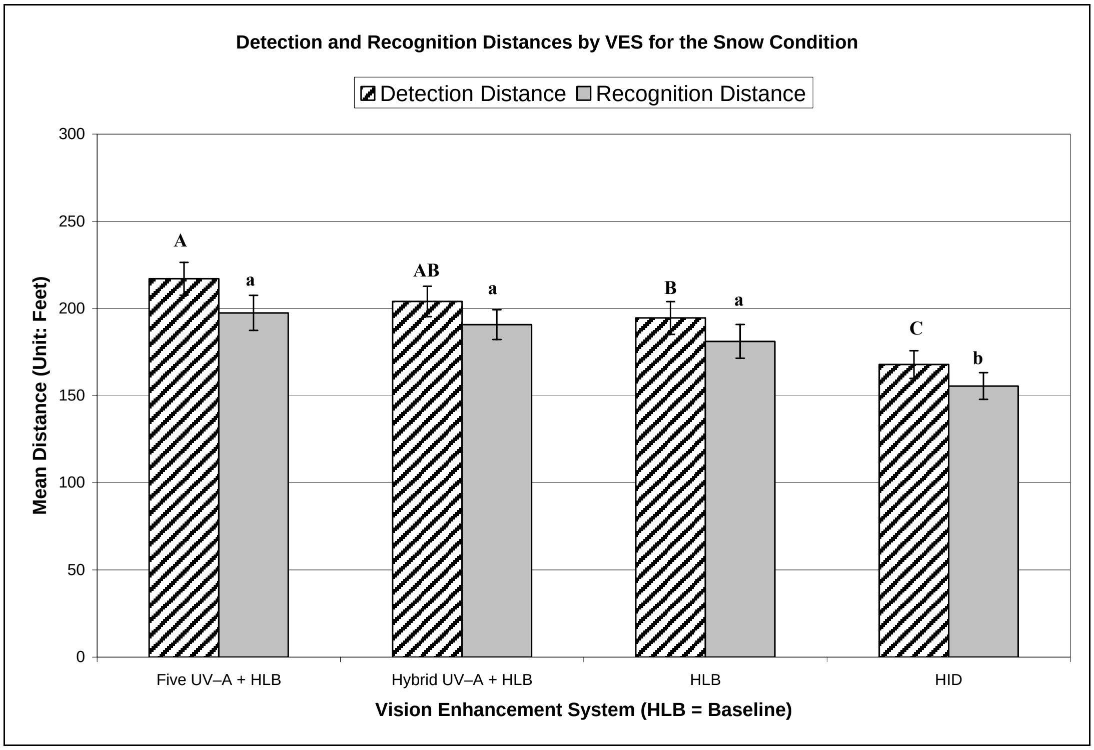
x = $p < 0.05$ (significant)

The post hoc results for the significant main effects are shown as graphs in figure 9 and figure 10. Standard error bars are provided with the means, and means with the same letter in their grouping were not considered significantly different (based on the Bonferroni post hoc test).

The HLB headlamp is the most commonly available VES, making its experimental results a baseline measure; therefore, it is suggested that a comparison of the results of other VESs be made 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, and the results are not necessarily representative of all halogen headlamps currently on the market.

VES Main Effect

The VES main effect for both detection and recognition distances can be seen in figure 9. For detection distance, the supplemental UV–A showed a significant benefit over the baseline HLB. The average detection distance for the five UV–A + HLB configuration was 66.1 m (217 ft), and the detection distance for the hybrid UV–A + HLB was 62.2 m (204 ft). The detection distance for the HLB was 59.4 m (195 ft). Detection distances for all the VESs were significantly different than that for the HID configuration (51.2 m, 168 ft), which performed the worst. HID performed similarly on recognition distances, with both UV–A + HLB pairings and the HLB alone having significantly greater distances. The recognition distances for HLB and the HLB with supplemental UV–A were not significantly different from each other.

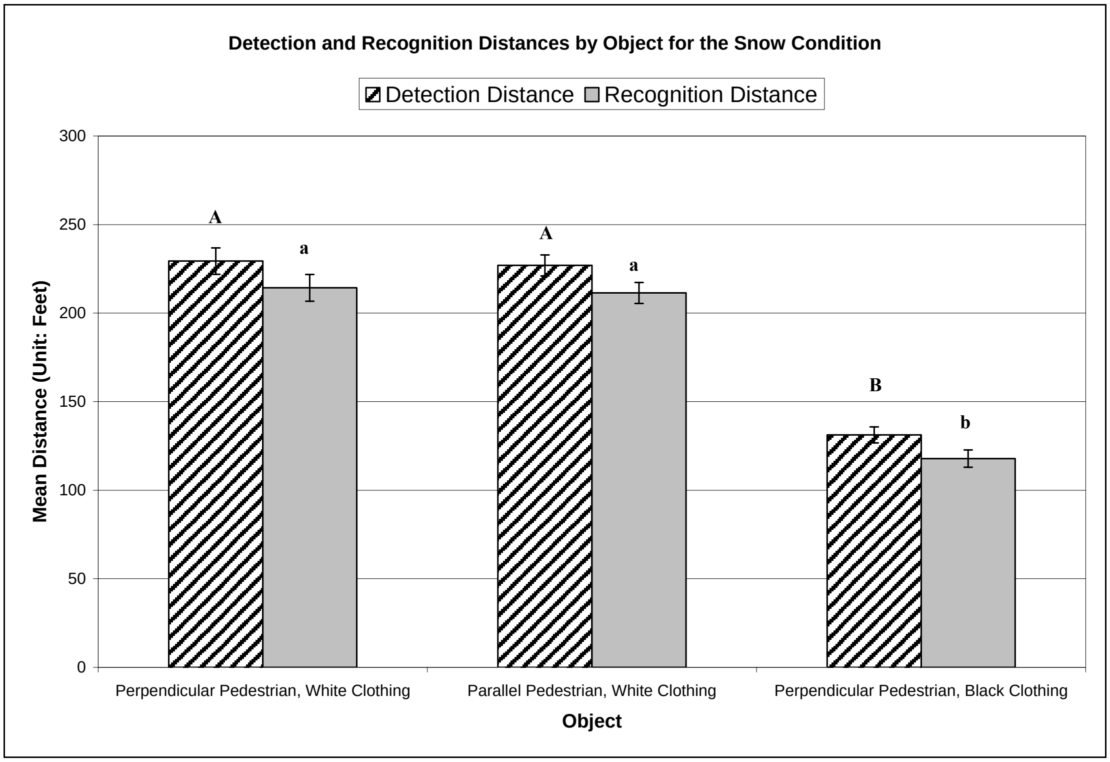


1 ft = 0.305 m
Means with the same letter are not significantly different.

Figure 9. Bar graph. Bonferroni post hoc results on detection and recognition distances for the main effect: VES.

Object Main Effect

The post hoc results suggest that the clothing color (white versus black) determined the significant differences for the object main effect (figure 10). The detection distances of both the perpendicular and parallel pedestrians wearing white clothing—69.8 m (229 ft) and 69.2 m (227 ft), respectively—were significantly greater than the 39.9-m (131-ft) detection distance of the perpendicular pedestrian wearing black clothing. This suggests that, overall, the clothing color rather than the motion of the object caused the observed differences. These trends were also followed by the recognition distances, where the perpendicular and parallel pedestrians wearing white clothing—65.2 m (214 ft) and 64.3 m (211 ft), respectively—outperformed the 36.0-m (118-ft) detection distance for the perpendicular pedestrian wearing black clothing.



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

Figure 10. Bar graph. Bonferroni post hoc results on detection and recognition distances for the main effect: object.

SUBJECTIVE MEASUREMENTS

An ANOVA was performed to analyze the subjective measurements using a 4 (VES) by 2 (Age) mixed factorial model. ANOVA summary tables were generated for each of the seven subjective statements, shown in table 9 through table 15. No significant difference was found for any of the statements. Missing values for statement 1 (one response), statement 5 (one response), and statement 6 (two responses) resulted in total degrees of freedom (DF) for these statements that were different from those of statements 2, 3, 4, and 7.

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	1	3.6	3.6	0.79	0.3868
Subject/Age	18	82.8	4.6		
Within					
VES	3	14.5	4.8	2.20	0.0989
VES by Age	3	5.0	1.7	0.75	0.5245
VES by Subject/Age	53	116.4	2.2		
TOTAL	78	222.4			

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	1	7.8	7.8	1.67	0.2132
Subject/Age	18	84.4	4.7		
Within					
VES	3	13.4	4.5	1.83	0.1524
VES by Age	3	4.2	1.4	0.58	0.6323
VES by Subject/Age	54	132.1	2.4		
TOTAL	79	242.0			

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	1	0.1	0.1	0.01	0.9196
Subject/Age	18	96.0	4.8		
Within					
VES	3	3.1	1.0	0.59	0.6213
VES by Age	3	4.1	1.4	0.78	0.5121
VES by Subject/Age	54	93.9	1.7		
TOTAL	79	197.0			

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	1	0.2	0.2	0.04	0.8510
Subject/Age	18	99.1	5.5		
Within					
VES	3	2.1	0.7	0.41	0.7499
VES by Age	3	4.1	1.4	0.79	0.5042
VES by Subject/Age	54	93.3	1.7		
TOTAL	79	198.8			

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	1	7.5	7.5	1.93	0.1822
Subject/Age	18	70.3	3.9		
Within					
VES	3	13.1	4.4	2.10	0.1111
VES by Age	3	1.3	0.4	0.20	0.8951
VES by Subject/Age	53	110.4	2.1		
TOTAL	78	202.6			

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	1	0.1	0.1	0.01	0.9156
Subject/Age	18	84.1	4.7		
Within					
VES	3	9.5	3.2	1.50	0.2243
VES by Age	3	4.2	1.4	0.66	0.5822
VES by Subject/Age	52	110.0	2.1		
TOTAL	77	207.9			

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	1	4.5	4.5	0.78	0.3899
Subject/Age	18	104.6	5.8		
Within					
VES	3	7.8	2.6	0.99	0.4025
VES by Age	3	5.5	1.8	0.70	0.5546
VES by Subject/Age	54	141.9	2.6		
TOTAL	79	264.4			

To understand drivers' ratings of the various VESs in terms of safety and comfort, the results for all seven statements for every VES were sorted by ascending mean rating. Although not significant, drivers rated the five UV–A + HLB VES as the top configuration that allowed them to detect objects sooner (statement 1), allowed them to recognize objects sooner (statement 2), helped them stay on the road better (statement 3), and made them feel safer (statement 6); it was perceived as being a better VES than their regular headlights (statement 7). The hybrid UV–A + HLB configuration had the top rating for seeing the direction of the roadway (statement 4), and the HLB was rated as the top configuration for not causing any more visual discomfort than the participant's regular headlights (statement 5).

It is interesting, although not statistically significant, that the HID was rated better than the HLB in all statements other than statement 4 (their averages were equal for statements 6 and 7), conflicting with the objective measurements. Although the subjective results were not significant, the conflicting results do exhibit the difference in driver perception and performance. The HLB was rated as the worst for detection, recognition, staying on the road, and seeing the road direction even though it significantly outperformed the HID on the objective measurements. Although it was the worst performer, the HID was the second-highest rated configuration with respect to feeling safer and being a better configuration than the participant's regular headlights. Following are the results by statement.

- ***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
Five UV–A + HLB	2.3
Hybrid UV–A + HLB	2.7
HID	3.2
HLB	3.4

- ***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
Five UV–A + HLB	2.3
Hybrid UV–A + HLB	2.8
HID	3.1
HLB	3.4

- ***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
Five UV–A + HLB	3.0
Hybrid UV–A + HLB	3.2
HID	3.4
HLB	3.5

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

VES	Mean Rating
Hybrid UV–A + HLB	3.0
Five UV–A + HLB	3.2
HID	3.2
HLB	3.5

- ***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	2.0
Five UV–A + HLB	2.1
HID	2.6
Hybrid UV–A + HLB	3.0

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

VES	Mean Rating
Five UV–A + HLB	2.4
HID	3.1
HLB	3.1
Hybrid UV–A + HLB	3.3

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

VES	Mean Rating
Five UV–A + HLB	2.2
HID	2.8
HLB	2.8
Hybrid UV–A + HLB	3.1

CHAPTER 4—DISCUSSION AND CONCLUSIONS

DETECTION AND RECOGNITION DISTANCES

While there were some significant differences in the detection and recognition distances among different VESs during nighttime driving in snow, these differences would result in minimal improvements to driver reaction times for the objects tested. The HLB supplemented with UV–A allowed drivers to detect objects farther away than with the HLB system alone by as much as 6.7 m (22 ft), as shown in table 16, representing an 11 percent increase. On average, the HID configuration provided the lowest detection and recognition distances. When compared to the HLB, the HID headlamps resulted in object detection distances that were 8.2 m (27 ft) closer to the object of interest, a 14 percent decrease in distance. Visibility for all the VESs was severely decreased by the snow, approximately 5.1 cm/h (2 inches/h) to 12.7 cm/h (5 inches/h), when compared to the clear weather condition, a decrease ranging from 65 to 68 percent depending on the VES (table 17). These results were comparable to the decrease in visibility seen in the rain condition study (ENV Volume IV). It is important to note that all VES configurations used in this study appear to have been affected equally by the low visibility, with a range of only 3 percent separating the percentile reductions in detection distances for the four configurations when compared to the results from the clear weather condition study (ENV Volume III).

Table 16. Mean detection and recognition distances (units: feet) during nighttime driving.

VES	Mean Detection	Mean Recognition	Comparison to HLB Detection	Comparison to HLB Recognition
Five UV–A + HLB	217	197	22	16
Hybrid UV–A + HLB	204	191	10	10
HLB	195	181	0	0
HID	168	155	−27	−26

1 ft = 0.305 m

Table 17. Differences in detection distances (units: feet) between clear, rain, and snow environments.

VES	Clear Detection	Rain Detection	Snow Detection	Detection Difference (Clear – Snow)	Percent Reduction (Clear – Snow)	Detection Difference (Rain – Snow)	Percent Reduction (Rain – Snow)
Five UV–A + HLB	625	221	217	408	65	4	2
Hybrid UV–A + HLB	617	210	204	413	67	6	3
HLB	605	198	195	410	68	3	2
HID	506	179	168	338	67	11	6

1 ft = 0.305 m

These differences in distance can be translated to gains or losses in reaction time (table 18). Reaction time has been used in the past to evaluate time margins for crash avoidance behavior when encountering obstacles in the driving path.[19] As mentioned previously, significant differences between the HLB and the other VESs were less than 8.2 m (27 ft), which translates to less than one second of additional reaction time, even at relatively low speeds (table 18).

Table 18. Difference in reaction time (units: seconds) available depending on vehicle speed, based on the difference of detection time from HLB.

VES	Detection difference (ft)	25 mi/h	35 mi/h	45 mi/h	55 mi/h	65 mi/h
Five UV–A + HLB	22.5	0.6	0.4	0.3	0.3	0.2
Hybrid UV–A + HLB	9.5	0.3	0.2	0.1	0.1	0.1
HLB	0.0	0.0	0.0	0.0	0.0	0.0
HID	−26.7	−0.7	−0.5	−0.4	−0.3	−0.3

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 completely describe any potential safety benefits or concerns based on VES use; however, with a limited number of assumptions, the VES-specific detection distances in snow conditions 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.[20] For consistency, time-to-collision will be presented as distance-to-collision, or stopping distance, for direct comparisons to detection distances from this study. Stopping distance is the sum of two components: (1) the distance needed for the braking reaction time (BRT) and (2) braking distance (table 19). Braking distance is the distance that a vehicle travels while slowing to a complete stop.(21) 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 11 provides the calculation of the braking distance (d_{BD}) under these conditions:

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

Figure 11. 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 22, 23, 24, and 25.) 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 12:

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

Figure 12. Equation. Total stopping distance for brake reaction time plus braking distance.

The equation in figure 12 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.(22) The equation in figure 12 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, this study used AASHTO's suggested deceleration rate (*a*) of 11.2 ft/s^2 (3.4 m/s^2), resulting in a friction coefficient for wet pavement of 0.35 as seen in the equation in figure 13.[(22)]

$$\boldsymbol{f = a/g = 11.2\ \mathrm{ft/s^2}\ /\ 32.2\ \mathrm{ft/s^2} = 0.35}$$

Figure 13. Equation. AASHTO calculation of coefficient of friction for wet pavement.

Stopping distances in snow conditions increase over dry-pavement distances because of the reduced coefficient of friction between the tires and the pavement. Using the equations and variables, stopping distances were calculated as shown in table 19.

Table 19. Stopping distances needed for wet roadways due to snow.

	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)	60	117	193	289	403	468
Stopping Distance (ft)	**151**	**245**	**358**	**490**	**642**	**724**

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

The calculations in table 19 represent a simple condition, but they allow for some visualization of the VESs' capabilities. Based on these calculations, the average detection distances shown in table 16 for each VES tested in the snow condition (i.e., precipitation rate of approximately 5.1 cm/h (2 inches/h) to 12.7 cm/h (5 inches/h) with windshield wiper on high speed) are long enough to provide sufficient time to react to pedestrians dressed in white clothing and brake, as long as the speed is less than or equal to 40 km/h (25 mi/h), or less than 56 km/h (35 mi/h) with the five UV–A + HLB configuration (table 20 through table 23, in which an "X" means stopping distance might be compromised); however, some caveats do apply. First, these distances were obtained while drivers were moving at approximately 16 km/h (10 mi/h) or less, and their ability to detect objects will not necessarily remain the same as speed increases. Second, VESs that provide detection distances close to the stopping distance or that need a larger stopping distance might quickly become less effective when conditions such as worn tires or downhill slope worsen.

As seen in the clear condition study (ENV Volume III) and rain condition study (ENV Volume IV), detection and recognition distances in the snow condition are deeply affected by the characteristics of the object, but this effect is modulated by the type of VES. The HID provided the shortest detection distance for low-contrast objects; the HLB supplemented by UV–A allowed drivers to detect the pedestrians dressed in white clothing farther away. These observations are even more apparent when described in terms of stopping distances. As shown in table 20 through table 23, it is important that only the five UV–A + HLB configuration appears to allow for an uncompromised stopping distance from a traveling speed of 56.35 km/h (35 mi/h) when the object is a pedestrian wearing white clothing.

Table 20. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: five UV–A + HLB.

Type of Object	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
Perpendicular Pedestrian, Black Clothing	140	X	X	X	X	X	X
Parallel Pedestrian, White Clothing	248			X	X	X	X
Perpendicular Pedestrian, White Clothing	263			X	X	X	X

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

Table 21. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: hybrid UV–A + HLB.

Type of Object	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
Perpendicular Pedestrian, Black Clothing	144	X	X	X	X	X	X
Perpendicular Pedestrian, White Clothing	233		X	X	X	X	X
Parallel Pedestrian, White Clothing	235		X	X	X	X	X

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

Table 22. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HLB.

Type of Object	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
Perpendicular Pedestrian, Black Clothing	131	X	X	X	X	X	X
Parallel Pedestrian, White Clothing	221		X	X	X	X	X
Perpendicular Pedestrian, White Clothing	232		X	X	X	X	X

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

Table 23. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HID.

Type of Object	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
Perpendicular Pedestrian, Black Clothing	111	X	X	X	X	X	X
Perpendicular Pedestrian, White Clothing	189		X	X	X	X	X
Parallel Pedestrian, White Clothing	204		X	X	X	X	X

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

As discussed in ENV Volume III, the literature review suggested that new VES technologies including HID and configurations supplemented by UV–A headlamps would outperform HLB in the experimental conditions for this study. The HID configuration did not reach that expectation. Although the HLB supplemented by UV–A did outperform HLB alone, the improvements (< 0.6 s), while statistically significant, do not represent a meaningful improvement in reaction time.

In general, HID systems followed the same trend discussed during the clear and rain weather conditions (ENV Volumes III and IV), where they were outperformed by the rest of the systems. The same issues that were suggested then may have negatively affected the performance of this technology in the snow condition. It is possible that the HID system tested here differs significantly from the HID systems tested in other investigations in terms of cutoff and intensity; the characteristics of these systems vary considerably among manufacturers of the headlamps. While unpublished data generated by this investigation (refer to ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*) agrees with Jost that an HID system provides more luminous flux than regular tungsten-halogen headlamps, there appear to be some shortcomings with how that luminous flux is used.(26) The large amount of visible light generated by HID systems requires a dramatic cutoff angle to comply with glare standards. While this provides more foreground luminance, less illumination is actually provided by the HID VES as the distance from the vehicle increases when compared to the other VESs such as halogen. The increased foreground luminance of the HID might have an adverse effect on a driver's performance by increasing the driver's light adaptation, thus decreasing the driver's capability to detect objects in dark environments; however, this hypothesis was not reflected in the subjective ratings, where the HID VES received better though not statistically different ratings than the HLB for six out of the seven statements. These results do correspond with the rain condition (ENV Volume IV). It is possible that the increased foreground luminance deceives drivers into believing that they can see farther, when in fact the results of this study show that they cannot. It is interesting that the subjective ratings for ability to detect and recognize objects (statements 1 and 2) matched the objective measurement rankings except for the order of HID and HLB even though the HLB, on average, provided detection and recognition distances that were approximately 8.2 m (27 ft) and 7.9 m (26 ft) longer, respectively.

UV–A headlamps improved detection and recognition of various objects when five UV–A headlamps were used together with HLB, especially for pedestrians with white clothing; however, the improvement suggested by this study were not of the magnitude of the ones reported by Mahach et al.(27) and Nitzburg et al.(28) In addition, this extra 6.7 m (22 ft), which resulted in an improvement of 10 percent, is statistically significant but not a meaningful improvement for implementation purposes.

One item of interest with respect to the five UV–A + HLB configuration is the larger distance between the points of detection and recognition compared to the other configurations (table 24). On average, for the five UV–A + HLB configuration, participants traveled 6.1 m (20 ft) after detecting an object before recognizing what the object was. This is compared to between 13.7 and 4 m (12 and 13 ft) for the three other configurations. This is not necessarily a negative attribute because the five UV–A + HLB configuration still had the highest detection and recognition distances.

Table 24. Comparison of distance between detection and recognition.

VES	Mean Detection (ft)	Mean Recognition (ft)	Detection − Recognition Distance (ft)
Five UV–A + HLB	217	197	20
Hybrid UV–A + HLB	204	191	13
HLB	195	181	13
HID	168	155	12

1 ft = 0.305 m

AGE EFFECTS ON DETECTION AND RECOGNITION DISTANCES

In the snow condition, in contrast to the clear condition but similar to the rain condition, age does not significantly affect drivers' detection and recognition distances. During the snow condition, visibility is severely restricted across both age groups, and overall no significant difference between age groups is observed in terms of detection and recognition distances; however, some trends did exist. Younger participants detected and recognized the pedestrians wearing white clothing slightly better than the middle-aged participants (longer detection distance of 4.3 m (14 ft) for perpendicular, 1.8 m (6 ft) for parallel), but the distances for the low-contrast (black clothing) pedestrian were essentially the same.

As mentioned in ENV Volumes III and IV, visual acuity and contrast sensitivity decline with age. The same-age dependent trends of decreased visual acuity and contrast sensitivity mentioned in ENV Volume III are evident for this group of participants, as illustrated in figure 14 through figure 19.

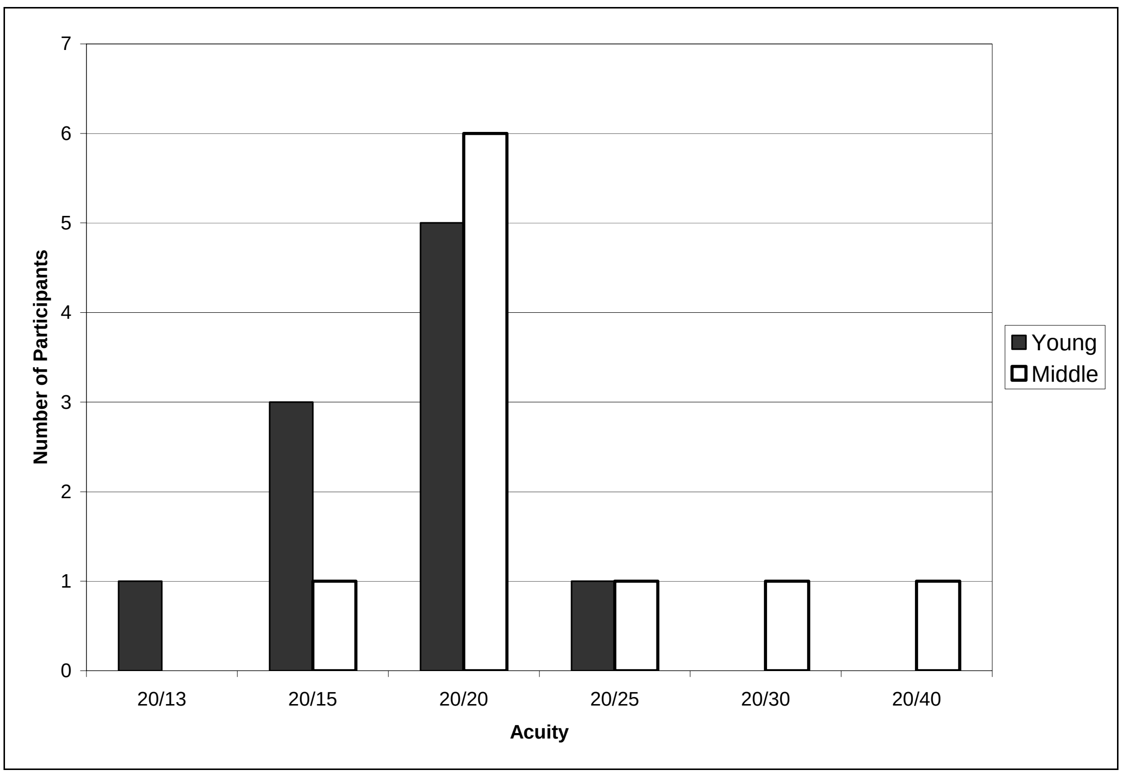


Figure 14. Bar graph. Participants' visual acuity divided by age group.

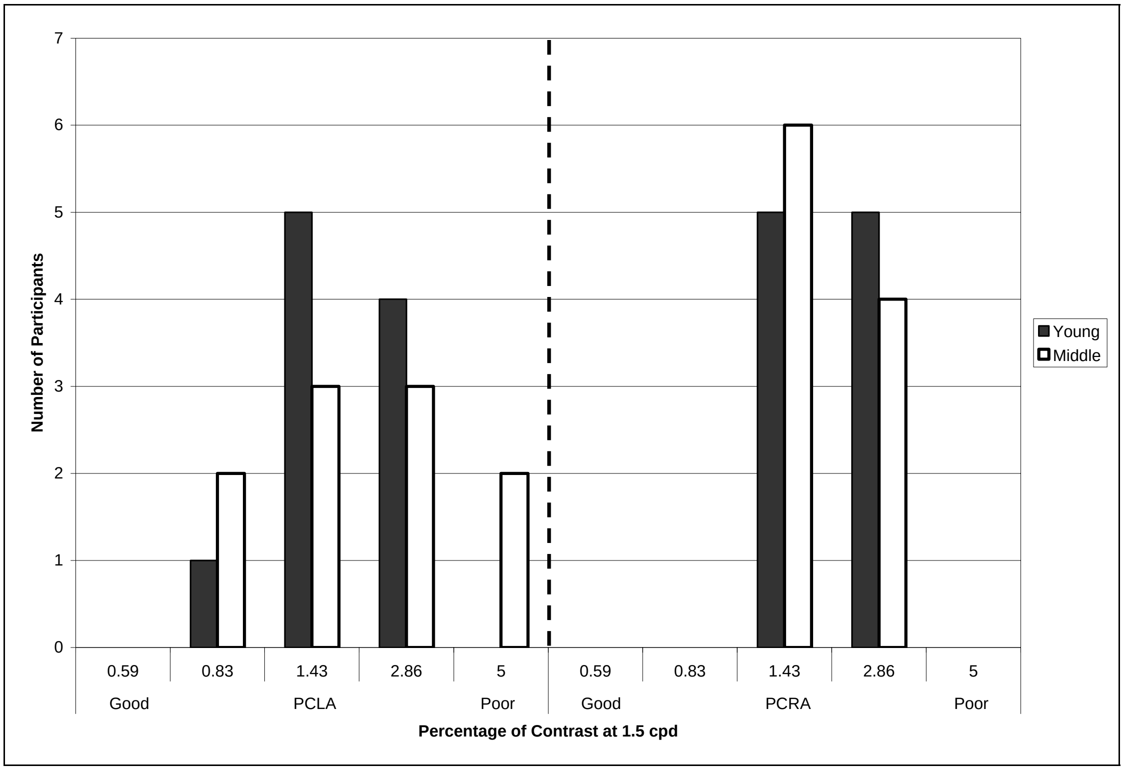


Figure 15. Bar graph. Participants' contrast sensitivity at 1.5 cycles per degree (cpd) divided by age group.

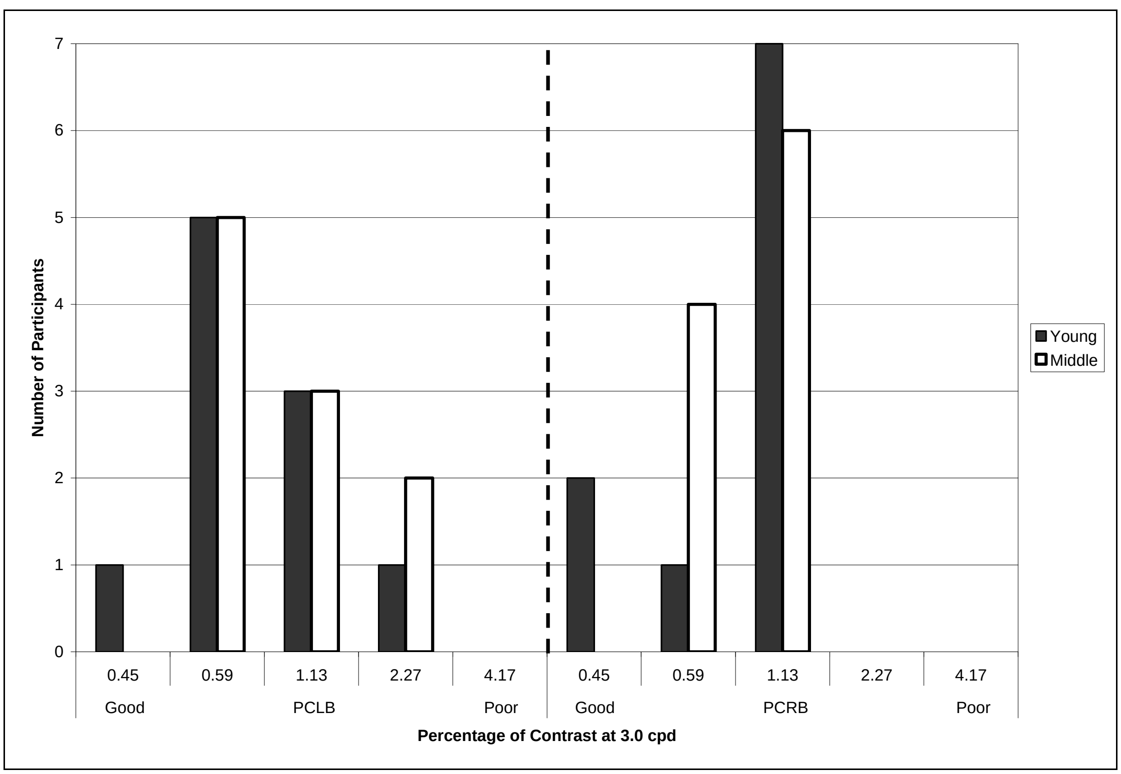


Figure 16. Bar graph. Participants' contrast sensitivity at 3.0 cpd divided by age group.

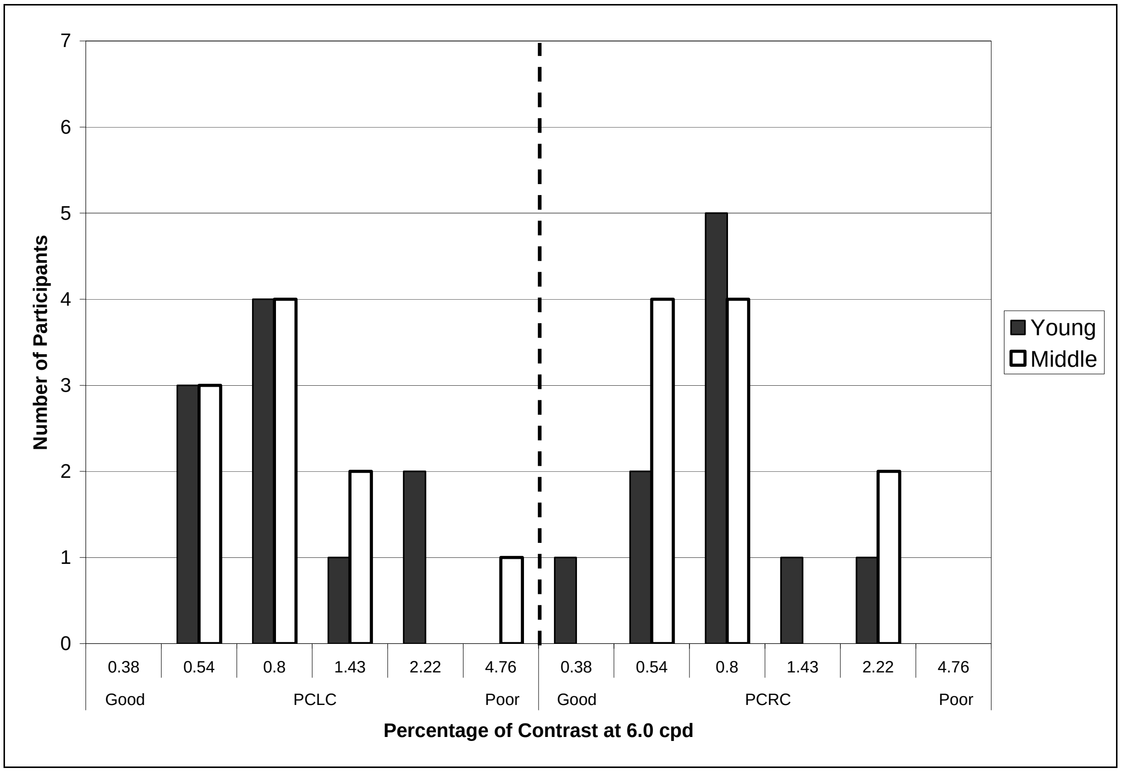


Figure 17. Bar graph. Participants' contrast sensitivity at 6.0 cpd divided by age group.

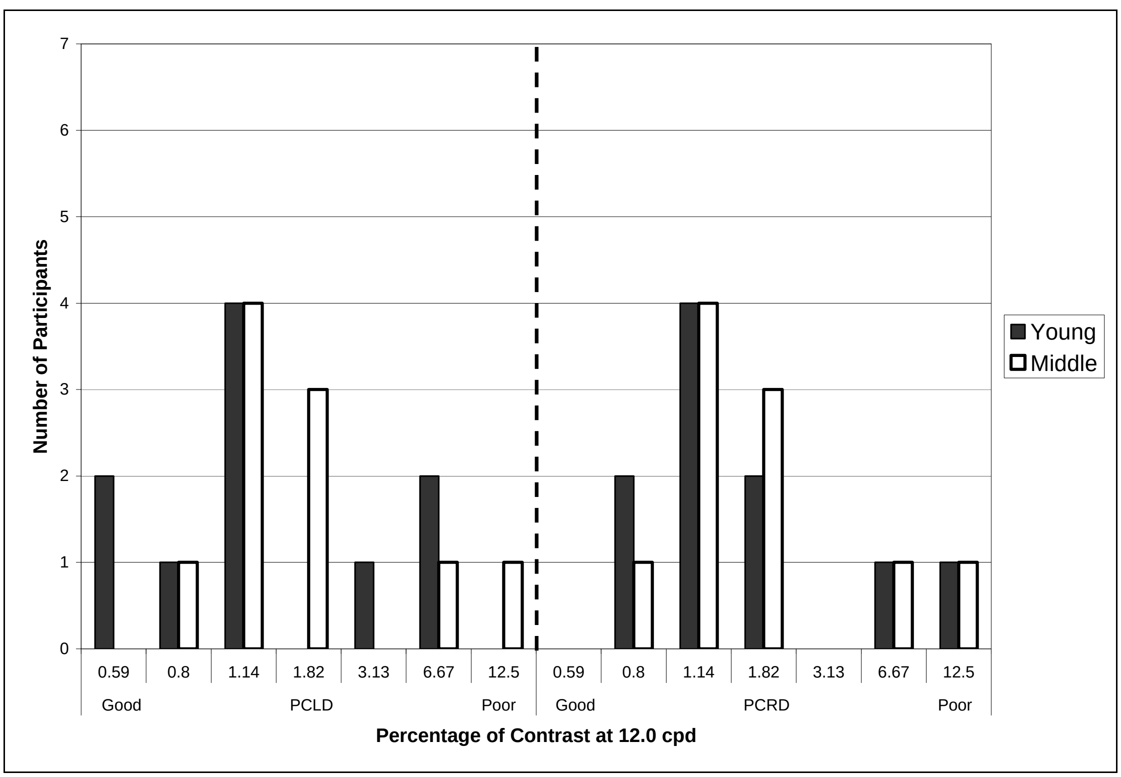


Figure 18. Bar graph. Participants' contrast sensitivity at 12.0 cpd divided by age group.

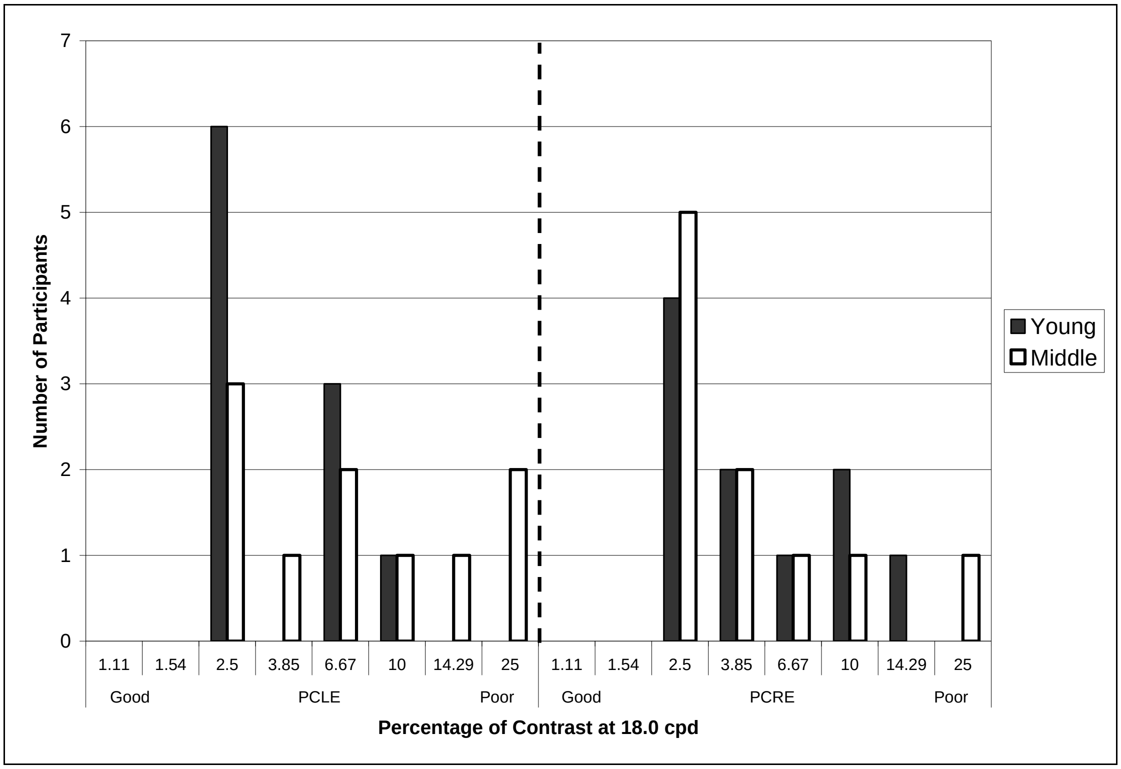


Figure 19. Bar graph. Participants' contrast sensitivity at 18.0 cpd divided by age group.

SUMMARY

In summary, during the snow condition the HLB configuration alone and HLB configurations supplemented with UV–A were consistently the best in facilitating long detection and recognition distances; however, the overall improvement of UV–A does not seem to be meaningful. The following conclusions can be reached regarding the VESs tested during the snow conditions for Phase II—Study 3:

- Halogen supplemented with UV–A is the best configuration for detecting all pedestrian objects, regardless of clothing color or motion.
- UV–A technology does not represent a dramatic improvement over the halogen and HID headlamps used in this research.
- The drivers' subjective evaluations suggest they thought that HID helped them more to detect and recognize the different objects. This finding conflicts with the objective data.
- Most of the findings for the snow condition are consistent with the findings obtained in the clear condition (ENV Volume III) and rain condition (ENV Volume IV) studies.

APPENDIX A—SCREENING QUESTIONNAIRE

Driver Screening and Demographic Questionnaire: ENV-Snow

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 experimental vehicles for one 3 to 4 hour session on the Smart Road. The Smart Road is a test facility equipped with advanced data recording systems. It is equipped with technology that will allow us to create snow, fog, and rain. We will pay you $20 per hour. The total amount will be given to you at the end of the session. 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 to 25 or 40 to 50 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 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: ________
Rejected: ________ Reason:____

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

Willing to drive in snow? Y N Willing to come in 11 p.m. or later? Y N

APPENDIX B—INFORMED CONSENT FORM

[Contractor Facility]
Informed Consent for Participants of Investigative Projects

Title of Project: Detection and Recognition of Pedestrians, 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. Follow the experimental procedures as well as you can.

2. 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: __________

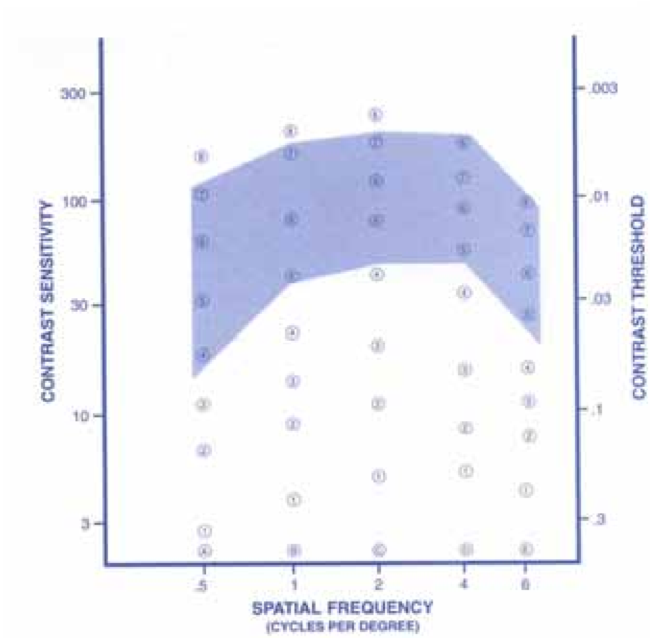
VISION TESTS

Acuity Test

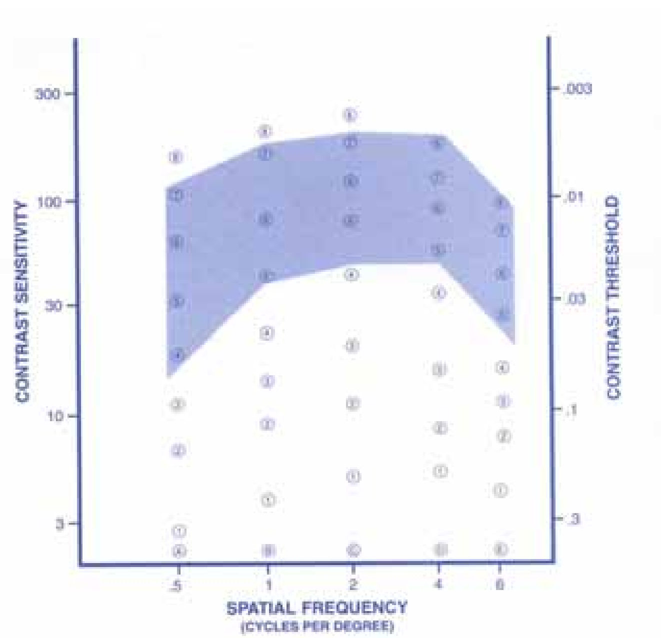
- Acuity Score:_________

Contrast Sensitivity Test

Left



Right



Ishihara Test for Color Blindness

1._____ 4._____ 7.____

2._____ 5._____

3._____ 6._____

APPENDIX D—TRAINING PROTOCOL

Protocol for Enhanced Night Visibility—SNOW

In-Vehicle 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 from prep room.

3. Greet participant.

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

5. Show driver's license.

Before we begin, it is required for me to verify that you have a driver's license. Would you please show me your 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 filling out some forms now and then driving different cars on the Smart Road. The entire study will take approximately 3 hours. We will pay you $20 per hour. The total amount will be given to you at the end of the third session.

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, an experimenter will be in the vehicle with you at all times. The 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 during the drive.

You will be exposed to four 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.

Now I have some paperwork for you to fill out. This first form tells you about the study, what your job is, and any safety risks involved in the study. Please read through the document. If you have any questions, please feel free to ask. If not, please sign and date the paper on the last page.

- Give the participant the form.
- 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.

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 relate 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 participant's answers on the vision test form.

9. ENV training.

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 miles per hour, 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.*

Slide 2: *This is a timeline of how the night will break down. We are in the laboratory training portion right now.*

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 three different vehicles during the onroad study. All three vehicles are sport utility vehicles. The onroad portion will take place out on the Smart Road once it is completely dark. You will be performing the study in a snow 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: *Each vehicle might include more than one configuration of Vision Enhancement Systems for a total of 4 different configurations. All of the Vision Enhancement Systems are different headlight systems.*

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 button again.

Slide 11: *The objects that we will present you are pedestrians and cyclists. The pedestrians will be people walking across or along the road.*

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

Slide 13: *We will also have some questionnaires for you to complete. 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*). For each question, 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 1 and 7. 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 about this questionnaire?*
Answer any questions.

APPENDIX E—TRAINING SLIDES

Enhanced Night Visibility

Schedule and Training

1

Schedule

Orientation

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

On-Road Study

2

What is the Enhanced Night Visibility study?

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

3

Lab Training

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

4

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.

5

The Smart Road

6

Experimental Vehicles

- Vision Enhancement Systems
  - Prototype Headlamps

7

Detection and Identification

- Your primary task is to drive safely
  - Snow; General speed limit once the experiment begins is 10mph. However, when you are driving on the section of road where the snow towers are turned on, we would like you to try to go 5 mph .
- Your job will be to detect and identify different objects on the Smart Road
- You will be required to press a button when you can detect and identify objects

8

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.

9

Identification of Objects

- Identification 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 identify the object, you must push the button and, at the same time, identify the object to the experimenter by saying, "I see a person." or, "I see a cyclist."
- In case of an Unsuccessful Identification press the push button again as soon as you notice what the right object is and tell the experimenter.

10

Types of objects

- Objects
  - Pedestrians: People may be walking across the road.
  - Cyclist: Cyclists may be riding across the road.

11

Objects

Walking Pedestrian and Cyclist

12

Note that a cyclist was included in the training slides to avoid automatic assumption of object type on detection.

Questionnaires

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

13

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 **Identify** an object
- Verbally identify all objects as you press the button for the **Identification** portion
- Respond to the questionnaires
- Ask questions whenever you need to

14

QUESTIONS?

15

APPENDIX F—IN-VEHICLE EXPERIMENTAL PROTOCOL

1. Greet participant.

2. Record the time of their arrival on the debriefing sheet.

3. Orient them to the vehicle.
   - Take participant to the vehicle 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. 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.*
   - Explain to them how to turn on and off the parking lights.
   - Make sure they are wearing their seatbelt.

4. Turn on the baseline VES (HLB) for the drive to the road for the practice lap. Do not turn on the UV VES.
   - 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 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.
   - Follow these instructions 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 SUVs. Depress the appropriate red button corresponding to the desired light. The button will remain in the depressed position and light up red until depressed a second time to release the button and turn the light off.

5. Make sure you are wearing your seatbelt.

6. Communicate to the onroad experimenter, and let him or her know that you are on your way to the road.

7. Instruct the participant to drive to the Smart Road.

8. Radio the control room to ask for the gate to be opened, and tell them the number of cars entering the road.

9. The first vehicle will drive down to T3.

10. Radio the relay station to let them know that you are driving down.
11. The second vehicle will park at the entrance of T2 and wait for the relay station to say that the participant can come down.

12. 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 10 miles per hour. 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 snow on it.

The in-vehicle experimenter is responsible for:

- Allowing the participant to drive down the road.
- Giving permission to the second vehicle to begin after receiving notification that the first vehicle is at T3.
- Reminding the participant of the speed limit if necessary.
- Telling the participant to start slowing down as soon as he or she can see the snow, so he or she can make a smooth entrance at 16.1 km/h (10 mi/h) or slower.

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.
- Wait for valet to clean the headlights and completely move away from vehicle, prior to heading back up the hill.

The instructions for the participant in the second vehicle at the bottom of the hill are to:

- Pull into the nearest parking space.
- Put the vehicle in park and take your foot off the brake.
- Let the valet clean the headlights.

13. Review instructions with the participant. This may be done while waiting at T2 or T3 during the practice drive:
    - Show the participant the button.
    - Read the following instructions:

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 recognize 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, 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 recognize the object.

14. Hand the button to the participant.

15. After both vehicles are at T3, radio the onroad experimenters that you are ready to begin.

16. Allow the participant to do a practice run down the Smart Road. Say to the participant: *We will now practice while you drive down the hill to help you get used to driving the vehicle on the Smart Road and using the buttons. I would like you to drive at 10 miles per hour or less (we don't want the speed dial to go over the 10 miles per hour mark at any point).*

17. Remind the participant how to identify the different objects. Say to the participant: *On the way down we will practice how to detect and recognize objects. You will see two objects. Please remember to say "I see a person" or "I see a cyclist." If you perform an unsuccessful recognition, you can press the button again and orally identify the object.*

18. Make the following checks:
    - Check power supply/inverter of the laptop is connected to the black box and the back of the laptop. A green light on the inverter means that it is connected. If it is not connected, you might run out of power in the middle of the experiment and lose data.
    - Make sure the cable that inputs data to the computer is screwed all the way in.
    - Check that the button with the yellow sticker is on the Velcro.
    - Turn laptop power on.
    - Enter participant number, age, gender, weather condition, target order, and VES.
    - Start the computer program.

It is *very* important that you do not talk to the drivers when you are collecting data, *emergencies excluded.*

19. Monitor the computer while going up the hill. Follow these instructions:
    - Make sure that the value in the "Current Distance" field is increasing. This ensures the program is working.
    - When the participant presses the button the first time, the computer should beep and record the "Detection Dist."
    - After the participant presses the button the second time, the computer should beep and record the "Recognize Dist."
    - Press the keyboard spacebar when your body is in line with the object. After pressing the keyboard spacebar, the arrow will scroll down to the next object.
    - Press the keyboard ESC key if the participant presses the button by accident or states that he or she made a false detection.
    - Press the keyboard ESC key if the participant makes an unsuccessful recognition.
    - After you are aligned with the object, press the keyboard spacebar to reflect the distance of the object.

20. During the practice run, you may need to assist the participant. For example, if he or she does not indicate the detection or recognition points, and the object is within nearly

12.19 m (40 ft), say to the participant: We are very close to the first object, please press the button as soon as you can detect it and then again when you can identify it.

21. 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 identifies the pedestrian.
    - If driver does not see pedestrian, use the computer readout to determine when the vehicle is within 40 ft 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 could be verified using the computer read out.
    - The screen starts flashing when the vehicle is (40 ft) from the station. If there is a pedestrian at the station, say into the radio "Station # XX–Clear" as soon as the screen starts flashing.
    - If you forget to press the keyboard 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.

22. Pull into the turnaround and follow these directions:
    First car at T2:
    - Pull into the turn around and keep to the right 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 gets out of the snow, notify the second vehicle that it can proceed up the road.

    Second car at T2:
    - Pull up to the cone on the left side of the turnaround.
    - Wait until the first car is out of sight before going down the road.

23. Lead experimenter will radio the snowplow operator when both vehicles have reached T2.

24. Ask Driver the Questions about the VES
    - You may begin to ask the questions when the driver is past the snow, 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.
25. Document any unexpected events that occurred during the previous run on the In-vehicle Note Sheet.

26. Show them 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 he or she gets in.

27. Orient the participant to the next vehicle and turn on the lights. Follow these instructions:
    - If the participant has been in the vehicle before, ask if he or she remembers the controls. Be sure to offer to answer questions.
    - Be sure to turn on the lights yourself and show the participant where to turn off the parking lights.
    - Turn on UV lights as soon as you get in the vehicle to allow them time to warm up before data collection.
    - Explain to the participant where the dimmer switch is.
    - Remind the participant to keep his or her seatbelt on at all times.
    - Ask the participant if he or she has any questions.
    - Hand the participant the keys and ask him or her to start the car.
    - Follow the orientation instructions for the appropriate vehicle listed below.

    White SUVs and large SUV:
    - 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.
    - Turn on the parking lights (one click only).
    - Show the participant how to adjust the interior lights. If necessary, help him or her to adjust it by asking him or her to tell you when it is comfortable.

28. Prepare for the first VES
    - Let the valet check the headlamps
    - 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.

29. 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 identifies the pedestrian.
    - If driver does not see the pedestrian, use the computer readout to determine when the vehicle is within 12.19 m (40 ft) of the pedestrian. Use the radio to tell the pedestrian to clear at that time.
    - Make sure the participant is not driving faster than 16.1 km/h (10 mi/h).

30. Continue the same procedure for the remainder of the VES tests.

31. Take the participants and in-vehicle experimenters from both vehicles back to the building in the large SUV.

32. Document the time on the participant’s debriefing sheet.
    - Ask the participant to fill out the payment receipt log.
    - Pay the participant, and thank him or her for participating.

APPENDIX G—SMART ROAD

Figure 20. Photo. Aerial view of the Virginia Smart Road.

The Virginia Smart Road (figure 20) 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 H—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. (Name of investigators) 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 I—ONROAD EXPERIMENTER'S PROTOCOL

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 mi/h speed limit on the road and 10 mi/h if the snowmaking has started, or if there is snow on the road.
- Use a spotter when moving vehicles in and out of the garage.
- Wear closed-toe shoes at all times.
- Wear dark clothes and dark shoes.
- Always wear your vest on the road.
- Do not travel with the tailgate open.
- Wear your safety glasses when you are exposed to headlights.
- Always drive with your lights on.
- If equipment breaks, tell the lead experimenter as soon as possible.
- Attend the nightly meeting.

Each night, you need to arrive at [contractor 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 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 in-vehicle 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 in-vehicle experimenters extra time to reply.

PRE-EXPERIMENT

Onroad experimenters are expected to:

- Attend nightly meeting
- Review changes in protocol
- Lead experimenter will distribute the following forms:
    - Vehicle and road prep sheets to the valets.
    - Lead valet vehicle checklist.
    - Participant eye measurement sheets to valets.
    - VES order sheets with VES diagram to valets.
    - Object order to onroad experimenters.

Onroad experimenters are responsible for obtaining the following equipment:

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

- Vest.
- Flash light.
- Safety glasses.

The valets are responsible for preparing the vehicles each night. However, onroad experimenters will need to assist them with this if they have any down time. Valets are to:

- Put on vests.
- Load nine cones into pickup to be placed at the turnarounds when you reach the road. Five will be dropped at the first turnaround and four at the bottom turnaround.
- Place the tarps that will be used to cover the seat in one of the SUVs.
- Park two SUVs at the front of the building for the participants.
- Transport the onroad personnel to the road using the pickup (Valet #2) – stations 2 and 4, and the large SUV (lead valet) – stations 1 and 5.
- The lead valet is in charge of moving the generator cart from either the garage or the road storage container. This can be towed by the large SUV, SUV 2, and the pickup. At no point is the generator to be driven through the snow. It must be left at the turnaround before the onroad personnel are dropped off. The generator must not be driven faster than 32.19 km/h (20 mi/h).
- The valets will be responsible for setting up the parking locations at each turnaround. The onroad personnel will be asked to help with the setup in each case.
- 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 and objects on the road that are not part of the ENV study are removed from the road.
- Receive nightly assignment to one of the following locations:
    - Stations 1 and 5.
    - Stations 2 and 4.
- Before getting to your station, double check to make sure you have all of the necessary items.
- Wear a radio at all times. Either hold it or attach it to your clothing. Also, make sure one of your radios is set to channel 8.
- In an emergency, immediately radio the relay station experimenter. The relay station experimenter will make sure the in-vehicle experimenters heard the message.
- As the trials progress, make sure you are ready in the proper position before the experimental vehicle gets to your station and clear the location before the vehicle comes back up the road. Also make sure you are hidden if you are not the designated object.
- Use the radio to indicate your station and where the snow has the greatest concentration, such as “Station X–Guardrail,” and “Station Y–Other.” Wind affects where the snow is falling such as toward the guardrail or to the side opposed to the guardrail. The experimental vehicle will always drive on the center of the road.

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: Perpendicular Pedestrian, White Clothing.
Station 5: Parallel Pedestrian, White Clothing.

In-vehicle experimenters will assume that all stations are ready, unless an onroad experimenter radios to say otherwise. Below is a table of the objects and their placement locations. These locations assume that the vehicle is driving in the middle of the roadway. If the objects need to be shifted toward the guardrail or the other side, move the locations accordingly.

OBJECT	LOCATION	SPECIAL INSTRUCTIONS
Perpendicular black pedestrian	Straight (perpendicular) line between center of each lane	Wear black 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.
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.
Parallel white pedestrian	In middle of lane on passenger side of vehicle	Wear white clothing. Walk ten paces towards the vehicle, then ten paces back. Be sure you are always facing the vehicle. Repeat
Blank	None	Remain out of view.

- After the first lap, onroad experimenters are to begin as indicated on object order sheets. The in-vehicle experimenters will indicate when the object trials begin.
- Onroad experimenters need to be out of view of the participants if they are not listed on the order sheet for that run.
- Put safety glasses on.
- *Safety Note:* Experimental vehicles are not to come within 40 feet of a mobile object on the roadway. Also, the in-vehicle 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 in-vehicle experimenters to record the distances of detection and recognition on the distance measuring devices.
- This methodology will be repeated for all four VES configurations. If there will be two sessions that night, the valet will drive around and collect the onroad experimenters to provide a break. You will return to the road after your break and set up for the second

session that will begin shortly. If there is only one session that night, the valets will drive around and collect all experimenters and cones after the fourth configuration.
- If you notice any problems or mistakes occurring during the night, record them on the vehicle preparation sheets.

BETWEEN SUBJECTS PROTOCOL

- If a double or a triple experiment is being run on a particular night. The onroad people will be given a break between subjects. Valet number 1 will use SUV2 to take the ambient light measurements.
- The two SUVs will be returned to the front entranceway of the building for the next subjects.
- The onroad people will be returned to the road by the Large SUV and the pickup as before.

ENDING PROTOCOL

- Gather all experimental equipment and return to the building.
- Valet #2 will collect cones from the turnarounds and carry them in the pickup.
- Check the gas level of each vehicle.
- Return SUVs to the garage-use spotter when pulling into the bay.
- Put dirty scrubs in the bin.
- Note any vehicle problems on the vehicle preparation sheets.
- Return the radios (personal and in-vehicle).
- Sign radios back in. Make sure all radios that have been checked out are returned at the end of the night.
- Make sure the power is off when you put the radios into the charger. If not they won't charge.
- Submit paperwork to in-vehicle experimenter.

APPENDIX J—AIMING PROTOCOL

[Note: The alignment procedure for this study took place in a different location from the alignment procedure used in Study 2 (ENV Volume IV).]

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	Large SUV 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)
Large SUV 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 Large SUV. 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.

<u>Using the Photometer:</u>
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."

<u>Zero the Photometer:</u>
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.

<u>Isolating the Hotspot:</u>
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.

<u>Special Instructions for HID alignment in the Blue Box:</u>

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

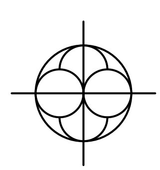
Applies to the following Vehicle/Headlamp combinations:
SUV #2 Five UV–A (1-5)
SUV #1 Hybrid UV–A (1&2)

- 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.

<u>Finding the Hotspot:</u>
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.



<u>Using the Photometer:</u>
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.”

<u>Zero the Photometer:</u>
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.

<u>Isolating the Hotspot:</u>
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 <u>*target board*</u> 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 K—VALET PROTOCOL

VALET PROTOCOL FOR ENV OBJECTS—SNOW

Pre-Experiment Duties

1. Attend the nightly meeting. Get the following forms from the in-vehicle experimenter:
   - VES order and diagram hand out.
   - Vehicle prep sheets.
   - Participant eye measurement sheet.
   - Lead valet vehicle checklist.
   - Ambient light reading (lux) form.
2. Prep the vehicles according to the vehicle prep sheet.
3. Make sure that you have the following equipment:
   - Flashlight.
   - Safety glasses.
   - Radios.
   - Eye measurement equipment.
   - Vest.
   - Rags to wipe headlamps if needed.
   - Deicer.
   - 10 cones.
   - Ice scraper.
4. Park the SUVs in front of the building.
5. With the assistance of the onroad experimenters, perform the road prep according the road prep sheet.
6. Drop off all onroad experimenters at their stations:
   - Valet #2 (in pickup) to stations 2 and 4.
   - Lead valet (in large SUV) to stations 1 and 5.
7. Valet # 2 - Park the pickup in the gravel below T3 perpendicular to the road (facing away from the mountain.
8. Valet # 1 - Park the Large SUV at T2.
9. Make sure that your radio is on channel 8.
10. Wait for drivers to arrive at T2.

Duties During the Experiment

WHEN DRIVERS ARRIVE AT T2 – lead valet

1. Check that headlamps are clean on the two vehicles. If not, clean and apply more deicer.
2. Remove ice from windshield on the two vehicles. If there is significant buildup of ice on the wipers, the defrost heater setting should be used, but it must be turned to heat while the vehicle is sitting.
3. Whenever SUV 2 arrives at the turnaround, the generator must be connected to the vehicle. This is done by moving the generator cart close to the rear of the SUV and connecting the red plug of the generator to that of the SUV. The AC power switch on the generator is then turned on. A road cone must be placed at the tongue of the generator cart to ensure that participants do not trip if they are moving between vehicles.
4. 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.
5. When SUV 2 is ready to return to the road for the next lap, the generator must be disconnected from the vehicle. This is performed by turning the AC power switch on the generator to off and unplugging the power connector. The connector should be returned to the holding location on the side of the cart. The cart must then be moved back to the location at the side of the turn around.
6. 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 valets will move any vehicle that is left in those locations to the parking spots outside the turn around. The generator and cart must be moved as well.
7. Whenever possible, the first driver that returns to the middle turnaround should have their next vehicle waiting for them at the foremost parking spot. Valets 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.
8. The status of temperature and battery must be recorded on the lead valet checklist for all vehicles (This must be done with the generator unhooked for SUV 2). This is read from the instrument panel of the vehicle. If the participant has the instrument panel lights off, after the in-vehicle experimenter has completed their questions radio to them and ask that the participant turn on the lighting for the readings.
    - If the temperature is too high, radio to the in-vehicle experimenter that the defrost system of the vehicle must be turned off and the setting should be to the floor setting only. The temperature should start to drop. At no point should the heating system be turned off. This will cause the vehicle to overheat.

- If the voltage is too low (likely in SUV 2 only), radio to the in-vehicle experimenter that the voltage is low and that more time is needed with the generator. It is likely that an outside of the vehicle discussion will be required. Do not let the participant know the nature of the discussion.

9. Before driver goes down the road, ensure the headlights are on and working. use safety glasses.
   - *White SUV1:* If Low UV–A is required, make sure they are working. Otherwise, make sure the two HLBs are on.
   - *White SUV2:* If High 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.
   - *Large SUV:* The two HID headlamps on the front of the vehicle should be on.

10. Valet 2 wait outside turnaround 3 until the vehicle has come to a complete stop.
11. Check VES configuration for the experimenter.
12. Check that headlamps are clean on the two vehicles. If not, clean and apply more de icer.
13. Remove ice from windshield on the two vehicles.

Between Subject Procedures

1. Valet 2 should retrieve the pickup and retrieve stations 2 and 4.
2. Valet 2 should then drive to turnaround 2 and drop someone at SUV 1, who will then go back and pick up stations 1 and 5.
3. The lead valet should take SUV 2 and begin taking the ambient light measurements. Do not take them if the other vehicle is on the road.
4. The onroad experimenters will return to the building for a break.
5. Change the following radio batteries before returning to the road:
   - Two in-vehicle radios.
   - Two radios from stations 1 and 5.
   - Two radios from stations 2 and 4.

6. The two SUVs must be returned to the front of the building in preparation for the next participants.
7. The onroad experimenters will be returned to the road in the pickup and large SUV as at the beginning of the experiment.
8. Repeat this protocol when running a double or triple shift.

Shut Down Procedures

1. Pick up all onroad experimenters and all onroad materials.
2. Sign in all the radios.
3. Make sure that all radios and batteries are accounted for.
4. Make sure the power is off when you put the radios into the charger.
5. Submit paperwork to in-vehicle experimenter.

General Notes for the Valet

Outside of the vehicle discussion should be had with the in-vehicle 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 with hearing distance of the participant.
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.

APPENDIX L—SNOWMAKING EQUIPMENT

The Smart Road's snowmaking equipment and facilities include a 1,892,706-liter (500,000-gallon) water tank and 80 aluminum snow towers. The towers span a 0.8-km (0.5-mi) section of the road and are spaced at intervals of approximately 10 m (33 ft). At 12.2 m (40 ft) long, the towers can be adjusted for use at various heights, but they are most commonly used at a height of 7.6 m (25 ft). At full capacity, the towers can produce up to 0.3 m (1 ft) of snow per hour.

The snowmaking system uses municipal water; therefore, the water tank is used to avoid placing large burdens on municipal facilities during snow production. During snowmaking, water from the tank is pumped at 206.84 Newtons per square centimeter (N/cm^2) to 344.74 N/cm^2 (300 to 500 psi). The amount of water used varies according to the size of the nozzle used on the snow towers. Each snow tower uses four nozzles. Depending on weather conditions and snow quality, the system uses between 4,295,000 to 6,750,000 liters per hectare-meter (140,000 to 220,000 gallons of water per one acre foot) of snow. In addition to its function as a buffer for municipal water facilities, the water tank is used to avoid water shortages and subsequent problems during snow production.

The water arrives in the tank at approximately 10 °C to 21.11 °C (50 °F to 70 °F). To produce snow, the water must be cooled to approximately −1.11 °C to 0 °C (30 °F to 32 °F) before being pumped to the snow towers. During snow production, the chilled water is drained out of the tank into a wet well from which it is drawn by pumps to the snow towers. The water travels through the ground through a concrete-lined pipe, which acts as an insulator to lessen the transfer of ground heat to the water.

The quality and quantity of the snow produced depends largely on the ambient weather conditions. The ideal snowmaking conditions are dry and cold; however, temperatures of −6 °C (21.2 °F) and below are optimal, regardless of the humidity level. As temperatures rise, lower humidity levels are required to produce snow. For example, high-quality snow can be produced at temperatures as high as −2 °C (28.4 °F), but only at humidity levels of 20 percent or below. As the temperatures and humidity levels rise, the quality of the snow produced begins to dramatically decrease. Snow can still be produced at temperatures as high as 2.79 °C (37 °F), at humidity levels of 10 percent or less.

Snow created on the Smart Road has only a short distance to form, grow, and strengthen; therefore, it is extremely important that the water emitted from the snow towers is on the verge of freezing. After it is sprayed from the nozzles, it is frozen quickly by the supercooled, compressed air that is blown from the air jets on the nozzles.

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