Volume IV

Enhanced Night Visibility Series: Phase II–Study 2: Visual Performance During Nightime Driving in Rain

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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 rain. 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 IV. 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.

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16. Abstract

Phase II, Study 2 (rainy weather) was performed following the same procedures used for Study 1 (clear weather). Study 2 helped expand the knowledge of how current vision enhancement systems can affect detection and recognition of different types of objects while driving during adverse weather, specifically during rain conditions. The empirical testing for this study was performed on the Virginia Smart Road; the rain was controlled by weathermaking equipment. Thirty participants were involved in the study. A 12 by 7 by 3 mixed factorial design was used to investigate the effects of different types of vision enhancement systems, different types of objects on the roadway, and driver's age on detection and recognition distances; subjective evaluations also were obtained for the different vision enhancement systems.

The results of the empirical testing suggest that vision enhancement systems that include halogen headlamps as their main component (i.e., halogen alone or halogen with ultraviolet A) consistently allow drivers the best detections during rain conditions. In fact, the halogen headlamp (low-beam configuration) provides the longest detection and recognition distances overall; in the few trials where other systems allow farther detection distances, these differences did not represent meaningful improvements. Even drivers using the infrared thermal imaging system, which resulted in farther detection distances for pedestrians and cyclists under clear conditions, perform no differently in the rain than when only the low beams of the vehicle were used.

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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 fourth 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," etc. 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
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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
VES ....vision enhancement system
SUV...................................sport utility vehicle
UV–A.................................ultraviolet A (wavelength 315 to 400 nanometers)
VDOT ....Virginia Department of Transportation
VTRC.................................Virginia Transportation Research Council

Vision Enhancement Systems

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

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......................................centimeters
ft ....feet
h...hours
m ....meters
mi/h ....miles per hour
km/h ....kilometers per hour
s ....seconds

W/cm^2 ....watts per square centimeter
$\mu W/cm^2$ ....microwatts per square centimeter

Stopping Distance

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

Contrast Sensitivity

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

CHAPTER 1—INTRODUCTION

Study 2 in Phase II of the Enhanced Night Visibility (ENV) project was the first in a series of three studies conducted at the Virginia Smart Road testing facility that focused on drivers' visual performance during adverse weather conditions (i.e., rain, snow, and fog). The experimental tasks for this study consisted of driving at nighttime in rainy conditions using 12 different vision enhancement system (VES) configurations (the same set used for Phase II, Study 1; see ENV Volume III). Drivers' visual performance was 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. The road was closed to all traffic except for experimental vehicles, of which there were no more than two on the road at any time. Participants underwent a one-night training session on the night before their two nights of participation in the onroad study. The following chapter describes the methodology for Study 2.

CHAPTER 2—METHODS

PARTICIPANTS

Thirty individuals participated in this study. Participants were divided into three age categories: 10 drivers were between the ages of 18 and 25 (younger category), 10 were between the ages of 40 and 50 (middle-aged category), and 10 were over 65 (older category). Each category had five males and five females. Selected participants had to meet the conditions of a screening questionnaire (appendix A). Participants also had to sign an informed consent form (appendix B), present a valid driver's license, pass the visual acuity test (appendix C) with a score of 20/40 or better (as required by Virginia State law), and have no health conditions that made operating the research vehicles a risk.

Participants were 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 they chose at any time not to participate further, they were instructed that they would be paid for the amount of actual participation time. Participants received $20 per hour for their participation. All data gathered as part of this experiment were treated with complete anonymity.

EXPERIMENTAL DESIGN

A mixed-factor design was used to collect data during the onroad portion of the study (i.e., detection and recognition tasks, table 1 and table 2). There were three independent variables:

- VES configuration.
- Age.
- Type of object.

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; a detailed explanation of each of the independent variables of interest is presented afterward.

Table 1. Experimental design: 12 by 3 by 7 mixed-factor design (12 VES configurations, 3 age groups, 7 objects—see table 2 for objects).

VES Configuration	Young Age Group	Middle Age Group	Older Age Group
HLB			
Hybrid UV–A + HLB			
Three UV–A + HLB			
Five UV–A + HLB			
HLB–LP			
HHB			
HOH			
HID			
Hybrid UV–A + HID			
Three UV–A + HID			
Five UV–A + HID			
IR–TIS			

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

Table 2. Seven objects presented in each cell of table 1.

	Object
Dynamic	Parallel Pedestrian, Black Clothing
	Perpendicular Pedestrian, Black Clothing
	Parallel Pedestrian, White Clothing
	Perpendicular Pedestrian, White Clothing
	Cyclist, White Clothing
Static	Tire Tread
	Child’s Bicycle

INDEPENDENT VARIABLES

Age

The age factor had three levels: younger participants (18 to 25), middle-aged participants (40 to 50), and older participants (65 or older). These age groups were created based on literature review findings (refer to ENV Volume II) that suggest changes in vision during certain ages.

(See references 1, 2, 3, 4, and 5.) Each age group comprised five males and five females. Gender was used as a control but not as a factor of interest.

VES

The VES configurations were defined as follows:

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

In-depth technical specifications of each headlamp appear in ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*.

The presentation orders for each VES and object combination were counterbalanced. Table 3 provides an example of the VES configuration order for a pair of participants. The first column, labeled “Order,” indicates the order in which the VESs were presented. The second column, labeled “VES,” presents the VES configuration that was used. The third column, labeled “Vehicle,” presents the vehicle upon which the headlamps were mounted, either a sedan, pickup truck, white sports utility vehicle (SUV), or black SUV.

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

	Order	VES	Vehicle
Participant 1, Night 1	0	Practice	
	1	Five UV–A + HID	White SUV
	2	HLB	Black SUV
	3	HOH	Pickup
	4	Three UV–A + HID	White SUV
	5	IR–TIS	Sedan
	6	Hybrid UV–A + HLB	Black SUV
Participant 2, Night 1	0	Practice	
	1	HLB	Black SUV
	2	HOH	Pickup
	3	Hybrid UV–A + HLB	Black SUV
	4	IR–TIS	Sedan
	5	Five UV–A + HID	White SUV
	6	Three UV–A + HID	White SUV
Participant 1, Night 2	7	HLB–LP	Sedan
	8	Five UV–A + HLB	White SUV
	9	HHB	Pickup
	10	HID	Black SUV
	11	Three UV–A + HLB	White SUV
	12	Hybrid UV–A + HID	Black SUV
Participant 2, Night 2	7	Three UV–A + HLB	White SUV
	8	Hybrid UV–A + HID	Black SUV
	9	Five UV–A + HLB	White SUV
	10	HLB–LP	Sedan
	11	HID	Black SUV
	12	HHB	Pickup

The 12 VES configurations tested were selected based on several considerations. The HLB and the HID headlamps currently are available on the market and reflect the most commonly used headlamps (HLB) and a growing section of the market (HID); therefore, they were added as two of the configurations to allow the comparison of new VES alternatives with what is readily available.

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

All of the UV–A headlamps had to be paired with HLB and HID headlamps because UV–A headlamps provide minimal visible light. These UV–A headlamps stimulate the fluorescent properties of objects irradiated by the UV radiation, producing visible light. Their purpose is to supplement, not eliminate, the regular headlamps. These UV–A and HLB/HID pairings resulted in six different VES configurations: three in which the pairing was made with HLB lamps and three in which HID lamps were used. The three different UV–A conditions inside each pairing category resulted from the use of three different forms of UV–A headlamp configurations: five UV–A lamps, three UV–A lamps, or hybrid UV–A headlamps. The hybrid UV–A headlamp is an experimental prototype that produces a significant amount of visible light, although not enough light to allow driving without standard headlamps. The UV–A headlamps used in the five UV–A and three UV–A configurations produce far less visible light.

The HHB configuration was included to compare detection and recognition distances of the VESs of interest in this study with those of commonly available halogen high-beam headlamps. In addition, a new alternative to the standard halogen low-beams, which is intended to provide drivers with more visible light output (HOH), was considered.

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

Object

The seven different objects selected for this study included pedestrians, cyclists, and static objects (table 4 and figure 1 through figure 5). The main reason for including the pedestrians and cyclists was because of the high crash-fatality rates for these nonmotorists.[6,7] This study used actual pedestrians and cyclists to evaluate the effects of object motion on detection and recognition distances, although pedestrian mockups have been used in previous research of this type.[8] In this study, using mockups would have improperly restricted the performance capabilities of the IR–TIS and would have limited the external validity of the study.

Figure 1. Photo. Pedestrian in black clothing.

Figure 2. Photo. Cyclist in white clothing.

Figure 3. Photo. Pedestrian in white clothing.

Figure 4. Photo. Child's bicycle.

Figure 5. Photo. Tire tread.

Pedestrians and cyclists were presented to the drivers at two different contrast levels: (1) black clothing against a rainy night background and (2) white clothing against a rainy night background. The dynamic pedestrians walked in two different directions: (1) perpendicular to the vehicle path, representing a pedestrian crossing the road, and (2) parallel to the vehicle path, representing a pedestrian walking along the shoulder.

Two objects other than pedestrians or cyclists also were used: a child's 25-cm (10-inch) bicycle and a tire tread from a 71- by 23-cm (28- by 9-inch) steel-belted truck radial tire. The tire tread was selected because of its potential for very low detection distances, which often lead to last-moment object-avoidance maneuvers. The child's bicycle was intended to represent the possible presence of a child in the area.

The seven objects of interest are described in table 4. Detailed information about the characterization of the different objects appears in ENV Volume IX.

Table 4. Description of the objects.

Object	Percentage of Reflectance at 61 m (200 ft)	Location	Special Instructions
Parallel Pedestrian, Black Clothing	4	Shoulder side of right edgeline.	Wear black clothing. Walk 10 paces along shoulder line toward oncoming vehicle; then walk backward 10 paces. Repeat.
Parallel Pedestrian, White Clothing	22	Shoulder side of right edgeline.	Wear white clothing. Walk 10 paces along shoulder line toward oncoming vehicle; then walk backward 10 paces. Repeat.
Perpendicular Pedestrian, Black Clothing	4	Straight (perpendicular) line from right edgeline to centerline.	Wear black clothing. Walk to centerline; then walk backward to right edgeline. Repeat.
Perpendicular Pedestrian, White Clothing	22	Straight (perpendicular) line from right edgeline to centerline.	Wear white clothing. Walk to centerline; then walk backward to right edgeline. Repeat.
Cyclist, White Clothing	22 (Cyclist) 27 (Specular—Bike Rims)	Between edgelines, perpendicular to the vehicle path.	Wear white clothing. Ride bike in circles across the road, from one edgeline to opposite edgeline.
Tire Tread	7	Centered on right edgeline.	None.
Child's Bicycle	18	Centered across right edgeline, one wheel on either side.	Lay bike on one side, wheels facing approaching traffic, handlebars facing lane of oncoming traffic.

OBJECTIVE DEPENDENT VARIABLES

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

During training and practice, each participant was instructed on the use of a hand-held wand used to mark the moments when he or she detected and recognized objects. The participant was instructed to press a button on the wand when he or she detected an object on the road, then perform a second button press when he or she recognized the object. The in-vehicle experimenter flagged the data collection the moment the participant drove past the object. Detection and recognition distances were calculated from distance data collected at these three points in time.

SUBJECTIVE RATINGS

Subjective ratings also were collected as dependent variables. Each participant was asked to evaluate each VES on seven statements 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. The participant was asked to compare each experimental VES to his or her regular headlamps (i.e., the headlamps on the participant’s own vehicle). Researchers assumed that the participant’s own vehicle represented what he or she knew best, and therefore, was most comfortable using. 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 (i.e., left, right, 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 foreseeable hazard to the driver nor did it interfere with any part of the driver's normal field of view.
- Each participant wore the seatbelt restraint system anytime the car was on the road.
- A trained experimenter was in the test vehicle at all times.
- An emergency protocol was established before testing.

The onroad pedestrians and cyclists were trained when to clear 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

All vehicles were equipped with an electronic distance-measuring instrument. The measuring device was connected to a laptop computer that was equipped with software specifically developed for this study. The software allowed the experimenter to mark locations and record whether the trial was successful (figure 6). Only the driver portion of the software was used. The software gathers information such as the participant's age and gender, as well as the identification number assigned to that participant. In addition, the software shows the object order presented to the participant during a given VES configuration. Onroad driving was conducted using four vehicles: two SUVs, a pickup truck, and a luxury passenger vehicle (figure 7 through figure 10).

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

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

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

Figure 6. Diagram. Data collection display screen.

The VESs were distributed among the different vehicles. The two SUVs and the pickup truck had light bars installed that allowed the headlamps (i.e., HLB and HID) to be switched to maintain a more consistent horizontal and vertical position among the different VESs (figure 7 through figure 10). The HLB–LP and IR–TIS were the only exceptions; these were factory-installed on the sedan.

Figure 7. Photo. Five or three UV–A + HLB.

Figure 8. Photo. HOH or HHB.

Figure 9. Photo. Hybrid UV–A + HID.

Figure 10. Photo. HLB–LP with IR–TIS.

Smart Road

The all-weather testing facility on the Smart Road (overhead lighting turned off) was used in this study (figure 11, figure 12, and appendix G). The different objects were presented at four locations on the Smart Road (figure 13). The participants changed vehicles on the turnaround next to the entrance of the Smart Road. One onroad experimenter was assigned to each participant; this experimenter was responsible for escorting the participant to the next vehicle, showing him or her where the controls were, and verifying that the right VES configuration was being tested. Four other onroad experimenters were positioned at the various locations. Two onroad experimenters were assigned to locations 1 and 5, and two additional experimenters were assigned to locations 2 and 4. Appendix I contains additional details on the protocol for the onroad experimenters. A total of six onroad and two in-vehicle experimenters were part of the study each night.

Figure 11. Photo. Smart Road.

The all-weather testing facility on the Virginia Smart Road generated the rain (figure 12). This ensured a constant amount of precipitation throughout the data collection effort. Data were not collected during heavy wind conditions. The precipitation rate selected was 10.2 cm/h (4 inches/h), which required most of the participants to use the vehicles' windshield wipers at a high speed.

Figure 12. Photo. Smart Road rain towers.

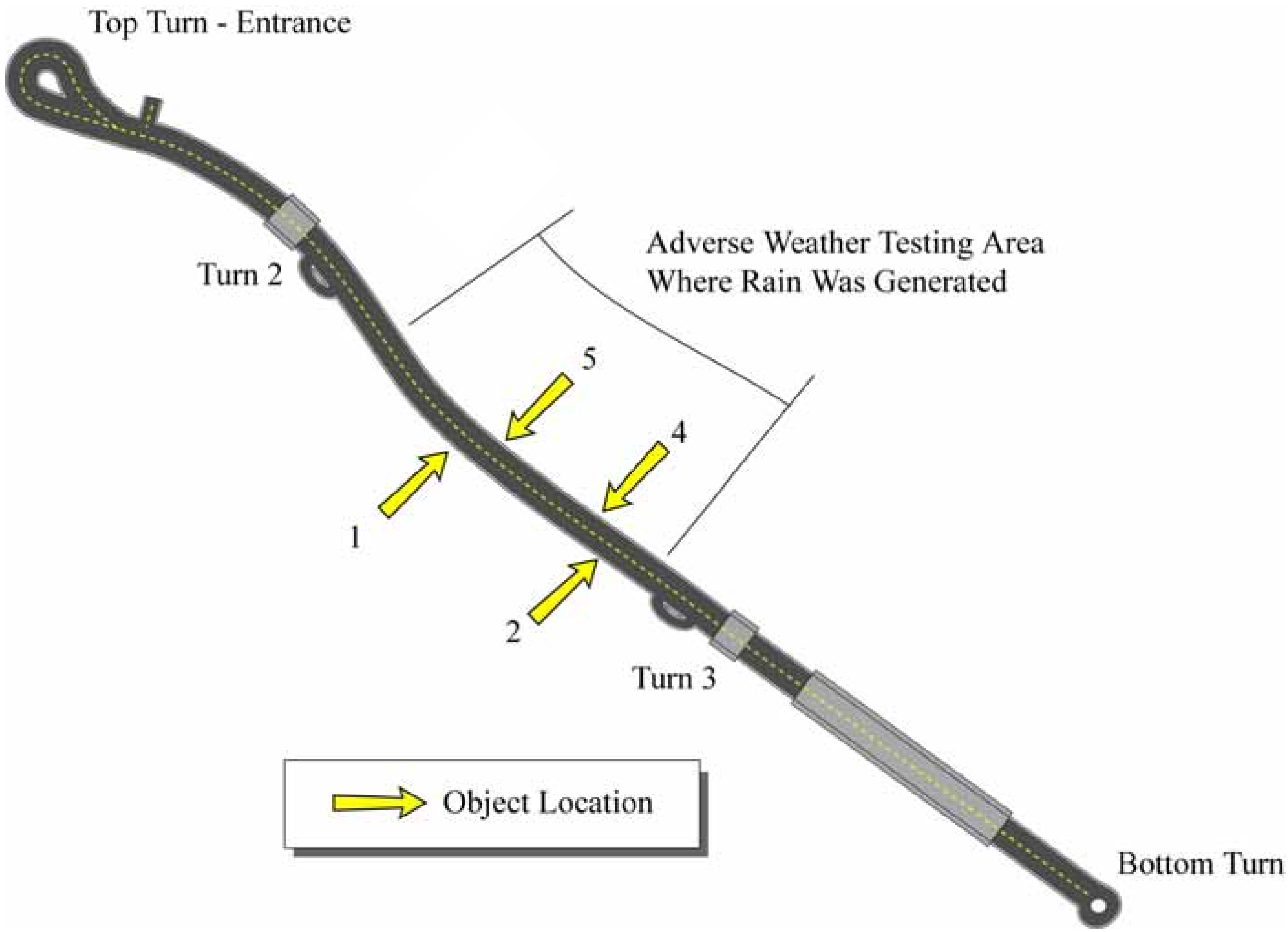


Figure 13. Diagram. Locations where the objects were presented for the adverse weather condition (note the area where rain was generated).

Headlamp Aiming

The headlamps used for the HLB, HID, HOH, HHB, and UV–A configurations were located on external light bars. To change from one configuration to another, the HLB and HID headlamps were moved onto, off of, and between vehicles. Each light assembly movement required a re-aiming process, which took place before starting the experimental session each night. At the beginning of the Phase II studies, a headlamp aimer was not available to the contractor, so an aiming protocol was developed with the help of experts in the field. (See references 14, 15, 16, and 17.) The details of the aiming protocol used for this specific study are described in appendix J. During the photometric characterization of the headlamps, it was discovered that the position of the maximum intensity location of the HLB, HOH, and HHB configurations was aimed higher and more toward the left than typical. This aiming deviation likely increased detection and recognition distances for the HLB and HOH configurations and likely decreased them for the HHB configuration. Details about the aiming procedure and the maximum intensity location are discussed in ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*.

EXPERIMENTAL PROCEDURE

Two participants performed the experiment simultaneously. The experiment consisted of three sessions, and each experimental session lasted approximately 3.5 h. The first session included screening, laboratory training, and IR–TIS training. The other two sessions involved two nights of the experiment on the Smart Road. During the first onroad session, participants were familiarized with the Smart Road and the experimental objects before starting the experiment. Six VES configurations were presented to the participants during the first onroad session, and the remaining six configurations were presented during the second session. The order was counterbalanced. The following paragraphs discuss the procedure details.

Participant Screening

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

Training

Each participant was taught how to perform the tasks associated with object detection and recognition and told how the questionnaires would be used. The study protocol and pictures of the objects were presented at this point (appendixes D and E). Each participant also was familiarized with the detection and recognition definitions, use of the pushbutton wand, and Likert-type scales for the questionnaire. The training presentation outlined the procedures, showed pictures of the objects, and allowed for questions. The purpose of this lab training and practice was to allow all participants to begin the experiment with a standard knowledge base. After the lab training, the participant practiced with the IR–TIS, and examples of the experimental objects were presented as part of the training practice.

Familiarization

Because participants changed vehicles as part of the study, the familiarization process occurred as soon as the participant reached each experimental vehicle. While the vehicle was parked, the onroad experimenter reviewed general information concerning the vehicle's operation (appendix K). The 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 begin.

Driving Instructions

The participant was instructed to place the vehicle in park after reaching each of the turnarounds while the onroad objects were changed. The participant was instructed to drive at 16 km/h (10 mi/h) during the experimental sessions and follow instructions from the in-vehicle experimenter at all times.

Driving and Practice Lap

The participant drove down the road to become familiar with the road and the vehicle; no objects were presented at this point. At the bottom turnaround, the experimenter gave the pushbutton wand to the participant and told him or her 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 first group of six VESs in the order assigned to the first night.

General Onroad Procedure

Distance data were collected while the participant drove with each VES. 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), the participant performed no other tasks while driving. The experimenter sat in the passenger seat and told the participant when he or she could begin driving and where to park. The in-vehicle experimenter also administered the subjective questionnaires after each VES configuration and controlled the data collection program. Additional details on the in-vehicle experimenter protocol appear in appendix F.

Sequence of Data Collection

Every participant followed the same sequence of events when collecting the data for each of the VES configurations. This sequence was as follows:

1. One object or blank location was presented at each of the four locations for the rain condition in a counterbalanced order for a total of seven objects and one blank for each VES.
2. While approaching each location, the participant pressed the pushbutton when he or she could detect the object.
3. When the participant could recognize the object, he or she pressed the pushbutton 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 continued for two laps, which completed a run for a given VES. Then the participant answered a subjective rating questionnaire for the VES. The participant changed vehicles (if needed) and started the next VES run.
6. After all VES configurations were completed, the participant was instructed to return to be debriefed (appendix H).

The study was performed twice every night (first shift: 7:45 p.m. 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 drove during the first shift. Participants were paid for the total number of hours (training and both experimental sessions) at the end of the second 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 30 participants were merged into a single database that included objective and subjective data. An analysis of variance (ANOVA) was performed to evaluate drivers' visual performance under each of the different treatments. PROC ANOVA was used in SAS® statistical software to compute the ANOVA. The full experimental design model was used in the data analysis (table 5).

Table 5. Model for the experimental design.

SOURCE
BETWEEN
Age
Subject (Age)
WITHIN
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 ANOVA evaluated whether there were significant differences among the different VESs in terms of the dependent variables. 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 ($p < 0.05$). For the significant interactions, the means and standard errors were graphed and discussed. 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 interior levels significantly different. For a detailed discussion of post hoc tests, see Winer, Brown, and Michels.[18]

CHAPTER 3—RESULTS

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

OBJECTIVE MEASUREMENTS

An ANOVA was performed on the objective measurements taken during the Smart Road portion of the study. The model for this portion of the study was a 12 (VES) by 3 (Age) by 7 (Object) mixed factorial design. ANOVA summary tables were obtained for both objective dependent measurements (table 6 and table 7). A total of 2,509 observations were obtained from the experiment for each objective measurement. When drivers were not able to detect and recognize an object, a value of 0 was assigned. Several main effects and interactions were considered significant (table 8).

ANOVA results showed no significant differences between the three age groups in terms of detection distances as seen below:

- Younger age group: mean = 60.3 m (198 ft), standard error (SE) = 0.8 m (2.7 ft).
- Middle-aged group: mean = 58.8 m (193 ft), SE = 0.8 m (2.7 ft).
- Older age group: mean = 58.8 m (193 ft), SE = 0.9 m (2.9 ft).

The results also showed no differences between the recognition distances of the three age groups as follows:

- Younger age group: mean = 53.0 m (174 ft), SE = 0.8 m (2.5 ft).
- Middle-aged group: mean = 52.1 m (171 ft), SE = 0.8 m (2.5 ft).
- Older age group: mean = 51.2 m (168 ft), SE = 0.8 m (2.7 ft).

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

Source	DF	SS	MS	F value	P value	
Between						
Age	2	11699.1	5849.5	0.20	0.8187	
Subject/Age	27	783683.3	29025.3			
Within						
VES	11	495073.4	45006.7	14.49	<0.0001	*
VES by Age	22	46920.7	2132.8	0.69	0.8524	
VES by Subject/Age	297	922560.2	3106.3			
Object	6	9460693.4	1576782.2	726.7	<0.0001	*
Object by Age	12	26194.2	2182.9	1.01	0.4458	
Object by Subject/Age	162	351506.1	2169.8			
VES by Object	66	240227.8	3639.8	1.86	<0.0001	*
VES by Object by Age	132	325313.9	2464.5	1.26	0.0279	*
VES by Object by Subject/Age	1771	3462517.4	1955.1			
TOTAL	2508	16126389.6				

* $p < 0.05$ (significant)

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

Source	DF	SS	MS	F value	P value	
Between						
Age	2	14070.7	7035.4	0.24	0.7856	
Subject/Age	27	780184.4	28895.7			
Within						
VES	11	420087.0	38189.7	13.93	<0.0001	*
VES by Age	22	28862.3	1311.9	0.48	0.9789	
VES by Subject/Age	297	814502.9	2742.4			
Object	6	7907939.2	1317989.9	728.05	<0.0001	*
Object by Age	12	29927.3	2493.9	1.38	0.1814	
Object by Subject/Age	162	293269.2	1810.3			
VES by Object	66	167976.5	2545.1	1.46	0.0104	*
VES by Object by Age	132	258250.7	1956.4	1.12	0.1722	
VES by Object by Subject/Age	1771	3091123.4	1745.4			
TOTAL	2508	13806193.9				

* $p < 0.05$ (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	x	x
VES by Object by Age	x	
VES by Object by Subject/Age		

x = $p < 0.05$ (significant)

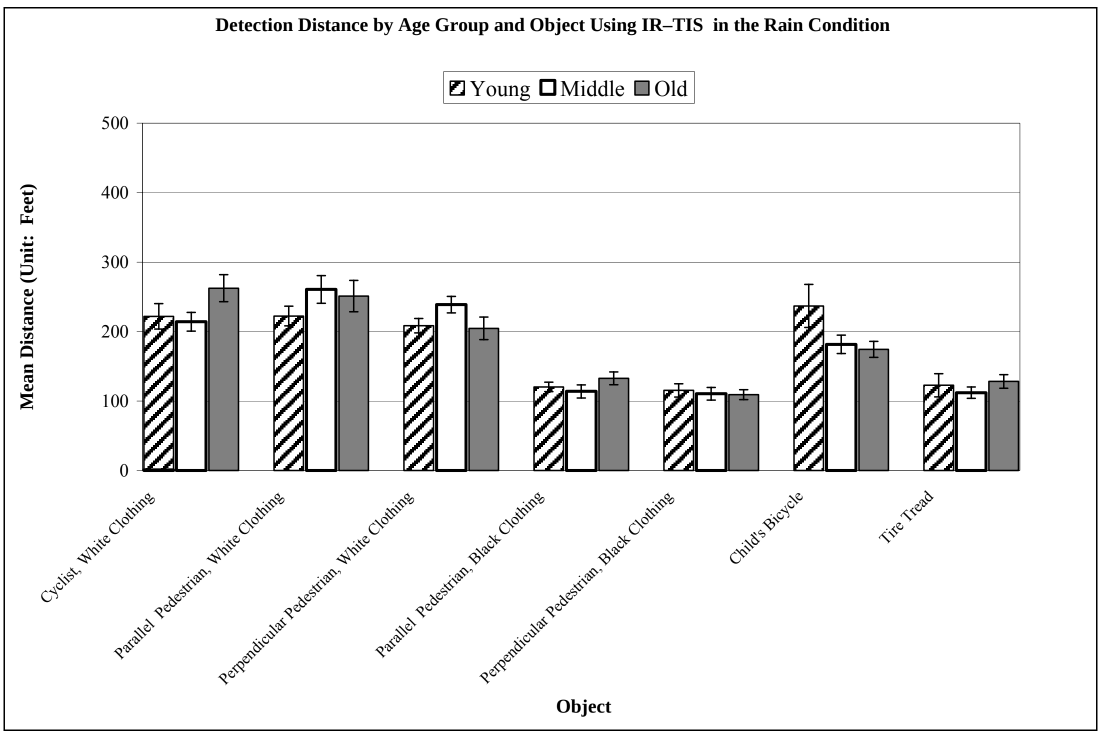
The main effects of and interactions between VES and object were significant ($p < 0.05$) for both detection and recognition. The VES, object, and age interaction was significant ($p < 0.05$) only in terms of detection distances (figure 14 through figure 25).

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

VES by Object by Age Interaction

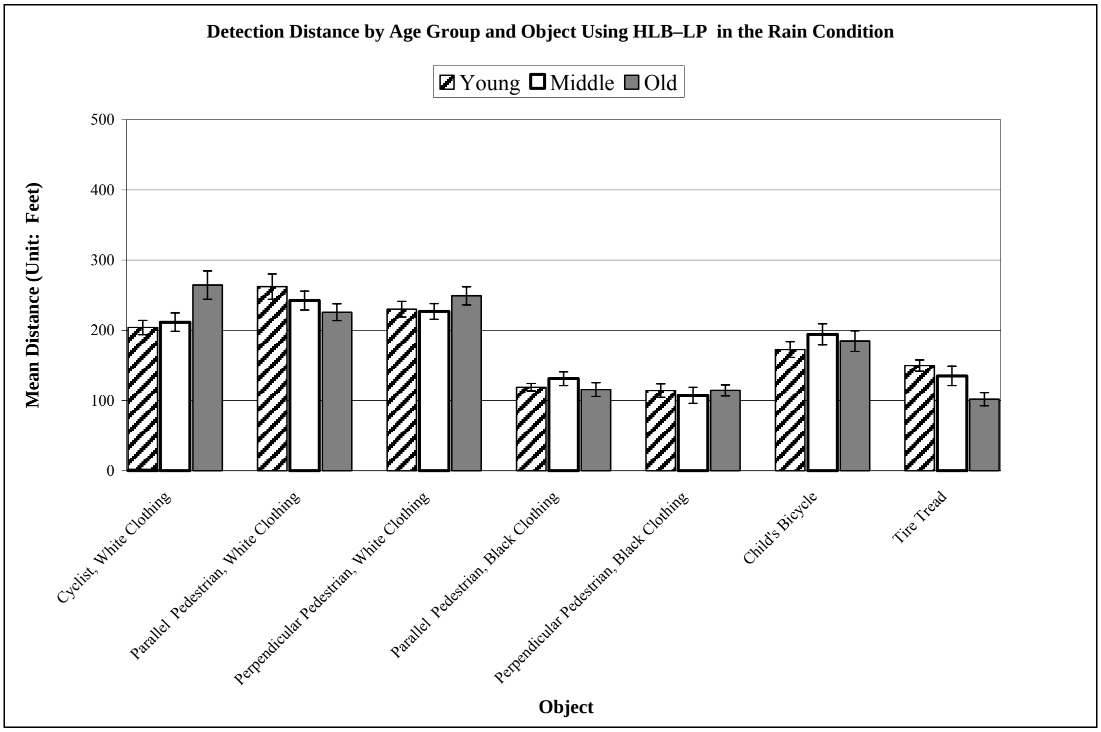
For the significant three-way interaction VES by Object by Age (figure 14 through figure 25), there were no marked differences between VES configurations in terms of detection distances. On average, all detections were less than 100 m (328 ft); a few levels of the interactions stood out as the ones that caused the significant difference. For example, the five UV–A + HLB configuration increased detection distances of pedestrians and cyclists with white clothing for older drivers up to 36 percent. This increase in detection for older drivers was less than 26.5 m (87 ft) farther than detection distances of HLB alone, but it was the biggest difference for this interaction.

The other levels of the three-way interaction did not show differences with a meaningful improvement; the detection distances for low-contrast objects (i.e., parallel pedestrian, black clothing; perpendicular pedestrian, black clothing; and tire tread) under all age by VES combinations were less than 51.8 m (170 ft). Age did not seem to follow any trends on this particular three-way interaction. Overall, the different UV–A + HLB configurations resulted in the best detection distances for all objects under the different age groups.



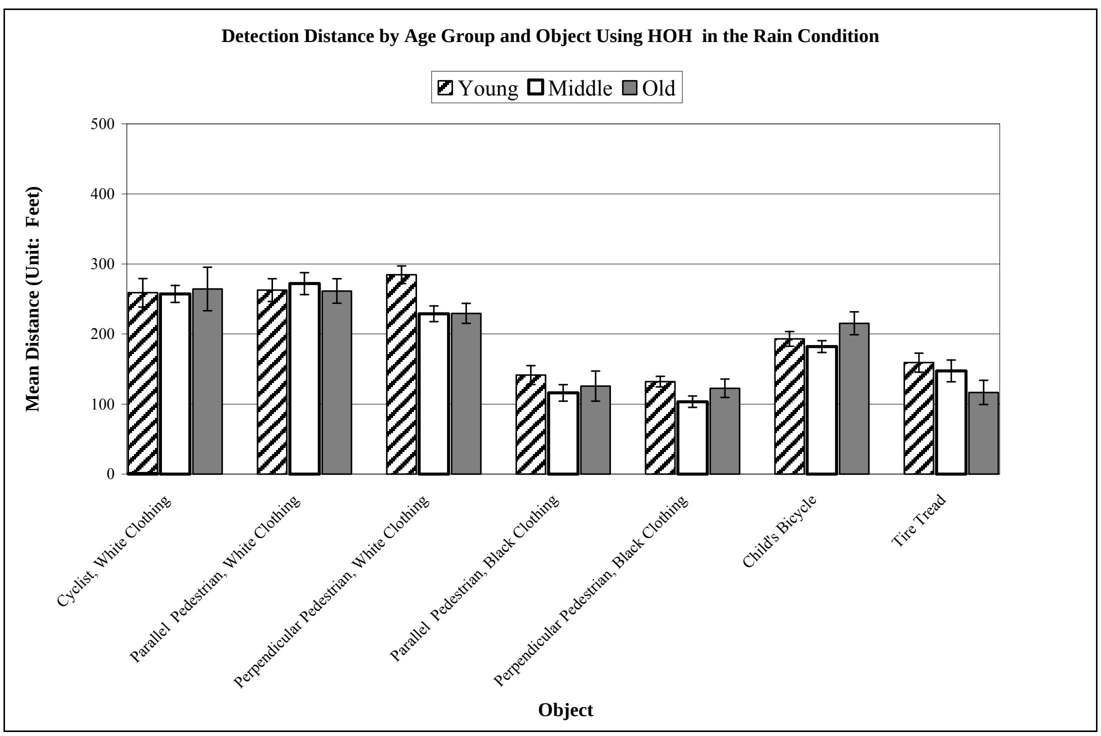
1 ft = 0.305 m

Figure 14. Bar graph. Results for the interaction: VES by Object by Age for IR–TIS.



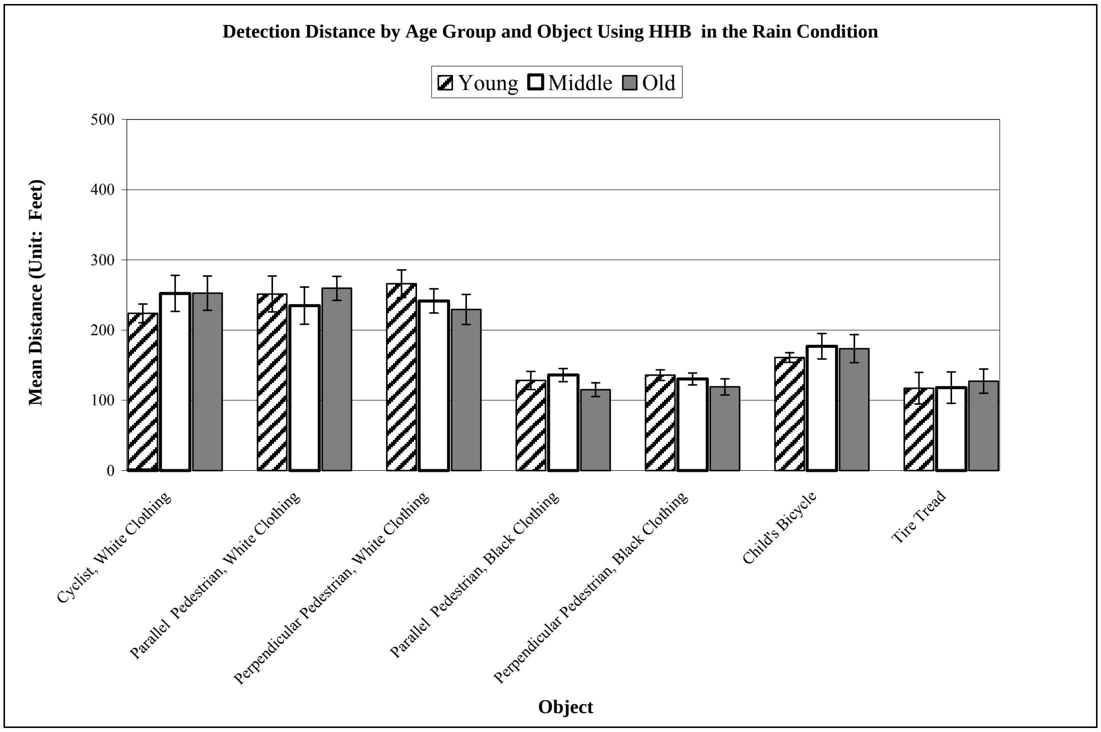
1 ft = 0.305 m

Figure 15. Bar graph. Results for the interaction: VES by Object by Age for HLB–LP.



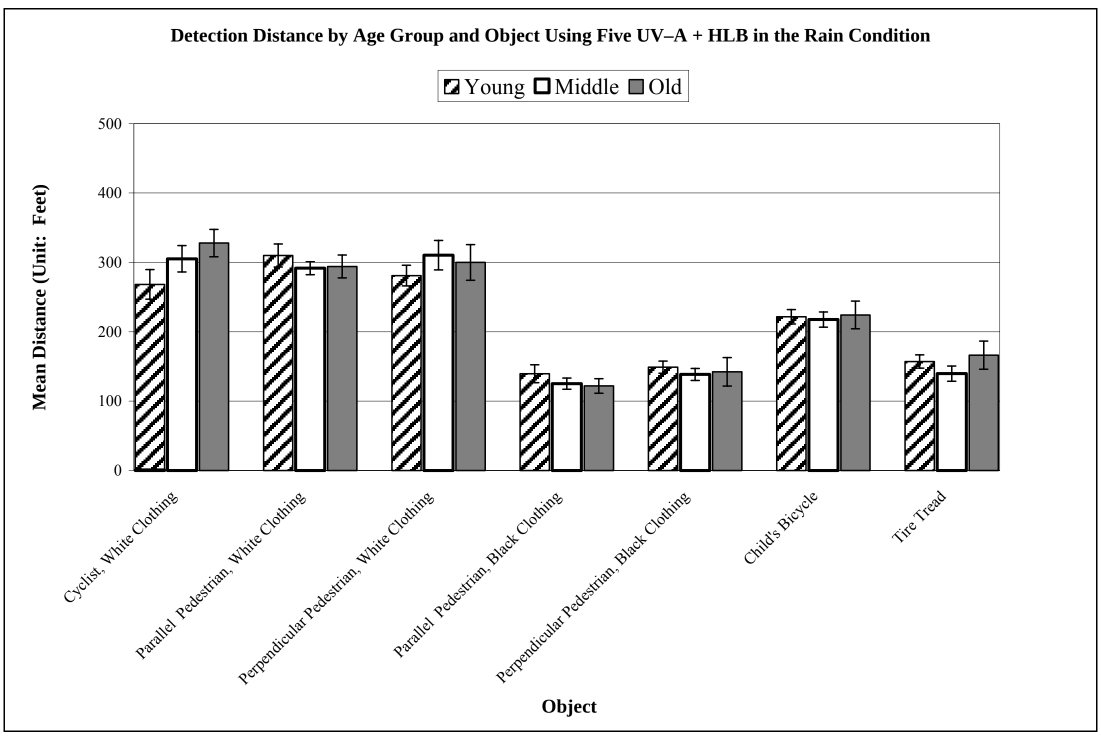
1 ft = 0.305 m

Figure 16. Bar graph. Results for the interaction: VES by Object by Age for HOH.



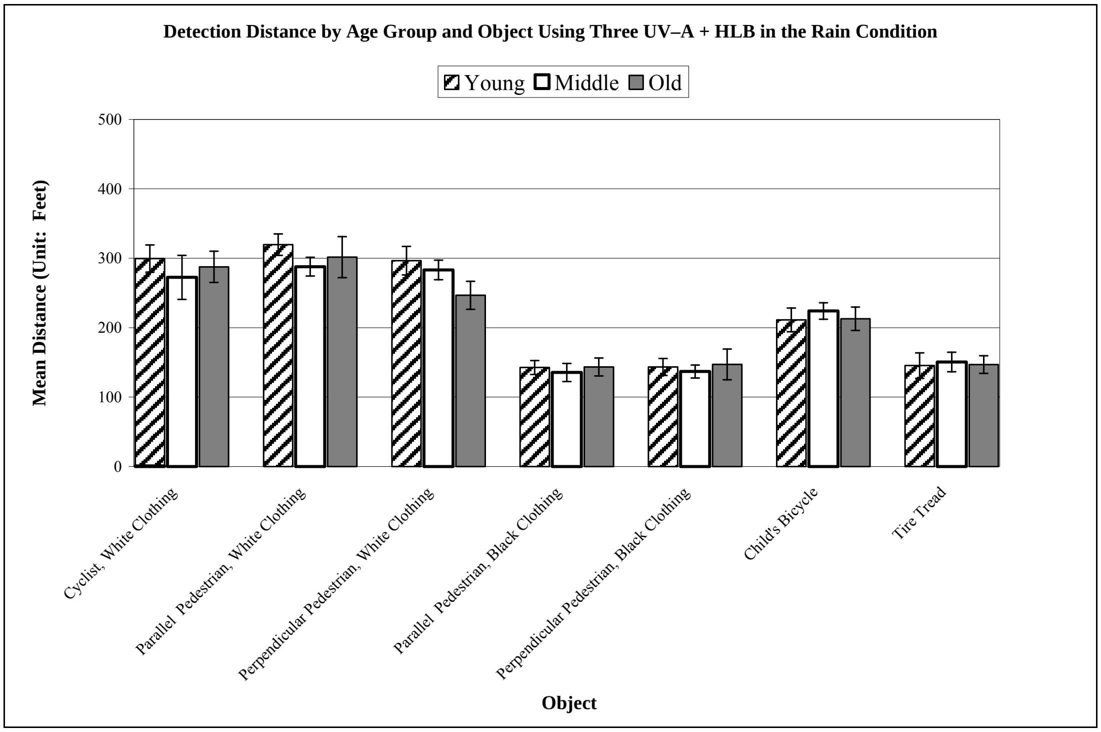
1 ft = 0.305 m

Figure 17. Bar graph. Results for the interaction: VES by Object by Age for HHB.



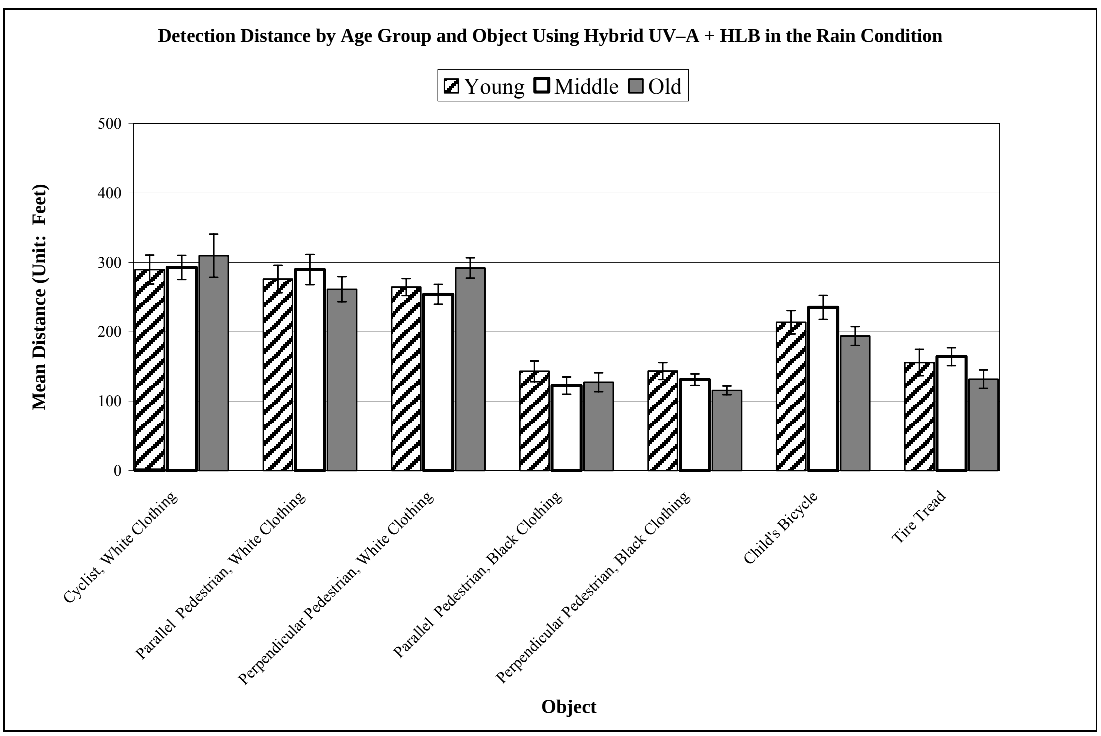
1 ft = 0.305 m

Figure 18. Bar graph. Results for the interaction: VES by Object by Age for five UV–A + HLB.



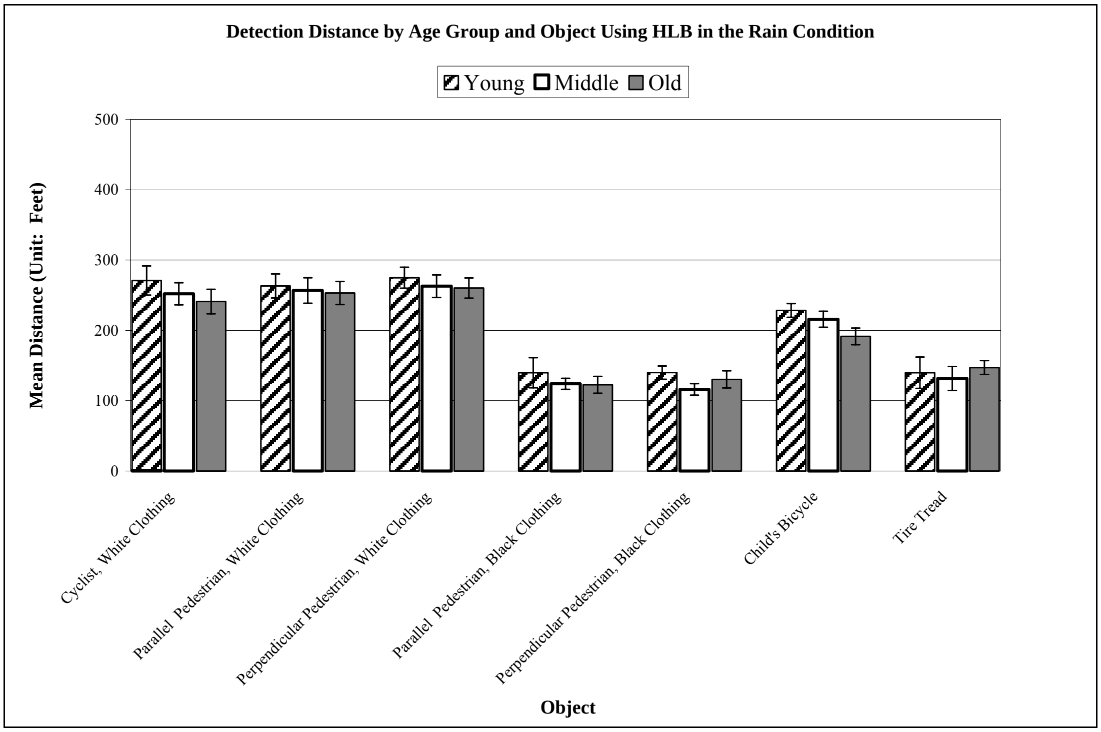
1 ft = 0.305 m

Figure 19. Bar graph. Results for the interaction: VES by Object by Age for three UV–A + HLB.



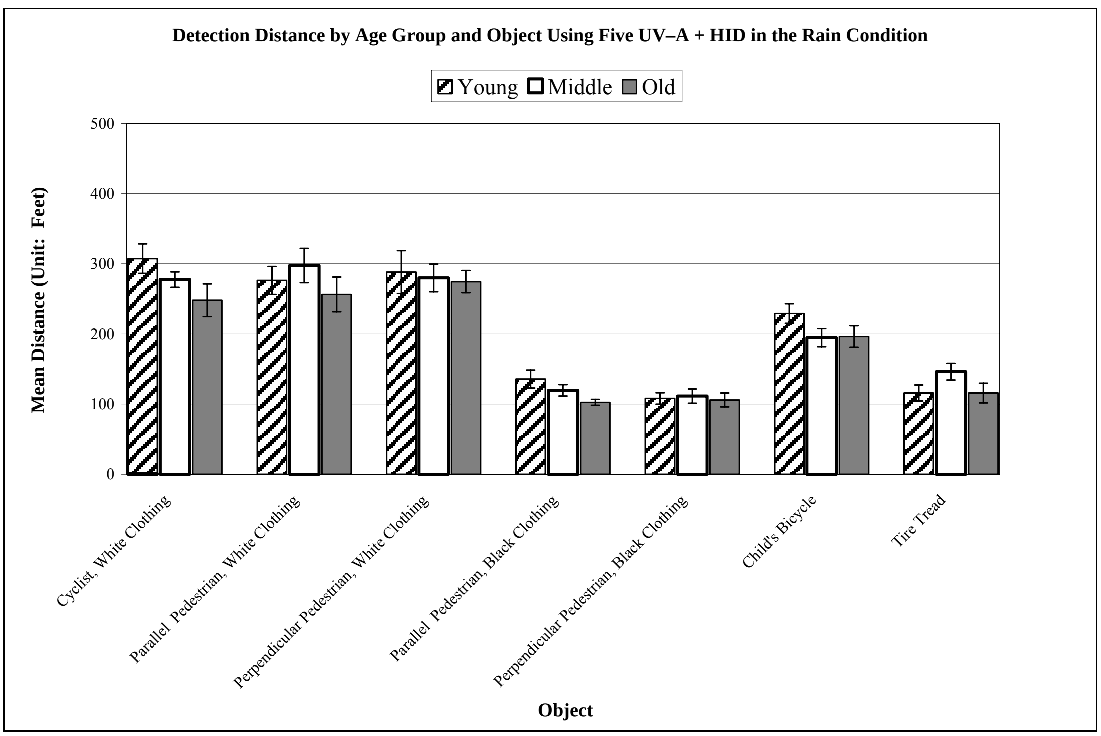
1 ft = 0.305 m

Figure 20. Bar graph. Results for the interaction: VES by Object by Age for hybrid UV–A + HLB.



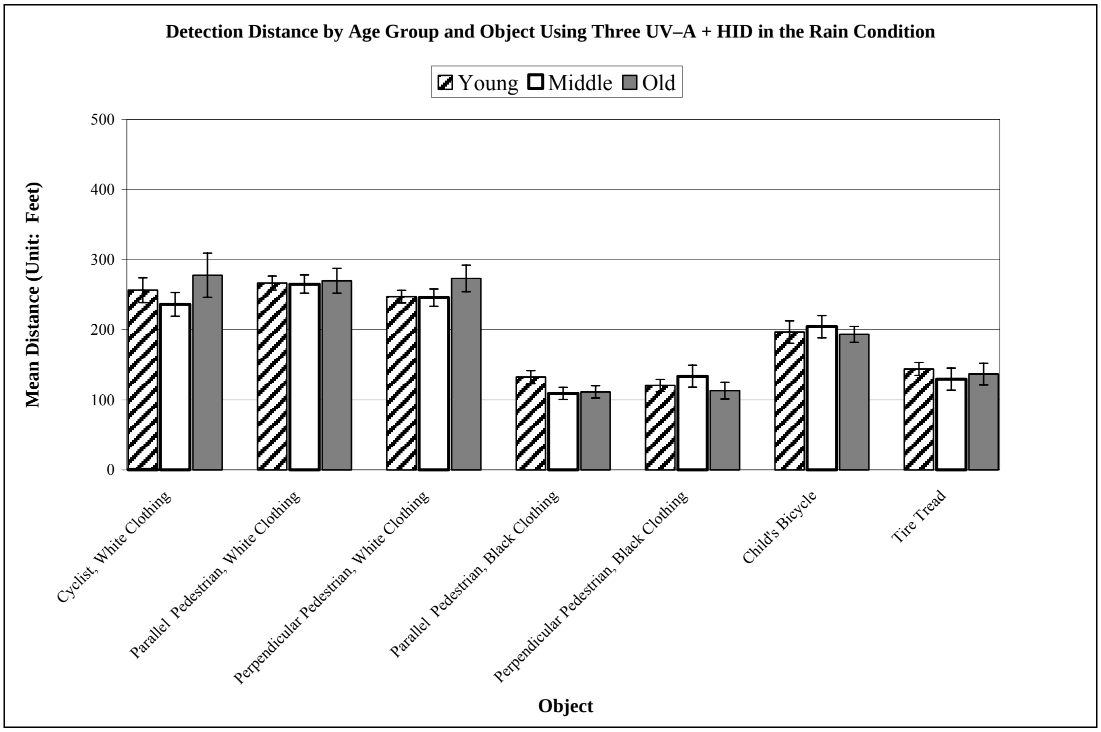
1 ft = 0.305 m

Figure 21. Bar graph. Results for the interaction: VES by Object by Age for HLB.



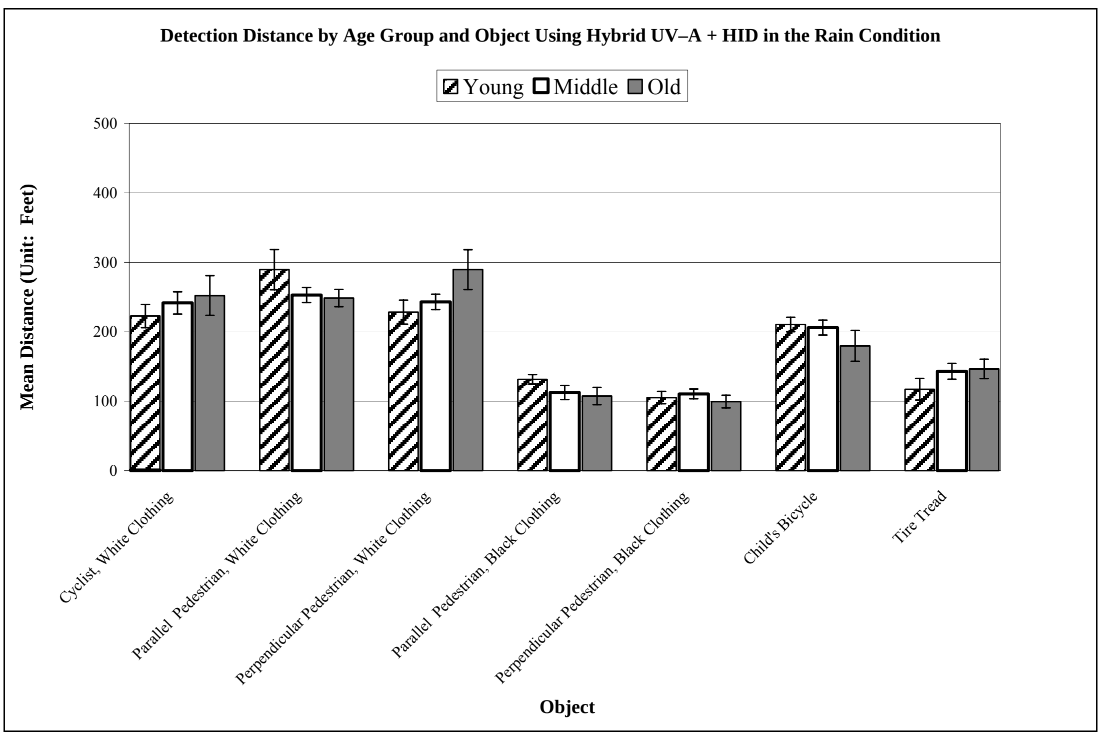
1 ft = 0.305 m

Figure 22. Bar graph. Results for the interaction: VES by Object by Age for five UV–A + HID.



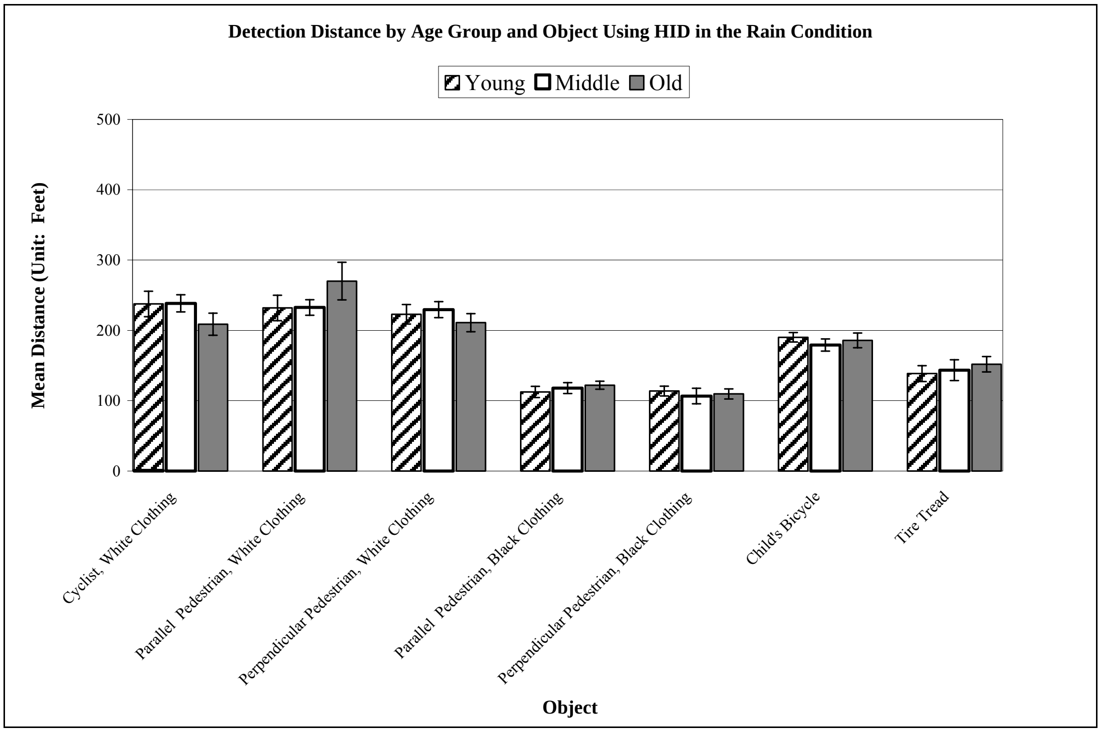
1 ft = 0.305 m

Figure 23. Bar graph. Results for the interaction: VES by Object by Age for three UV–A + HID.



1 ft = 0.305 m

Figure 24. Bar graph. Results for the interaction: VES by Object by Age for hybrid UV–A + HID.



1 ft = 0.305 m

Figure 25. Bar graph. Results for the interaction: VES by Object by Age for HID.

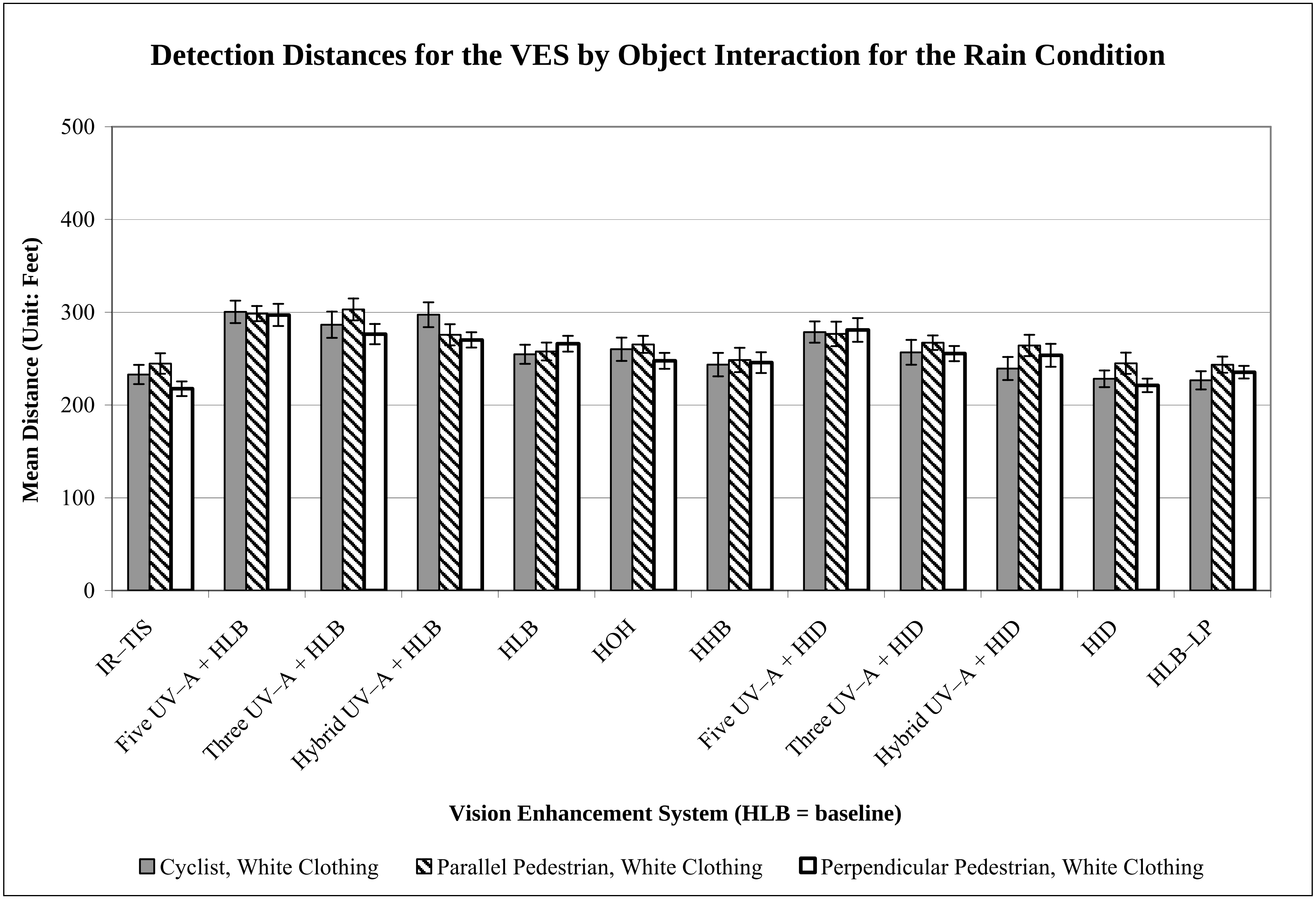
VES by Object Interaction

The significant difference ($p < 0.05$) for the VES by Object interaction under both detection and recognition distances appears to be mainly the result of the object contrast levels: black (low contrast) versus white (high contrast) objects (figure 26 through figure 29).

In general, the HLB performed as well as or better than the other VESs for the detection and recognition of high-contrast objects (figure 26 and figure 28). The only exception was the HLB with five UV–A, which enhanced drivers' detection and recognition of the white-clothed pedestrians and cyclist. However, with five UV–A + HLB the detection of white-clothed pedestrians and nonmotorists was less than 15.2 m (50 ft) farther away than with HLB (12 to 18 percent farther on average), and recognition was less than 12.2 m (40 ft) farther away (12 to 17 percent farther on average). On the other hand, the detection and recognition distances with HID were significantly shorter than with HLB for the cyclist and the perpendicular pedestrian with white clothing (10 to 12 percent and 17 percent closer to the object, respectively). Overall, detection and recognition distances with the IR–TIS were not different from HLB.

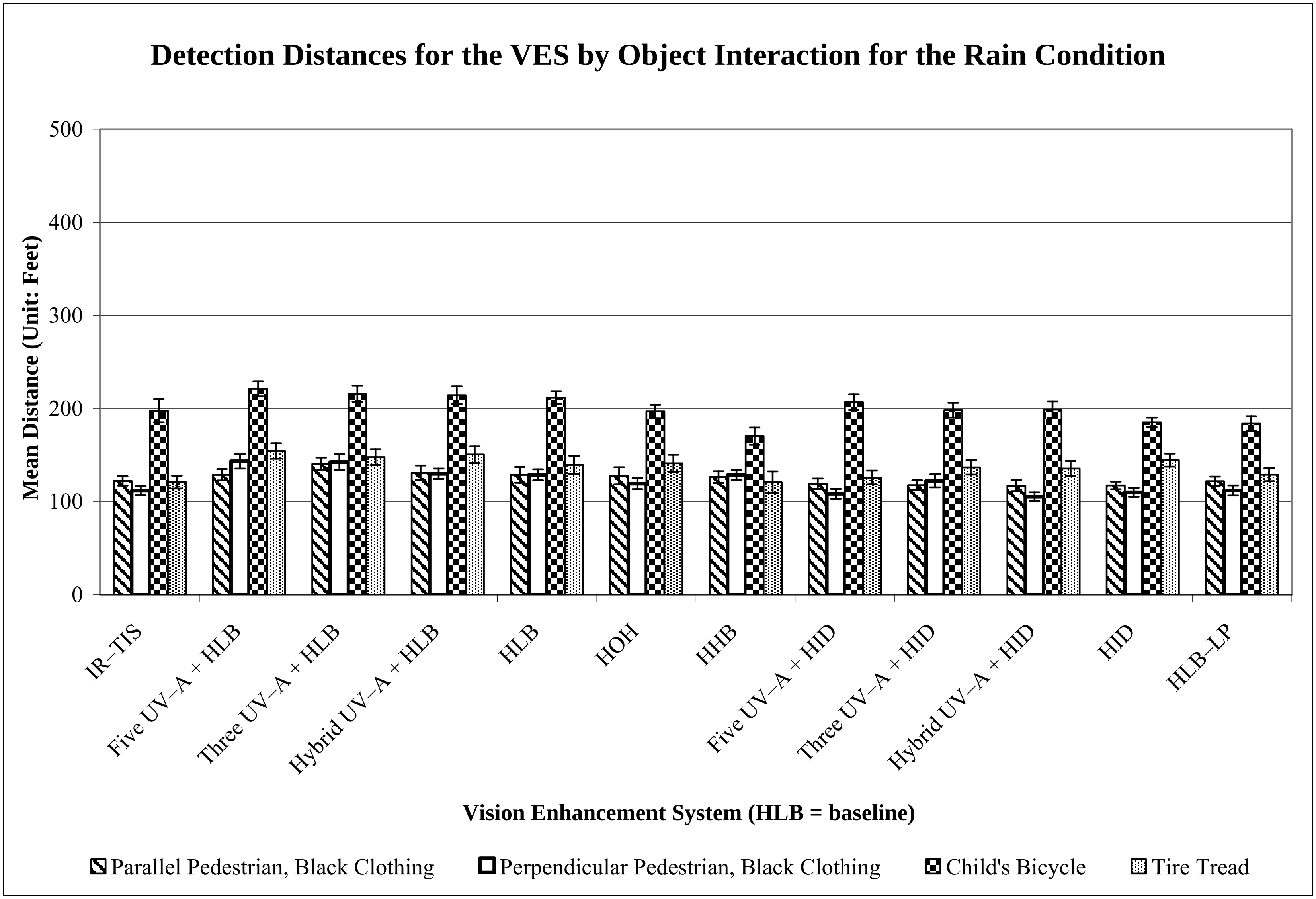
With respect to the low-contrast objects (figure 27 and figure 29), HLB was either better or no different than other VESs. For the parallel pedestrian with black clothing and the tire tread, there was no significant difference between HLB and all the other VESs for either detection or recognition distances. When drivers used HLB, they were able to detect and recognize the child's bicycle farther away than when they used the HID, HHB, or the HLB–LP (25 to 27 percent, 36 to 41 percent, and 27 to 28 percent farther, respectively). The detection and recognition distances for the perpendicular pedestrian with black clothing were farther away with HLB than with IR–TIS, HID, HID with any of the UV–A configurations, or the HLB–LP.

Across all objects, the halogen baseline configuration allowed drivers to detect and recognize objects sooner than did its HID counterpart. Depending on the type of object, the HLB allowed object detection ranging from 5.8 to 13.7 m (19 to 45 ft) farther away (15 percent farther for low-contrast objects and 17 percent farther for high-contrast objects, respectively) than the HID.



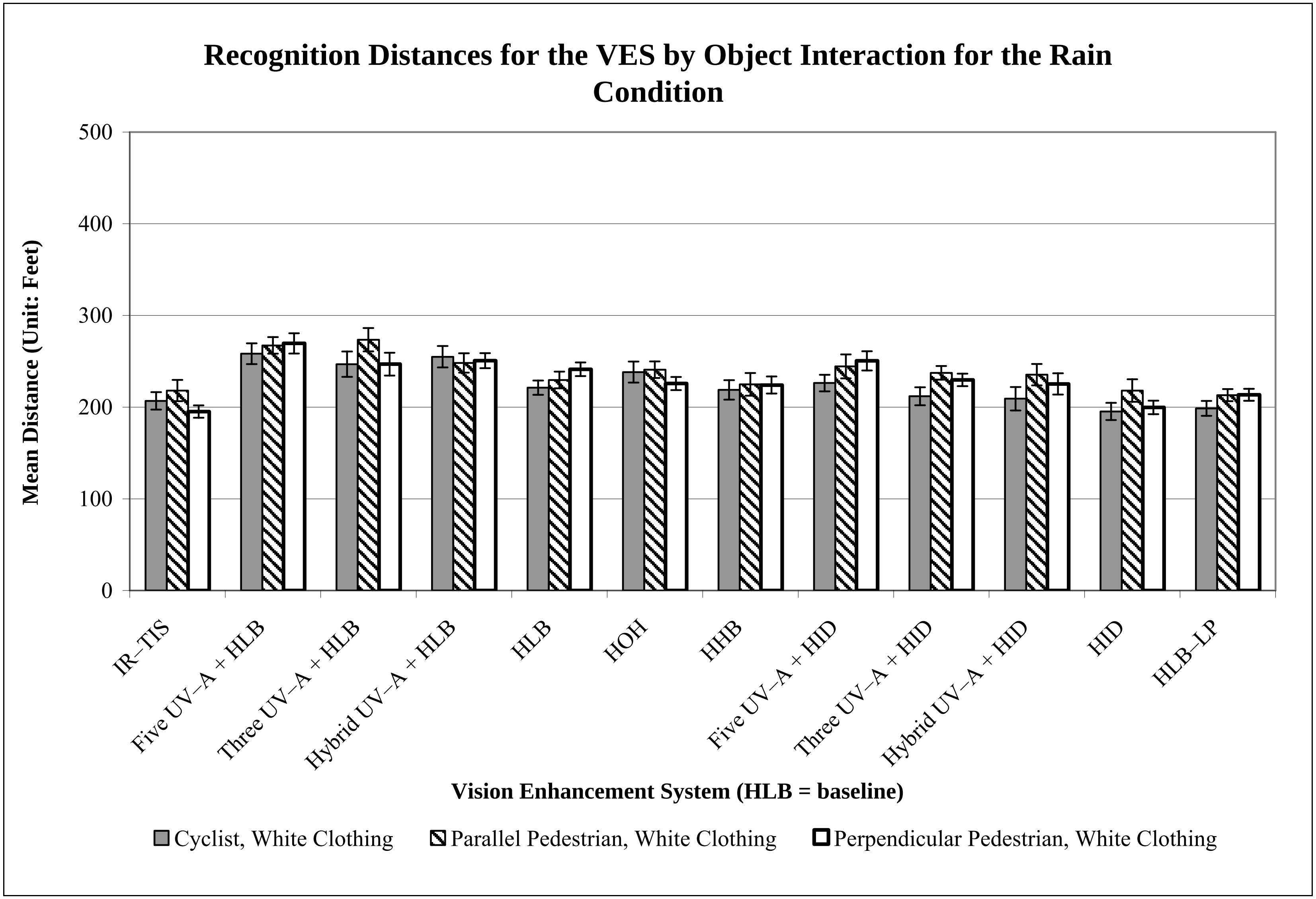
1 ft = 0.305 m

Figure 26. Bar graph. Results on detection distances for the VES by Object interaction for pedestrians and cyclist with white clothing.



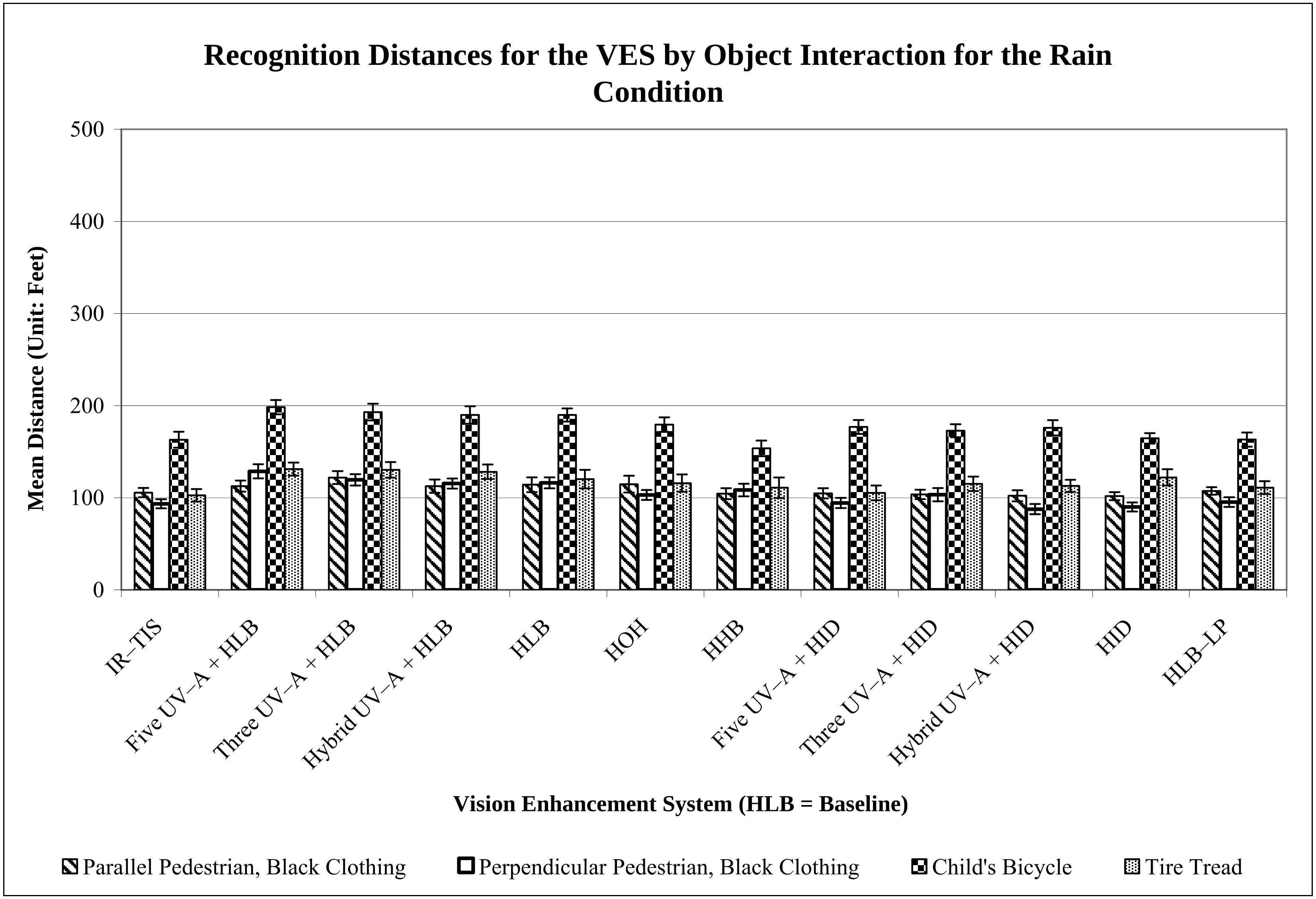
1 ft = 0.305 m

Figure 27. Bar graph. Results on detection distances for the VES by Object interaction for pedestrians with black clothing and other objects.



1 ft = 0.305 m

Figure 28. Bar graph. Results on recognition distances for the VES by Object interaction for pedestrians and cyclist with white clothing.

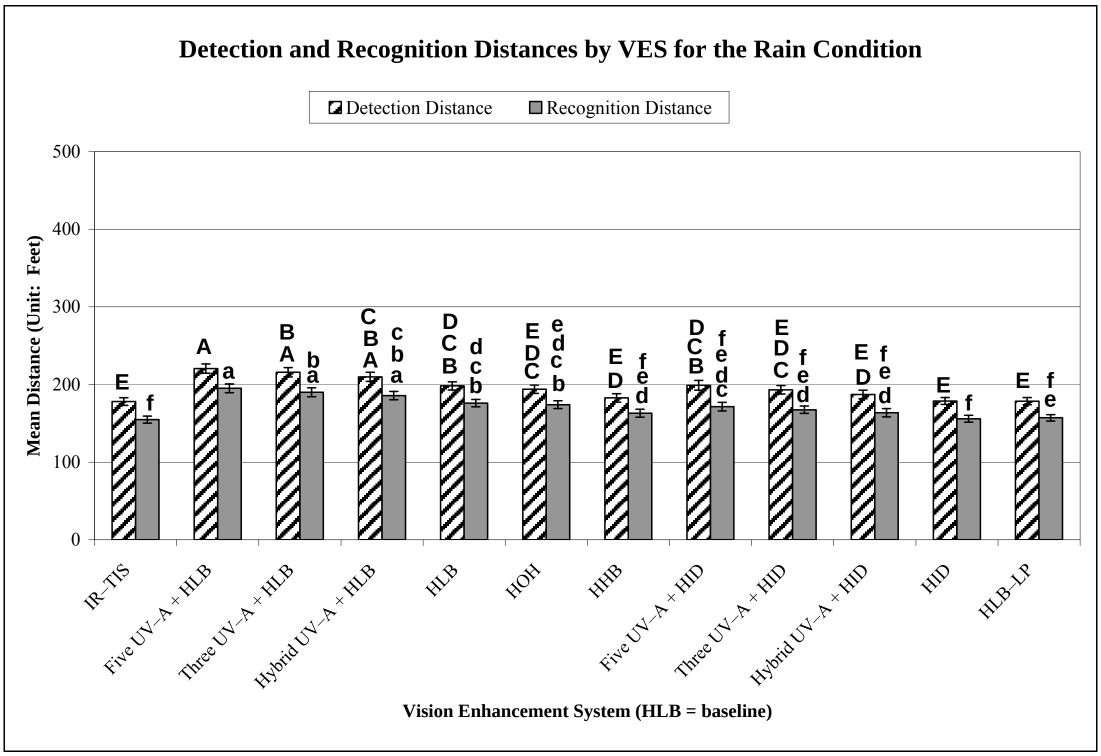


1 ft = 0.305 m

Figure 29. Bar graph. Results on recognition distances for the VES by Object interaction for pedestrians with black clothing and other objects.

VES Main Effect

VESs were significantly different from each other ($p < 0.05$) in terms of the detection and recognition distances. Post hoc analyses showed that the HLB provided detection and recognition distances that were significantly longer than the IR–TIS, HID, and HLB–LP VESs by approximately 6.1 m (20 ft). The HLB distances were significantly less than those provided by the five UV–A + HLB VES by 6.7 m (22 ft) (figure 30); however, the magnitude of these differences was relatively small, representing only 10 percent of the HLB performance levels.

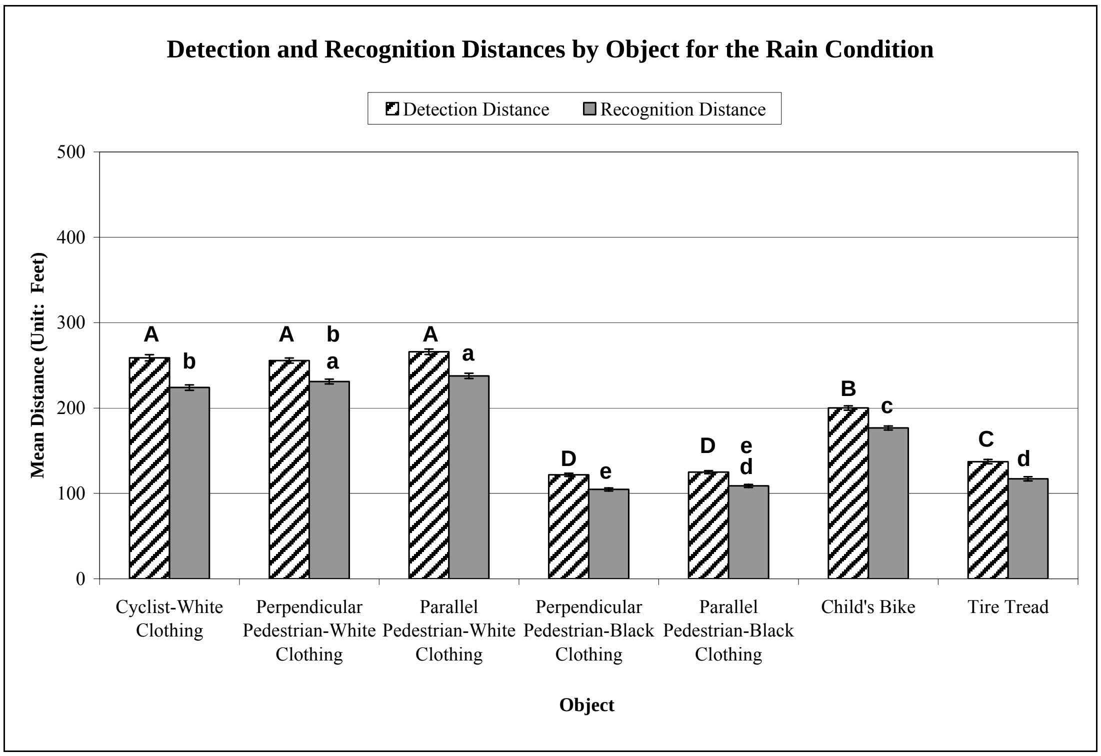


1 ft = 0.305 m
Means with the same letter are not significantly different.

Figure 30. Bar graph. Bonferroni post hoc results for the main effect: VES.

Object Main Effect

Type of object was also significant for both detection and recognition distances. Post hoc test results showed three distinct groups: white clothing, black clothing, and ground-level objects (figure 31). This suggests that overall the contrast rather than the motion of the object (or lack of) caused the observed differences. The high-contrast objects (i.e., pedestrians and cyclist with white clothing) were detected and recognized from farther away than were the other objects. The detection distances for the tire tread and child's bicycle were statistically different ($p < 0.05$) from the other objects; they were detected farther away than were black-clothed pedestrians but closer than were pedestrians with white clothing. The detection distances for pedestrians wearing black clothing were the closest to the actual object, and recognition distances were either as close (parallel pedestrian wearing black clothing) or closer (perpendicular pedestrian wearing black clothing) than the tire tread's recognition distance. The child's bicycle was detected and recognized farther away than were the pedestrians with black clothing and the tire tread.



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

Figure 31. Bar graph. Bonferroni post hoc results for main effect: Object.

SUBJECTIVE MEASUREMENTS

An ANOVA was performed to analyze the subjective measurements taken on the Smart Road. The model for this portion of the study was a 12 (VES) by 3 (Age) factorial design. ANOVA summary tables were generated for each of the seven subjective statements (table 9 through table 15), and significant main effects and interactions were summarized (table 16).

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

Statement 1: Detection						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	24.0	12.0	0.82	0.4499	
Subject/Age	27	394.4	14.6			
Within						
VES	11	244.0	22.2	14.86	<0.0001	*
VES by Age	22	32.4	1.5	0.99	0.4800	
VES by Subject/Age	297	443.3	1.5			
TOTAL	359	1138.2				

* = $p < 0.05$ (significant)

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

Statement 2: Recognition						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	26.8	13.4	0.87	0.4320	
Subject/Age	27	418.1	15.5			
Within						
VES	11	217.3	19.8	13.01	<0.0001	*
VES by Age	22	36.8	1.7	1.10	0.3439	
VES by Subject/Age	297	450.9	1.5			
TOTAL	359	1149.9				

* = $p < 0.05$ (significant)

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

Statement 3: Lane-keeping assistance						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	30.8	15.4	1.29	0.2922	
Subject/Age	27	323.2	12.0			
Within						
VES	11	297.5	27.0	18.83	<0.0001	*
VES by Age	22	26.8	1.2	0.85	0.6655	
VES by Subject/Age	297	426.6	1.4			
TOTAL	359	1104.9				

* = $p < 0.05$ (significant)

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

Statement 4: Roadway direction						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	13.2	6.6	0.70	0.5074	
Subject/Age	27	256.9	9.5			
Within						
VES	11	223.0	20.3	13.25	<0.0001	*
VES by Age	22	34.8	1.6	1.03	0.4240	
VES by Subject/Age	297	454.6	1.5			
TOTAL	359	982.5				

* = $p < 0.05$ (significant)

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

Statement 5: Visual discomfort						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	21.0	10.5	0.80	0.4580	
Subject/Age	27	352.9	13.1			
Within						
VES	11	230.6	21.0	13.56	<0.0001	*
VES by Age	22	38.3	1.7	1.13	0.3167	
VES by Subject/Age	297	459.1	1.5			
TOTAL	359	1101.9				

* = $p < 0.05$ (significant)

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

Statement 6: Overall safety rating						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	11.9	5.9	0.39	0.6794	
Subject/Age	27	407.9	15.1			
Within						
VES	11	262.1	23.8	15.73	<0.0001	*
VES by Age	22	39.5	1.8	1.18	0.2599	
VES by Subject/Age	297	450.0	1.5			
TOTAL	359	1171.4				

* = $p < 0.05$ (significant)

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

Statement 7: Overall VES evaluation						
Source	**DF**	**SS**	**MS**	**F value**	**P value**	
Between						
Age	2	10.0	5.0	0.30	0.7428	
Subject/Age	27	446.8	16.5			
Within						
VES	11	245.1	22.3	14.77	<0.0001	*
VES by Age	22	44.1	2.0	1.33	0.1513	
VES by Subject/Age	297	448.0	1.5			
TOTAL	359	1193.9				

* = $p < 0.05$ (significant)

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

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

x = $p < 0.05$ (significant)

To understand drivers' ratings of the various VESs in terms of safety and comfort, the results of all seven statements for every VES were sorted by ascending mean rating. Drivers rated the five UV–A + HID configuration as the most likely to help them detect and recognize objects sooner. The IR–TIS fared the worst on these same statements, obtaining a neutral rating. In general, HIDs received better rankings than did HLBs on statements relating to farther detection and recognition distances, effectiveness in lane-keeping assistance, less visual discomfort, and overall perception of safety. A list of all statements and mean ratings for each VES is presented next.

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

VES	**Mean Rating**
Five UV–A + HID	1.93
Three UV–A + HID	2.10
Hybrid UV–A + HID	2.27
Hybrid UV–A + HLB	2.37
HOH	2.37
HID	2.47
Five UV–A + HLB	2.53
Three UV–A + HLB	2.60
HLB	2.77
HLB–LP	3.27
HHB	4.03
IR–TIS	4.87

- ***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 + HID	1.90
Three UV–A + HID	2.07
Hybrid UV–A + HLB	2.37
HOH	2.47
Hybrid UV–A + HID	2.47
HID	2.50
Three UV–A + HLB	2.63
Five UV–A + HLB	2.67
HLB	2.73
HLB–LP	3.30
HHB	3.97
IR–TIS	4.73

- ***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 + HID	2.03
Three UV–A + HID	2.07
HOH	2.30
Hybrid UV–A + HID	2.33
HID	2.33
Hybrid UV–A + HLB	2.63
Three UV–A + HLB	2.77
Five UV–A + HLB	2.87
HLB	3.00
HLB–LP	3.53
HHB	4.37
IR–TIS	5.10

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

VES	**Mean Rating**
Five UV–A + HID	2.07
Hybrid UV–A + HID	2.37
HID	2.37
Three UVA + HID	2.43
Three UV–A + HLB	2.70
Hybrid UV–A + HLB	2.70
HOH	2.70
Five UV–A + HLB	2.83
HLB	3.07
HLB–LP	3.23
HHB	4.17
IR–TIS	4.93

- ***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**
Five UV–A + HID	1.53
HOH	1.73
Three UVA + HID	1.80
HID	1.80
Three UV–A + HLB	1.97
HLB	2.03
Five UV–A + HLB	2.20
HLB–LP	2.30
Hybrid UV–A + HLB	2.40
Hybrid UV–A + HID	2.40
HHB	3.70
IR–TIS	4.33

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

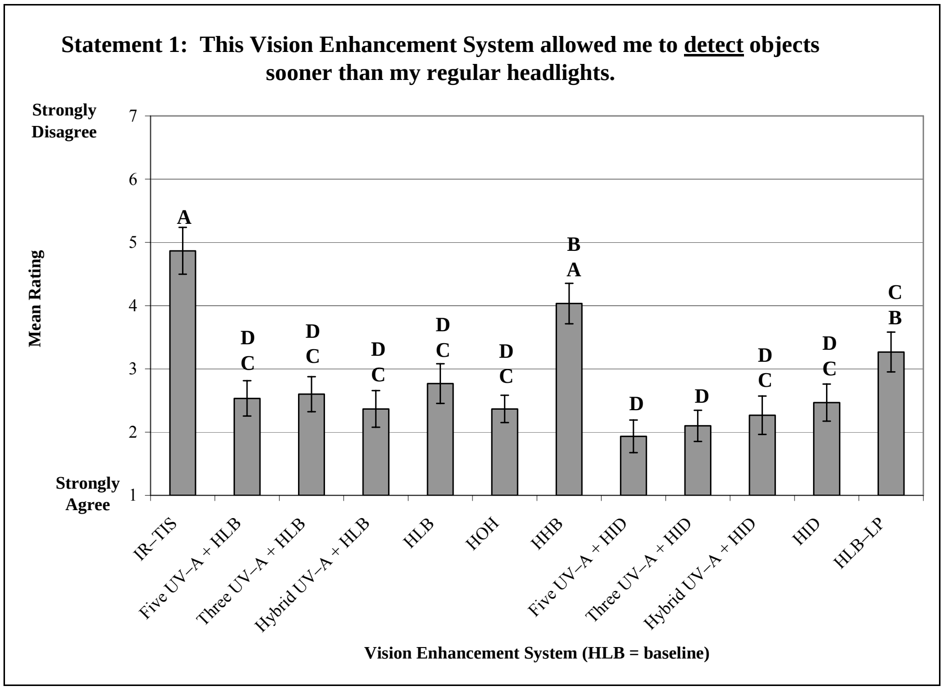
VES	**Mean Rating**
Five UV–A + HID	1.90
Three UVA + HID	1.93
HOH	2.30
Hybrid UV–A + HID	2.30
Hybrid UV–A + HLB	2.40
HID	2.43
Three UV–A + HLB	2.53
HLB	2.67
Five UV–A + HLB	2.87
HLB–LP	3.17
HHB	4.07
IR–TIS	4.93

- ***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 + HID	1.73
Three UVA + HID	1.90
HOH	2.20
Hybrid UV–A + HID	2.20
HID	2.27
Hybrid UV–A + HLB	2.33
Three UV–A + HLB	2.43
HLB	2.60
Five UV–A + HLB	2.67
HLB–LP	2.80
HHB	3.90
IR–TIS	4.77

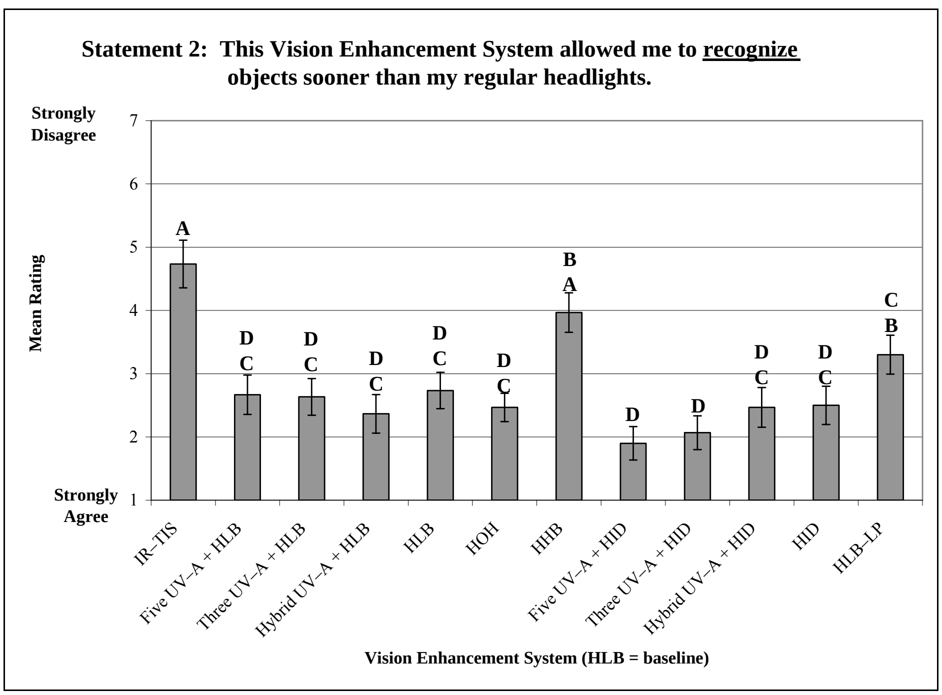
Post hoc test results were graphed for ease of interpretation (figure 32 through figure 38). Type of VES had the only significant effect on statements 1 through 7 (table 9 through table 16).

In statement 1, "This vision enhancement system allowed me to detect objects sooner than my regular headlights," a significant difference ($p < 0.05$) was observed between the IR–TIS configuration and all other configurations except HHB. IR–TIS received a mean rating of 4.87 (i.e., above "Neutral" with a tendency toward "Disagree"), while the HLB baseline received a mean rating of 2.77 (figure 32). Statements 2 through 7 followed a grouping pattern similar to that of statement 1 (figure 33 through figure 38).



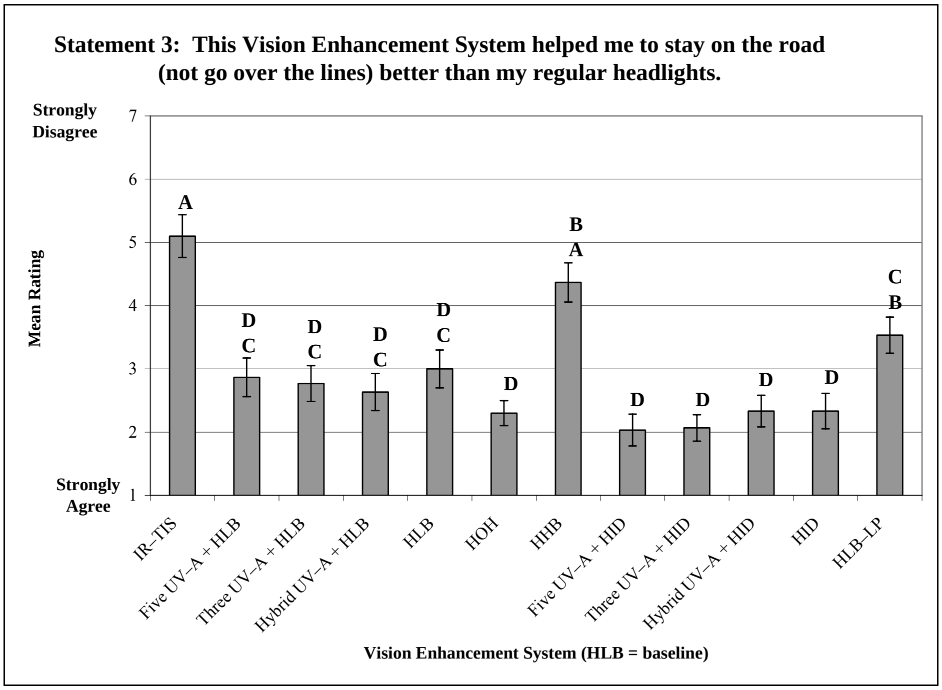
Means with the same letter are not significantly different.

Figure 32. Bar graph. Bonferroni post hoc results on the ratings evaluating detection for the main effect: VES.



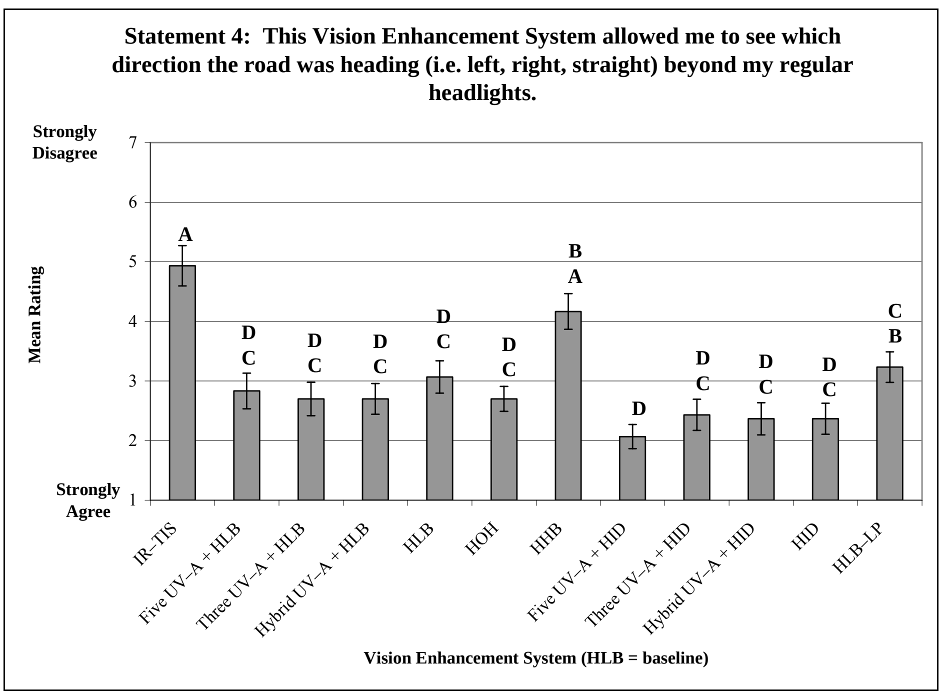
Means with the same letter are not significantly different.

Figure 33. Bar graph. Bonferroni post hoc results on the ratings evaluating recognition for the main effect: VES.



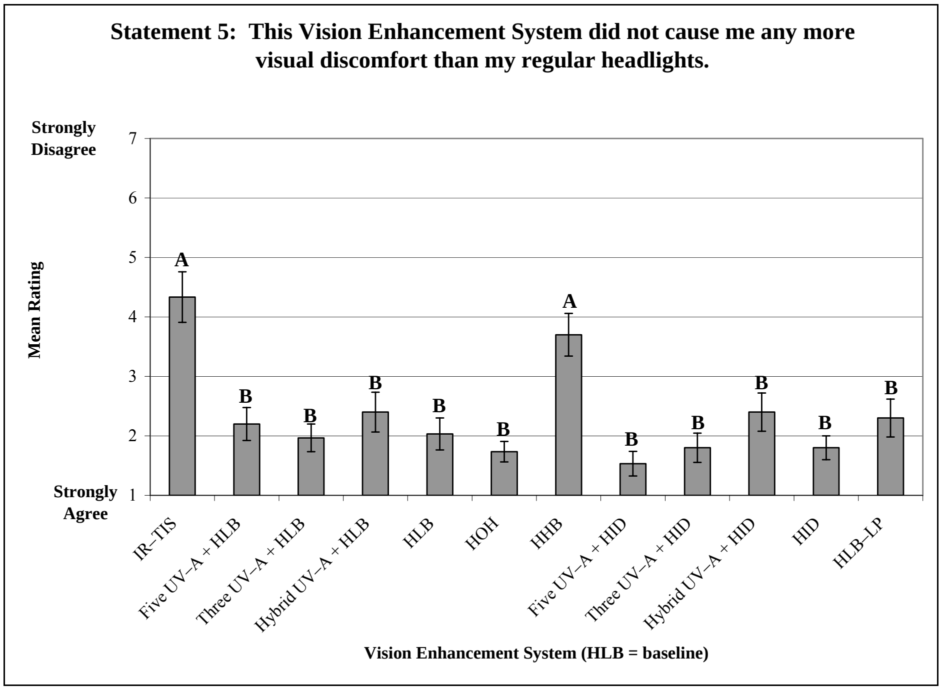
Means with the same letter are not significantly different.

Figure 34. Bar graph. Bonferroni post hoc results on the ratings evaluating lane-keeping assistance for the main effect: VES.



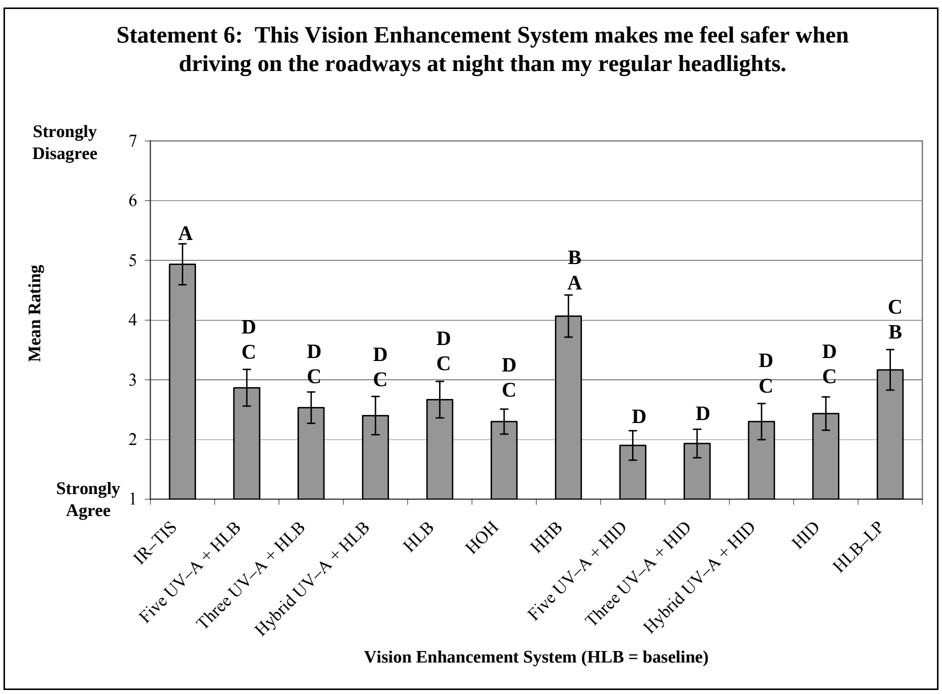
Means with the same letter are not significantly different.

Figure 35. Bar graph. Bonferroni post hoc results on the ratings evaluating roadway direction for the main effect: VES.



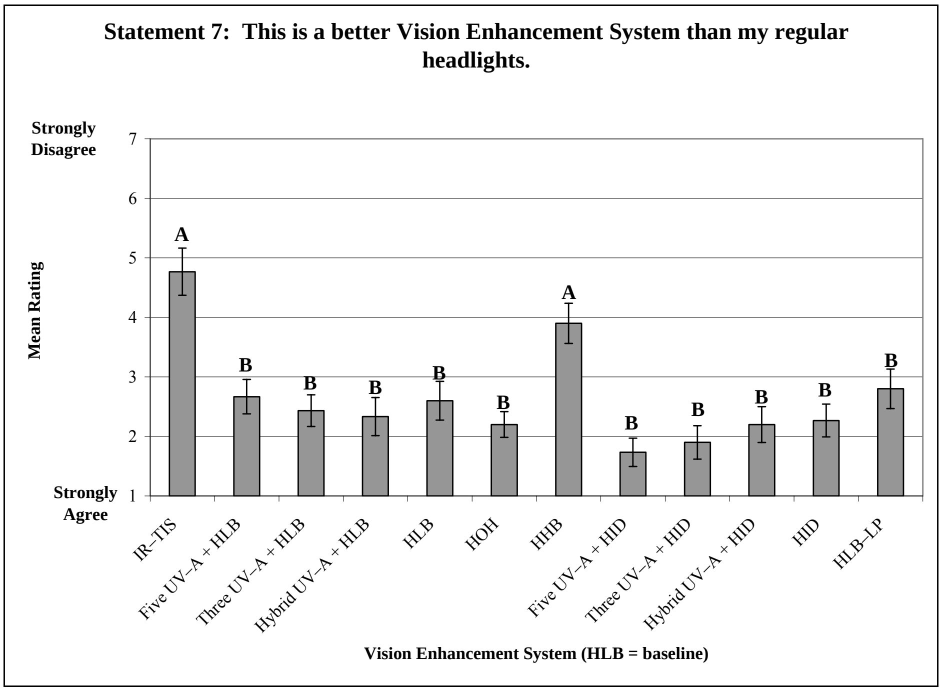
Means with the same letter are not significantly different.

Figure 36. Bar graph. Bonferroni post hoc results on the ratings evaluating visual discomfort for the main effect: VES.



Means with the same letter are not significantly different.

Figure 37. Bar graph. Bonferroni post hoc results on the ratings evaluating overall safety for the main effect: VES.



Means with the same letter are not significantly different.

Figure 38. Bar graph. Bonferroni post hoc results on the overall rating for the main effect: VES.

CHAPTER 4—DISCUSSION AND CONCLUSIONS

As mentioned in the Methods section (chapter 2), the headlamp aiming protocol used for this study resulted in a deviation in the maximum intensity location from where it typically is specified for some headlamp types. Details about this deviation are discussed in ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*. As a result of the headlamp aiming, the presented detection and recognition distances were likely increased for the HLB and HOH configurations and likely decreased for the HHB configuration. It is important to consider the results presented in this study in the context and conditions tested. If different halogen headlamps or aiming methods are used, different results might be obtained.

DETECTION AND RECOGNITION CAPABILITIES

While there were some significant differences in the detection and recognition distances among different VESs during nighttime driving in rain conditions, these differences would result in minimal improvements to driver reaction times for the objects tested. On average, objects were detected at distances of 67.4 m (221 ft) or closer. The HLB system, which was used as a baseline due to its widespread availability, provided an average detection distance of 60.4 m (198 ft). In this particular study, only the five UV–A + HLB system outperformed the HLB system, and only by 6.7 m (22 ft), representing an 11 percent difference. Faring the worst were the IR–TIS (in a reversal of the results from Phase II, Study 1, *Clear Weather*, ENV Volume III), HID, and HLB–LP, which all underperformed compared to the HLB system by about 6.1 m (20 ft), or 10 percent (table 17). When compared to the clear weather condition, rain (approximately 10.2 cm/h or 4 inches/h) severely decreased visibility for the IR–TIS by 74 percent and decreased visibility evenly for all the other VESs by 64 percent to 68 percent (table 19). Thus, except for the IR–TIS (which was more heavily affected by the rain), the rank order of the VESs by detection distance stayed fairly similar from the clear condition to the rain condition. This result might lead to a hypothesis that the rank order would remain constant under any rainfall rate. While a definitive finding would require testing at varying rainfall rates, there is nothing in the data to suggest that UV–A augmentation would significantly improve detection or recognition distances under lower rain rates. It is also intriguing to note that, while very subtle, the five and three UV–A systems (both HLB and HID) retained slightly greater detection distances than did the base HLB and HID systems (table 19).

Table 17. Mean detection and recognition distances during nighttime driving in rain.

VES	Mean Detection (ft)	Mean Recognition (ft)	Comparison to HLB: Detection (ft)	Comparison to HLB: Recognition (ft)
IR–TIS	178	155	−20	−21
Five UV–A + HLB	221	195	22	19
Three UV–A + HLB	216	190	18	14
Hybrid UV–A + HLB	210	186	12	10
HLB	198	176	0	0
HOH	194	174	−4	−2
HHB	183	163	−15	−13
Five UV–A + HID	199	172	1	−5
Three UV–A + HID	193	167	−5	−9
Hybrid UV–A + HID	187	164	−11	−12
HID	179	156	−19	−20
HLB–LP	179	157	−20	−19

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 other VESs were less than 6.7 m (22 ft), which translates to less than 1 second of additional reaction time, even at relatively low speeds (i.e., 40 km/h (25 mi/h); see table 18).

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

VES	Detection Distance Difference(ft)	25 mi/h	35 mi/h	45 mi/h	55 mi/h	65 mi/h
IR–TIS	−20	−0.5	−0.4	−0.3	−0.2	−0.2
Five UV–A + HLB	22	0.6	0.4	0.3	0.3	0.2
Three UV–A + HLB	18	0.5	0.3	0.3	0.2	0.2
Hybrid UV–A + HLB	12	0.3	0.2	0.2	0.1	0.1
HLB	0	0.0	0.0	0.0	0.0	0.0
HOH	−4	−0.1	−0.1	−0.1	−0.1	0.0
HHB	−15	−0.4	−0.3	−0.2	−0.2	−0.2
Five UV–A + HID	1	0.0	0.0	0.0	0.0	0.0
Three UV–A + HID	−5	−0.1	−0.1	−0.1	−0.1	−0.1
Hybrid UV–A + HID	−11	−0.3	−0.2	−0.2	−0.1	−0.1
HID	−19	−0.5	−0.4	−0.3	−0.2	−0.2
HLB–LP	−20	−0.5	−0.4	−0.3	−0.2	−0.2

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

Table 19. Differences in detection distances between clear and rain environments.

VES	Clear Detection (ft)	Rain Detection (ft)	Detection Difference (ft)	Reduction Percentage (ft)
IR–TIS	686	178	508	74
Five UV–A + HLB	625	221	404	65
Three UV–A + HLB	619	216	403	65
Hybrid UV–A + HLB	617	210	407	66
HLB	605	198	407	67
HOH	566	194	372	66
HHB	564	183	381	68
Five UV–A + HID	558	199	359	64
Three UV–A + HID	535	193	341	64
Hybrid UV–A + HID	533	187	346	65
HID	506	179	327	65
HLB–LP	527	179	349	66

1 ft = 0.305 m

While these distances and reaction times help indicate 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 under rain 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 is presented as distance-to-collision, or stopping distance, for direct comparisons to the detection distances from the current study. Stopping distance is the sum of two components: (1) the distance needed for the braking reaction time (BRT), and (2) braking distance (table 20). Braking distance is the distance that a vehicle travels while slowing to a complete stop.[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 39 provides the calculation of the braking distance (d_{BD}) under these conditions:

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

Figure 39. 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 40:

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

Figure 40. Equation. Total stopping distance for brake reaction time plus braking distance.

The equation in figure 40 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 40 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 41.[22]

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

Figure 41. Equation. AASHTO calculation of coefficient of friction for wet pavement.

Stopping distances in rain 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 (table 20).

Table 20. Stopping distances needed for a wet roadway.

	25 mi/h	35 mi/h	45 mi/h	55 mi/h	65 mi/h	70 mi/h
Speed (ft/s)	37	51	66	81	95	103
BRT in terms of Distance (ft)	92	128	165	202	238	257
Braking Distance(ft)	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 previous calculations represent a simple condition, but they allow for some visualization of VES capabilities. Based on these calculations, the average detection distances for each VES tested in the rain condition (i.e., rate of 10.2 cm/h (4 inches/h), windshield wiper on highest speed) are not long enough to provide adequate stopping distances for vehicle speeds at anything close to or greater than 56.3 km/h (35 mi/h); however, some caveats apply. First, these distances were obtained while drivers were moving at approximately 16.1 km/h (10 mi/h), and drivers' abilities to detect objects will not necessarily remain the same as speed increases. Second, systems that are currently close to the adequate stopping distance or that require a larger stopping distance might quickly become less effective when conditions worsen (e.g., worn tires, downhill condition, heavier rain). Third and most important, when detection distances are analyzed in more detail by examining the significant ($p < 0.05$) VES by Object interaction, different conclusions can be reached (table 21 through table 32). Several VES and object combinations resulted in detection distances that might compromise stopping distances.

As in the clear weather study (ENV Volume III), detection and recognition distances under the rain condition were strongly affected by the characteristics of the object, but the type of VES modulated this effect. The HID, HLB–LP, and IR–TIS provided the shortest detection distances for low-contrast objects; the HLB supplemented by UV–A allowed drivers to detect the pedestrians and cyclists dressed with white clothing farther away. These observations are even more apparent when described in terms of stopping distances (table 21 through table 32; in these tables, an “X” means the stopping distance might be compromised, and an asterisk means the same thing but in an unlikely scenario).

Table 21. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: IR–TIS.

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	112	X	X	X	X	X	X
Tire Tread	121	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	122	X	X	X	X	X	X
Child’s Bicycle	198		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	218		X	X	X	X	X
Cyclist, White Clothing	233		X	X	X	X	X
Parallel Pedestrian, White Clothing	245		X	X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
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: 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
Parallel Pedestrian, Black Clothing	129	X	X	X	X	X	X
Perpendicular Pedestrian, Black Clothing	143	X	X	X	X	X	X
Tire Tread	154		X	X	X	X	X
Child’s Bicycle	221		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	297			X	X	X	X
Parallel Pedestrian, White Clothing	299			X	X	X	X
Cyclist, White Clothing	300			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
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: three 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
Parallel Pedestrian, Black Clothing	141	X	X	X	X	X	X
Perpendicular Pedestrian, Black Clothing	142	X	X	X	X	X	X
Tire Tread	148	X	X	X	X	X	X
Child’s Bicycle	216		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	276			X	X	X	X
Cyclist, White Clothing	287			X	X	X	X
Parallel Pedestrian, White Clothing	303			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 24. 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	130	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	131	X	X	X	X	X	X
Tire Tread	151	X	X	X	X	X	X
Child’s Bicycle	214		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	270			X	X	X	X
Parallel Pedestrian, White Clothing	276			X	X	X	X
Cyclist, White Clothing	297			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 25. 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
Parallel Pedestrian, Black Clothing	129	X	X	X	X	X	X
Perpendicular Pedestrian, Black Clothing	129	X	X	X	X	X	X
Tire Tread	139	X	X	X	X	X	X
Child’s Bicycle	212		X	X	*	*	*
Cyclist, White Clothing	255			X	X	X	X
Parallel Pedestrian, White Clothing	258			X	X	X	X
Perpendicular Pedestrian, White Clothing	266			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 26. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HOH.

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	119	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	128	X	X	X	X	X	X
Tire Tread	141	X	X	X	X	X	X
Child’s Bicycle	197		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	248			X	X	X	X
Cyclist, White Clothing	260			X	X	X	X
Parallel Pedestrian, White Clothing	265			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 27. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HHB.

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
Tire Tread	121	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	126	X	X	X	X	X	X
Perpendicular Pedestrian, Black Clothing	128	X	X	X	X	X	X
Child’s Bicycle	170		X	X	*	*	*
Cyclist, White Clothing	244		X	X	X	X	X
Perpendicular Pedestrian, White Clothing	246			X	X	X	X
Parallel Pedestrian, White Clothing	248			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 28.Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: five UV–A + 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	108	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	119	X	X	X	X	X	X
Tire Tread	126	X	X	X	X	X	X
Child’s Bicycle	207		X	X	*	*	*
Parallel Pedestrian, White Clothing	277			X	X	X	X
Cyclist, White Clothing	279			X	X	X	X
Perpendicular Pedestrian, White Clothing	281			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 29. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: three UV–A + 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
Parallel Pedestrian, Black Clothing	118	X	X	X	X	X	X
Perpendicular Pedestrian, Black Clothing	122	X	X	X	X	X	X
Tire Tread	137	X	X	X	X	X	X
Child’s Bicycle	198		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	255			X	X	X	X
Cyclist, White Clothing	257			X	X	X	X
Parallel Pedestrian, White Clothing	267			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 30. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: hybrid UV–A + 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	105	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	117	X	X	X	X	X	X
Tire Tread	136	X	X	X	X	X	X
Child’s Bicycle	199		X	X	*	*	*
Cyclist, White Clothing	239		X	X	X	X	X
Perpendicular Pedestrian, White Clothing	254			X	X	X	X
Parallel Pedestrian, White Clothing	264			X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 31. 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	110	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	117	X	X	X	X	X	X
Tire Tread	145	X	X	X	X	X	X
Child’s Bicycle	185		X	X	*	*	*
Perpendicular Pedestrian, White Clothing	221		X	X	X	X	X
Cyclist, White Clothing	228		X	X	X	X	X
Parallel Pedestrian, White Clothing	245		X	X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
1 ft = 0.305 m
1 mi/h =1.6 km/h

Table 32. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HLB–LP.

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	112	X	X	X	X	X	X
Parallel Pedestrian, Black Clothing	122	X	X	X	X	X	X
Tire Tread	129	X	X	X	X	X	X
Child's Bicycle	184		X	X	*	*	*
Cyclist, White Clothing	227		X	X	X	X	X
Perpendicular Pedestrian, White Clothing	235		X	X	X	X	X
Parallel Pedestrian, White Clothing	243		X	X	X	X	X

X = stopping distance might be compromised
* = exceeds distance, but the scenario is not likely
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, configurations supplemented by UV–A headlamps, and IR-TIS, would outperform HLB in the experimental conditions for this study. Although some of these technologies indeed outperform HLB, not all do, and the improvements, while statistically significant, are not practical.

In general, HID systems followed the same trend discussed during the clear weather conditions study (ENV Volume III), in which 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 under the rain condition as well. It is possible that the HID system tested here differed significantly from the HID systems tested in other investigations in terms of cutoff and intensity; the characteristics of these systems vary considerably among manufacturers. While data generated by this investigation (see ENV Volume XVII, *Characterization of Experimental Vision Enhancement Systems*) agree with Jost's findings regarding the fact that an HID system provides more luminous flux than regular tungsten 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. Although this provides more foreground luminance, the HID VES provides less illumination as the distance from the vehicle increases when compared to the other VESs (e.g., halogen). This increased foreground luminance actually 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. An example of this potential safety concern is evident in the comparison of this study's subjective ratings of certain VESs to their detection and recognition distances. There were no significant differences between the subjective ratings of the HID VESs and the HLB VESs; however, in general, the HID systems received better ratings than the HLB systems even though the HLB systems (especially the five UV–A + HLB) provided longer detection and recognition distances. Thus, the higher level of foreground lighting appears to make drivers believe that the HID systems are better in terms of overall visibility and safety.

Rain negatively affected IR–TIS. While this system provided excellent performance levels under clear weather, it exhibited the shortest detection and recognition distances observed in the current study. System technology is the reason for this performance reversal. Because a temperature differential between the rain and the environment usually exists, rain droplets are visible to the IR system. Thus, rain droplets are displayed on the heads-up display (HUD), effectively washing out the display, like the picture on a television screen receiving considerable signal interference (i.e., "snow"). In the rain, drivers were not able to use the system effectively most of the time, and they were left with the HLB–LP (i.e., headlamps for that vehicle). Indeed, no performance differences are observed between the IR–TIS and the traditional HLB–LP. Following are some of the comments participants made about the system at the end of the study:

> "…the (sedan), you know with the night vision, it doesn't really do anything during the rain, it just looks all fuzzy." (Participant #37, younger male.)

> "This (sedan) with this heads-up display with night vision works good outside the rain. In the rain, it is terrible. When you see a person, it is like a ghost. I had to stop and the guy walked out there about 20 feet in front of me and I could barely see him in the rain. Outside the rain, it does good. I believe it needs some kind of contrasting detail to what's white turns up black there and what's black turns up white on this night vision. When rain is coming down it is like snow on an old television set, and you can't distinguish anybody out there. I could see them with my eyes but not on the heads-up display. I think it needs a contrasting knob or something that when you get in rain or snow, you will have to contrast up or down. In dry weather when I was outside the rain, I was impressed with it." (Participant #32, middle-aged male.)

> "I couldn't see through it (IR–TIS display) when it was raining. I couldn't see, I didn't like that at all, I enjoyed it a lot better the time I drove it and it didn't have it on (HLB–LP), but in the rain I could not see through that thing; maybe it's something I could get used to." (Participant #53, older male.)

UV–A headlamps improved detection and recognition of various objects when five UV–A headlamps were used together with HLB, especially for pedestrians and cyclists with white clothing; however, the improvements suggested by this study are not of the magnitude of the ones reported by Mahach et al. and Nitzburg et al.[27,28] In addition, this extra 6.7 m (22 ft) (i.e., 10 percent improvement) is statistically significant but not meaningful for implementation. At this point, it is not clear if UV–A's 10 percent improvement over HLB observed in this study might be exceeded during less severe weather conditions. Perhaps results in less severe rain might mimic the detection and recognition behavior under clear weather.

AGE EFFECTS ON DETECTION AND RECOGNITION DISTANCES

In the rain condition, in contrast to the clear weather condition, age did not significantly affect drivers' detection and recognition distances. During the rain condition, visibility was severely restricted across all age groups, and overall, no significant difference between age groups was observed in terms of detection and recognition distances. The data must be divided by age group, type of object, and VES (i.e., three-way interaction) before a few significant changes in performance appear (mainly for older drivers). However, as discussed in the results section for the three-way interactions, even those results that are statistically significant are not meaningful. Younger and middle-aged drivers exhibited more consistency in their performance across VESs and objects.

As explained in ENV Volume III, visual acuity and contrast sensitivity decline with age. It is theorized that, because of decreased contrast sensitivity and the low visibility conditions of adverse weather, older drivers were able to see from farther away only those objects that fluoresced because of the UV–A headlamps. The same age-dependent trends of decreased visual acuity and contrast sensitivity mentioned in ENV Volume III are evident for this group of participants. Figure 42 shows participants' visual acuity, and figure 43 through figure 47 show participants' percentage of contrast for the left eye (PCL) and right eye (PCR) for test lines A through E, which represent 1.5, 3.0, 6.0, 12.0, and 18.0 cycles per degree (cpd), respectively.

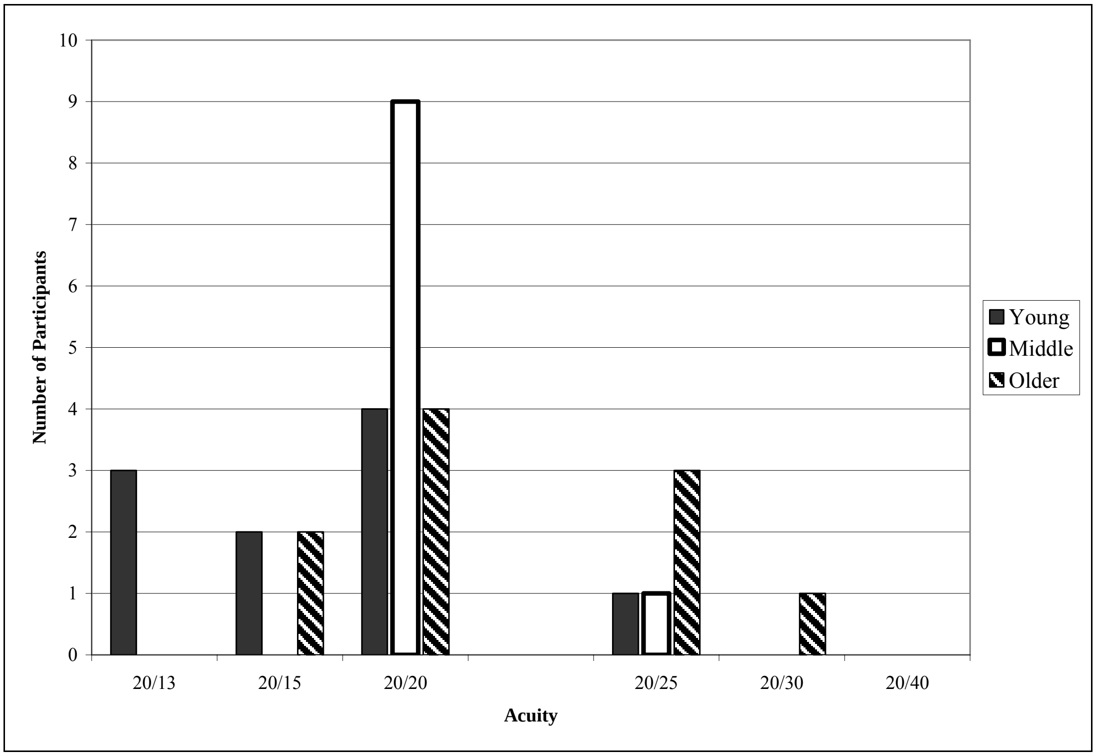


Figure 42. Bar graph. Participants' visual acuity divided by age group.

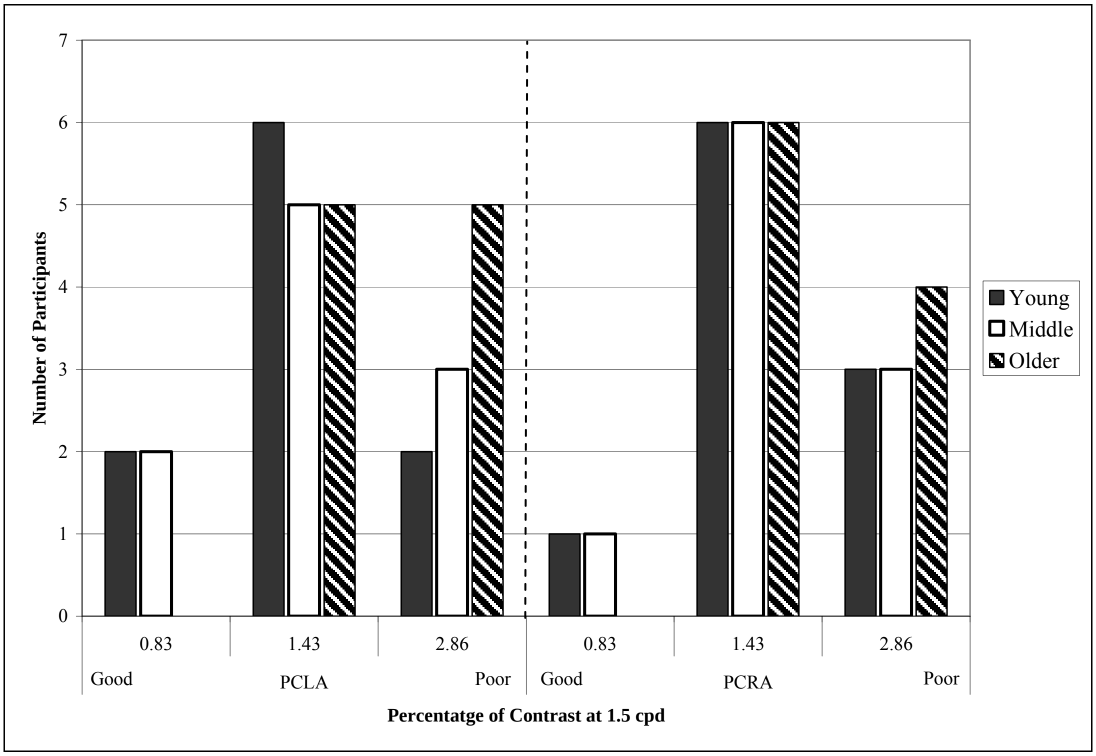


Figure 43. Bar graph. Participants' contrast sensitivity at 1.5 cpd (cycles per degree) divided by age group.

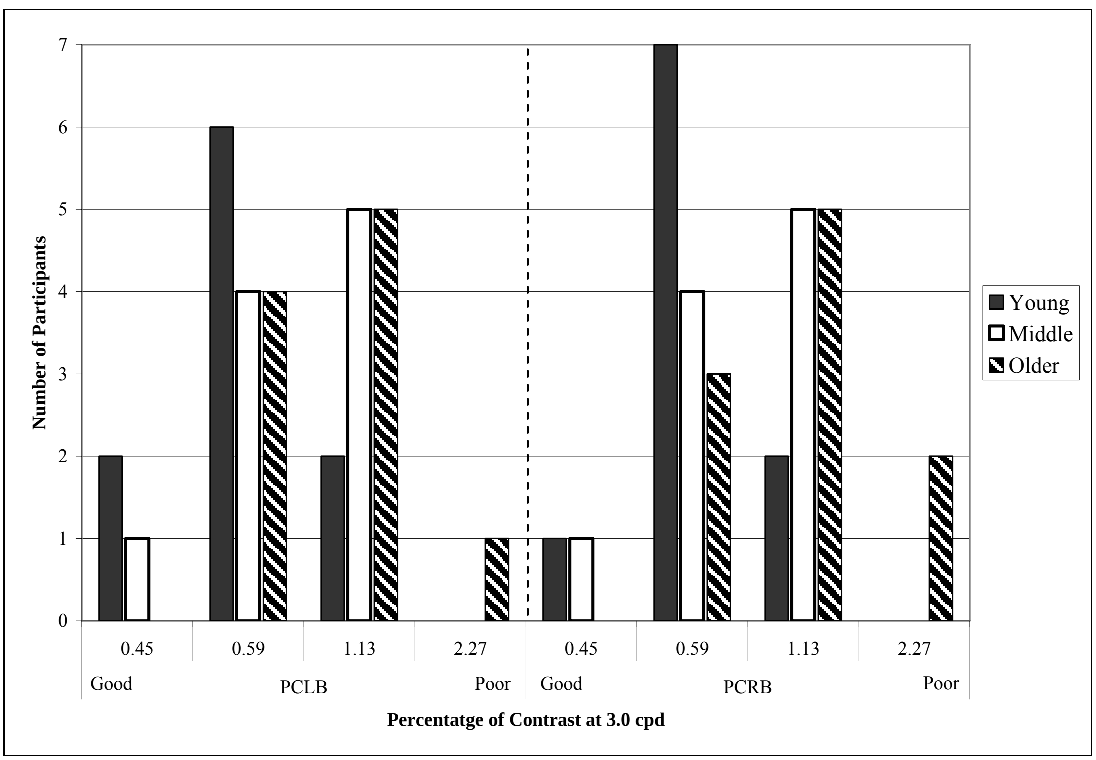


Figure 44. Bar graph. Participants' contrast sensitivity at 3.0 cpd divided by age group.

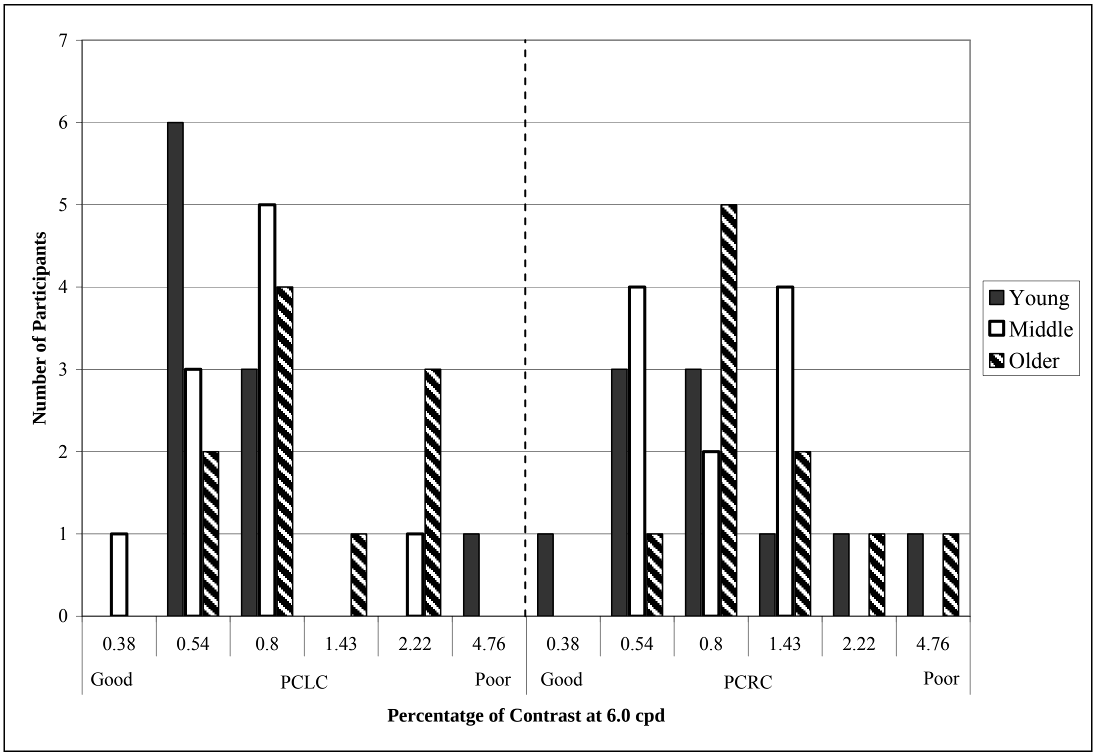


Figure 45. Bar graph. Participants' contrast sensitivity at 6.0 cpd divided by age group.

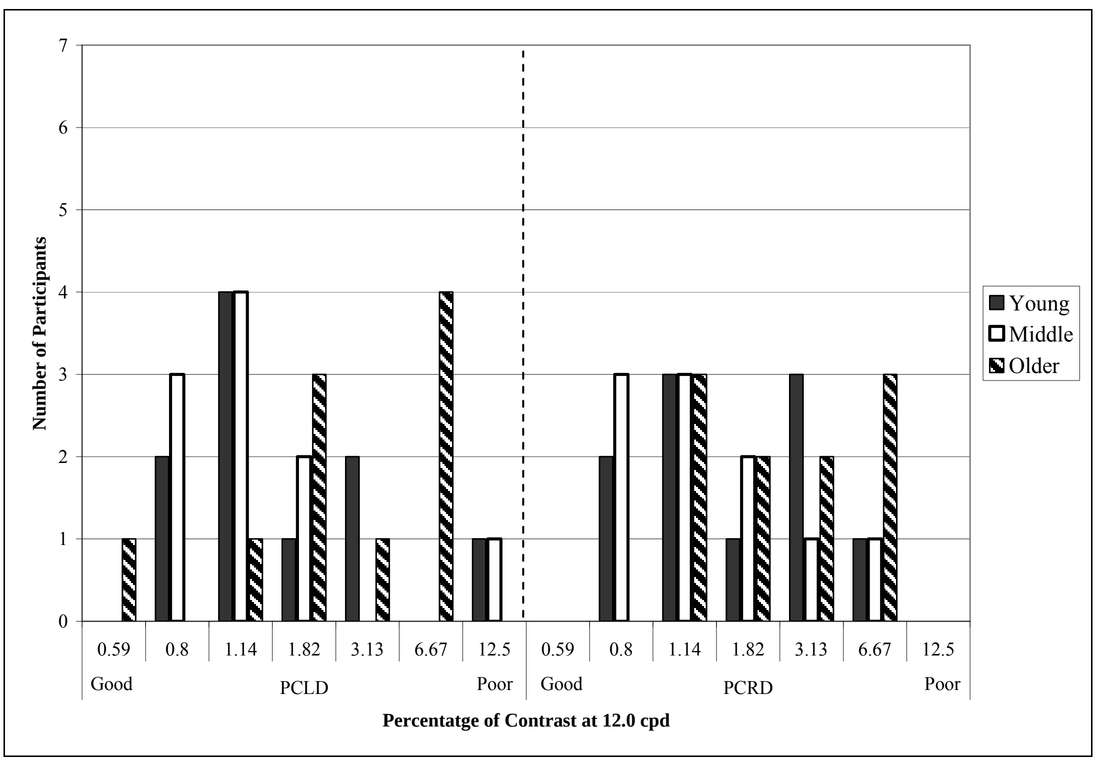


Figure 46. Bar graph. Participants' contrast sensitivity at 12.0 cpd divided by age group.

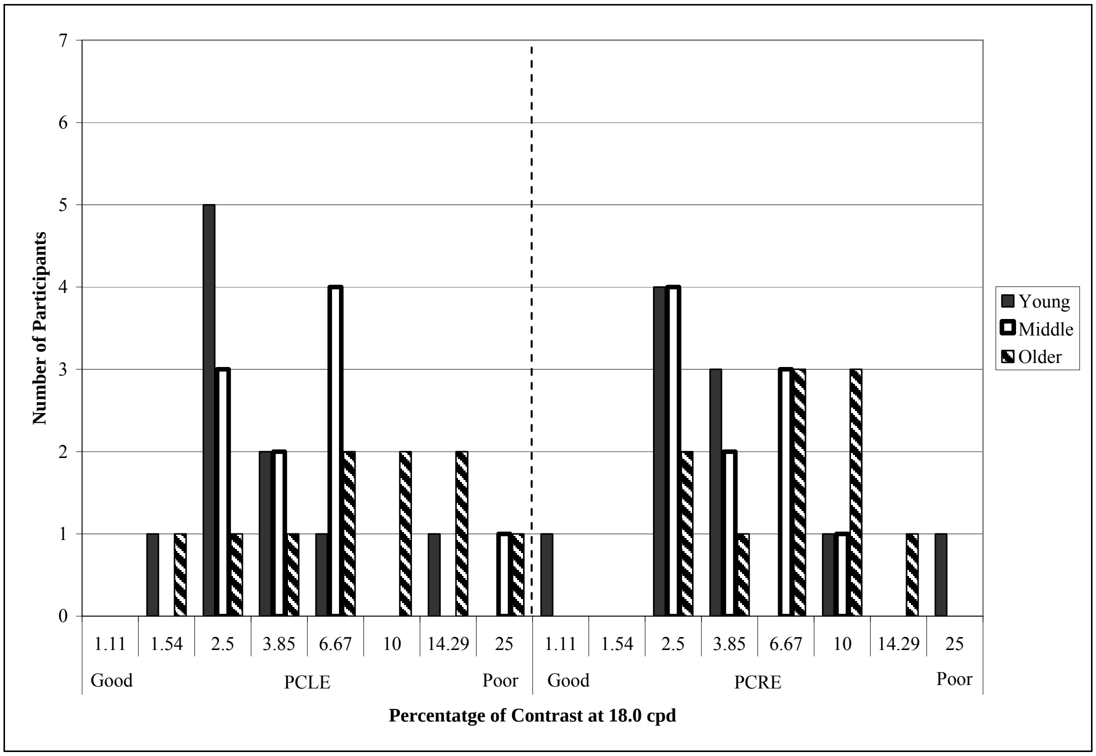


Figure 47. Bar graph. Participants' contrast sensitivity at 18.0 cpd divided by age group.

OBJECT EFFECT ON DETECTION AND RECOGNITION DISTANCES

Comparisons were made in this study to determine whether VESs that showed an increase in detection and recognition distances for pedestrians and cyclists also showed the same trend for other objects, such as the tire tread and the child's bicycle. HLB headlamps were used in this comparison as a baseline system (table 33 and table 36). The top three detection and recognition distances for each object are highlighted in table 34, table 35, table 37, and table 38 (1st = green, *; 2nd = blue, **; 3rd = yellow, ***).

Table 33. Detection distance differences by VES and type of object.

VES	Parallel Pedestrian, Black Clothing (ft)	Perpendicular Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perpendicular Pedestrian, White Clothing (ft)
	Type of Object						
IR–TIS	122	112	198	121	233	245	218
Five UV–A + HLB	129	143	221	154	300	299	297
Three UV–A + HLB	141	142	216	148	287	303	276
Hybrid UV–A + HLB	131	130	214	151	297	276	270
HLB	129	129	212	139	255	258	266
HOH	128	119	197	141	260	265	248
HHB	126	128	170	121	244	248	246
Five UV–A + HID	119	108	207	126	279	277	281
Three UV–A + HID	118	122	198	137	257	267	255
Hybrid UV–A + HID	117	105	199	136	239	264	254
HID	117	110	185	145	228	245	221
HLB–LP	122	112	184	129	227	243	235

1 ft = 0.305 m

Table 34. Detection distance difference between the different VESs and HLB.

VES	Parallel Pedestrian, Black Clothing (ft)	Perpendicular Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perpendicular Pedestrian, White Clothing (ft)
	Type of Object						
IR–TIS	−6	−17	−14	−18	−22	−13	−48
Five UV–A + HLB	**0*** **	**14***	**9***	**15***	**46***	**41****	**31***
Three UV–A + HLB	**12***	**14****	**4****	**8*****	**32*****	**45***	**10*****
Hybrid UV–A + HLB	**2****	**1*****	**2*****	**11****	**43****	18	4
HLB	0	0	0	0	0	0	0
HOH	−1	−9	−15	2	5	8	−18
HHB	−2	0	−41	−19	−11	−9	−20
Five UV–A + HID	−10	−20	−5	−14	24	**19*****	**15****
Three UV–A + HID	−11	−6	−14	−3	2	9	−11
Hybrid UV–A + HID	−12	−24	−13	−4	−15	7	−12
HID	−11	−19	−27	5	−26	−13	−45
HLB–LP	−7	−17	−28	−11	−28	−14	−31

* = 1st, ** = 2nd, *** = 3rd
1 ft = 0.305 m

Table 35. Percentage of detection distance difference between the different VESs and HLB.

VES	Parallel Pedestrian, Black Clothing (%)	Perpendicular Pedestrian, Black Clothing (%)	Child's Bicycle (%)	Tire Tread (%)	Cyclist, White Clothing (%)	Parallel Pedestrian, White Clothing (%)	Perpendicular Pedestrian, White Clothing (%)
	Type of Object						
IR–TIS	−5	−13	−7	−13	−9	−5	−18
Five UV–A + HLB	**0*****	**11***	**4***	**11***	**18***	**16****	**12***
Three UV–A + HLB	**9***	**11****	**2****	**6*****	**13*****	**18***	**4*****
Hybrid UV–A + HLB	**2****	**1*****	**1*****	**8****	**17****	**7*****	2
HLB	0	0	0	0	0	0	0
HOH	−1	−7	−7	1	2	3	−7
HHB	−2	0	−20	−13	−4	−4	−8
Five UV–A + HID	−7	−16	−2	−10	9	**7*****	**6****
Three UV–A + HID	−9	−5	−6	−2	1	4	−4
Hybrid UV–A + HID	−9	−18	−6	−3	−6	3	−5
HID	−9	−15	−13	4	−10	−5	−17
HLB–LP	−5	−13	−13	−8	−11	−6	−12

* = 1st, ** = 2nd, *** = 3rd

Table 36. Mean recognition distance differences by VES and type of object.

VES	Type of Object: Parallel Pedestrian, Black Clothing (ft)	Perpendicular Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perpendicular Pedestrian, White Clothing (ft)
IR–TIS	106	93	163	103	207	218	195
Five UV–A + HLB	113	129	198	131	258	267	270
Three UV–A + HLB	122	119	193	130	247	274	247
Hybrid UV–A + HLB	113	115	190	128	255	248	251
HLB	114	116	190	120	221	230	241
HOH	115	103	179	116	238	241	226
HHB	104	108	154	111	219	225	224
Five UV–A + HID	105	94	177	105	226	244	251
Three UV–A + HID	104	103	173	115	212	237	230
Hybrid UV–A + HID	102	88	176	113	209	235	225
HID	102	90	165	122	195	218	200
HLB–LP	107	95	163	111	199	213	214

1 ft = 0.305 m

Table 37. Recognition distance difference between the different VESs and HLB.

VES	Type of Object: Parallel Pedestrian, Black Clothing (ft)	Perpendicular Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perpendicular Pedestrian, White Clothing (ft)
IR–TIS	−9	−23	−27	−18	−14	−12	−46
Five UV–A + HLB	−2	**12***	**9***	**11***	**37***	**38****	**28***
Three UV–A + HLB	**8***	**3****	**3****	**10****	**26*****	**44***	6
Hybrid UV–A + HLB	−2	−1	0	**8*****	**34****	**19*****	9**
HLB	**0*****	**0*****	**0*****	0	0	0	0
HOH	**1****	−13	−10	−4	17	11	−16
HHB	−10	−8	−36	−9	−2	−5	−17
Five UV–A + HID	−9	−22	−13	−15	5	15	**9*****
Three UV–A + HID	−11	−13	−17	−5	−9	8	−12
Hybrid UV–A + HID	−12	−29	−14	−7	−12	6	−16
HID	−12	−26	−25	2	−26	−12	−42
HLB–LP	−7	−21	−27	−9	−23	−17	−28

* = 1st, ** = 2nd, *** = 3rd
1 ft = 0.305 m

Table 38. Percentage of difference between the different VESs and HLB.

VES	Type of Object: Parallel Pedestrian, Black Clothing (%)	Perpendicular Pedestrian, Black Clothing (%)	Child's Bicycle (%)	Tire Tread (%)	Cyclist, White Clothing (%)	Parallel Pedestrian, White Clothing (%)	Perpendicular Pedestrian, White Clothing (%)
IR–TIS	−8	−20	−14	−15	−7	−5	−19
Five UV–A + HLB	−1	**11***	**4***	**9***	**17***	**16****	**12***
Three UV–A + HLB	**7***	**3****	**2****	**8****	**12*****	**19***	2
Hybrid UV–A + HLB	−1	−1	0	**7*****	**15****	**8*****	**4****
HLB	**0*****	**0*****	**0*****	0	0	0	0
HOH	**1****	−11	−5	−4	8	5	−6
HHB	−9	−7	−19	−8	−1	−2	−7
Five UV–A + HID	−8	−19	−7	−12	2	6	**4*****
Three UV–A + HID	−9	−11	−9	−4	−4	3	−5
Hybrid UV–A + HID	−11	−25	−7	−6	−5	3	−7
HID	−11	−23	−13	2	−12	−5	−17
HLB–LP	−6	−18	−14	−8	−10	−7	−12

* = 1st, ** = 2nd, *** = 3rd

For this study, there is a marked trend of HLB and HLB with UV–A consistently providing the driver with the best (farthest away from the object) detection and recognition across all objects. The effect of adding UV–A ranges from a 0.03- to a 14.0-m (0.1- to 46-ft) improvement (less than 1 percent to 18 percent) over HLB for detection distances and up to a 13.4-m (44-ft) improvement (19 percent) for recognition distances. When pedestrian detection and recognition results are compared between HLB and HLB with UV–A, the biggest difference is due to pedestrian clothing color. The UV–A allows drivers to detect and recognize pedestrians dressed in light-colored clothing farther away than HLB alone. Following are some of the comments participants made about the UV–A headlamps at the end of the study:

> "One of the trucks I drove, I could see the objects the best, I think it was UV–A; it made the white guy look purple, that was a really good headlight, it was my favorite one; I could see further than anything else." (Participant #55, younger female.)

> "The lights that I liked the best I didn't know that they had UV on at all until I saw the white pedestrian from far away. I could tell those lights were on and those were the ones that I said were the best." (Participant #1, younger male.)

As mentioned previously, the rain affected the detection and recognition distances for the different objects with the IR–TIS. The pedestrians and the cyclist, who were detected farther away with the IR–TIS during clear weather than with any other VES, were detected primarily with the HLB–LP headlamps on the IR–TIS vehicle during rain. The HID headlamps consistently had the worst (closest to the object) detection and recognition distances across all objects.

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

- UV–A technology does not represent a meaningful improvement over the halogen and HID headlamps used in this research.
- The image presented to the drivers from the IR–TIS is negatively affected by heavy rain.

- Clothing contrast, rather than object motion, appears to be responsible for the differences observed between the different types of pedestrians and nonmotorists.
- Although the halogen supplemented with UV–A allowed pedestrians and cyclists with white clothing to be detected farther away, the drivers' subjective evaluation indicated that HIDs were more helpful in object detection.
- HLB and HLB supplemented with UV–A were consistently the best in facilitating long detection and recognition distances, although the aiming protocol used for this study likely increased detection and recognition distances for the HLB headlamps.

APPENDIX A—SCREENING QUESTIONNAIRE

Driver Screening and Demographic Questionnaire: ENV-Rain

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 a car for three sessions. The first session will be a training session, and the other two will be 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. The first session should be less than an hour, and the other two sessions will take approximately 2-3 hours. We will pay you $20 per hour. The total amount will be given to you at the end of the third 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 18-25, 40-50, or 65+ years of age.
3. Must drive at least two times a week.
4. Must have normal (or corrected to normal) hearing and vision.
5. Must be able to drive an automatic transmission without special equipment.
6. Must not have more than two driving violations in the past 3 years.
7. Must not have caused an injurious accident in the past 2 years.
8. Cannot have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures within 12 months, respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.
9. Must not be pregnant.
10. Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).
11. No history of radial keratotomy, (laser) eye surgery, or any other ophthalmic surgeries.

****

Accepted: ________ Days that will attend study:
(T):_________(N1):_________(N2):________

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 Nonmotorists, Objects, and Traffic Control Devices under Various Weather Conditions and Different Vision Enhancement Systems

Investigators: ________________________________

THE PURPOSE OF THIS RESEARCH/PROJECT

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

I. PROCEDURES

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

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

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

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

II. RISKS

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

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

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

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

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

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

III. BENEFITS OF THIS PROJECT

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

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

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

V. COMPENSATION

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

VI. FREEDOM TO WITHDRAW

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

VII. APPROVAL OF RESEARCH

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

VIII. SUBJECT'S RESPONSIBILITIES

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

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

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

3. Wear your seatbelt.

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

IX. SUBJECT'S PERMISSION

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

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

Signature Date

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

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

APPENDIX C—VISION TEST FORM

PARTICIPANT NUMBER: __________

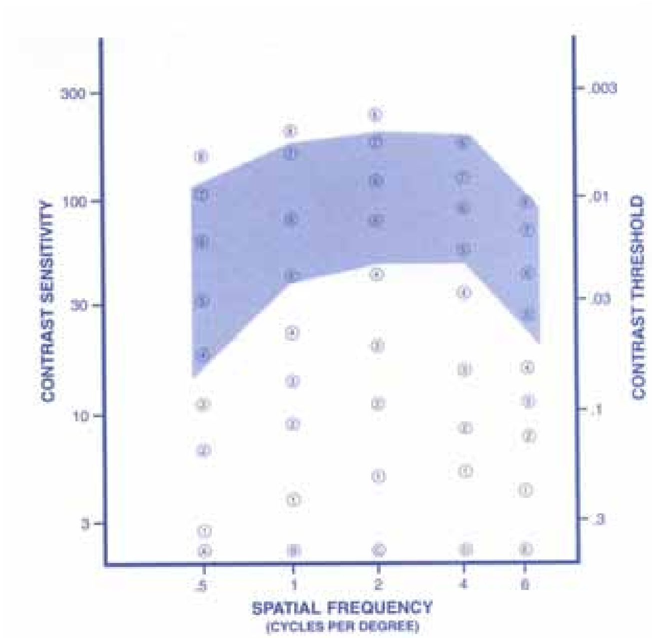
VISION TESTS

Acuity Test

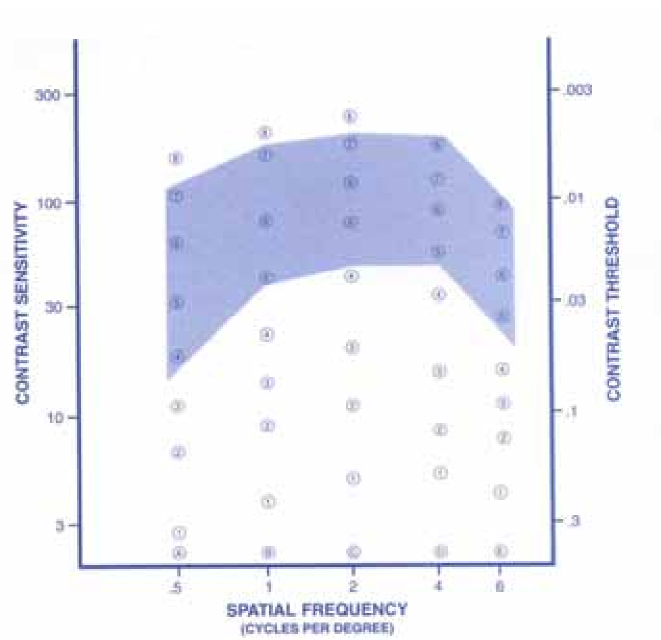
- Acuity Score:_________

Contrast Sensitivity Test

Left



Right



Ishihara Test for Color Blindness

1._____ 4._____ 7.____

2._____ 5._____

3._____ 6._____

APPENDIX D—TRAINING PROTOCOL

Protocol for ENV-Objects

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 driving different cars for three sessions. The first session will be a training session. That is what we will be doing today. The other two will be on the Smart Road. The first session should be less than an hour, and the other two sessions will take approximately 2-3 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 12 different vision enhancement systems. You will make two laps 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.

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

8. Vision tests.

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

The results for all three parts must be recorded on the vision test form.

The first test is the Snellen eye chart test.

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

Procedure: *Look at the wall and read aloud the smallest line you can comfortably read.*

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

The next vision test is the contrast sensitivity test. Take the participant over to the eye chart test area.

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

Procedure: *We are going to test how well you see bars at different levels of contrast. Your ability to see these bars 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. Nighttime driving questionnaire.

Have subject complete the nighttime driving questionnaire located in the participant package. The participant needs to read each question and complete the questionnaire based on their driving practices. Ensure them that it is not going to be used against them but instead will be used to get a better idea of their current practices.

10. 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. Tonight, I will be the experimenter that will be riding with you during the training session. For the other two sessions, you will also be riding with an experimenter.*

Slide 2: *This is a timeline of how the night will break down. We are in the laboratory training portion right now. Once we are done with the lab training, we will familiarize you with the thermal imaging system and the procedure for the experiment.*

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

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

We will be using four different vehicles over the two nights of onroad studies: one car with a thermal imaging system, a pickup truck, and two sport utility vehicles.

The next two nights of the study will take place out in the Smart Road once it is completely dark. We will perform this study under several weather conditions. You will be performing the study under a rainy 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 or part of the Smart Road during daytime.*

Slide 7: *You will drive a total of four vehicles between the two nights. Each vehicle might include more than one configuration of vision enhancement systems, for a total of 12 different configurations. Eleven of those configurations are headlamps; the 12th configuration is an Infrared-Thermal Imaging System. This last one is a "heads-up" display positioned over the steering wheel. You will have the opportunity to practice with this system tonight.*

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

Show them the button

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

Press the button

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

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

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

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

For example,
"I see a person"
"I see a cyclist"
"I see a kid's bike"
"I see a tire tread"

If you perform an unsuccessful recognition, you can press the push button again.

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

Slide 12: *You will also see static objects along the road. The first, a child's bicycle, will be lying along the right side of the road. The second, a tire tread, will also be lying on the right-hand side of the road. Finally, a person will be standing on the right-hand side of the road to simulate a person waiting to cross the road.*

Slide 13-15: *Here are pictures of a few 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.*

**Tell the participant what they are and whether they are static or dynamic **

Slide 16: *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 the first set of questions, 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.*

The second set consists of two statements that use different scales. One deals with the likelihood of driving at night, and the other deals with carefulness while driving at night. For these last two questions and scales, imagine that you have this vision enhancement system available in your own vehicle. Considering this, you will first rate the likelihood that you would drive at night in rainy conditions. Then you would rate how carefully you would drive in rainy conditions with that vision enhancement system. When you are considering the rating, ask yourself if you think you need to be more careful driving with that VES than you normally would be when driving on a rainy night (i.e., extremely careful) or the opposite (i.e., not at all careful).

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 17: Go over main points.

Slide 18: *Do you have any questions about this questionnaire?*

Answer any questions.

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

Show them diagram

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

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

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

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

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

*****ANY QUESTIONS?*****

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

- Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.
- Turn on the HUD and adjust brightness.
- There are two controls used to power and adjust the HUD, located to the left of the steering wheel and under the dashboard. The right control, an up/down sliding switch, is used to power the display. The display is powered on when the sliding switch is pulled into the top position and is powered off when the sliding switch is pushed down into the lowest position. The position of this sliding switch will change the brightness of the HUD.
- Adjust position of the HUD.
- The left control is used to adjust the vertical position of the display. Press the top or bottom of the switch to move the display up or down in the driver's field of view, but make sure that the driver can see the display over the top of the steering wheel.
- Describe the HUD to the driver.

The thermal imaging system is composed of infrared technology that lights up the road ahead. The idea is to provide the driver with an enhanced view of the roadway ahead when traveling at night.

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

13. Take eye height measurements on all vehicles that are available.
    - To do this, first explain to the participant that you are going to make a mark on the window 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.

14. Remind participant of the day and time they are scheduled to return.

15. Document the time they leave on the debriefing form.

16. Shut down.
    - File the following forms in the appropriate binders:
        - Tax form.
        - Informed consent.

    - Make sure completed envelopes contain the following:

- Eye height measurement sheet.
- Debriefing/time in-out form.
- Vision tests.
- Night driving questionnaire.

*The only form with participant's name on it is the debriefing form.

APPENDIX E—TRAINING SLIDES

Enhanced Night Visibility

- Schedule and Training

Schedule

Training

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

Night 1 and 2

- On Road Study

What is the Enhanced Night Visibility study?

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

Lab Training

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

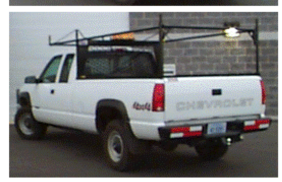
The Smart Road

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

The Smart Road

Experimental Vehicles

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



Detection and Recognition

- Your primary task is to drive safely
  - Training; 15 mph in gravel lot, 25 mph on paved road
  - Night 1 & 2; 10 mph on Smart Road
- Your job will be to detect and recognize different objects on the Smart Road
- You will be required to press a button when you both detect and recognize objects

Detection of Objects

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

Recognition of Objects

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

Types of objects

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

Types of objects

- Static Objects
  - Bicycle: A children’s bicycle will be laying on the right side of the road.
  - Tire Tread: A vehicle tire tread will be laying on the right side of the road.
  - Static pedestrian: A pedestrian will be standing still on the right side of the road.

Dynamic Objects

Bicyclists

Dynamic Objects

Walking Pedestrians

Static Objects

Children’s Bicycle

Tire Tread

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 questionnaires and different rating scales.

What we need from you

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

QUESTIONS?

APPENDIX F—IN-VEHICLE EXPERIMENTAL PROTOCOL

IN-VEHICLE PROTOCOL FOR NIGHT 1 AND 2

Night 1

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 for the drive to the road and practice lap.
   - SUVs use HLB or HID—NO UV.
   - Pickup use HOH or HHB.
   - Sedan use regular lights—NO IR.

5. Make sure that you are wearing your seatbelt.

6. Instruct the driver to drive to the Smart Road.

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

8. Proceed to the parking spots at the bottom turnaround. Keep a moderate distance between vehicles.

First vehicle at the bottom of the hill:
Pull all the way to the first parking space.
Put the vehicle in park and have the participant take their foot off the brake.
Ask driver to turn off wipers if it is not raining at the turnaround.
Ask the driver to turn off the parking lights so the brake lights do not create a lighter background when reflected on the rain.

Second vehicle at the bottom of the hill:
Pull into the second parking space.
Put the vehicle in park and have the participant take their foot off the brake.

Ask driver to turn off wipers if it is not raining at the turnaround.
On the second lap of each VES, the second car down should pull up to the second lap parking space instead of the usual space.

9. Review instructions with participant (This may be done while driving down the road or while parked at the bottom turnaround).
   - Show them 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,
"I see a person"
"I see a cyclist"
"I see a kid's bike"
"I see a tire tread"

If you perform an unsuccessful recognition, you can press the push button again and then verbally recognize the object.

- Hand them the button.

10. Radio the onroad experimenters that you are ready to begin.

11. Orient participant to Smart Road.

First we will drive up the road to get you used to the road, the rain, and the vehicle. You will need to drive up the center of the road. Go ahead and drive up the road at 25 miles per hour. When we enter the section of road where the rain towers are turned on, you need to be going 10 miles per hour.

- Allow the participant to drive up the road.
- Remind the driver to turn on the windshield wipers before they get to the rain.
- Remind them to drive in the center of the road.
- The second vehicle can begin once the first vehicle is out of sight.

- Remind them of the speed limit if necessary.

First vehicle at the top of the hill:

- Pull all the way to the cone at front parking space in the left lane.
- Put the vehicle in park and have the participant take their foot off the brake.
- Ask driver to turn off the wipers if it is not raining at the turnaround.
- Reverse into the entrance of the gravel lot after the second car is out of sight.
- Wait for station 2 to tell you it is alright to proceed down the hill.

Second vehicle at the top of the hill:

- Pull into the second parking space at the cone in the right lane.
- Ask driver to turn off the wipers if it is not raining at the turnaround.
- Reverse into the entrance of the gravel lot and proceed down the hill.

12. Let drivers do a practice run down the Smart Road.

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 push buttons. I would like you to drive down the center of the road at 10 miles per hour.

- Remind the driver to turn on the windshield wipers.
- Remind the participant how to recognize the different objects.

On the way down we will practice how to detect and recognize objects. You will see two different objects. Please remember to say:

"I see a person"
"I see a tire tread"

If you perform an unsuccessful recognition, you can press the push button again and then verbally recognize the object.

13. Set up the computer at the top of the hill parking area if you haven't already done so.

- Enter participant information (ID, Age, Gender).
- Enter current setup information (VES, object order, night 1, 2, or 3).
- Start the computer program.
- Check that the computer program is reading the correct calibration value.
- Start the data collection when you are parallel to luminaire 6 (the first light tower after the gravel lot).
- Note that there is space at the bottom of the screen for error messages. Check to make sure that you are not receiving any error messages.

It is VERY important that you do not talk to the drivers when you are collecting data. This means no talking during the entire section of the road where the rain towers are on. EMERGENCIES EXCLUDED!

14. Monitor the computer while going down the hill.
  - Make sure that the value in the “Current Distance” field is increasing. This ensures the DMI is working.
  - When driver presses button the first time, the computer should beep and record the “Detection Dist.”
  - After they press button the second time, the computer should beep and record the “Recognize Dist.”
  - Press the computer space bar again when your body is in line with the object. After space bar is pressed, the arrow will scroll down to the next object.
  - Press the ESC key if the driver presses the button on accident or states that they made a false detection.
  - Press the ESC key if the driver makes an unsuccessful recognition.
  - During the practice run, you may need to assist the participant. For example, if they do not indicate the detection or recognition points and the object is close to 50 feet, you need to say, *“We are very close to the first object please press the push button as soon as you can detect it and then once again when you can recognize it.”*

15. Proceed to the parking spots at the bottom turnaround.

First vehicle at the bottom of the hill:
  - Pull all the way to the first parking space.
  - Put the vehicle in park and have the participant take their foot off the brake.
  - Ask driver to turn off the wipers if it is not raining at the turnaround.
  - Ask the driver to turn off the parking lights so the brake lights do not create a lighter background when reflected on the rain.

Second vehicle at the bottom of the hill:
  - Pull into the parking space next to the first car.
  - Put the vehicle in park and have the participant take their foot off the brake.
  - Ask driver to turn off the wipers if it is not raining at the turnaround.

16. Ask driver the nine questions about the VES.
  - You may begin to ask the questions when the driver is past the rain, if you are comfortable doing so. If not, wait until they are parked.
  - Remind subjects of the 1-7 scale, where 1 is Strongly Agree and 7 is Strongly Disagree.
  - Type in their response.

17. Document the windshield wiper speed for each run.
  - This is a subjective rating of “low,” “med,” or “high.” It is recorded on the back of the data error sheet.
  - If driver changes the wiper speed significantly in the middle of a run, the experimenter will document the wiper speed used for each of the two stations.

18. Document any unexpected events that occurred during the previous run on the data error sheet.

19. Prepare for the first VES.
    - Make sure you are in the correct vehicle, using your VES order sheet.
    - Select the proper VES and order on the computer.
    - Let the valet check the headlamps—make sure valet uses the diagram to ensure the proper VES is being used.
    - Wait for the OK from the onroad experimenters.
    - Continue up the road.

20. Start data collection for first VES when you are parallel with the guardrail at the bottom of the hill.
    - Monitor the safety of the cyclists on the road.
    - Use the computer program to determine when you are approaching a cyclist.
    - Say "station X, clear" as soon as the participant identifies the cyclist.
    - If driver does not see cyclist, use the computer DMI readout to determine when the vehicle is within 50 feet of cyclist. Tell the cyclist to clear at that time.

21. Continue the same procedure for the rest of the VES.

22. Bring participants back to the building.
    - Have both participants and both experimenters get in the nonexperimental vehicle. One experimenter will drive all four back to the building.

23. Remind participants of their next scheduled drive.

Night 2

Protocol is very similar to night 1.

- Follow steps 1 through 9.
- Skip the orientation run.
- Skip the practice run.
- Set up the computer at the bottom of the road.
- Wait for onroad to radio that they are ready.
- Collect data using the protocol from night 1.
- Take drivers back to the building.
- Complete the hours/amount paid section of debriefing form.
- Ask drivers to fill out the payment receipt log.
- Pay the drivers, and thank them for their participation.

APPENDIX G—SMART ROAD

Figure 48. Photo. Smart Road testing facility.

The Virginia Smart Road (figure 48) 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. Originating in Blacksburg, VA, the Smart Road presently consists of 3.2 km (2 mi) of two lanes of roadway, 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 (I) 81. This connection will serve an important role in the I–81 and 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.

- 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

ENV-Objects Protocol for Onroad Experimenters—Rain

1. General Policies

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

- Drive in a safe manner at all times. This means observing the 25 miles per hour speed limit 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 whenever you are exposed to headlamps.
- Always drive with your lights on.
- If it's broken, tell someone.
- Attend the nightly meeting.

Over the course of the study, it is likely that apparatus will break. If you notice something is broken or you are the one who broke it, tell (name of experimenter in charge) immediately if it is crucial to the study, or as soon as it is convenient if it is not crucial. At any rate, you must report such damage before you leave from your shift.

Each night, you will need to arrive to the [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 and make a note of them on the message board.

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

While the study is being conducted, radio communications on channel 3 need to be minimized (emergencies excluded). If, however, you have a question, first address it to another onroad experimenter on channel 2. On channel 2 you can speak freely. If none of the onroad experimenters can answer the question one of you will need to address it to the in-vehicle experimenters. 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.

2. Pre-Experiment

- Nightly meeting.
- Car prep sheets need to be picked up in the prep room.
- Participant measurement sheets will be distributed by the in-vehicle experimenter (if needed) during the meeting of night 2.
- Valets are in charge of signing out radios for all of the onroad and in-vehicle experimenters. Each onroad experimenter is to have two radios for themselves, except for the valets, who will have one each. (One valet will keep radio on channel 2. The other valet will keep radio on channel 3. The valets need to communicate with each other about necessary information received on each channel. This way, no communications will be missed by either valet).
- Valets need to get vests for all the onroad experimenters.
- Experimenters assigned to the four onroad stations are each required to prepare a vehicle. They need to perform the tasks listed on the individual vehicle checklists. All items on the checklist must be completed. Make sure you know which session (night 1 or night 2) is to be completed that night. This way you will know which vehicles are needed at the front of the [contractor building] for the participants. You must sign off on the sheet at the end of the night.
- Valets are responsible for making sure that the onroad experimenters have everything in the blue boxes that they need. They are also expected to load the specified equipment into the proper vehicles.
- Put on vests.
- Load two fluorescent large bikes, two kid's bikes, and two tire treads into the pickup.
- Load boxes, cones, and tarps into the SUVs.
- Make sure that there is a tarp over the back seat of the SUV to protect it.
- Set up parking spaces by putting out the cones at the appropriate locations (SUVs).
- Set up cone at second turnaround (SUVs).
- Make sure all cones and/or objects on the road that are not part of the night visibility study are removed from the road.
- Cover up the "Road Closed" signs at the end of the road (SUVs).
- Unload large bikes, kid's bikes, and tire treads at each station (pickup).
- Unload boxes at each station (SUVs).
- Each night two people will be assigned one of the following locations:
  - Station 1, 4.
  - Station 2, 3.
  - One experimenter will wear white scrubs; the other will wear black scrubs.

Valets will be responsible for making sure everyone has a complete set of equipment, including the following:

- Storage container with black and white scrubs, flashlight, safety glasses, RAIN order sheets, etc.
- Tire tread.
- Small bicycle.

- Two radios. (One radio will be left on channel 3 to communicate with in-vehicle experimenters. The other radio will be left on channel 2 to communicate among onroad experimenters.)
- Large fluorescent bike.

Once you have the equipment at your station, DOUBLE CHECK to make sure you have all of the necessary items. Also, make sure one of your radios is set to channel 3, and either hold it or attach it to your clothing. Leave your other radio on channel 2 on the ground beside your station. Radios are to be worn at all times, even when transporting bicycles.

Radios are only to be used for communicating information pertaining to the experiment. There is to be no communication about procedure on channel 3 unless there is a deviation from the usual protocol. All onroad experimenters are expected to know the protocol without confirmation from others. However, you may radio other onroad experimenters for assistance at any time on channel 2.

There will be a relay at station 2 to repeat any messages not heard by geographically opposite stations. Station 2 will be responsible for relaying for the second car when the first car notifies that they are at the second turnaround.

If there is an emergency, you are to get on the radio IMMEDIATELY and contact the relay station experimenter. The relay station experimenter will make sure the in-vehicle experimenters heard the message.

As the trials progress, you will need to make sure the objects are out before the experimental vehicle gets to your station and cleared before the vehicle comes back up the road. You also need to make sure all objects (including yourselves) are hidden. To ensure least visibility, you need to wear dark clothing on the side of the road as much as possible.

If a given run needs to be repeated, confirm your object with station 2.

3. Objects Protocol

On the first night, drivers will be oriented to the road by driving up the hill. During this time, onroad experimenters are to remain hidden. However, on the way down the hill, the following stations will need to put out objects:

Station 4	***White Static Pedestrian***
Station 5	***Tire Tread***

We are assuming that all stations are ready, so we are not waiting for the stations to say that they are ready. The in-vehicle experimenter will just go as soon as the other vehicle arrives at the turnaround. Below is a table of the objects along with placement locations.

OBJECT	LOCATION	SPECIAL INSTRUCTIONS
Parallel pedestrian in black clothing	Shoulder side of white line.	Wear black clothing. Walk 10 paces along the middle of the lane toward oncoming vehicle, then walk backward 10 paces. Repeat.
Parallel pedestrian in white clothing	Shoulder side of white line.	Wear white clothing. Walk 10 paces along the middle of the lane toward oncoming vehicle, then walk backward 10 paces. Repeat.
Perpendicular pedestrian in black clothing	Straight (perpendicular) line between white line and centerline.	Wear black clothing. Walk from center of one lane to the center of the other lane and then walk backward to the white line (not the end of the shoulder). Repeat.
Perpendicular pedestrian in white clothing	Straight (perpendicular) line between white line and centerline.	Wear white clothing. Walk from center of one lane to center of the other lane and then walk backward to the white line (not the end of the shoulder). Repeat.
Cyclist in white clothing	Between white lines in front of station	Wear white clothing. Ride bike in circles across the road staying inside the white lines (do not go all the way out to the shoulder).
Tire tread	Centered on white line.	None.
Kid’s bicycle	Centered across white line, one wheel on either side of white line.	Lay on one side, wheels facing approaching traffic, handlebars lane of oncoming traffic.

- After the first lap, onroad experimenters are to begin putting out objects as indicated on object order sheets. The in-vehicle experimenters will indicate when the object trials begin.
- There will not be a practice or orientation run when a driver is here for their second night. VES order sheets will reflect this.
- Set up so that the first object needed is readily accessible.
- Hide all objects from view of the participants when not being used.
- Put safety glasses on.
- If you are wearing white shoes and/or shoes with reflective fabric, cover your shoes with the provided shoe covers.
- SAFETY NOTE: Experimental vehicles are not to come within 50 feet of a mobile object on the roadway. That is especially true for all pedestrians and bicyclists. It is primarily your responsibility to make sure you move off the road at that distance, as in-vehicle experimenters will be primarily concerned with the participants. As a guideline, motion sensors will be placed 50 feet from your station. Also, the in-vehicle experimenters will ask you to clear once they have detected you. In that case, you can clear as soon as you hear "station X clear." However, you cannot rely on that and you MUST clear at a safe distance.
- After you step off the road, maintain your position on the white line. 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 six headlamp configurations. If there will be two sessions that night, the pickup 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 pickup truck will drive around and collect all experimenters and objects after the sixth configuration.
- If you notice any problems or mistakes occurring during the night, record them on the vehicle preparation sheets.

4. Valet (see "Valet Protocol" for more details)

- Each valet has to get their valet box that contains measurement materials if measurements need to be taken.
- Take care of all the radios, object orders, and materials. This includes changing out the radio batteries during the break on evenings when we run doubles.
- As a valet, you will be assigned and responsible for one participant each session. Once you have a participant, you should stay with them the entire night.
- Overall goal is to make participant feel as comfortable as possible in each car.
- Be sure to be wearing a vest at all time.
- Valets need to explain to the participants where to turn off the parking lights when they are at the second turnaround and how to work the windshield wipers.
- NIGHT ONE: After the participants have completed their practice lap and first VES, show them to their next vehicle (sedan or black SUV).

- NIGHT TWO: Meet participants at first vehicle and take measurements if necessary. Escort participants between vehicles as listed on the valet order sheets and be sure to take measurements on all four vehicles.
- Whenever possible, the first driver that returns to the bottom of the hill 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 vehicles should be parked in each parking spot to ensure that the drivers' wait time is minimized.

5. Repeat Procedures (Night 2)

All procedures will repeat as described above. Therefore, you will need to get into the appropriate object position. There will be no practice laps for the second session.

6. Ending Protocol

Gather all experimental equipment and return to the [contractor facility]. The pickup driver will be responsible for picking up large bikes, kid's bikes, and tire treads. SUVs will be responsible for picking up boxes, cones, and tarps. At the end of each night, there will be a list of items for you to complete (see below). After the items are checked, you will be free to leave.

- Collect cone from the second turnaround (SUVs).
- Uncover the signs at the bottom of the road (SUVs).
- Collect the parking cones from the first turnaround (SUVs).
- Return the vehicles to the [contractor facility].
- Check the gas level of each vehicle. If it is below one quarter of a tank, write a note at end of prep sheet.
- Return SUVs to the garage.
- Note any vehicle problems on the vehicle preparation sheets, and then write them down on the message board.
- Return the radios (personal and in-vehicle).
- Put wet scrubs on racks to dry.
- 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.
- Submit paperwork to the in-vehicle experimenter.

APPENDIX J—AIMING PROTOCOL

[Note that the HOH lamp and the HHB lamp were paired within the same housing and in fixed positions relative to each other. Therefore, when the HOH was aimed, the HHB was automatically aimed in the high-beam position, making individual aiming for HHB unnecessary.]

PROTOCOL SUMMARY

The protocol presented below represents the consensus of experts in the field on the appropriate procedure that should be followed for headlamp alignment:

- An alignment plate should be mounted onto the ground 35 ft from and parallel to the alignment wall.
- The alignment wall should be as flat as possible.
- The wheels should be straight against the plate and perpendicular to the alignment wall.
- The perpendicular position can be reached by creating a 90-degree angle configuration on the floor that will guide the vehicle to the right position. A simple "L"-shaped mark on the floor should suffice.
- A laser that marks the center of the vehicle should be used to make sure the screen is centered to the vehicle. Each vehicle should have its own line on the screen. The lines are labeled directly on the screen to avoid confusion.
- Markings of the photometric center of the headlamp beam should be performed for each headlamp with respect to the floor.
- The appropriate headlamps should be turned on, while making sure no auxiliary lights (parking lights, fog lights, daytime running lights) are on.
- One headlamp should be covered up or unplugged so that readings are taken for only one light at a time.
- For the HID, HLB, and HOH configurations, align the headlamps so that the "hotspot" is located in the lower right quadrant. This can be performed by positioning the photometer sensor tangent to both the horizontal and vertical lines. When measuring the hotspot in that quadrant, the outside top and left borders of the sensor's circumference (the sensor is one inch in diameter) need to touch both axes of the crosshairs. This will position the hotspot one half inch down and to the right from the center of the crosshair.
- The photometer should be zeroed prior to checking each measurement. To do this, make sure that all headlamps are turned off. Remove the cap from the 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 the background and remove its effects from the actual source value. After zeroing, turn the headlamp on and begin alignment.
- Adjustment of the headlamp aim should be performed as needed.

The only difference between the alignment of the UV–A headlamps and this previous headlamp alignment procedure (HID, HLB, and HOH) is that the "hotspot" must be at the center of the crosshairs.

DETAILED PROTOCOL

Vehicle/Headlamp Combinations Acronym List

BLK HID1	BLK HID 2	Black SUV High Intensity Discharge 1 and 2
BLK HLB 1	BLK HLB 2	Black SUV Halogen Low Beam 1 and 2
BLK LO UV–A 1	BLK LO UV–A 2	Black SUV Low Output UV–A 1 and 2
WH HID 1	WH HID 2	White SUV High Intensity Discharge 1 and 2
WH HLB 1	WH HLB 2	White SUV Halogen Low Beam 1 and 2
WH MID/HI UV–A 1 through WH MID/HI UV–A 5		White SUV Mid/High Output UV–A 1 through 5
P/U HOH (HHB) 1	P/U HOH (HHB) 2	Pickup Truck, High Output Halogen (Halogen High Beam)

SPECIAL NOTES FOR SIM BAY ROOM PREP

- It is very important to make sure that you have enough time to align all of the headlamps 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 1.25 to 1.5 hours as a general rule. Alignment times will be greater on days when headlamps must be moved.
- Turn on the ventilation fans prior to beginning the alignment process.
- Since we are leaving half of the lights, 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.

1. Setting Up the Non-UV–A Headlamps

Applies to the following vehicle/headlamp combinations:
- WH HID (1 and 2), BLK HID (1 and 2).
- WH HLB (1 and 2), BLK HLB (1 and 2).
- P/U HOH (HHB) (1 and 2).

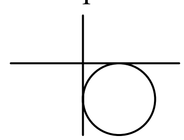
- Pull the vehicle up to the alignment plate mounted onto the ground. This should be located 35 ft from the alignment wall. Make sure the wheels are straight against the plate.
- Use the laser to make sure the screen is centered to the vehicle. Each vehicle has a different line on the screen. The lines are labeled directly on the screen.
- Locate the appropriate markings on the wall 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.
- Align the VES so that the “hotspot” is located in the first (or lower right) quadrant, tangent to both the horizontal and vertical lines. The sensor, when measuring the hotspot in that quadrant, will touch both axes of the crosshairs. The headlamps have both gross and fine adjustments. Typically, only fine adjustments will be required if the headlamps are not switched; gross will be required if the headlamps are switched.

Note: Why do we align these lights off center point?

When these types of lights are aligned straight ahead, the lights are placed in a high beam configuration. We do not want to use the high beam for these configurations. Our alignment procedure allows each light to be directed slightly to the right and below the exact centerline for that light.

Hotspot Location: The circle represents the target hotspot location with respect to the target crosshairs. The center of the circle is the center of the hotspot.



To determine if the hotspot is in the correct location, you will need to use the 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.”

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.

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).

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.

2. Setting Up the UV–A Headlamps

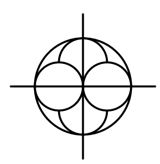
Applies to the following vehicle/headlamp combinations:

- WH MID/HI UV–A (1 through 5).
- BLK LO UV–A (1 and 2).

- Pull the vehicle up to the alignment plate on the ground. This should be located 35 ft from the alignment wall. Make sure the wheels are straight against the plate. In addition, the vehicle needs to be centered along the white line painted from the wall.
- 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 wall for that headlamp.
- Cover up one headlamp so that you are only taking readings for one light at a time.
- Align the headlamps so that the "hotspot" is located on the crosshairs. The UV–A low headlamps have fine adjustments. The UV–A high 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.



To determine if the hotspot is in the correct location, you will need to use the 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."

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.

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: Look at this table as you look at the wall for calibration; it is backwards when looking directly at the vehicles.

P/U HOH (HHB) (Pickup Truck)	
1 (Left)	*2 (Right)*
42.2 W/cm^2	45.2 W/cm^2

WH HID; BLK HID (Either SUV)	
1 (Left)	*2 (Right)*
Visual alignment based on other light	41.6 W/cm^2

WH HLB; BLK HLB (Either SUV)	
1 (Left)	*2 (Right)*
44.7 W/cm^2	50.1 W/cm^2

BLK LO UV–A (Black SUV)	
1 (Left)	*2 (Right)*
100 $\mu W/cm^2$	92.0 $\mu W/cm^2$

WH MID/HI UV–A (White SUV)		
Top Row Lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 $\mu W/cm^2$	472 $\mu W/cm^2$	484 $\mu W/cm^2$
Bottom Row Lights		
4 (Bottom Left)	*5 (Bottom Right)*	
486 $\mu W/cm^2$	565 $\mu W/cm^2$	

HEADLAMP ALIGNMENT FORM

Date: ________________
Initials: ________________
Reference values for the various headlamps are included on the top line. Actual/current values are written inside each box as appropriate. Alignment data should be recorded once a week to provide a continuous record of the health of the headlamps. Note: Look at this table as you look at the <u>wall</u> for calibration; it is backwards when looking directly at the vehicles.

P/U HOH (HHB) (Pickup Truck)	
1 (Left)	*2 (Right)*
42.2 W/cm^2 Actual:	45.2 W/cm^2 Actual:

WH HID; BLK HID (either SUV)	
1 (Left)	*2 (Right)*
Visual alignment based on other light Actual:	41.6 W/cm^2 Actual:

WH HLB; BLK HLB (Either SUV)	
1 (Left)	*2 (Right)*
44.7 W/cm^2 Actual:	50.1 W/cm^2 Actual:

BLK LO UV–A (Black SUV)	
1 (Left)	*2 (Right)*
100 μW/cm^2 Actual:	92.0 μW/cm^2 Actual:

WH MID/HI UV–A (White SUV)		
Top Row Lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 μW/cm^2 Actual:	472 μW/cm^2 Actual:	484 μW/cm^2 Actual:
Bottom Row Lights		
4 (Bottom Left)	*5 (Bottom Right)*	
486 μW/cm^2 Actual:	565 μW/cm^2 Actual:	

APPENDIX K—VALET PROTOCOL

VALET PROTOCOL FOR ENV-OBJECTS—RAIN

1. Pick up all necessary items from the building.
- Valet box: tape measure, leveler, safety glasses, dry erase marker, eraser, and a pen or pencil.
- Flashlight.
- Umbrella.
- Radio.
- Vest.
- Stepping stool.
- VES order sheet for the evening.
- Object order for the onroad experimenters.

2. Take care of all the experimental materials.
- Get radios for onroad and in-vehicle.
- Prepare radios for onroad with plastic bag and microphone/receiver.
- Check that all the materials needed are in the boxes (rain order sheets included).
- Make sure that the tarps are secure on the back seat of the SUVs.

3. Make sure that defrost is on in all the vehicles and that the fan is set to the second speed (one above low).

4. Park the first vehicles that drivers will use at the front of the building.
- If it is the first night the drivers are here, it will always be the two SUVs.
- If it is the second night, then use the order sheet to determine the first vehicle they will drive that night.
- Drive remaining vehicles to the road.

5. Assist onroad experimenters with road setup.
- See vehicle prep sheet.

6. Drop off all onroad staff at their stations.

7. Park vehicles at the bottom turnaround.

8. Make sure that radios are on.
- One valet will be on channel 2.
- One valet will be on channel 3.

9. Place the stepstools on the side of the road.

10. Wait for drivers to arrive at the bottom turnaround.

Basic Duties of a Valet

1. Show them to their next vehicle as per the experimenter sheet.
- Ask the participant to turn off the vehicle and to hand you the keys.
- Turn off lights.
- Turn off the windshield wipers if they leave them on.
- Put the keys to each car in the door lock when it is not being used.
- Assist driver in getting out of the vehicle if necessary.
- Use the stepstools if necessary.
- Meet the driver with an open umbrella if it is raining.
- Wait until the other car has the lights off.
- Lead/guide participant from one vehicle to the next by shining the flashlight on the road in front of them. Walk them in a direction that they will not face the other car lights.
- Open the door for the participant and move the seat back before they get in.

2. Orient person to next vehicle and turn on the lights.
- If they have been in the vehicle before, ask them if they remember the controls (specifically, where the wiper controls are as well as where to turn off the parking lights). Be sure to offer to answer questions.
- See each vehicle's orientation instructions below.
- Be sure to turn on the lights yourselves. Do not let the participant do it. If they reach for the light switch, tell them, "That's OK, I'll take care of this for you."
- Explain to the participant where the dimmer switch is.
- Remind the participant to keep their seatbelt on at all times.
- Ask them if they have any questions.

3. Complete the measurements (night 2 only).
- 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.

4. Before driver goes down the road, ensure the headlamps are on and working. USE SAFETY GLASSES.
- Sedan: Regular headlamps only.
- Black SUV: If UV is required, make sure they are working. Otherwise, make sure the two standard ones are on (HLB or HID).

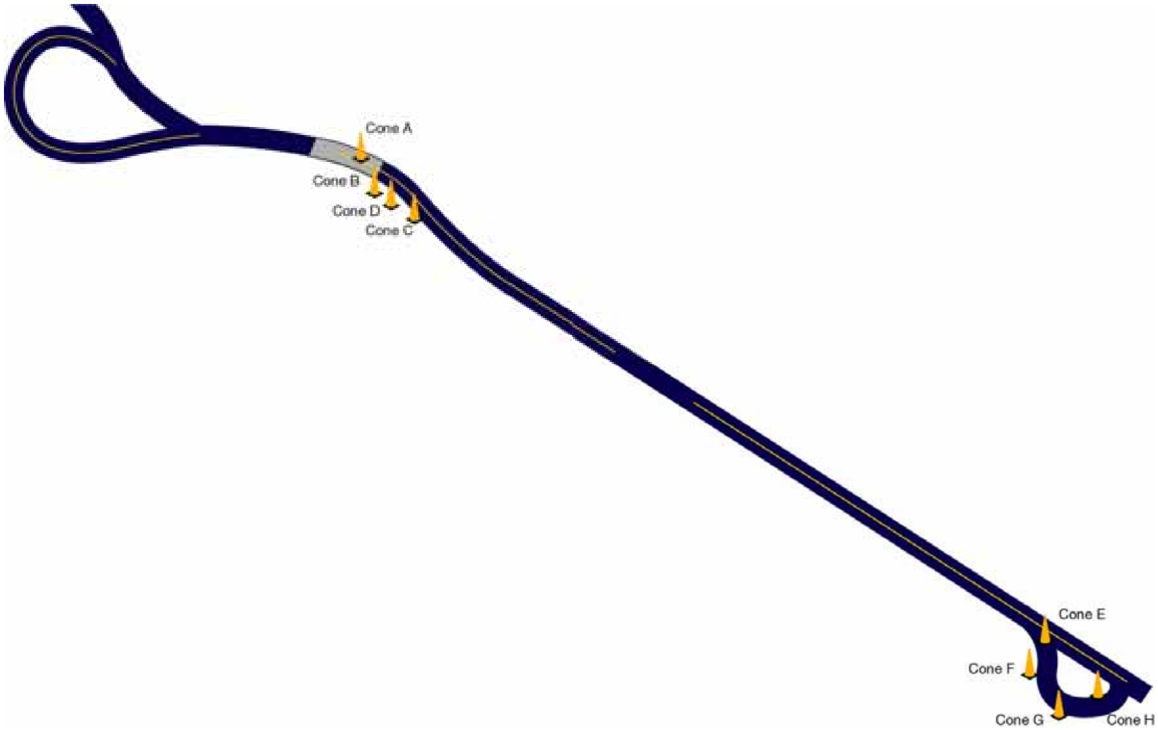
- White SUV: The top three UV lights should be on for medium conditions, while all five should be on for high conditions. Report if one is not working or extremely dull. The standard lights (HLB and HID) should be working at all times.
- Pickup: The two external headlamps on the front of the vehicle should be on. (Upper bulbs should be lit for HOH. Lower bulbs should be lit for HHB.)

5. Take a 15-minute break between sessions (if running a double).
   - Pickup onroad crew and return to the building for a break.
   - Change the radio batteries prior to returning to the road.

6. Repeat the above protocol if running a double or triple shift.

7. Protocol for running rain (see diagram).

Both valets will wait at the bottom of the hill for the participants to arrive. The first vehicle will park next to cone H. The second vehicle will park next to cone F. Cone G will only be used when the second vehicle arrives at the bottom after the second lap. Under these circumstances, cone G will be used in order to keep the first participant from being blinded. If it is night 1 (practice lap), valet A will get in the back seat of the vehicle that the first participant is in and ride up to the top of the hill with them (turn off your radio). Valet B will remain at the bottom of the hill. At the top of the hill, valet A will direct the first participant to the stopping point, next to cone A (facing the top of the hill in the left lane, cone A should also be a reflector cone) and have the driver put the car in park. As the second vehicle approaches the top turnaround, valet A will direct them to pull up in the right lane (the cars will now be staggered and in opposite lanes). This second car will then back up between cones B and C (these cones should be reflector cones). To aid the driver, the window should be rolled down so the valet can walk and talk to the driver. They should back in up to cone D. The second car up the hill now becomes the first down the hill. Valet A will then back the first participant into the gravel lot. Valet A will get into the vehicle with the first participant to head back downhill. The traveling valet will ride up on run 1 and down on run 4.



Once the second car gets back to the turnaround at the bottom of the hill, valet B will escort their participant to the vehicle needed for VES 1. This vehicle should be parked just behind the edge of the guardrail at the bottom turnaround if possible. (The people in the first car down will walk forward to get to their new car.) Once the lights are checked and normal valet protocol is followed, valet B will get into the back seat of this vehicle (now becoming the traveling valet, and turning off their radio), which will then wait for the second vehicle to get to the bottom turnaround before proceeding uphill. Once at the bottom of the hill in the second vehicle, valet A will then escort their participant to the vehicle needed for VES 1 and check the lights along with the usual protocol. Valet A will then wait at the bottom of the hill.

If this was night 2 (no practice lap), the only difference would be that valet A would have waited at the top of the hill until riding down the hill with the second vehicle on the second lap. Essentially, this would involve turning the cars around twice per VES (the traveling valet will be dropped off at the top of the hill after run 1 and will ride back down during run 4). This would be repeated for the remainder of the night with valets alternating between each VES. That is, the valet that travels for VES 1 will not travel for VES 2, then will travel again for VES 3 and VES 5.

Also, one [contractor facility] setup vehicle will be positioned on the portion of the road where the tarps are. This is for the end of the night. When the cars go up for the final lap of VES 6/12, the setup vehicle should be positioned as if it were the next experimental vehicle (at the edge of the guardrail). This is so both in-vehicle experimenters and both participants can get into the setup vehicle and leave the road. This allows onroad personnel use of all experimental vehicles (SUVs, truck, sedan) when breaking down the road.

8. Shutdown procedures
    - Assist onroad with gathering all items from the road.
    - Place wet scrubs on the drying racks.
    - Sign all the radios back in.
    - Make sure that all radios and batteries are accounted for.
    - Make sure the power is off when you put the radios into the charger.
    - Submit paperwork to in-vehicle experimenter.

VEHICLE ORIENTATION SHEET

Sedan

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

Black 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.
- Hand the participant the keys and have them start the car.
- Turn on the parking lights (one click only).
- Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.
- Show the participant how to turn on and adjust the windshield wipers.

White 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.
- Hand the participant the keys and have them start the car.
- Turn on the parking lights (one click only).
- Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.
- Show the participant how to turn on and adjust the windshield wipers.

Pickup

- Lever in front of seat moves seat back and forth, (show lever).
- Hand the participant the keys and have them start the car.
- Turn on the parking lights (one click only).
- Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is as bright as they would normally have it.
- Show the participant how to turn on and adjust the windshield wipers.

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