Volume III

Enhanced Night Visibility Series: Phase II–Study 1: Visual Performance During Nightime Driving in Clear Weather

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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 clear weather. 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 III. 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 1 was performed as a stepping stone to expand the knowledge of how different vision enhancement systems can affect detection and recognition of different types of objects. The empirical testing for this study was performed on the Smart Road testing facility during clear weather conditions. A total of 30 participants were involved in the study. A 12 by 9 by 3 mixed-factorial design was used to investigate the effects of different types of vision enhancement systems, types of objects on the roadway, and driver's age on detection and recognition distances; subjective evaluations were obtained for the different systems as well.

The results of the empirical testing suggest that no vision enhancement system consistently performs best in clear weather conditions. However, the halogen headlamp tested (low-beam configuration) consistently provided one of the longest detection and recognition distances, and even when other systems provided farther detection distances, these distances were generally not significantly different from halogen low beam. The only exception was the infrared thermal imaging system tested, which resulted in significantly farther detection distances for pedestrians and cyclists wearing dark-colored (low-contrast) clothing.

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

Volume	Title	Report Number
I	Enhanced Night Visibility Series: Executive Summary	FHWA-HRT-04-132
II	Enhanced Night Visibility Series: Overview of Phase I and Development of Phase II Experimental Plan	FHWA-HRT-04-133
III	Enhanced Night Visibility Series: Phase II—Study 1: Visual Performance During Nighttime Driving in Clear Weather	FHWA-HRT-04-134
IV	Enhanced Night Visibility Series: Phase II—Study 2: Visual Performance During Nighttime Driving in Rain	FHWA-HRT-04-135
V	Enhanced Night Visibility Series: Phase II—Study 3: Visual Performance During Nighttime Driving in Snow	FHWA-HRT-04-136
VI	Enhanced Night Visibility Series: Phase II—Study 4: Visual Performance During Nighttime Driving in Fog	FHWA-HRT-04-137
VII	Enhanced Night Visibility Series: Phase II—Study 5: Evaluation of Discomfort Glare During Nighttime Driving in Clear Weather	FHWA-HRT-04-138
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X	Enhanced Night Visibility Series: Phase II—Visual Performance Simulation Software for Objects and Traffic Control Devices	FHWA-HRT-04-141
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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
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LIST OF ACRONYMS AND ABBREVIATIONS

General Terms

AASHTO ....American Association of State Highway and Transportation Officials
ENV ....Enhanced Night Visibility
VES ....vision enhancement system
SUV...................................sport utility vehicle
UV–A ....ultraviolet A (wavelength 315 to 400 nanometers)

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
second ....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 1 was conducted as a baseline for nighttime visual performance against which the other studies in Phase II of the Enhanced Night Visibility (ENV) project were compared. The project evaluated visual performance during nighttime driving under clear weather conditions in terms of detection and recognition distances when different vision enhancement systems (VES) were used.

The experimental tasks for Phase II—Study 1 consisted of driving during nighttime under clear conditions using 12 different VES configurations. To assess visual performance during nighttime driving, the distances at which the drivers were able to detect and recognize different objects were evaluated. Subjective performance ratings were also garnered from questionnaires administered to participants following the use of each VES.

The driving performance portion of the study took place at the Smart Road testing facility in Virginia for two consecutive nights per driver. The road was closed to all traffic except for experimental vehicles, and there were no more than two experimental vehicles on the road at one time. A 1-night training session was conducted for participants on the night before their participation in the onroad study. The following chapter details the characteristics of Study 1.

CHAPTER 2—METHODS

PARTICIPANTS

Thirty individuals participated in Study 1. Participants were divided into three different age categories: 10 participants were between the ages of 18 and 25 (younger category of drivers), 10 were between the ages of 40 and 50 (middle-aged category of drivers), and 10 were over 65 (older category of drivers). Five males and five females comprised each age category. Participation was allowed after a screening questionnaire was completed and only if the selection conditions were fulfilled (appendix A). Participants had to successfully comply with the following: (1) sign an informed consent form (appendix B), (2) present a valid driver's license, (3) pass the visual acuity test (appendix C) with a score of 20/40, uncorrected or corrected, or better (as required by Virginia State law), and (4) have no health conditions that made operating the research vehicles a risk.

Participants were instructed about their right to freely withdraw from the research program at any time without penalty. 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 time of actual participation. All data gathered as part of this experiment were treated with complete anonymity. Participants received $20 per hour for their participation.

EXPERIMENTAL DESIGN

A mixed-factor design was used for the data collection during the onroad portion of the study (i.e., different detection and recognition tasks). There were three independent variables: (1) VES configuration, (2) age, and (3) 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 present a representation of the experimental design; a detailed explanation of each of the independent variables of interest follows.

Table 1. Experimental design: 12 by 3 by 9 mixed-factor design (12 VES configurations, 3 age groups, 9 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. Nine objects presented in each cell in table 1.

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

INDEPENDENT VARIABLES

Age

The age factor had three levels: younger participants (18 to 25 years), middle-aged participants (40 to 50 years), and older participants (65 years or older). These age groups were created based on literature review findings (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 following list defines the VES configurations for Study 1:

- Halogen (i.e., tungsten-halogen) low beam (HLB).
- Hybrid ultraviolet A band and 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/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).

More in-depth technical specifications for 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 actual configuration that was performed. 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 are currently 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 was also some concern about the possible effect of changes in the detection and recognition distances because of the use of high profile headlamps (e.g., halogen of a sport utility vehicle) versus lower profile headlamps (e.g., halogen of a regular passenger vehicle).

All of the configurations that use 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 contacted by the UV radiation, producing visible light. Their purpose is to supplement the regular headlamps, not to eliminate their use. The UV–A and HLB/HID pairings resulted in six different UV configurations: three in which the pairing was made with HLB lamps and three in which HID lamps were used. The three UV configurations inside each pairing category resulted from the use of three different forms of UV headlamp configurations: five UV–A, three UV–A, or hybrid UV–A headlamps. The hybrid UV–A headlamp is an experimental prototype that has a significant amount of visible light, although it is still not enough light to allow driving without low beam headlamps. The UV–A headlamps (used for the five UV–A and three UV–A configurations) produce less visible light.

The HHB configuration was included to compare detection and recognition distances with the other VESs of interest in this study with a commonly available halogen headlamp in a high beam position. In addition, a new alternative to the HLB that provides the driver with more visible light output in a low beam configuration (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 for very early detection of pedestrians, cyclists, animals (i.e., objects generating heat) or infrastructure objects that shed heat (e.g., guard rails, light posts) on the roadway.

The objects selected for this study were pedestrians, cyclists, and static objects. The main reason for including the pedestrians and cyclists was because of the high crash-fatality rates for these nonmotorists.(6,7) Real pedestrians and cyclists were used 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) actual pedestrians and cyclists seemed more appropriate, especially for understanding the effects of motion as a cue for detection. Moreover, the use of mockups would have improperly restricted the performance capabilities of VESs that use temperature characteristics of the object of interest and would have limited the external validity of this study.

Object

Pedestrians and cyclists were presented to the drivers at two different contrast levels: (1) with black clothing against a clear night background and (2) with white clothing against a clear night background. Table 4 describes each of the nine objects of interest. The pedestrians were either static on the side of the road (i.e., representing a pedestrian who is waiting to cross the road) or dynamic. The dynamic pedestrians were walking 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 were also used: a child's bicycle and tire tread. The child's bicycle was a 25-cm (10-inch) bicycle, and the tire tread was obtained 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 leads to last moment object-avoidance maneuvers. The child's bicycle was intended to represent the possible presence of a child in the area. Figure 1 through figure 6 show the objects presented in this study.

Table 4. Description of the objects.

Object	Percentage of Reflectance at 61 m (200 ft)	Location	Special Instructions
Parallel Pedestrian, Black Clothing	3	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	50	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	3	Straight (perpendicular) line between right edgeline and centerline.	Wear black clothing. Walk to centerline; then walk backward to right edgeline. Repeat.
Perpendicular Pedestrian, White Clothing	50	Straight (perpendicular) line between right edgeline and centerline.	Wear white clothing. Walk to centerline; then walk backward to right edgeline. Repeat.
Cyclist, Black Clothing	3 (cyclist) 27 (specular–bike rims)	Between edgelines in front of location.	Wear black clothing. Ride bike in circles across the road, from one edgeline to opposite edgeline.
Cyclist, White Clothing	50 (cyclist) 27 (specular–bike rims)	Between edgelines in front of location.	Wear white clothing. Ride bike in circles across the road, from one edgeline to opposite edgeline.
Static Pedestrian, White Clothing	50	Centered on right edgeline.	Wear white clothing. Stand facing traffic.
Tire Tread	4	Centered on right edgeline.	None.
Child's Bicycle	18	Centered across right edgeline, one wheel on either side of right edgeline.	Lay bike on one side, wheels facing approaching traffic, handlebars facing lane of oncoming traffic.

Figure 1. Photo. Pedestrian in black clothing.

Figure 2. Photo. Cyclist in black clothing.

Figure 3. Photo. Cyclist in white clothing.

Figure 4. Photo. Pedestrian in white clothing.

Figure 5. Photo. Child's bicycle.

Figure 6. Photo. Tire tread.

OBJECTIVE DEPENDENT VARIABLES

Detection and Recognition Distances

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 due to their common use and acceptance in the human factors transportation literature. (See references 9, 10, 11, 12, and 13.) Both terms, detection and recognition, were explained to the participants during the training session. Detection was explained as follows: "Detection is when you can just tell that something is on the road in front of you. You cannot tell what the object is, but you know something is there." Recognition was explained as follows: "Recognition is when you not only know something is there, but you also know what it is."

During training and practice, the participants were instructed to press a button on a hand-held wand when they could detect an object on the road. The participants performed a second button press when they could recognize the object. The in-vehicle experimenter performed a third button press when the object of interest was aligned with the driver (i.e., the participant drove past the object). Detection and recognition distances were calculated from distance data collected at each of these three points in time.

SUBJECTIVE RATINGS

Subjective ratings were also collected as dependent variables. Participants were asked to evaluate a series of seven statements for each VES using a seven-point Likert-type scale. The two anchor points of the scale were "1" (indicating "Strongly Agree") and "7" (indicating "Strongly Disagree"). The statements addressed each participant's perception of improved vision, safety, and comfort after experiencing a particular VES. Participants were asked to compare the VES that they were evaluating at a given point in time with their "regular headlights" (i.e., the headlamps on their own vehicle). The assumption was made that the participants' own vehicles represented what they knew best and, therefore, were most comfortable using. Following are the statements used for the questionnaire. 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 instrumented-vehicle system. These procedures were used to minimize possible risks to participants during the experiment. The safety measures required that: (1) all data collection equipment had to be mounted such that it, to the greatest extent possible, did not pose a hazard to the driver in any foreseeable instance; (2) participants had to wear the seatbelt restraint system anytime the car was on the road; (3) none of the data collection equipment could interfere with any part of the driver's normal field-of-view; (4) a trained in-vehicle experimenter had to be in the vehicle at all times; and (5) an emergency protocol had to be established before testing.

The pedestrians and cyclists on the road were trained about 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

Onroad driving was conducted using four vehicles. The experimental vehicles included two sport utility vehicles, a pickup truck, and a luxury passenger vehicle. All vehicles were equipped with an electronic odometer. 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 7). The software was developed to gather distance data from the driver and the passenger (if needed). Only the driver portion of the software was used for Study 1. The software gathers information such as the participant's age and gender as well as the identification number assigned to that participant. In addition, it shows the object order that the participant was presented during a given VES configuration.

```
-------------------------- 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]: Clear
------------------------------------------------------ ----------------------

  ==>SETUP MODE                              DRIVER:
     [1  ](3520) Black Perp Pedestrian          Detection Dist.: ---.--
     [2  ](4530) BLANK                          Recognize Dist.: ---.--
     [3  ](5842) White Cyclist                  Success:        YES
     [4  ](2204) White Perp Pedestrian
     [5  ](3115) BLANK                        PASSENGER:
     [6  ](3990) Tire Tread                     Last Dist.: ---.--
     [1  ](3520) Black Cyclist                  Recognize Dist.: ---.--
     [2  ](4530) Kids Bike                      Success:        YES
     [3  ](5842) Static White Pedestrian
     [4  ](2204) White Parallel Pedestrian          CALIBRATION VAL:
4294967295
     [5  ](3115) Black Parallel Pedestrian          CURRENT DISTANCE:  0.00
     [6  ](3990) BLANK                              NEXT TARGET AT:  0.00

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

Figure 7. Diagram. Data collection display screen.

The VESs were distributed among the different vehicles. Most vehicles had light bars that allowed the headlamps (i.e., HLB and HID) to be switched out, thereby maintaining a more consistent horizontal and vertical position among the different VESs (figure 8 through figure 11). The HLB–LP and IR–TIS served as the only exceptions because they were installed by the factory.

Figure 8. Photo. Five or three UV–A + halogen low beam.

Figure 9. Photo. High output halogen or halogen high beam.

Figure 10. Photo. Hybrid UV–A + high intensity discharge.

Figure 11. Photo. Halogen low beam—low profile with infrared thermal imaging system.

Smart Road

The Virginia Smart Road (overhead lighting turned off) was used for the onroad study (figure 12 and appendix G). For Study 1, six different locations on the Smart Road were used to present the different objects (figure 13). The participants changed vehicles on the turnaround next to the entrance to 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 the location of different controls, and verifying that the correct VES configuration was being tested. Four other onroad experimenters were positioned at various locations. One onroad experimenter was assigned to locations 1 and 5, one to locations 2 and 4, and one to locations 3 and 6. See appendix I for more 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 12. Photo. Smart Road.

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, researchers moved the HLB and HID headlamps 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 typically specified. 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*.

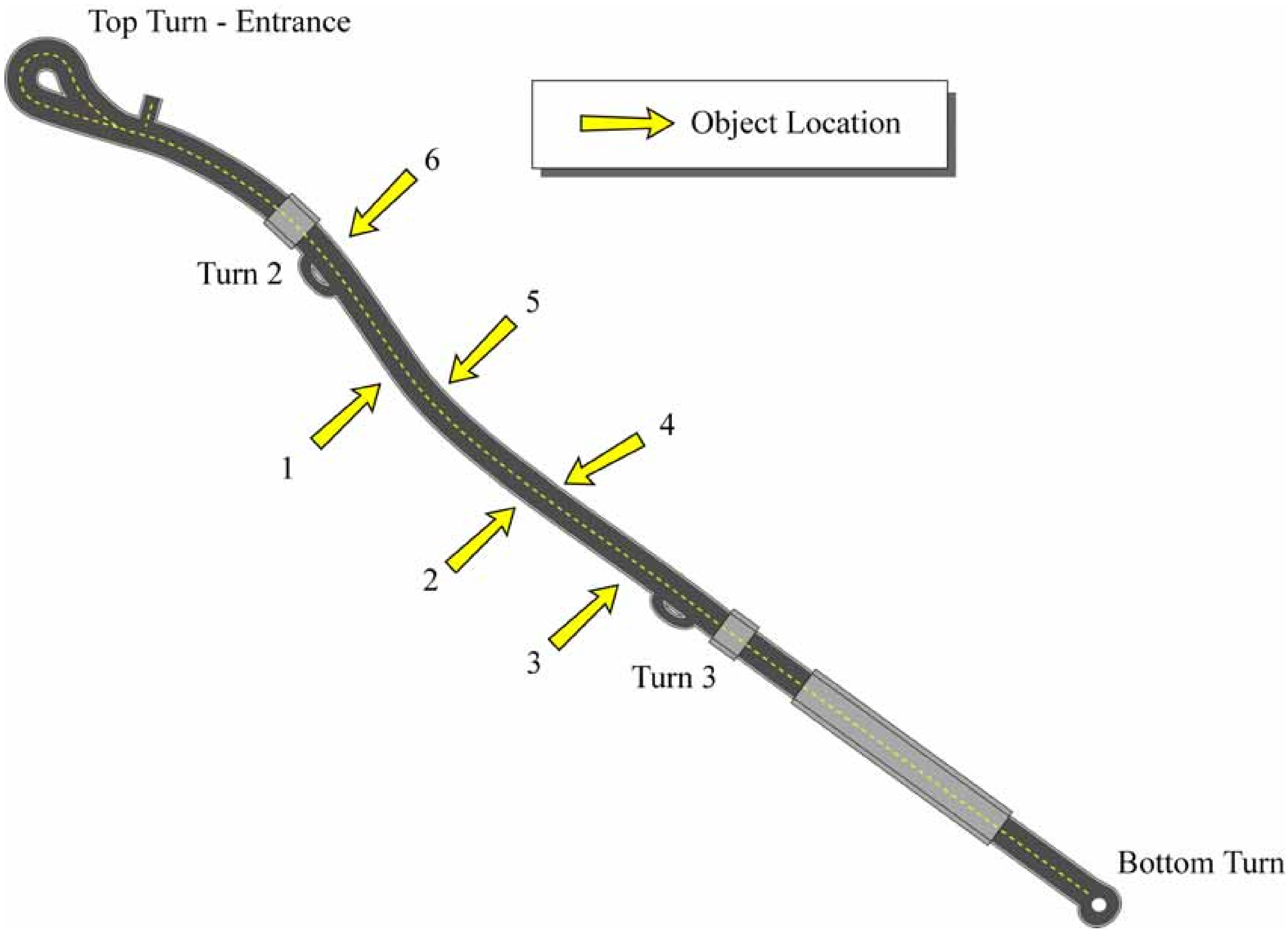


Figure 13. Diagram. Locations where the objects were presented for Study 1.

EXPERIMENTAL PROCEDURE

The experiment consisted of three sessions, each lasting about 3.5 h. The first session included a screening, laboratory training, and IR–TIS training. The other two sessions involved the two nights of the experiment at the Smart Road; two participants performed the experiment simultaneously. During the first onroad session, the participant was 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. Following is a description of procedure details.

Participant Screening

Participants were initially screened in telephone interviews (appendix A). If a participant qualified for the study, a time was scheduled for testing. Participants were instructed to meet the experimenter at the contractor facility. After each participant arrived, he or she received an overview of the study. Subsequently, each participant 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 test was performed to verify that all participants had at least 20/40 vision, corrected or uncorrected, and to identify any type of vision disparity that might have influenced the results. After completing these steps, and if no problems were identified, each participant received training on the experimental tasks to be performed during the drive. A detailed experimenter protocol for vision testing is included in appendix D.

Training

Each participant was instructed on how to perform the tasks associated with the object detection and recognition and how the questionnaires would be used. The study protocol and pictures of the objects were presented at this point (appendixes E and F). The detection and recognition definitions, the use of the pushbutton for detection and recognition, and the Likert-type scales for the questionnaire were also shown and explained to each participant. 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, practice using the heads-up display (HUD) that presents images captured by the infrared thermal imaging system (IR–TIS) took place. Examples of the objects shown during the experimental sessions were presented as part of the training practice.

Familiarization

Because the participants were changing vehicles as part of the study, the familiarization process took place as soon as they reached each experimental vehicle. While the vehicle was parked, the onroad experimenter reviewed general information concerning the operation of the test vehicle (appendix K). Each participant was asked to adjust the vehicle seat and steering wheel position controls for his or her driving comfort. When the participant felt comfortable with the controls of the vehicle, the experiment was ready to start.

Driving Instructions

Participants were instructed to remain in the right-hand lane while driving and place the vehicle in park upon reaching each of the turnarounds. Participants were instructed to drive at 40 km/h (25 mi/h) during the experimental sessions and follow instructions from the in-vehicle experimenter at all times.

Driving and Practice Lap

Each participant drove down the road to become familiar with the road and the vehicle; no objects were presented during this familiarization. At the bottom turnaround, the experimenter gave the wand with the pushbutton to the participant and instructed the participant that the purpose of this portion of the session was to familiarize him or her with the objects. The participant then drove back up the road for a practice run of detection and recognition, obtaining feedback from the experimenter as needed. After the practice tasks, the participant drove with the first group of six VESs, corresponding to the order assigned for 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 at both detection and recognition. Other than detection, recognition, and maintaining 40 km/h

(25 mi/h), the participants performed no other tasks while driving. The experimenter sat in the passenger seat and let the participant know when he or she could start driving and where to park. The in-vehicle experimenter also administered the subjective questionnaires after each VES configuration and controlled the data collection program. Appendix F contains details on the in-vehicle experimenter protocol.

Sequence of Data Collection

Each of the participants followed the same sequence of events to collect 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 six locations for the clear condition in a counterbalanced order for a total of nine objects and three blanks for each VES.
2. While approaching each location, the participant pressed the pushbutton when able to detect an object.
3. When the participant was able to 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 when the object was aligned with the participant.
5. When two laps were completed, all the objects for a given VES configuration had been presented, and the subjective ratings (a questionnaire) for that VES configuration were collected. This completed data collection for a given participant and VES configuration combination.
6. After all VES configurations were completed, the participant was instructed to return to the contractor facility to be debriefed (appendix H).

The study was performed twice every night (i.e., first shift: 7:45 p.m. to 11 p.m.; second shift: 11:30 p.m. to 2:30 a.m.). Participants who worked until late and usually drove late at night drove in the second shift to minimize the possibility of fatigue. Other participants drove during the first shift. Payment for the total number of hours (training, experimental session one, and experimental session two) was provided 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. The data were evaluated to examine drivers' visual performance under each of the different treatments. An analysis of variance (ANOVA) was performed. 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
<u>*BETWEEN*</u>
Age
Subject (Age)
<u>*WITHIN*</u>
VES
Age by VES
VES by Subject (Age)
Object
Age by Object
Object by Subject (Age)
VES by Object
Age by VES by Object
VES by Object by Subject (Age)

The ANOVA was used to evaluate whether there were significant differences among the different VESs in terms of 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 effect. Note that a significant main effect, or interaction, does not make all levels inside it significantly different. A detailed discussion of post hoc tests appears in Winer, Brown, and Michels.[18]

CHAPTER 3—RESULTS

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 9 (Object) mixed factorial design. ANOVA summary tables were obtained for both objective dependent measurements (table 6 and table 7). A total of 3,229 observations were obtained from the experiment for each objective measurement. When drivers were unable to detect and recognize an object, a value of 0 was assigned. Several main effects and interactions were considered significant (table 8).

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

Source	DF	SS	MS	F value	P value	
Between						
Age	2	3875582.0	1937791.0	4.29	0.0242	*
Subject/Age	27	12205792.2	452066.4			
Within						
VES	11	8082226.5	734747.9	28.42	<0.0001	*
VES by Age	22	1277750.3	58079.6	2.25	0.0014	*
VES by Subject/Age	296	7653255.8	25855.6			
Object	8	180324344.1	22540543.0	679.70	<0.0001	*
Object by Age	16	1249341.1	78083.8	2.35	0.0031	*
Object by Subject/Age	216	7163085.5	33162.4			
VES by Object	88	9250704.6	105121.6	3.00	<0.0001	*
VES by Object by Age	176	5645156.3	32074.8	0.92	0.7750	
VES by Object by Subject/Age	2366	82880763.4	35029.9			
TOTAL	3228	319608001.8				

* $p < 0.05$ (significant)

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

Source	DF	SS	MS	F value	P value	
Between						
Age	2	3482588.4	1741294.2	3.97	0.0308	*
Subject/Age	27	11836662.6	438394.9			
Within						
VES	11	5493301.2	499391	19.65	<0.0001	*
VES by Age	22	577886.9	26267.6	1.03	0.4223	
VES by Subject/Age	296	7521854	25411.7			
Object	8	136027251.9	17003406.5	545.65	<0.0001	*
Object by Age	16	1046045.2	65377.8	2.10	0.0094	*
Object by Subject/Age	216	6730986.1	31162			
VES by Object	88	5043266.7	57309.8	2.31	<0.0001	*
VES by Object by Age	176	3618771.5	20561.2	0.83	0.9481	
VES by Object by Subject/Age	2366	58728710.6	24821.9			
TOTAL	3228	240107325.1				

* $p < 0.05$ (significant)

Table 8. Summary of significant main effects and interactions.

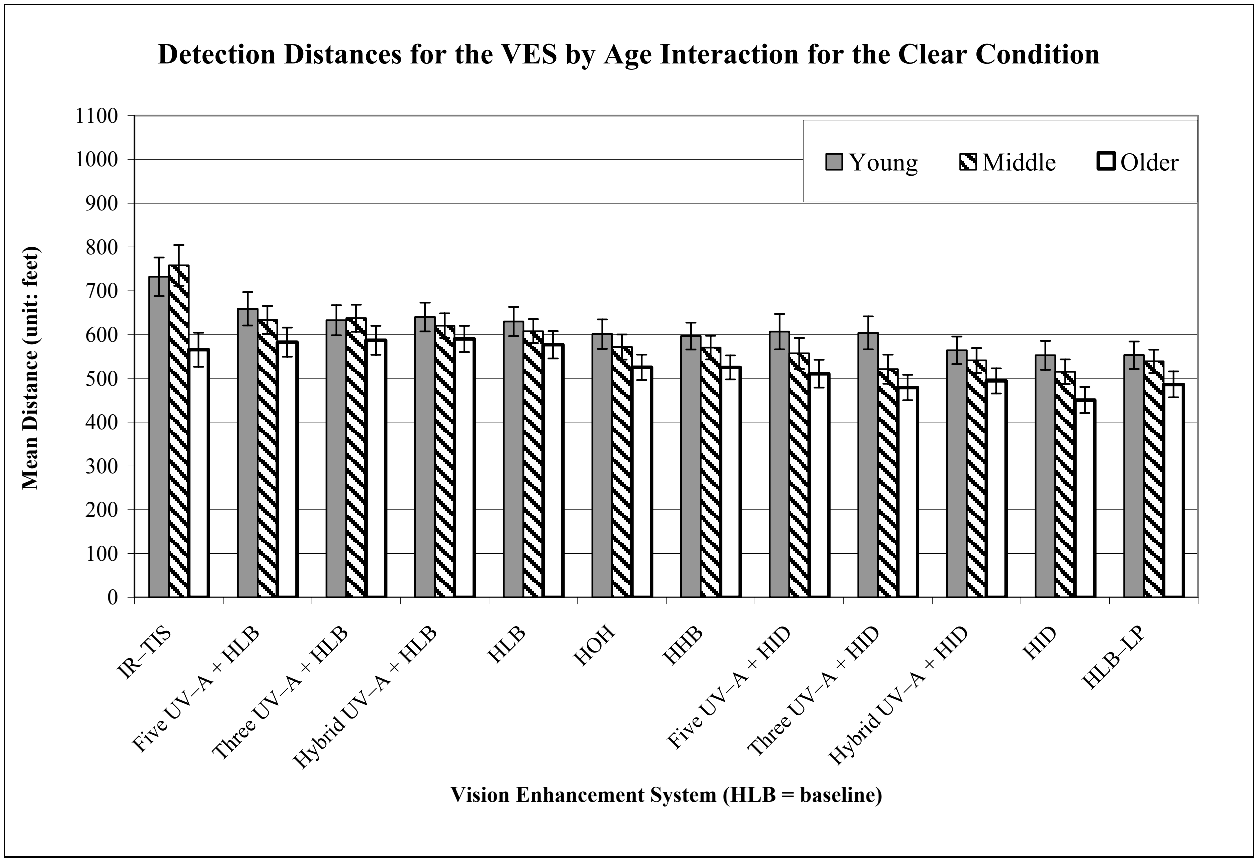
Source	Significant Detection	Significant Recognition
Between		
Age	x	x
Subject/Age		
Within		
VES	x	x
VES by Age	x	
VES by Subject/Age		
Object	x	x
Object by Age	x	x
Object by Subject/Age		
VES by Object	x	x
VES by Object by Age		
VES by Object by Subject/Age		

x = $p < 0.05$ (significant)

The main effects and most two-way interactions between age, VES, and type of object were significant ($p < 0.05$) for both visual-performance measurements. The VES by Age interaction lacked significance for recognition distance; this interaction was only significant for detection distance. The post hoc results for the significant main effects and interactions were graphed (figure 14 to figure 23; standard error bars are provided with the means). In the main effect graphs, means with the same letter in their grouping are not significantly different (based on the Bonferroni post hoc test).

The HLB headlamps are the most commonly available VES; therefore, the reader is urged to compare the results of other VESs to results obtained for the HLB, thus making the HLB a baseline measure. Note that this is only one halogen headlamp type and beam pattern, and not necessarily representative of all halogen lamps currently in the market.

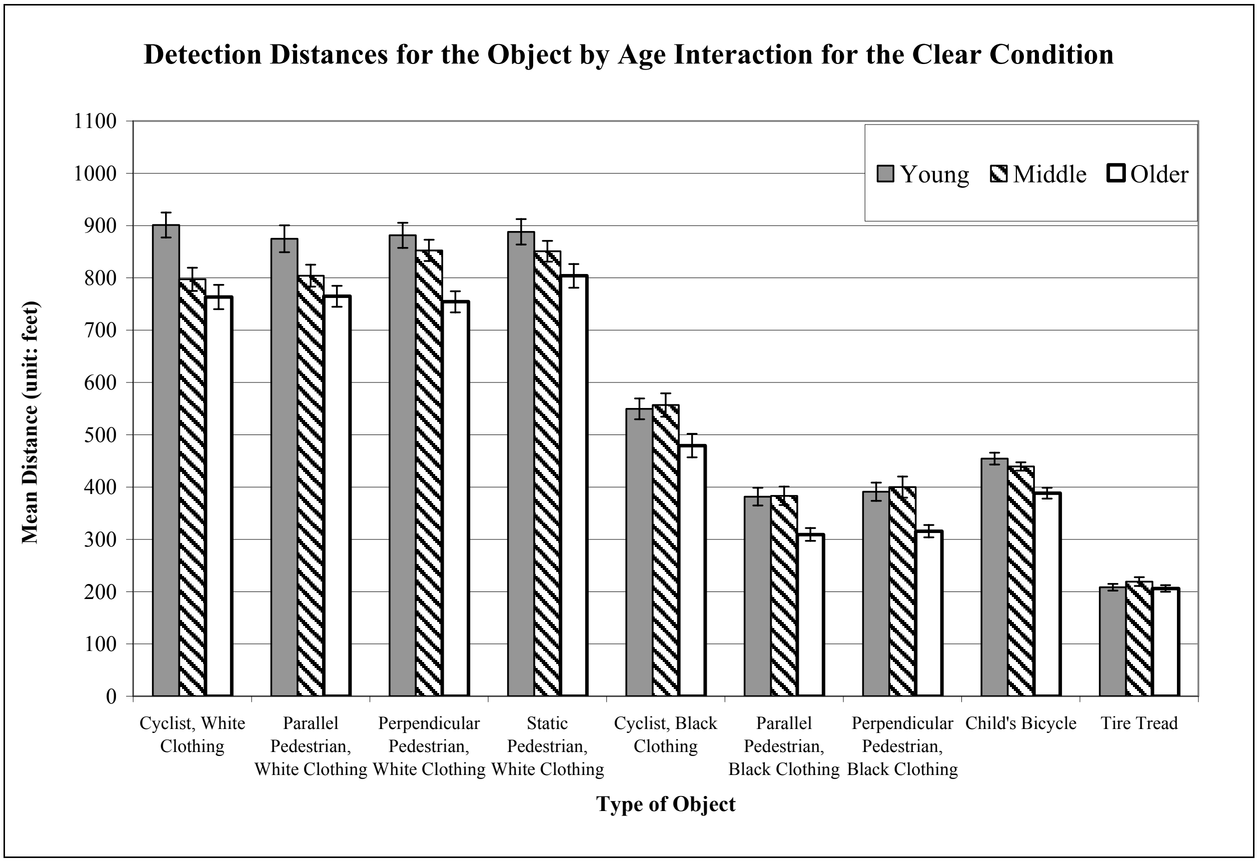
On average, the VES by Age interaction, significant for detection distance, showed that the HOH, HHB, HLB–LP, HID, and all of the UV–A configurations with HID failed to perform better than the HLB across all three age groups (table 6). Configurations of HLB with UV–A (i.e., five UV–A, three UV–A, hybrid) across the three age groups exhibited improvements on detection distances, but these improvements averaged less than 9.1 m (30 ft); however, performance of the IR–TIS was age dependent. The younger and middle-aged drivers had farther detection distances when using the IR–TIS than when using the HLB. The younger and middle-aged participants were able to see objects 31.1 m and 45.7 m (102 ft and 150 ft) farther, respectively, with the IR–TIS compared to HLB. However, there was no improvement on detection distance for older drivers when using IR–TIS; in fact, these drivers saw, on average, 3.4 m (11 ft) farther in the HLB configuration.



1 ft = 0.305 m

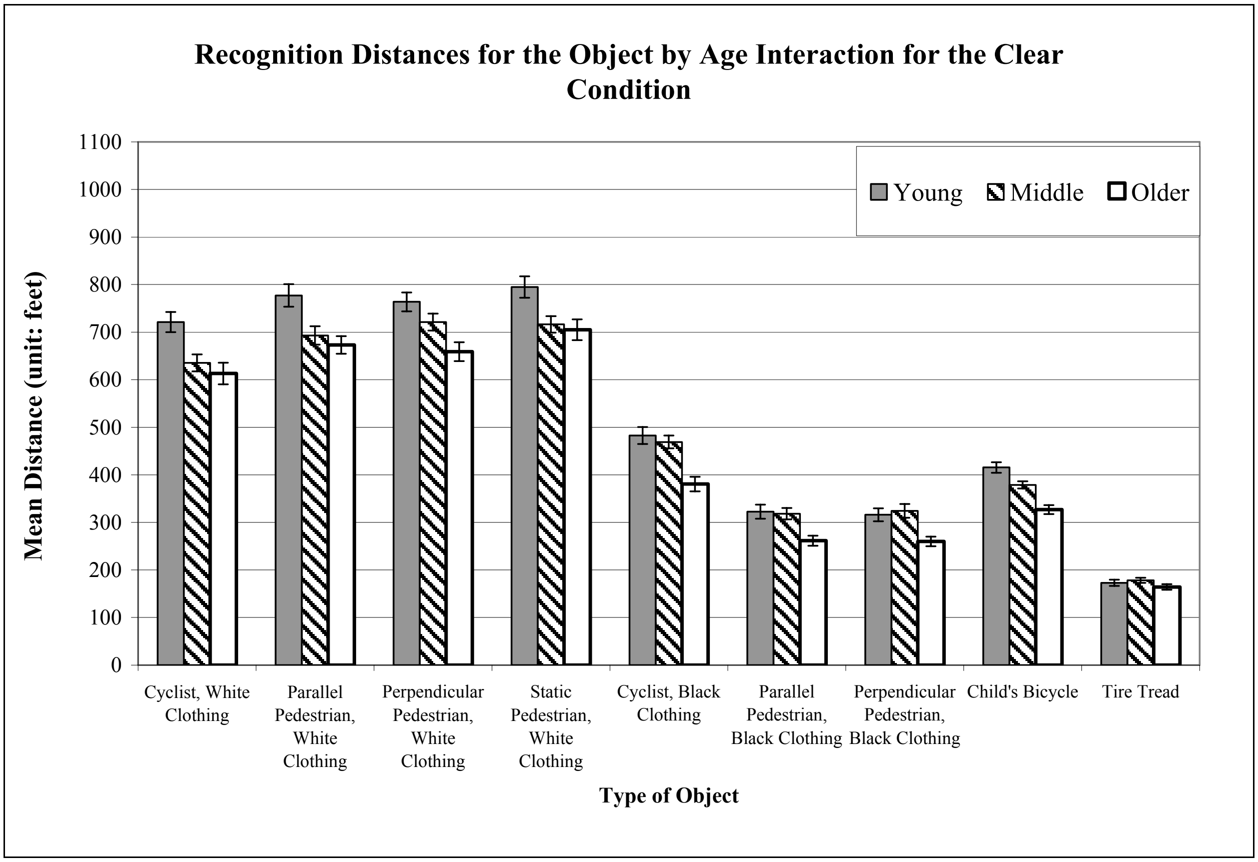
Figure 14. Bar graph. Results on detection distances for the interaction: VES by Age.

A significant separation of results based on object contrast and the age of the driver can be observed from the Object by Age interaction for both detection and recognition (figure 15 and figure 16). For pedestrians and cyclists dressed in white clothing (i.e., high contrast), there was a significant difference between younger and older drivers' detection and recognition. The younger drivers had the longest detection and recognition distances for all high contrast objects. The detection and recognition distances of these high contrast objects for middle-aged drivers was not statistically different from the ones for the older drivers for three out of the four objects. For pedestrians and cyclist dressed in black clothing (i.e., low contrast), there was not a significant difference between younger and middle-aged drivers, but these two age groups were significantly different from the older drivers in terms of detection and recognition distances. Both detection and recognition were shorter for older drivers than the distances for their younger counterparts. For objects that had fairly low contrast and were close to the ground (e.g., tire tread), there was no difference among age groups, and the points of detection and recognition happened close to each other.



1 ft = 0.305 m

Figure 15. Bar Graph. Results on detection distances for the interaction: Object by Age.



1 ft = 0.305 m

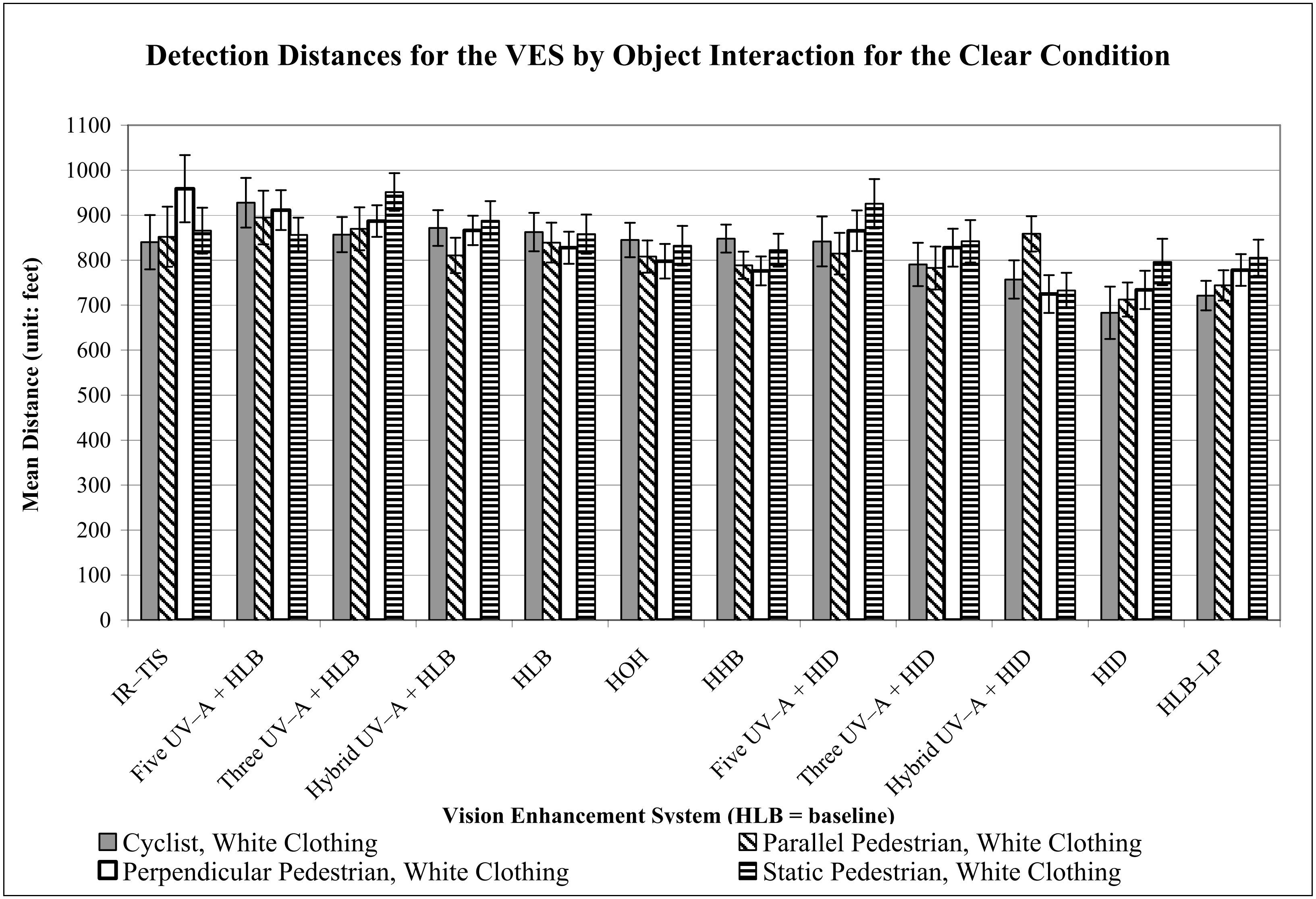
Figure 16. Bar graph. Results on recognition distances for the interaction: Object by Age.

The significant difference ($p < 0.05$) for VES by Object under both detection and recognition distances also appears to be mainly the result of the two sets of different objects: black (low contrast) versus white (high contrast) objects (figure 17 through figure 20).

In general, the HLB performed as well as or better than the other VESs for the detection and recognition of high contrast objects (figure 17 and figure 19). The only exception was the perpendicular pedestrian with white clothing, which was detected 39.9 m (131 ft) (16 percent) farther away with the IR–TIS than with the HLB. On the other hand, the detection and recognition distances with HID were significantly different (i.e., 7 to 21 percent closer to the object) than HLB.

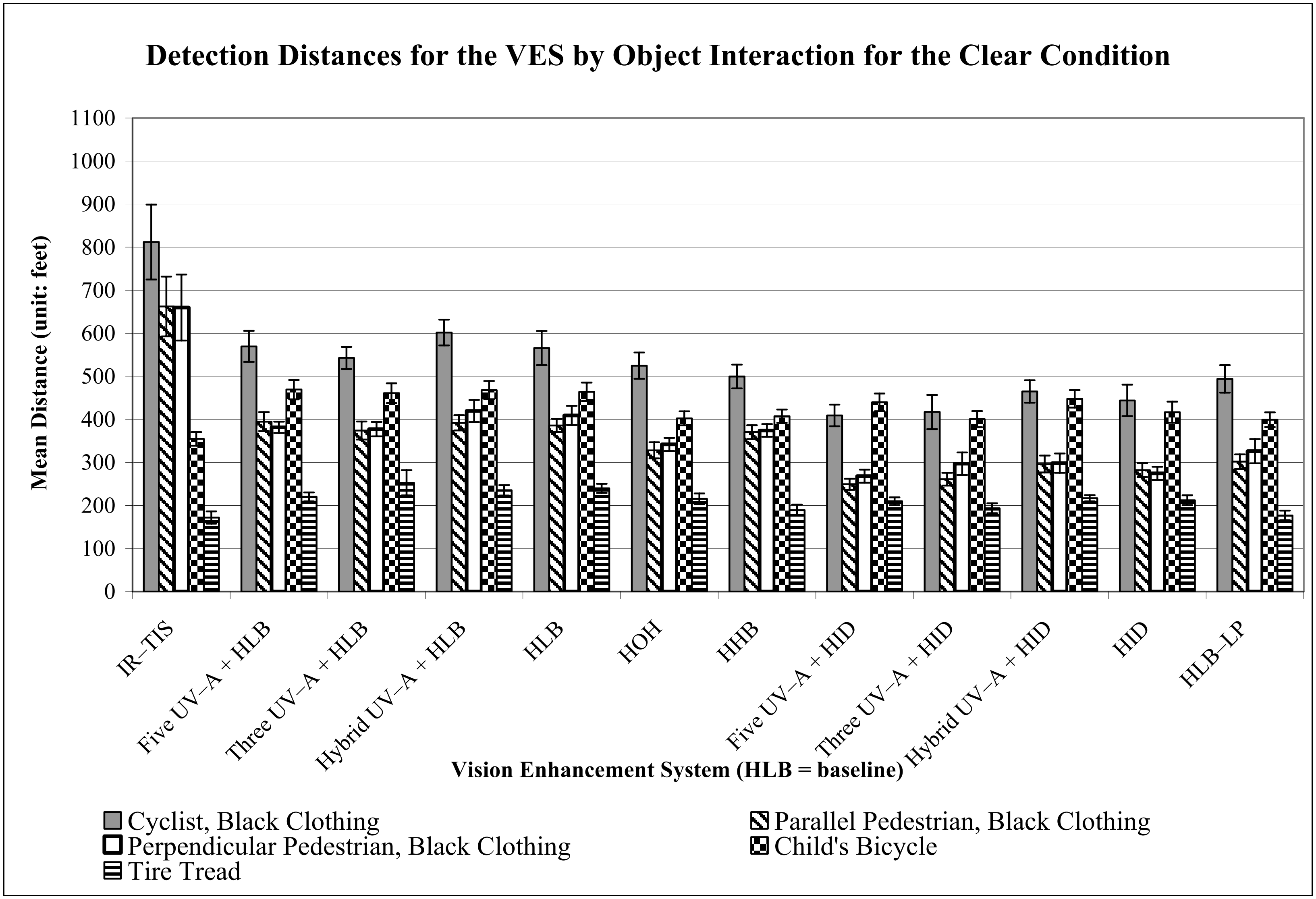
For low-contrast objects (figure 18 and figure 20), the HLB outperformed most of the VESs, with the IR–TIS again being the exception. The IR–TIS detected the cyclist and pedestrians with black clothing significantly farther away than the HLB; however, the other dark objects closer to ground level that do not produce heat, such as the child's bicycle and the tire tread, were not detected or recognized as far away with the IR–TIS as they were by using the HLB.

Across all objects, the halogen baseline configuration allowed drivers to detect and recognize objects sooner than its HID counterpart. Depending on the type of object, the halogen allowed object detection ranging from 54.6 m (179 ft) (21 percent for high contrast objects) to 40.8 m (134 ft) (33 percent for low contrast objects) farther than the HIDs.



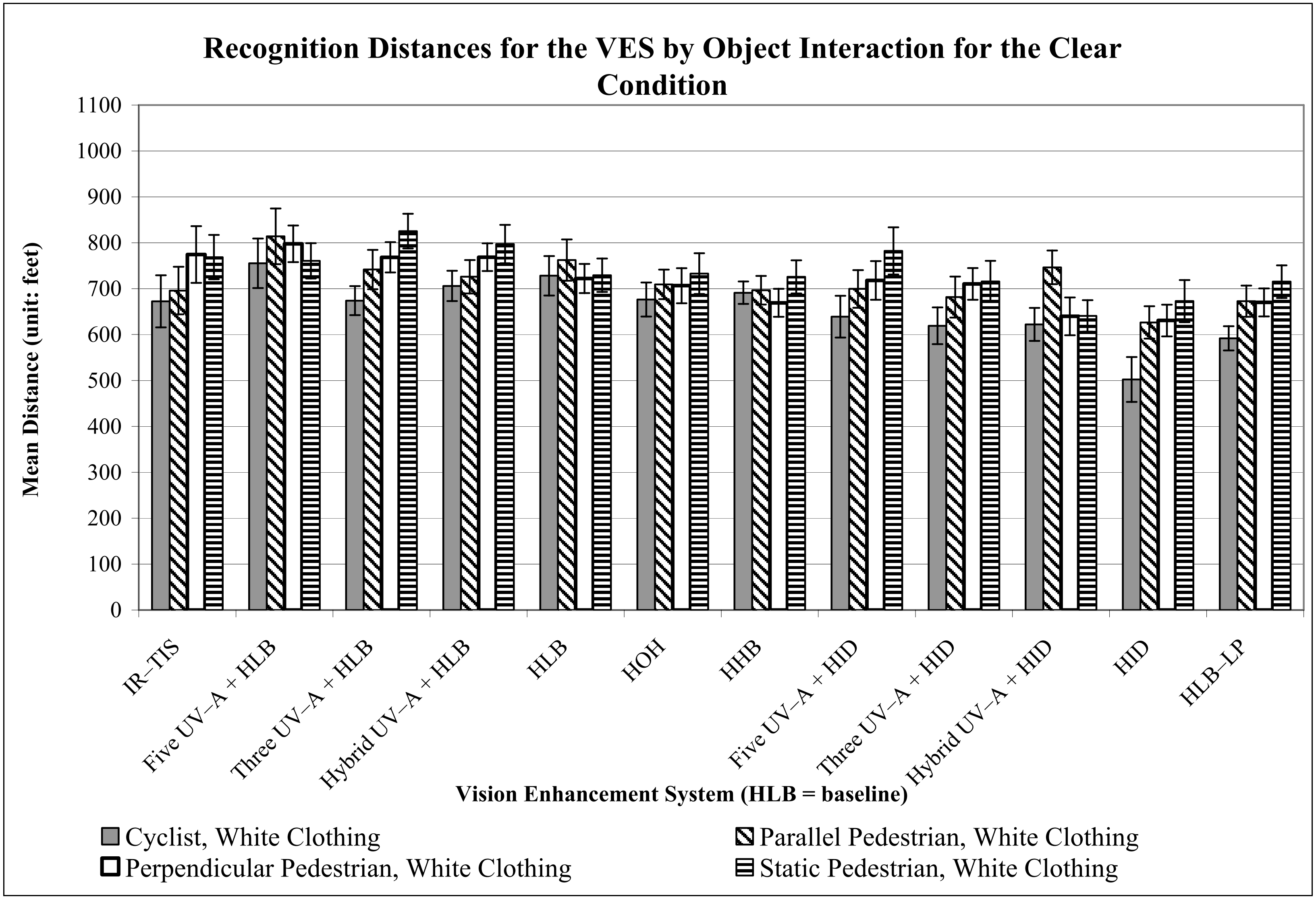
1 ft = 0.305 m

Figure 17. Bar graph. Results on detection distances for the interaction: VES by Object: pedestrians and cyclists in white clothing.



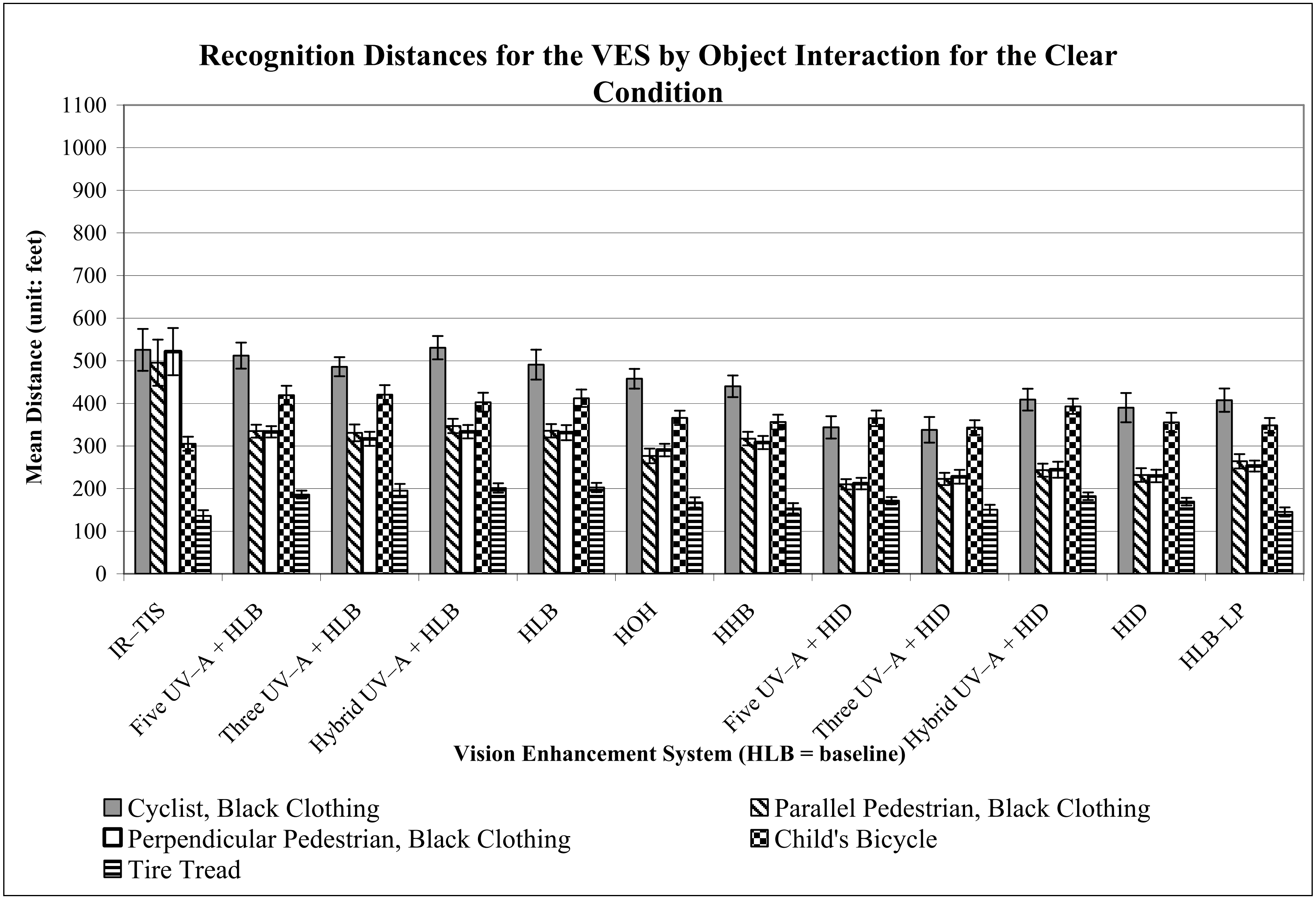
1 ft = 0.305 m

Figure 18. Bar graph. Results on detection distances for the interaction: VES by Object: child's bicycle, tire tread, and pedestrians and cyclists in black clothing.



1 ft = 0.305 m

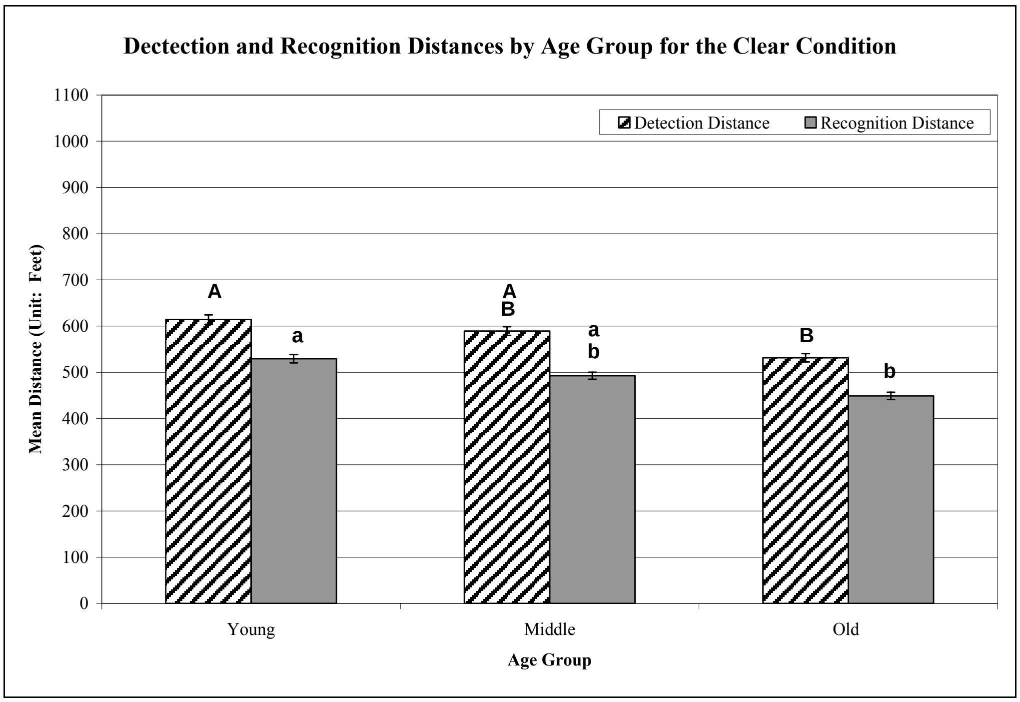
Figure 19. Bar graph. Results on recognition distances for the interaction: VES by Object: pedestrians and cyclists in white clothing.



1 ft = 0.305 m

Figure 20. Bar graph. Results on recognition distances for the interaction: VES by Object: child's bicycle, tire tread, and pedestrians and cyclists in black clothing.

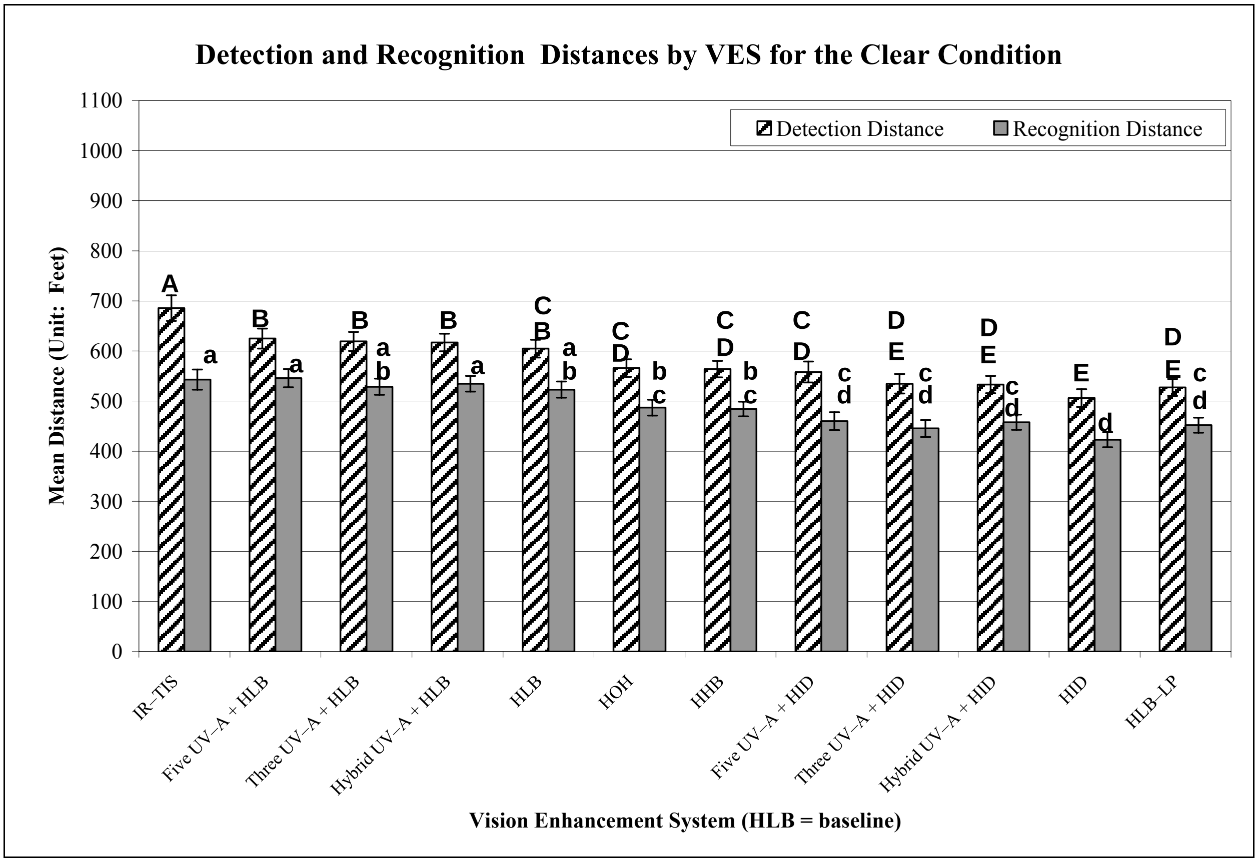
The results from the ANOVA showed a significant difference ($p < 0.05$) among the three age groups in terms of detection and recognition distances (figure 21). Both detection and recognition follow the same pattern with respect to age: distances were not significantly different between younger and middle-aged drivers or middle-aged and older drivers, but they were significantly different between younger and older drivers. The detection and recognition distances for the older drivers were the shortest; the younger drivers had the longest detection and recognition distances.



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

Figure 21. Bar graph. Bonferroni post hoc results on detection and recognition distances for the main effect: age.

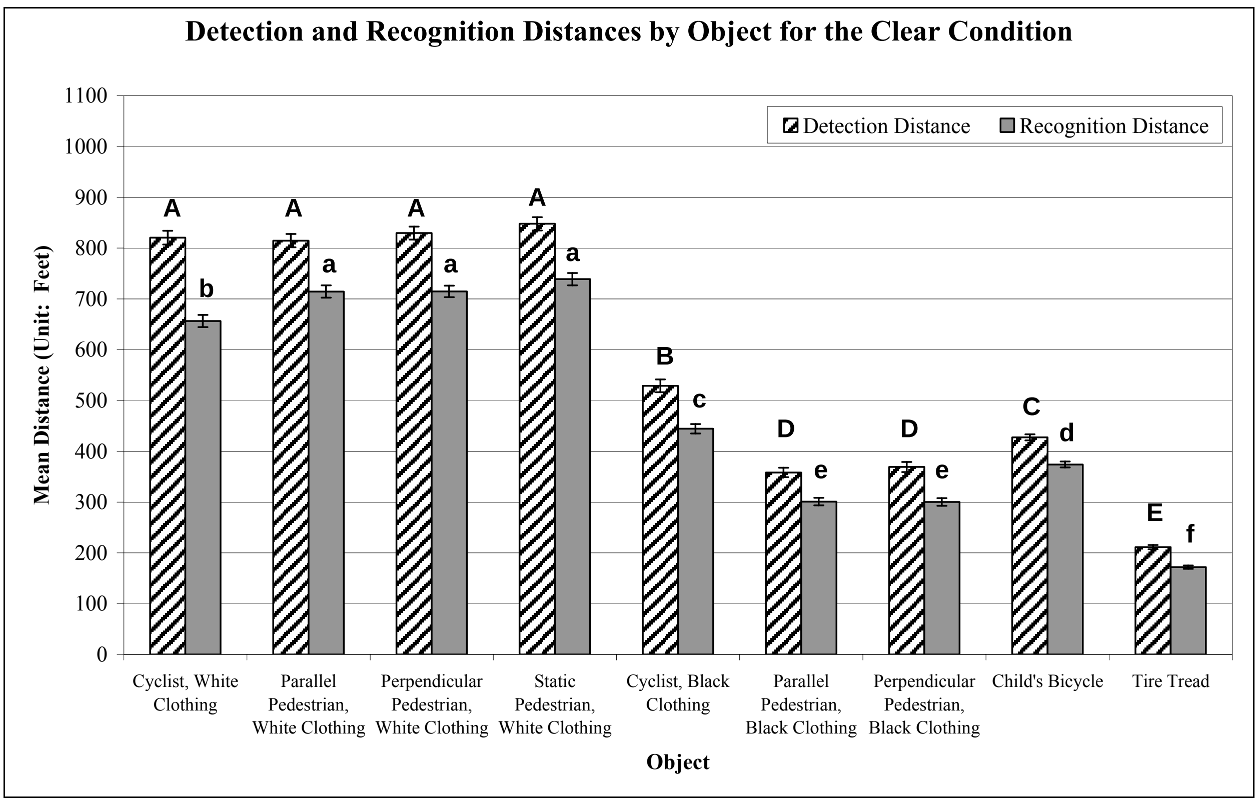
VESs were significantly different ($p < 0.05$) in terms of detection and recognition distances. The post hoc analysis for the VES main effect suggests that there was a significant difference between the detection distances for the HLB baseline and the IR–TIS, where drivers with the IR–TIS were able to detect objects 24.7 m (81 ft) sooner than with HLB. Furthermore, there was a significant difference between detection distances for the HLB and the HID, HLB–LP, and hybrid and three UV–A headlamps added to the HIDs (figure 22). The HLB was able to provide for detection of objects, on average, of 21.3 to 30.2 m (70 to 99 ft) farther away than the other five VESs. There was a significant difference between recognition distances for HLB and recognition distances for any of the HID configurations and the HLB–LP. Drivers using the HLB were able to recognize objects over 18.3 m (60 ft) farther away than drivers using any of the other five configurations. Recognition distances were not significantly different between HLB and the IR–TIS or between HLB and HLB supplemented with UV–A.



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

Figure 22. Bar graph. Bonferroni post hoc results on detection and recognition distances for the main effect: VES.

Post hoc tests for the type of object main effect show no significant difference among the pedestrians in white clothing and cyclist in white clothing in terms of detection. However, on average, drivers recognized the pedestrians in white clothing farther away than the cyclist in white clothing (figure 23). No significant difference was found among the pedestrians in black clothing in terms of detection or recognition. Thus, clothing contrast, rather than object motion, appears to be responsible for the significant differences observed (i.e., objects with light color clothing were detected and recognized farther away than the dark color clothing counterparts no matter if they were moving or still). While there was a significant difference between the cyclist in black clothing and the pedestrians in black clothing in terms of detection and recognition, it was probable that the increased distances for the cyclist in black clothing could be attributed to the detection of the bicycle's rims (high specular reflectance) rather than detection of the actual cyclist given that the cyclist was wearing the same type of clothing the pedestrians were wearing; however, the cyclist in black clothing was not detected or recognized as far away as the white-clothed counterpart. The tire tread and child's bicycle were statistically different ($p < 0.05$) from the other objects. The tire tread had the shortest detection and recognition distances. The detection and recognition distances for the child's bicycle were shorter than the cyclist in black clothing but larger than the pedestrians in black clothing and the tire tread. The child's bicycle was set on the side, centered across the right edgeline, and the rims were not facing the driver. Therefore, the drivers were not able to experience a specular reflectance similar to the one the rims of the cyclist bicycle, but the reflectance of the child's bicycle was higher than the one for the pedestrians in black clothing and the tire tread.



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

Figure 23. Bar graph. Bonferroni post hoc results on detection and recognition distances for the main effect: object.

SUBJECTIVE MEASUREMENTS

An ANOVA was performed to analyze the subjective measurements taken on the Smart Road portion of the study. 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 the 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	9.8	4.9	0.47	0.6285	
Subject/Age	27	280.0	10.4			
Within						
VES	11	91.3	8.3	7.36	<0.0001	*
VES by Age	22	33.1	1.5	1.33	0.1472	
VES by Subject/Age	296	333.6	1.1			
TOTAL	358	747.8				

* $p < 0.05$ (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	11.1	5.5	0.53	0.5925	
Subject/Age	27	280.3	10.4			
Within						
VES	11	54.8	5.0	4.66	<0.0001	*
VES by Age	22	28.6	1.3	1.22	0.2302	
VES by Subject/Age	296	315.9	1.1			
TOTAL	358	690.7				

* $p < 0.05$ (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	7.7	3.9	0.25	0.7802
Subject/Age	27	415.1	15.4		
Within					
VES	11	14.2	1.3	1.73	0.0663
VES by Age	22	23.2	1.1	1.42	0.1040
VES by Subject/Age	296	220.4	0.7		
TOTAL	358	680.6			

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	7.0	3.5	0.24	0.7860
Subject/Age	27	391.7	14.5		
Within					
VES	11	10.0	0.9	1.14	0.3265
VES by Age	22	22.9	1.0	1.31	0.1617
VES by Subject/Age	296	235.1	0.8		
TOTAL	358	666.7			

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	69.5	34.7	2.49	0.1021	
Subject/Age	27	377.2	14.0			
Within						
VES	11	41.9	3.8	2.77	0.0020	*
VES by Age	22	21.0	1.0	0.69	0.8454	
VES by Subject/Age	296	407.6	1.4			
TOTAL	358	917.2				

* $p < 0.05$ (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	12.9	6.5	0.41	0.6687
Subject/Age	27	427.8	15.8		
Within					
VES	11	20.0	1.8	1.53	0.1209
VES by Age	22	18.5	0.8	0.71	0.8338
VES by Subject/Age	296	352.7	1.2		
TOTAL	358	832.0			

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	12.2	6.1	0.42	0.6587
Subject/Age	27	387.5	14.4		
Within					
VES	11	32.3	2.9	2.02	0.0566
VES by Age	22	26.4	1.2	0.83	0.6929
VES by Subject/Age	296	430.5	1.5		
TOTAL	358	888.9			

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

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

x = $p < 0.05$ (significant)

To understand drivers' ratings of the various VESs in terms of safety and comfort, the results for all seven statements and each VES are sorted by ascending mean rating. Drivers rated the IR–TIS as the top configuration that (1) allowed them to detect and recognize objects sooner, (2) made them feel safer, and (3) performed as the best VES. However, drivers also gave the IR–TIS the lowest (i.e., worst) rating for its effectiveness with lane-keeping assistance and also rated it as the highest producer of visual discomfort when compared to the other VESs. The HID, HHB, and HID with three UV–A headlamps were the lowest in aiding drivers to detect and recognize objects sooner, with a tendency toward a neutral rating. In addition, when ranked on the mean subjective ratings, the HLB had a higher ranking than the HID for six out of the seven statements, which suggests that it is perceived as allowing faster detection and recognition, better lane-keeping assistance, less visual discomfort, and increased safety. A list of all statements follows.

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

VES	Mean Rating
IR–TIS	1.47
Five UV–A + HLB	2.47
Hybrid UV–A + HLB	2.50
Hybrid UV–A + HID	2.83
Five UV–A + HID	2.87
Three UV–A + HLB	2.97
HOH	2.97
HLB–LP	3.14
HLB	3.17
Three UV–A + HID	3.23
HHB	3.30
HID	3.40

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

VES	Mean Rating
IR–TIS	2.00
Five UV–A + HLB	2.50
Hybrid UV–A + HLB	2.57
Hybrid UV–A + HID	2.83
Three UV–A + HLB	2.90
HOH	2.97
Five UV–A + HID	3.00
HLB	3.07
HLB–LP	3.10
HHB	3.30
HID	3.37
Three UV–A + HID	3.43

- ***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
Hybrid UV–A + HID	3.07
Five UV–A + HID	3.10
HLB–LP	3.14
Five UV–A + HLB	3.17
Hybrid UV–A + HLB	3.17
HOH	3.17
HID	3.17
Three UV–A + HID	3.30
Three UV–A + HLB	3.40
HLB	3.43
HHB	3.50
IR–TIS	3.77

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

VES	Mean Rating
Five UV–A + HLB	3.00
HOH	3.07
Hybrid UV–A + HLB	3.17
Five UV–A + HID	3.20
HHB	3.23
Hybrid UV–A + HID	3.23
HLB	3.33
IR–TIS	3.40
Three UV–A + HLB	3.40
HID	3.47
HLB–LP	3.48
Three UV–A + HID	3.57

- ***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 + HLB	2.20
HLB	2.23
HOH	2.23
Hybrid UV–A + HLB	2.30
Three UV–A + HLB	2.37
Hybrid UV–A + HID	2.40
HLB–LP	2.48
Five UV–A + HID	2.57
HHB	2.60
HID	2.77
Three UV–A + HID	2.90
IR–TIS	3.43

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

VES	Mean Rating
IR–TIS	2.57
Five UV–A + HLB	2.87
Hybrid UV–A + HLB	2.97
Hybrid UV–A + HID	2.97
HOH	3.03
HLB–LP	3.10
Three UV–A + HID	3.13
HLB	3.17
Three UV–A + HLB	3.20
HHB	3.27
Five UV–A + HID	3.27
HID	3.57

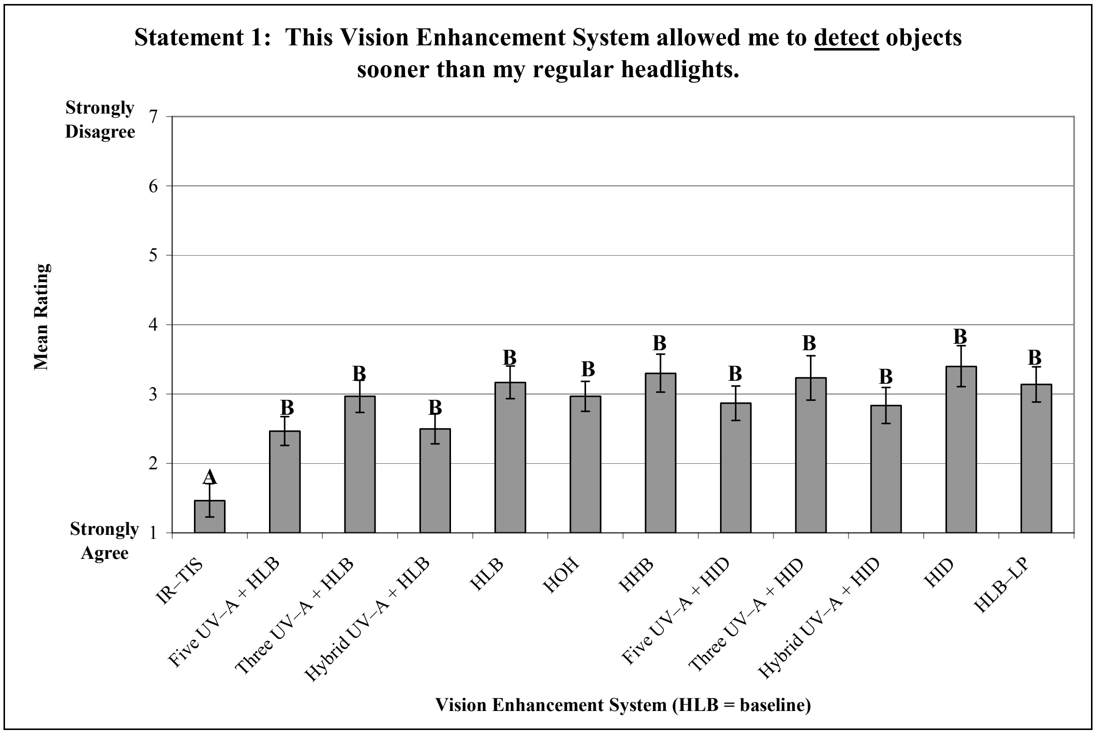
- ***Statement 7:*** This is a better vision enhancement system than my regular headlights (1=Strongly Agree; 7=Strongly Disagree).

VES	Mean Rating
IR–TIS	2.37
Five UV–A + HLB	2.57
Hybrid UV–A + HLB	2.73
HOH	2.87
Hybrid UV–A + HID	2.87
HLB	3.07
Three UV–A + HLB	3.13
Three UV–A + HID	3.13
HHB	3.17
Five UV–A + HID	3.20
HLB–LP	3.34
HID	3.40

The only significant difference for the statements was found in the VES main effect, specifically for statements 1, 2, and 5 (table 16). For statement 1—this vision enhancement system allowed me to detect objects sooner than my regular headlights—there is a significant difference ($p < 0.05$) between the IR–TIS configuration and all other configurations (figure 24). The IR–TIS received a mean rating of 1.42 (i.e., "Agree" to "Strongly Agree"), while other configurations remained clustered in the "Agree" range.

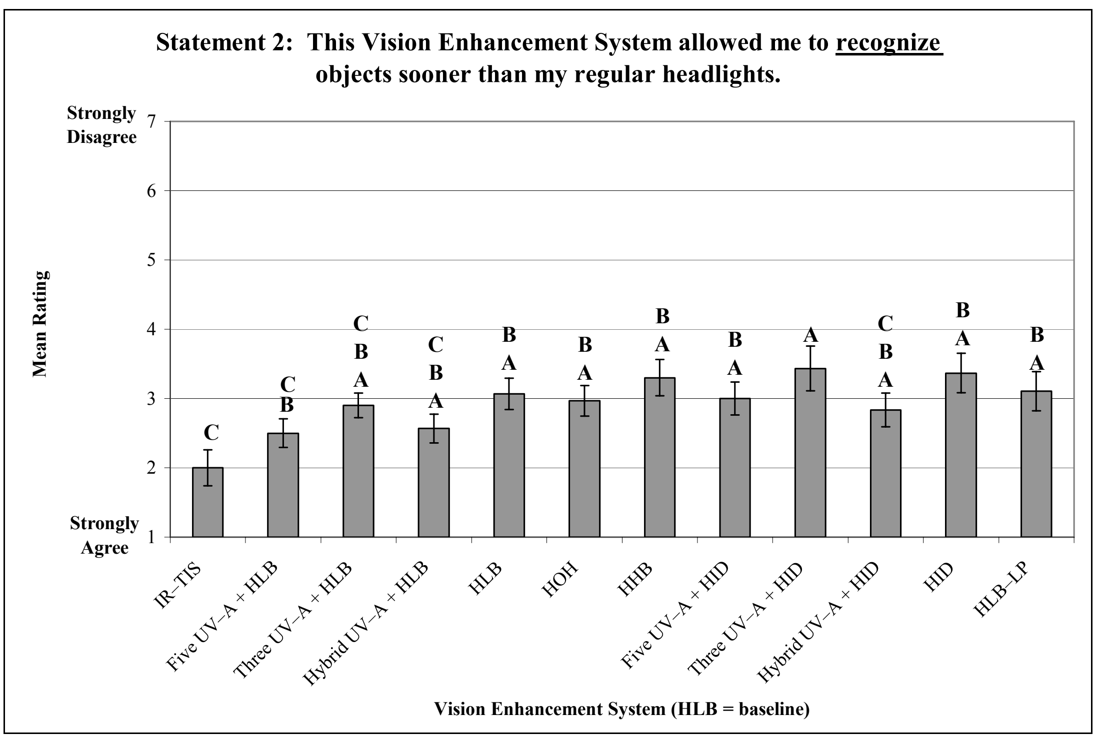
Post hoc results for statement 2—this vision enhancement system allowed me to recognize objects sooner than my regular headlights—again show the IR–TIS attaining the best mean rating (figure 25). The recognition rating was not as good as that given for detection, but it is still on the "Agree" range. However, while there is a significant difference ($p < 0.05$) in ratings between HLB and the IR–TIS, this difference does not exist between the IR–TIS and the HLB supplemented by the three UV–A configurations (five UV–A, three UV–A, hybrid). There are also no significant differences between HLB and the other 10 VESs. All the configurations remained in the "Agree" range.

Statement 5—this vision enhancement system did not cause me any more visual discomfort than my regular headlights—was also responsible for some significant differences ($p < 0.05$). There is a significant difference between HLB and the IR–TIS but not between HLB and the other 10 configurations. IR–TIS has a tendency toward neutral for that statement, but all other VESs align along the center of the "Agree" region (figure 26).



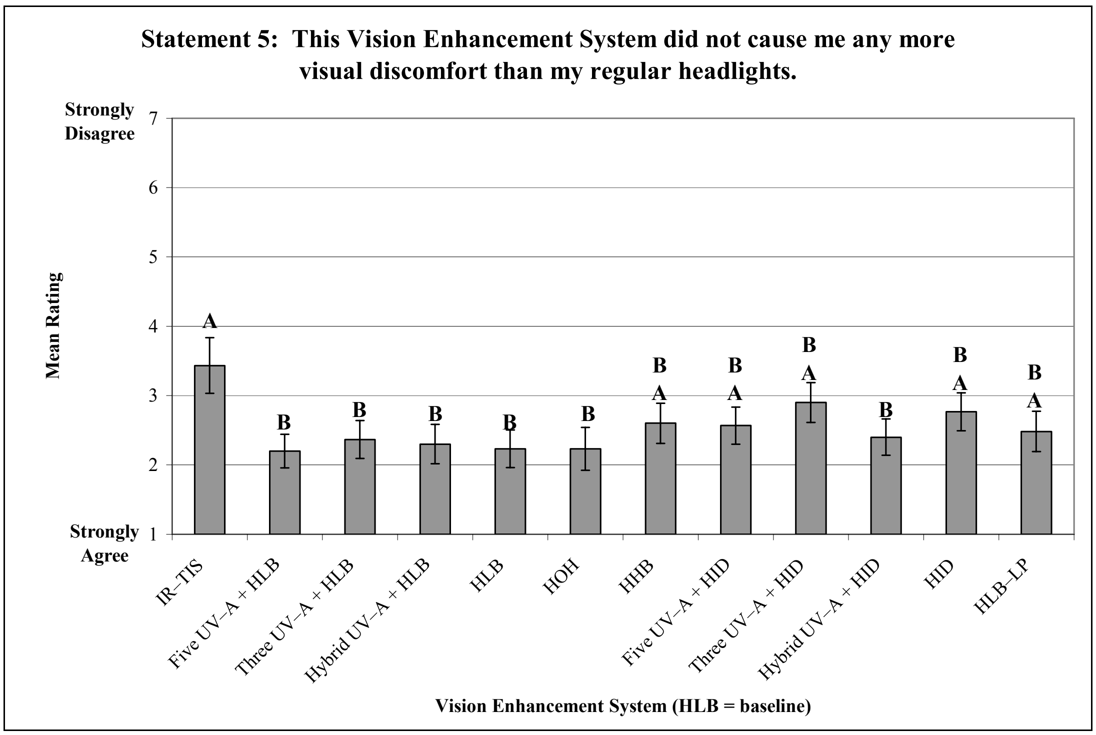
Means with the same letter are not significantly different.

Figure 24. 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 25. 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 26. Bar graph. Bonferroni post hoc results on the ratings evaluating visual discomfort 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 its typical placement 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. The results of this study should be considered in the context and conditions tested. If different halogen headlamps or aiming methods are used, the results might be different.

DETECTION AND RECOGNITION CAPABILITIES

Detection and recognition distances varied significantly among different VESs during nighttime driving in the clear weather condition. Throughout this discussion, the HLB system will be used as a baseline because of its widespread availability. In this particular study, several systems under- or over-performed the HLB system by as much as 30.5 m (100 ft) (table 17), representing a 19 percent difference. 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] Overall, use of the IR–TIS resulted in significant detection improvements over other systems. Specifically, participants were able to detect objects 24.7 m (81 ft) farther (i.e., a 13 percent increase in distance) with the IR–TIS than with the HLB. On average, the HID configuration provided the lowest detection and recognition distances. When compared to the HLB, the HID headlamps resulted in object detection distances that were 30.2 m (99 ft) closer to the object of interest (i.e., a 16 percent decrease in distance).

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

VES	Mean Detection (ft)	Mean Recognition (ft)	Comparison to HLB Detection (ft)	Comparison to HLB Recognition (ft)
IR–TIS	686	543	81	20
Five UV–A + HLB	625	546	20	23
Three UV–A + HLB	619	529	14	6
Hybrid UV–A + HLB	617	535	12	12
HLB	605	523	0	0
HOH	566	487	−39	−36
HHB	564	484	−41	−39
Five UV–A + HID	558	460	−47	−63
Three UV–A + HID	535	445	−70	−78
Hybrid UV–A + HID	533	458	−72	−65
HID	506	423	−99	−100
HLB–LP	527	452	−77	−71

1 ft = 0.305 m

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	81	2.2	1.6	1.2	1.0	0.8
Five UV–A + HLB	20	0.6	0.4	0.3	0.3	0.2
Three UV–A + HLB	14	0.4	0.3	0.2	0.2	0.2
Hybrid UV–A + HLB	12	0.3	0.2	0.2	0.2	0.1
HLB	0	0.0	0.0	0.0	0.0	0.0
HOH	−39	−1.1	−0.8	−0.6	−0.5	−0.4
HHB	−41	−1.1	−0.8	−0.6	−0.5	−0.4
Five UV–A + HID	−47	−1.3	−0.9	−0.7	−0.6	−0.5
Three UV–A + HID	−70	−1.9	−1.4	−1.1	−0.9	−0.7
Hybrid UV–A + HID	−72	−2.0	−1.4	−1.1	−0.9	−0.8
HID	−99	−2.7	−1.9	−1.5	−1.2	−1.0
HLB–LP	−77	−2.1	−1.5	−1.2	−1.0	−0.8

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

While these distances and reaction times provide an indication of the advantages of one system over another, they fail to describe completely any potential safety benefits or concerns based on VES use. With a limited number of assumptions, however, the VES-specific detection distances under clear weather 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 19). Braking distance is the distance that a vehicle travels while slowing to a complete stop.[21] For a vehicle that uniformly decelerates to a stop, the braking distance (d_{BD}) is dependent upon initial velocity (V), gravitational acceleration (g), coefficient of friction (f) between the vehicle tires and the pavement, and the gradient (G) of the road surface, with the gradient measured as a percent of slope. The equation in figure 27 provides the calculation of the braking distance (d_{BD}) under these conditions:

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

Figure 27. 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 28:

$$\boldsymbol{d = 2.5V + V^2/2gf}$$

Figure 28. Equation. Total stopping distance for brake reaction time plus braking distance.

The equation in figure 28 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 28 was used in this report because it does not require conversion factors and allows for a more direct comparison of the effect of varying the coefficient of friction (f).

To calculate total stopping distance, AASHTO suggests using a deceleration rate (a) of 11.2 ft/s^2 (3.4 m/s^2), resulting in a friction coefficient for wet pavement of 0.35 as seen in the equation in figure 29.[22]

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

Figure 29. Equation. AASHTO calculation of coefficient of friction for wet pavement.

The coefficient of friction used for these calculations is based on Lindeburg data for dry surface conditions.[26] The data obtained from Lindeburg is comprehensive in terms of type of surface, tire condition, and speed. A mean value of 0.65 was obtained for the coefficient of friction for dry surfaces (across all dry conditions). To accommodate most types of vehicles' braking capabilities, a conservative approach was taken for the calculations, and 0.60 was used as the coefficient of friction. Using this approach, stopping distances were calculated as shown in table 19.

Table 19. Stopping distances needed for a dry roadway.

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

1 ft = 0.305 m
1 mi = 1.6 km

The calculations represent a simple and ideal condition, but the formula allows for some visualization of the capabilities VES has. Based on these calculations, the average detection distances for each IR–TIS and HLB VES (table 17) provide enough time to react and brake up to speeds of less than approximately 105 km/h (65 mi/h). HID configurations supplemented with UV–A, HOH, and HHB show detection distances that will allow braking for up to 89 km/h (55 mi/h). The only two VESs that seem to be ineffective at more than 89 km/h (55 mi/h) are HID and HLB–LP; however, some caveats apply. First, these distances were obtained while drivers were moving at approximately 40 km/h (25 mi/h), and their ability to detect objects will not necessarily remain the same as speed increases. Second, VESs that are currently close to the stopping distance or that need a larger stopping distance (e.g., HID, HLB–LP) might quickly become more ineffective when conditions worsen (e.g., wet pavement, worn tires, downhill condition). 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. (In table 20 through table 31, an "X" means the stopping distance might be compromised; an asterisk means the same thing, but in an unlikely scenario.) Several VES and object combinations resulted in detection distances that might compromise stopping distances.

Table 20. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	172		X	X	X	X	X
Child's Bicycle	355				*	*	*
Perpendicular Pedestrian, Black Clothing	660						
Parallel Pedestrian, Black Clothing	662						
Cyclist, Black Clothing	812						
Cyclist, White Clothing	840						
Parallel Pedestrian, White Clothing	852						
Static Pedestrian, White Clothing	866						
Perpendicular Pedestrian, White Clothing	959						

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

Table 21. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	220			X	X	X	X
Perpendicular Pedestrian, Black Clothing	382					X	X
Parallel Pedestrian, Black Clothing	395					X	X
Child's Bicycle	469					*	*
Cyclist, Black Clothing	569						
Static Pedestrian, White Clothing	856						
Parallel Pedestrian, White Clothing	895						
Perpendicular Pedestrian, White Clothing	911						
Cyclist, White Clothing	928						

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

Table 22. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	253			X	X	X	X
Parallel Pedestrian, Black Clothing	374					X	X
Perpendicular Pedestrian, Black Clothing	377					X	X
Child's Bicycle	461					*	*
Cyclist, Black Clothing	542						
Cyclist, White Clothing	857						
Parallel Pedestrian, White Clothing	870						
Perpendicular Pedestrian, White Clothing	887						
Static Pedestrian, White Clothing	951						

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

Table 23. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	235			X	X	X	X
Parallel Pedestrian, Black Clothing	392					X	X
Perpendicular Pedestrian, Black Clothing	419					X	X
Child's Bicycle	468					*	*
Cyclist, Black Clothing	602						
Parallel Pedestrian, White Clothing	811						
Perpendicular Pedestrian, White Clothing	866						
Cyclist, White Clothing	872						
Static Pedestrian, White Clothing	888						

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

Table 24. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HLB.

Type of Object	Detection (ft)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	240			X	X	X	X
Parallel Pedestrian, Black Clothing	386					X	X
Perpendicular Pedestrian, Black Clothing	409					X	X
Child's Bicycle	464					*	*
Cyclist, Black Clothing	566						
Perpendicular Pedestrian, White Clothing	828						
Parallel Pedestrian, White Clothing	839						
Static Pedestrian, White Clothing	858						
Cyclist, White Clothing	862						

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

Table 25. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HOH.

Type of Object	Detection (ft)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	215			X	X	X	X
Parallel Pedestrian, Black Clothing	328				X	X	X
Perpendicular Pedestrian, Black Clothing	342				X	X	X
Child’s Bicycle	402					*	*
Cyclist, Black Clothing	525						X
Perpendicular Pedestrian, White Clothing	798						
Parallel Pedestrian, White Clothing	808						
Static Pedestrian, White Clothing	832						
Cyclist, White Clothing	845						

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

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

Type of Object	Detection (ft)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	189		X	X	X	X	X
Parallel Pedestrian, Black Clothing	370					X	X
Perpendicular Pedestrian, Black Clothing	374					X	X
Child’s Bicycle	407					*	*
Cyclist, Black Clothing	500						X
Perpendicular Pedestrian, White Clothing	776						
Parallel Pedestrian, White Clothing	789						
Static Pedestrian, White Clothing	822						
Cyclist, White Clothing	848						

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

Table 27. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	210			X	X	X	X
Parallel Pedestrian, Black Clothing	249			X	X	X	X
Perpendicular Pedestrian, Black Clothing	268			X	X	X	X
Cyclist, Black Clothing	409					X	X
Child’s Bicycle	440					*	*
Parallel Pedestrian, White Clothing	814						
Cyclist, White Clothing	842						
Perpendicular Pedestrian, White Clothing	866						
Static Pedestrian, White Clothing	925						

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

Table 28. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	194		X	X	X	X	X
Parallel Pedestrian, Black Clothing	261			X	X	X	X
Perpendicular Pedestrian, Black Clothing	297				X	X	X
Child's Bicycle	400					*	*
Cyclist, Black Clothing	417					X	X
Parallel Pedestrian, White Clothing	783						
Cyclist, White Clothing	790						
Perpendicular Pedestrian, White Clothing	828						
Static Pedestrian, White Clothing	842						

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

Table 29. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	217			X	X	X	X
Parallel Pedestrian, Black Clothing	296				X	X	X
Perpendicular Pedestrian, Black Clothing	298				X	X	X
Child's Bicycle	448					*	*
Cyclist, Black Clothing	465					X	X
Perpendicular Pedestrian, White Clothing	725						
Static Pedestrian, White Clothing	733						
Cyclist, White Clothing	757						
Parallel Pedestrian, White Clothing	858						

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

Table 30. Detection distances by type of object and potential detection inadequacy when compared to stopping distance at various speeds: HID.

Type of Object	Detection (ft)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	212			X	X	X	X
Perpendicular Pedestrian, Black Clothing	275			X	X	X	X
Parallel Pedestrian, Black Clothing	282				X	X	X
Child's Bicycle	417					*	*
Cyclist, Black Clothing	444					X	X
Cyclist, White Clothing	683						
Parallel Pedestrian, White Clothing	713						
Perpendicular Pedestrian, White Clothing	734						
Static Pedestrian, White Clothing	796						

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

Table 31. 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)	126 ft at 25 mi/h	197 ft at 35 mi/h	278 ft at 45 mi/h	370 ft at 55 mi/h	474 ft at 65 mi/h	529 ft at 70 mi/h
Tire Tread	177		X	X	X	X	X
Parallel Pedestrian, Black Clothing	302				X	X	X
Perpendicular Pedestrian, Black Clothing	326				X	X	X
Child's Bicycle	399					*	*
Cyclist, Black Clothing	494						X
Cyclist, White Clothing	721						
Parallel Pedestrian, White Clothing	744						
Perpendicular Pedestrian, White Clothing	778						
Static Pedestrian, White Clothing	805						

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

The literature review performed as part of the larger ENV project suggested that new headlamps (such as high intensity discharge, configurations supplemented by UV–A headlamps, and infrared thermal imaging systems) could be expected to outperform halogen headlamps (ENV Volume II). These expectations were not completely fulfilled.

As expected, the infrared technology allowed the detection of warm objects (i.e., pedestrians and cyclists) at distances of 201.2 to 292.3 m (660 to 959 ft), an improvement of more than 76.2 m (250 ft) beyond the halogen headlamps for dark-clothed perpendicular pedestrians. This improvement over HLB is consistent with results obtained by Barham et al.[9] Interestingly, the improvement obtained from infrared technology for pedestrians on the side of the road (e.g., a person on the side of the road waiting to cross the street, or static pedestrian) is not as dramatic: only 2.4 to 4 m (8 to 13 ft). It is possible that the size of the HUD does not allow for a sufficiently broad field of view. Participants tended to support this theory during interviews, with comments such as: "I thought that it kind of needed to be a little broader field. I felt like it cut down a little bit on my peripheral (vision)," referring to the image on the IR–TIS.

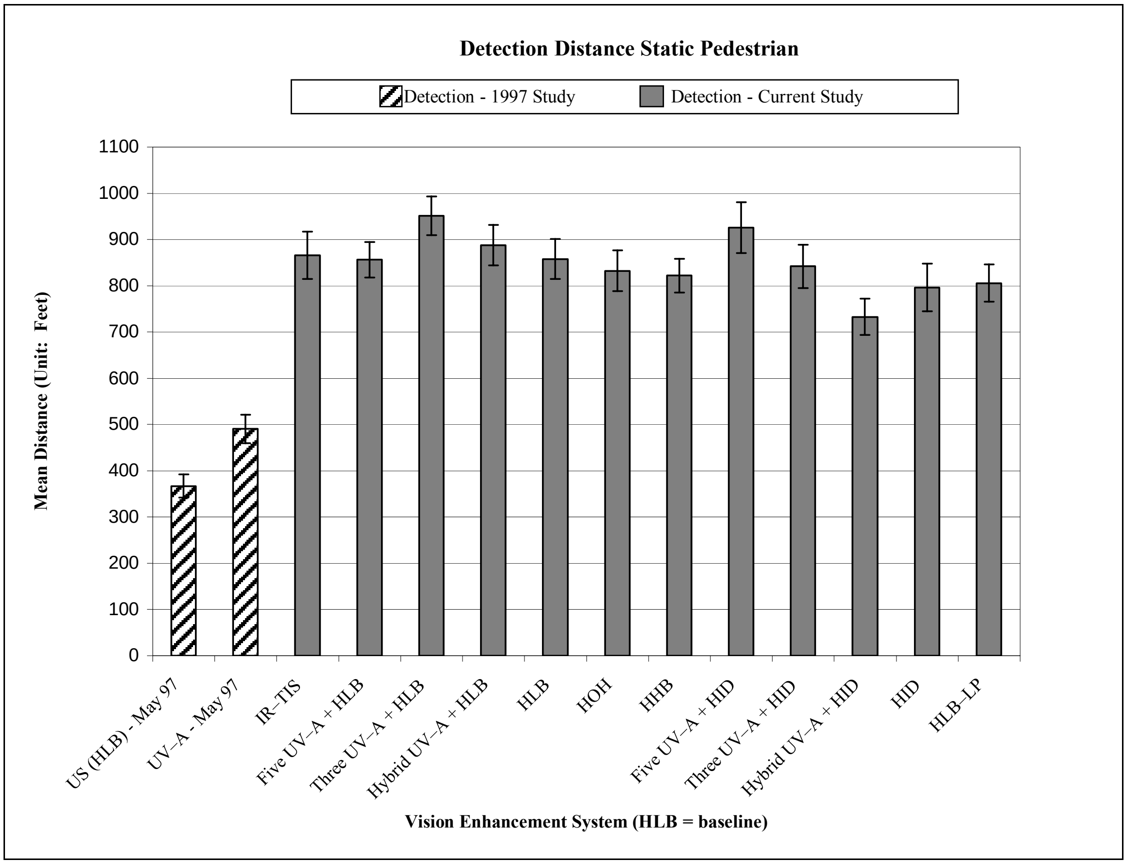
Jost suggested that HID systems should improve visibility distance by more than 50 percent compared to standard HLB systems.[27] The HID system used for this study did not perform up to this expectation. In fact, detection distances for the individual objects with this HID system were 8.5 to 54.9 m (28 to 180 ft) closer to the object that needed to be detected than were distances obtained using halogen headlamps. It is possible that the HID system tested here differed significantly in terms of cutoff and intensity from the HID systems tested in other investigations.

The characteristics of these systems vary considerably among manufacturers. While unpublished data generated by this investigation (refer to ENV Volume XVII) agree with Jost[27] that HIDs provided more luminous flux than regular halogen headlamps, the problem with the current HID system involves where the luminous flux is directed. The large amount of visible light generated by these systems requires a dramatic cutoff angle to comply with glare standards. While this provides more foreground luminance, less illumination is provided as the distance from the vehicle increases. This foreground luminance might affect driver performance by increasing the driver's light adaptation, thus decreasing the driver's capability to detect objects in dark environments.

Mahach et al.[28] and Nitzburg et al.[29] suggest that UV–A could improve visibility distances. This previous research on pedestrian visibility was performed in a static environment (i.e., the car's transmission was in the "park" position), and the participants were in the passenger side of the vehicle. Between detection and recognition trials, the vehicle moved in increments of 30.5 m (100 ft). A windshield shutter was used to limit the time available for visual search, and a 2-s stimulus exposure time was given for each trial (i.e., each time the vehicle moved 30.5 m (100 ft)). Results suggested improvements in visibility distances by more than 200 percent when UV–A detection distances were compared to halogen headlamp detection distances.

The current results dispute this finding; however, a comparison of similar trials from both studies can provide some information on the reasons for the apparent decrease in performance of UV–A technology in the current study. One reason why UV–A configurations did not result in a 200 percent improvement over HLB in this study might be that the halogen headlamp technology used was dramatically different from the one used in the Mahach et al.[28] study (figure 30). For example, the static pedestrian was a common object in Mahach et al.[28] and the current investigation. Note that static pedestrian detection distances obtained for Mahach's "HLB-May 97" were 191.4 and 176.2 m (628 and 578 ft) smaller for the HLB and HLB–LP systems, respectively, than the ones tested in this study. While an improvement in detection distance occurred with the UV–A technology used in the current study (compared to the UV–A technology used for the Mahach et al.[28] study), it was not large enough for the UV–A technology to maintain the advantage over the HLB and HID systems used in this study. Another possibility is that given the limited amount of environmental exposure time in the Mahach et al.

study (2-s window exposure every 30.5 m (100 ft)), those distances represent less of an absolute threshold, whereas the focus of the current investigation is to identify the exact distance that will produce detection during a dynamic condition.



1 ft = 0.305 m

Figure 30. Bar graph. Comparison of the results obtained for UV–A headlamps with previous research.

AGE EFFECTS ON DETECTION AND RECOGNITION DISTANCES

Depending on the VES, age was responsible for some of the variability in detection distances; however, this was not the case for recognition distances by VES, where the variability between age groups was not significant. On average, detection distances by VES for the younger drivers ranged from 168.6 to 223.1 m (553 to 732 ft), whereas detection distances for older drivers ranged from 137.5 to 179.8 m (451 to 590 ft). Across VESs, detection distances for the older drivers were consistently smaller than for the other age groups. The range of detection distances for middle-aged drivers was similar to distances for the younger drivers, 157 to 231 m (515 to

758 ft). These differences can be quantified in terms of a VES baseline (HLB, table 32), and in terms of the pair-wise differences between the three groups (table 33).

Table 32. Detection distances by age and VES: a comparison to HLB by age.

VES	Young (ft)	Middle (ft)	Older (ft)	Comparison to HLB: Young (ft)	Comparison to HLB: Middle (ft)	Comparison to HLB: Older (ft)
IR–TIS	732	758	566	102	150	−11
High UV–A + HLB	659	633	583	29	25	6
Three UV–A + HLB	633	637	587	3	30	10
Hybrid UV–A + HLB	640	620	590	10	13	13
HLB	630	608	577	0	0	0
HOH	601	572	525	−29	−36	−51
HHB	597	570	525	−33	−37	−52
Five UV–A + HID	607	557	511	−23	−51	−66
Three UV–A + HID	604	521	479	−26	−87	−98
Hybrid UV–A + HID	564	541	494	−66	−67	−82
HID	553	515	451	−77	−93	−126
HLB–LP	553	539	486	−77	−69	−91

1 ft = 0.305 m

Table 33. Detection distances by age and VES: a comparison between age groups.

VES	Young (ft)	Middle (ft)	Older (ft)	Comparison by Age: Young–Middle (ft)	Comparison by Age: Young–Older (ft)	Comparison by Age: Middle–Older (ft)
IR–TIS	732	758	566	−26	167	192
High UV–A + HLB	659	633	583	26	76	51
Three UV–A + HLB	633	637	587	−5	46	50
Hybrid UV–A + HLB	640	620	590	20	50	30
HLB	630	608	577	22	53	31
HOH	601	572	525	29	76	46
HHB	597	570	525	26	72	45
Five UV–A + HID	607	557	511	50	96	46
Three UV–A + HID	604	521	479	83	125	42
Hybrid UV–A + HID	564	541	494	23	70	47
HID	553	515	451	38	102	64
HLB–LP	553	539	486	14	67	53

1 ft = 0.305 m

The IR–TIS resulted in detection distances of more than 30.5 m (100 ft) longer than those obtained with the HLB for the younger and middle-aged groups. The detection distances for older drivers using the IR–TIS were the same as the distances obtained by this group using HLBs and only 24.1 m (79 ft) longer than the distances that this group obtained using HLB–LP. This difference between age groups might be the result of the information processing nature of the HUD task. Although all drivers were equally trained, older people in general take longer to retrieve information, and time-sharing among tasks tends to pose a greater informational demand.[30,31] In addition, HUD users risk cognitive capture, which might occur when there is inefficient switching of attention between the HUD and the external environment.[32,33] Inefficient switching is of paramount importance because it may result in missed external objects and delayed responses. It is possible that older drivers in this experiment were less efficient than those in the other two age groups at switching from the HUD to the task, or vice versa. Moreover, they might not have used the IR–TIS at all. Some drivers demonstrated concern about the time-sharing demand of the HUD during the interviews:

> "You felt like you had two things to look at. It's only a small image in front of you, but yet you have the entire picture on the windshield that you are trying to look at too, so you're afraid that if you just look at the image you might be missing something; it may not be broad enough to see something that's really out there, if you just looked at one or the other it would be a little bit different, but when you have the choice of looking at one or the other you feel like something may appear in the picture that you don't really see..." (Participant #42—middle-aged female)

> "…it is kind of down below and you don't know whether you should try to like drive with it, or look ahead and just kind of glance down there every once in a while. Or you should just look ahead and not use it, and just use if you see something flashing through there, then you look down at it… it was a little confusing to get used to; I mean I definitely think it's cool, but it was kind of down low and I kind of want to scrunch down to try to look through it." (Participant #37—younger male)

When the average detection distances for the three groups by VES configuration are compared to the stopping distances needed (table 19) for a highway-type environment (i.e., 105 km/h (65 mi/h)), the maximum stopping distance is close to the detection distance observed for older drivers when HIDs or HLB–LPs were used.

Age caused significant differences on detection and recognition distances depending on the type of object (table 34 and table 35). Older drivers appeared less capable of detecting and recognizing low-contrast objects than their younger counterparts. In fact, the ability of older drivers to detect and recognize pedestrians and cyclists with black clothing was reduced by 13 to 21 percent when compared to the abilities of the younger drivers. This difference in performance is likely the result of the decrease in visual acuity and contrast sensitivity that occurs with age. The decline generally begins slowly after 40, followed by an accelerated decline after 60.(2,3,5) This trend was observed between the various age groups in this investigation. Figure 31 shows participants' visual acuity, and figure 32 through figure 36 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.

Table 34. Detection distances by age and type of object.

Type of Object	Young (ft)	Middle (ft)	Older (ft)	Comparison by Age: Young–Middle (ft)	Comparison by Age: Young–Older (ft)	Comparison by Age: Middle–Older (ft)
Cyclist, White Clothing	901	797	763	104	138	34
Parallel Pedestrian, White Clothing	875	804	765	71	110	39
Perpendicular Pedestrian, White Clothing	881	853	754	29	127	98
Static Pedestrian, White Clothing	888	851	804	37	84	47
Cyclist, Black Clothing	550	557	479	−7	70	78
Parallel Pedestrian, Black Clothing	382	383	309	−1	73	74
Perpendicular Pedestrian, Black Clothing	391	400	316	−9	75	84
Child's Bicycle	454	440	388	15	66	51
Tire Tread	208	219	206	−11	2	13

1 ft = 0.305 m

Table 35. Recognition distances by age and type of object.

Type of Object	Young (ft)	Middle (ft)	Older (ft)	Comparison by Age: Young–Middle (ft)	Comparison by Age: Young–Older (ft)	Comparison by Age: Middle–Older (ft)
Cyclist, White Clothing	721	635	613	86	108	22
Parallel Pedestrian, White Clothing	777	693	673	84	104	20
Perpendicular Pedestrian, White Clothing	764	721	659	43	105	62
Static Pedestrian, White Clothing	795	716	705	78	90	11
Cyclist, Black Clothing	483	469	381	14	102	88
Parallel Pedestrian, Black Clothing	323	318	261	4	61	57
Perpendicular Pedestrian, Black Clothing	316	324	260	−8	56	64
Child's Bicycle	416	379	327	37	89	52
Tire Tread	173	178	164	−5	9	14

1 ft = 0.305 m

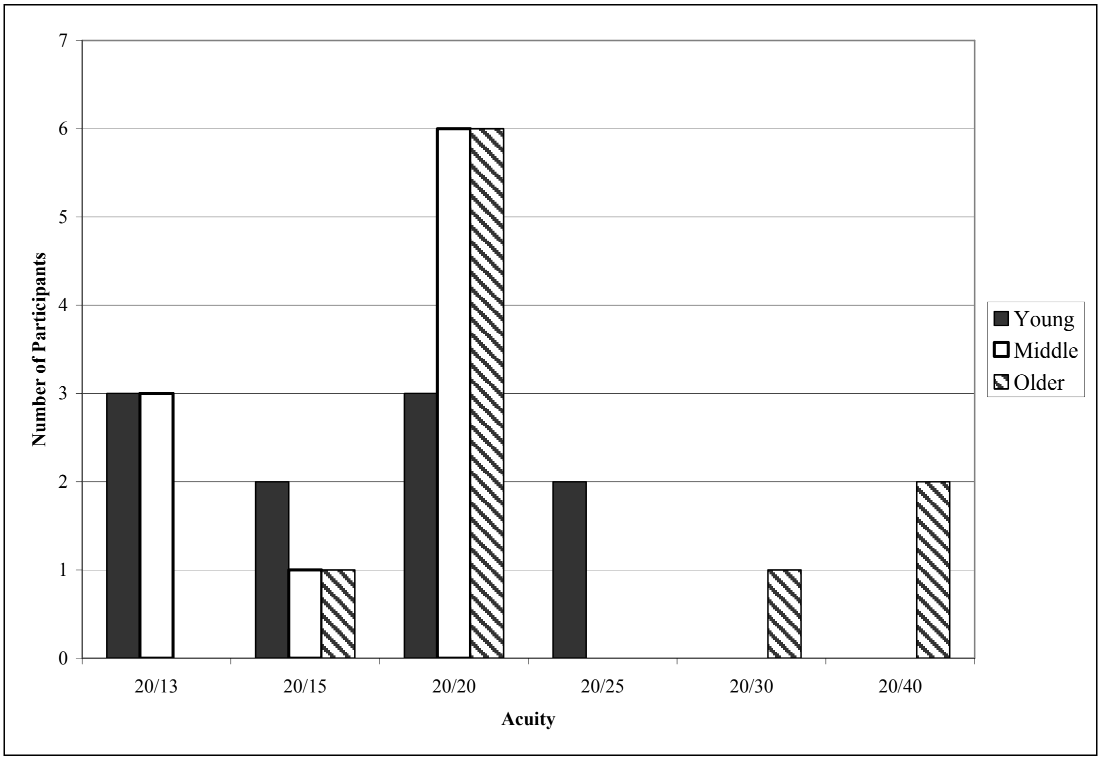


Figure 31. Bar graph. Participants' visual acuity divided by age group.

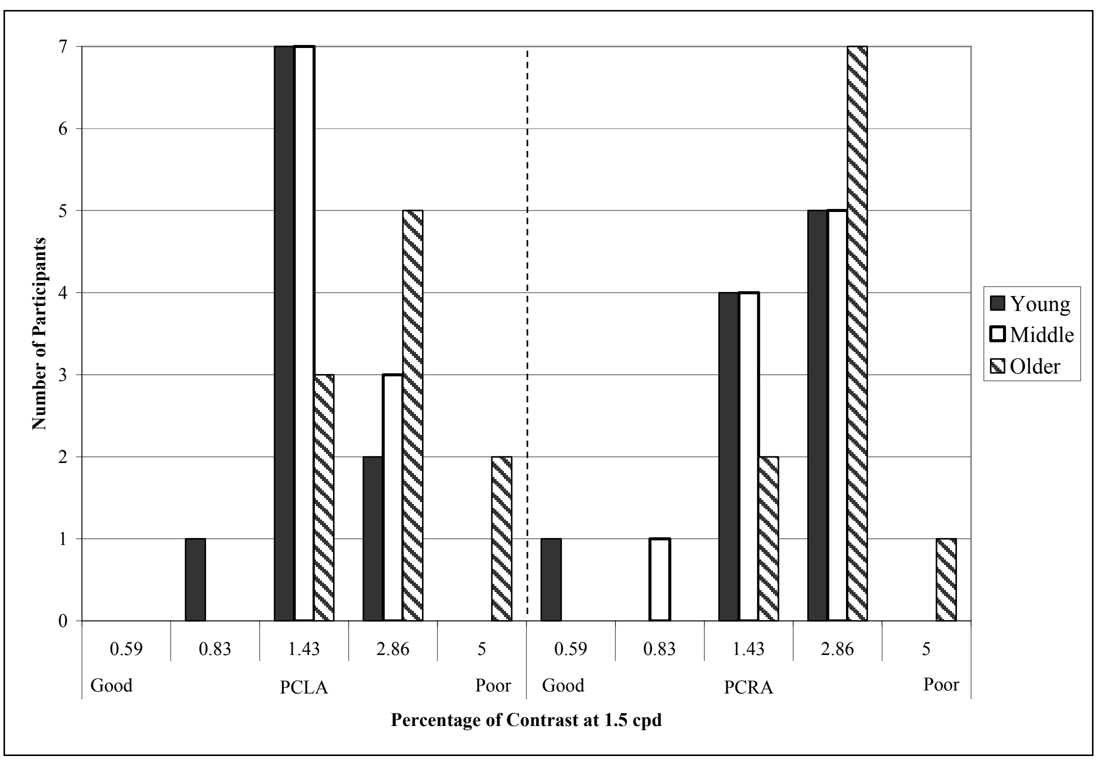


Figure 32. Bar graph. Participants' contrast sensitivity at 1.5 cpd (cycles per degree) divided by age group.

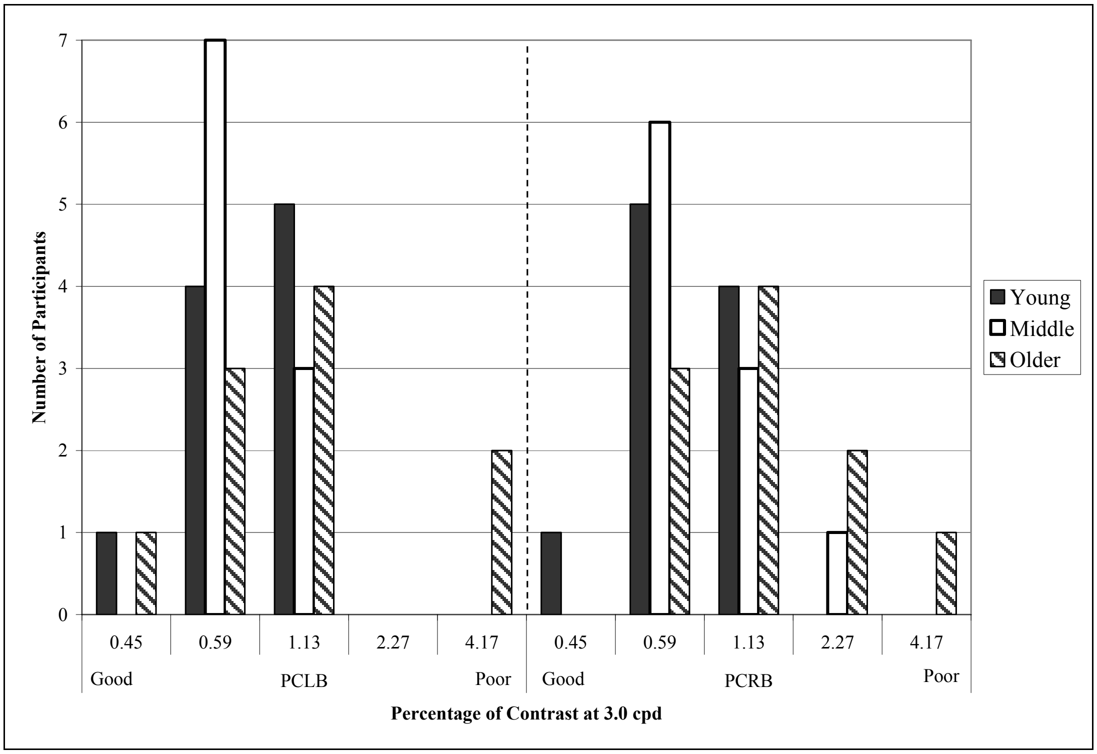


Figure 33. Bar graph. Participants' contrast sensitivity at 3.0 cpd divided by age group.

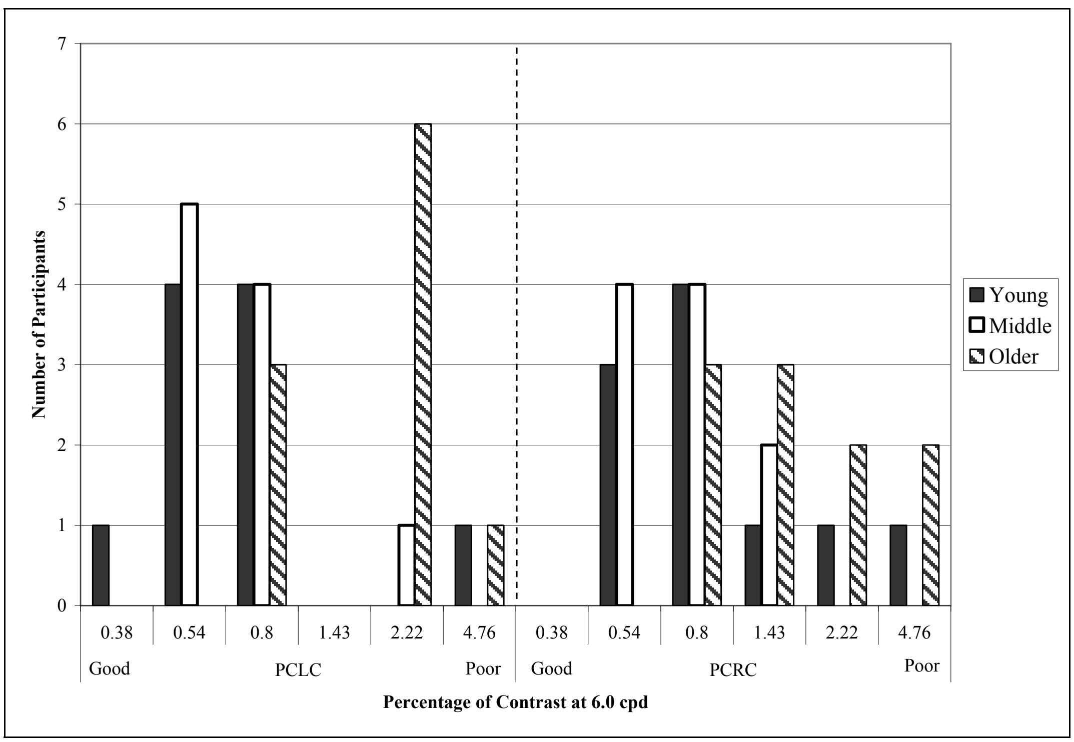


Figure 34. Bar graph. Participants' contrast sensitivity at 6.0 cpd divided by age group.

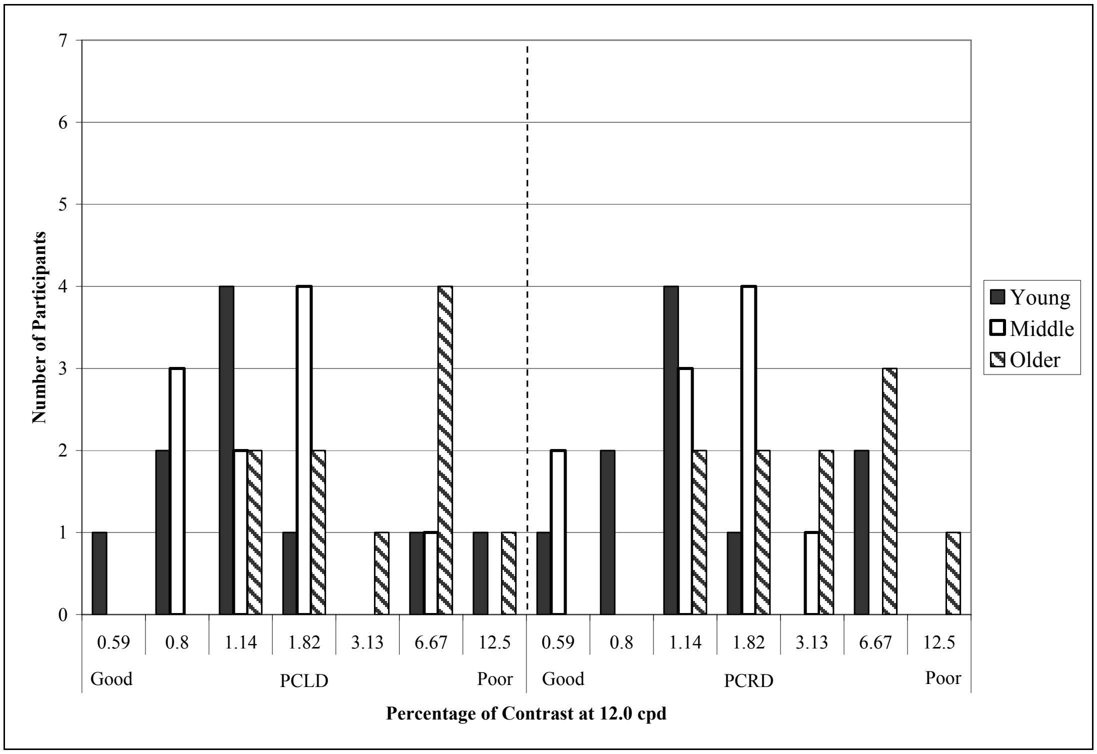


Figure 35. Bar graph. Participants' contrast sensitivity at 12.0 cpd divided by age group.

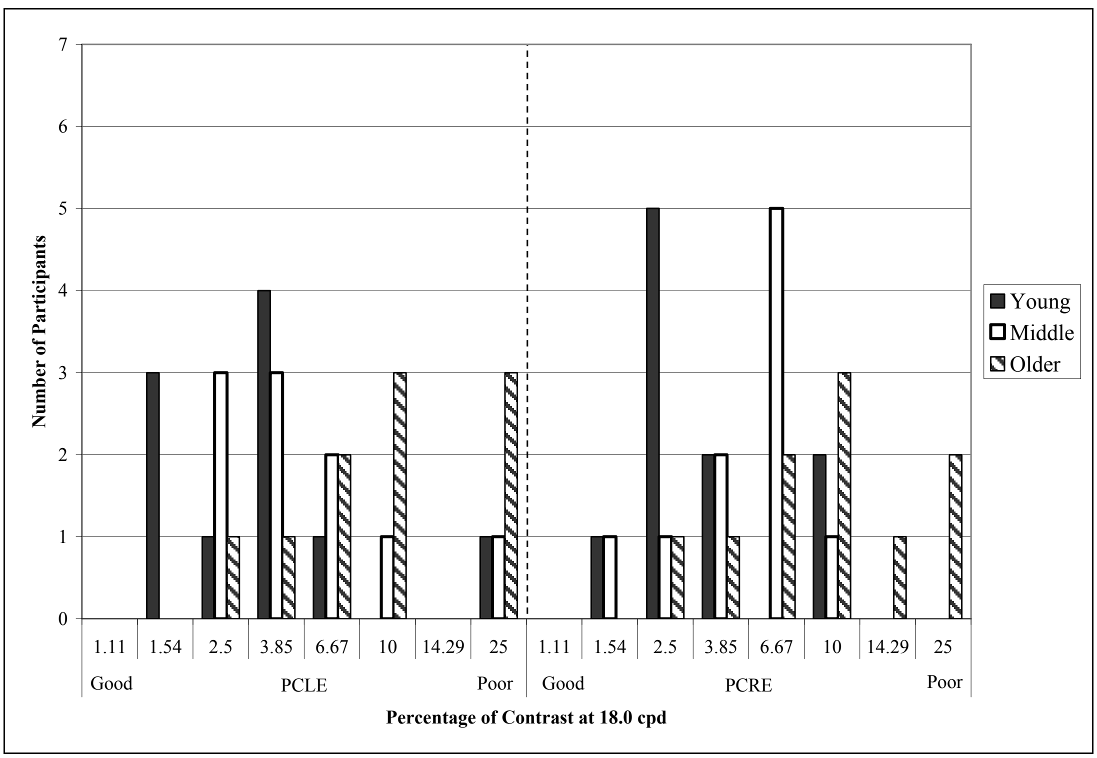


Figure 36. Bar graph. Participants' contrast sensitivity at 18.0 cpd divided by age group.

OBJECT EFFECT ON DETECTION AND RECOGNITION DISTANCES

Comparisons were made in Study 1 to determine whether VESs that show an increase in detection and recognition distances for pedestrians and cyclists also show the same trend for other objects such as the tire tread and the child's bicycle. HLB headlamps are used in this comparison as a baseline system. Table 36 and table 39 give the mean detection and recognition distances, respectively, for all VESs and objects. The top three detection and recognition distances for each object are highlighted in table 37, table 38, table 40, and table 41 (1st = green, *; 2nd = blue, **; 3rd = yellow, ***).

Table 36. Mean detection distances.

VES	Type of Object: Cyclist, Black Clothing (ft)	Parallel Pedestrian, Black Clothing (ft)	Perp. Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perp. Pedestrian, White Clothing (ft)	Static Pedestrian, White Clothing (ft)
IR–TIS	812	662	660	355	172	840	852	959	866
Five UV–A + HLB	569	395	382	469	220	928	895	911	856
Three UV–A + HLB	542	374	377	461	253	857	870	887	951
Hybrid UV–A + HLB	602	392	419	468	235	872	811	866	888
HLB	566	386	409	464	240	862	839	828	858
HOH	525	328	342	402	215	845	808	798	832
HHB	500	370	374	407	189	848	789	776	822
Five UV–A + HID	409	249	268	440	210	842	814	866	925
Three UV–A + HID	417	261	297	400	194	790	783	828	842
Hybrid UV–A + HID	465	296	298	448	217	757	858	725	733
HID	444	282	275	417	212	683	713	734	796
HLB–LP	494	302	326	399	177	721	744	778	805

1 ft = 0.305 m

Table 37. Detection distance difference between the different VES and HLB.

VES	Type of Object: Cyclist, Black Clothing (ft)	Parallel Pedestrian, Black Clothing (ft)	Perp. Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perp. Pedestrian, White Clothing (ft)	Static Pedestrian, White Clothing (ft)
IR–TIS	**246***	**277***	**251***	−109	−68	−22	13	**131***	8
Five UV–A + HLB	**4*****	**9****	−27	**5***	−20	**65***	**56***	**83****	−2
Three UV–A + HLB	−23	−12	−32	−3	**13***	−5	**31****	**59*****	**94***
Hybrid UV–A + HLB	**36****	**6*****	**10****	**4****	**−5*****	**9****	−28	38	**30*****
HLB	0	0	**0*****	**0*****	**0****	**0*****	0	0	0
HOH	−41	−58	−67	−62	−24	−18	−31	−30	−26
HHB	−66	−15	−35	−57	−50	−14	−50	−52	−36
Five UV–A + HID	−156	−136	−141	−24	−30	−21	−25	38	**68****
Three UV–A + HID	−149	−125	−112	−64	−46	−72	−56	0	−16
Hybrid UV–A + HID	−101	−90	−111	−16	−23	−105	**19*****	−103	−125
HID	−122	−104	−134	−47	−28	−179	−126	−94	−62
HLB–LP	−72	−84	−83	−65	−63	−141	−95	−50	−52

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

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

Type of Object

VES	Cyclist, Black Clothing (%)	Parallel Pedestrian, Black Clothing (%)	Perp. Pedestrian, Black Clothing (%)	Child's Bicycle (%)	Tire Tread (%)	Cyclist, White Clothing (%)	Parallel Pedestrian, White Clothing (%)	Perp. Pedestrian, White Clothing (%)	Static Pedestrian, White Clothing (%)
IR–TIS	**44***	**72***	**61***	−24	−28	−3	2	**16***	1
Five UV–A + HLB	**1*****	**2****	−7	**1***	−8	**8***	**7***	**10****	0
Three UV–A + HLB	−4	−3	−8	−1	**5***	−1	**4****	**7*****	**11***
Hybrid UV–A + HLB	**6****	**2*****	**3****	**1****	**−2*****	**1****	−3	5	**3*****
HLB	0	0	**0*****	**0*****	**0****	**0*****	0	0	0
HOH	−7	−15	−16	−13	−10	−2	−4	−4	−3
HHB	−12	−4	−9	−12	−21	−2	−6	−6	−4
Five UV–A + HID	−28	−35	−34	−5	−12	−2	−3	5	**8****
Three UV–A + HID	−26	−32	−27	−14	−19	−8	−7	0	−2
Hybrid UV–A + HID	−18	−23	−27	−3	−10	−12	**2*****	−12	−15
HID	−21	−27	−33	−10	−11	−21	−15	−11	−7
HLB–LP	−13	−22	−20	−14	−26	−16	−11	−6	−6

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

Table 39. Mean recognition distances.

Type of Object

VES	Cyclist, Black Clothing (ft)	Parallel Pedestrian, Black Clothing (ft)	Perp. Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perp. Pedestrian, White Clothing (ft)	Static Pedestrian, White Clothing (ft)
IR–TIS	526	495	522	305	136	673	696	774	769
Five UV–A + HLB	512	335	333	419	186	755	814	798	761
Three UV–A + HLB	486	331	317	420	195	674	742	768	825
Hybrid UV–A + HLB	531	347	333	403	201	706	726	769	797
HLB	491	336	331	412	203	728	762	722	729
HOH	458	277	290	366	167	676	709	706	733
HHB	440	317	308	356	154	691	697	669	726
Five UV–A + HID	344	210	212	365	172	639	699	718	782
Three UV–A + HID	338	223	228	343	150	619	682	710	716
Hybrid UV–A + HID	409	243	244	393	182	622	746	640	641
HID	390	232	230	355	169	502	626	631	673
HLB–LP	407	264	253	348	145	592	673	670	715

1 ft = 0.305 m

Table 40. Recognition distance difference between the different VESs and HLB.

Type of Object

VES	Cyclist, Black Clothing (ft)	Parallel Pedestrian, Black Clothing (ft)	Perp. Pedestrian, Black Clothing (ft)	Child's Bicycle (ft)	Tire Tread (ft)	Cyclist, White Clothing (ft)	Parallel Pedestrian, White Clothing (ft)	Perp. Pedestrian, White Clothing (ft)	Static Pedestrian, White Clothing (ft)
IR–TIS	**35****	**160***	**190***	−107	−67	−56	−67	**52****	39
Five UV–A + HLB	**21*****	−1	**2*****	**7****	−17	**27***	**52***	**76***	31
Three UV–A + HLB	−5	−5	−15	**8***	**−7*****	−54	−21	46	**96***
Hybrid UV–A + HLB	**40***	**11****	**2****	−9	**−1****	**−22*****	−36	**46*****	**68****
HLB	0	**0*****	0	**0*****	**0***	**0****	**0****	0	0
HOH	−33	−59	−41	−46	−35	−52	−53	−16	4
HHB	−51	−18	−23	−56	−49	−37	−66	−53	−4
Five UV–A + HID	−147	−126	−120	−47	−31	−89	−63	−4	**53*****
Three UV–A + HID	−153	−113	−104	−69	−52	−109	−81	−12	−14
Hybrid UV–A + HID	−82	−92	−87	−19	−20	−106	**−16*****	−83	−89
HID	−101	−104	−102	−57	−33	−226	−136	−91	−56
HLB–LP	−83	−71	−78	−64	−57	−136	−90	−52	−14

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

1 ft = 0.305 m

Table 41. Percentage of difference between the different VES and HLB.

VES	Cyclist, Black Clothing (%)	Parallel Pedestrian, Black Clothing (%)	Perp. Pedestrian, Black Clothing (%)	Child's Bicycle (%)	Tire Tread (%)	Cyclist, White Clothing (%)	Parallel Pedestrian, White Clothing (%)	Perp. Pedestrian, White Clothing (%)	Static Pedestrian, White Clothing (%)
IR–TIS	**7****	**48***	**57***	−26	−33	−8	−9	**7****	5
Five UV–A + HLB	**4*****	0	**1*****	**2****	−8	**4***	**7***	**10***	4
Three UV–A + HLB	−1	−1	−4	**2***	**−4*****	−7	−3	6	**13***
Hybrid UV–A + HLB	**8***	**3****	**1****	−2	**−1****	**−3*****	−5	**6*****	**9****
HLB	0	**0*****	0	**0*****	**0***	**0****	**0****	0	0
HOH	−7	−18	−12	−11	−17	−7	−7	−2	0
HHB	−10	−5	−7	−14	−24	−5	−9	−7	0
Five UV–A + HID	−30	−37	−36	−11	−15	−12	−8	−1	**7*****
Three UV–A + HID	−31	−34	−31	−17	−26	−15	−11	−2	−2
Hybrid UV–A + HID	−17	−28	−26	−5	−10	−15	**−2*****	−11	−12
HID	−21	−31	−31	−14	−16	−31	−18	−13	−8
HLB–LP	−17	−21	−24	−15	−28	−19	−12	−7	−2

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

While no single VES was superior across all objects, HLB and HLB with UV–A consistently provided the driver with the one of the top (farther away from the object) detection and recognition distances across all objects in clear weather conditions. The best VES for the detection of pedestrians and cyclists with black (low contrast) clothing (i.e., IR–TIS) did not perform as well for objects at ground level (i.e., tire tread and the child's bicycle). For pedestrians in white clothing, the IR–TIS allowed early detection of pedestrians in front of the vehicle path (i.e., perpendicular pedestrian in white clothing), but not those on the side of the road (i.e., static pedestrian in white clothing and parallel pedestrian in white clothing). This effect is probably the result of the system's limited field of view (limited size of the screen). The small screen required by the HUD application limits the amount of information that can be displayed while maintaining an acceptable level of resolution.

HLB, by itself or supplemented by UV–A, always placed either first or second across all different objects in both detection and recognition. The additional effect of UV–A was relatively small for pedestrians and nonmotorists with black clothing (i.e., less than 7 percent detection increase over HLB). However, HLB supplemented with the UV–A headlamps represented up to an 11 percent (i.e., 28.7 m (94 ft)) increase in detection distance and a 13 percent (i.e., 29.3 m (96 ft)) increase in recognition distances over HLB for pedestrians and nonmotorists with white clothing. Two of the UV–A supplemented HID configurations performed well for detection and recognition of high contrast objects on the side of the road (i.e., static and parallel pedestrians with white clothing). This result was not surprising because the HID headlamp beam pattern had increased illumination toward the driver's right side, the same spot in the road where these pedestrians were positioned. While HLB and HLB supplemented by UV–A were always in the first three positions (best) for both detection and recognition, the rankings were modified in some instances. For example, IR–TIS was the best for detecting the black-clothed cyclist and white-clothed perpendicular pedestrian, but it was not the best for recognition of these objects.

Several interesting aspects are found when the detection distance obtained with the IR–TIS for pedestrians with white (high contrast) versus black (low contrast) clothing is compared (table 36). Pedestrians dressed with dark clothing were not detected by the driver as far away as the ones with high contrast clothing. Pedestrians with dark clothing were detected more than 57.9 m (190 ft) closer than the ones with white clothing. This could be because some drivers are trying to find additional visual cues from the windshield (in addition to the IR–TIS image) that cannot be captured beyond 243.8 m (800 ft) due to the low contrast of the object. However, even for low contrast objects, their detection increased by more than 60 percent of the distances at which the objects can be detected with just halogen headlamps.

In summary, during the clear weather condition, no VES is consistently the best in facilitating long detection and recognition distances. In addition, both the HLB and HID baseline headlamps indicated little benefit from the additional UV–A sources, although the aiming protocol used for this study likely increased detection and recognition distances for the mechanically aimed HLB headlamps. The following conclusions can be reached regarding Study 1 of Phase II:

- IR–TIS is the best configuration for detecting pedestrians and cyclists with black clothing.
- Halogen and HID headlamps supplemented with UV–A were better configurations for detecting pedestrians and cyclists with white clothing than the halogen and HID headlamps alone.
- UV–A technology does not represent a dramatic improvement over the halogen and HID used in this research.
- Halogen and HID are the best configurations for detecting all other types of objects.
- Clothing contrast, rather than object motion, appears to be responsible for the differences observed between the detection of different types of pedestrians and nonmotorists.

APPENDIX A—SCREENING QUESTIONNAIRE

Driver Screening and Demographic Questionnaire: ENV-Clear

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 25 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 25 miles per hour (this will be maintained for all three studies) and to maintain a 200-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 25 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: __________

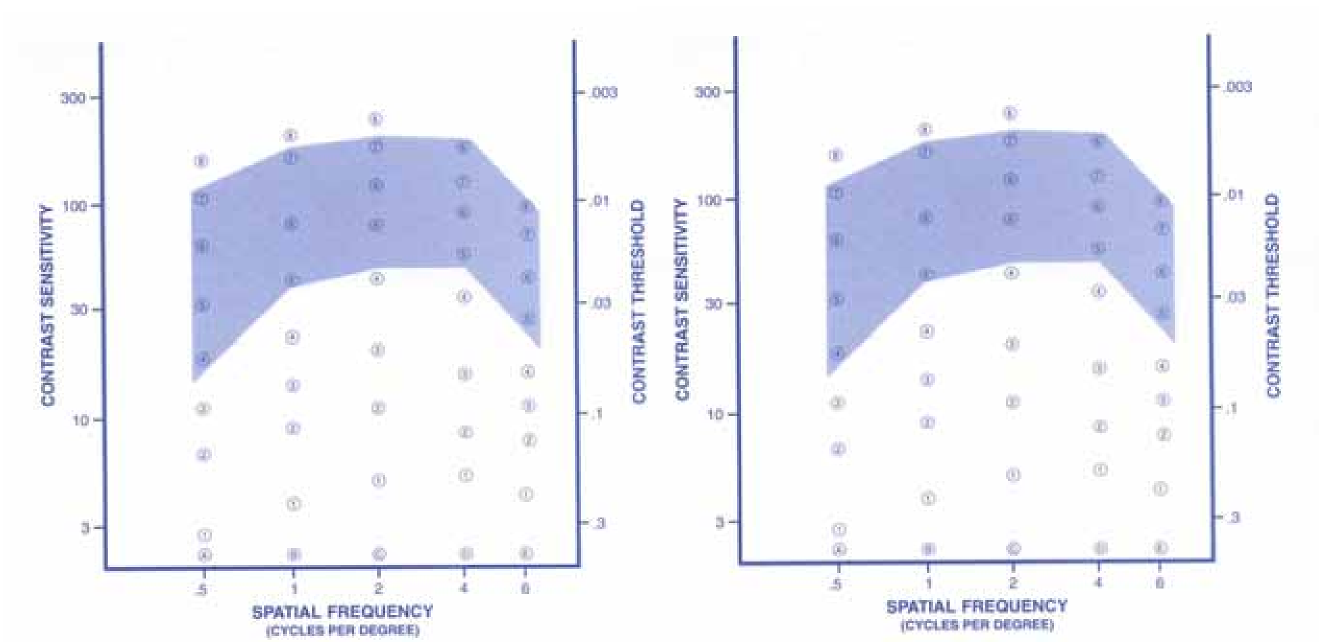
VISION TESTS

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. 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. 25 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 ___ 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.*

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?*****

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

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

12. 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.

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

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

15. 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.

*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
  - Night 1; 15 mph in gravel lot, 25 mph on paved road
  - Night 2; 25 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, verbally 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: You will be asked to recognize that the object is a pedestrian. The pedestrian will be either along the road 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 questionnaire

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, lights 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.*

4. Instruct the driver to drive to the Smart Road.
    - Have them stop before the gate in the right lane.
    - Radio the control room, ask for the gate to be opened and tell them the number of cars entering the road.
5. Proceed to the parking spots at the top of the first turnaround.
    - The first vehicle will always park on the left side of the road at the cone.
    - The second vehicle will always park on the right side of the road at the cone.
6. Review instructions with participant (This may be done while driving down the road or while parked at the first turn around.).

    - **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 identify the object verbally at the same time.

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

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

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

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

8. Orient participant to Smart Road.

First we will drive down the road to get you used to the road and the vehicle. Go ahead and drive down the road at 25 miles per hour.

- Allow the participant to drive down 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 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

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.

9. Let drivers do a practice run up the Smart Road.

We will now practice while you drive up the hill to help you get used to driving the vehicle on the Smart Road and using the push buttons. I would like you to drive up the road at 25 miles per hour.

- Remind the participant how to recognize the different objects.

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

"I see a Kids Bike"
"I see a Pedestrian"
"I see a Tire Tread"

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

10. Set up the computer at the second turn around if you haven't already done so.

    - Enter in 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":

Sedan	1318
Black SUV	660
White SUV	660
Pickup	46

    - Start the data collection when you are parallel with the guardrail at the bottom turn around:
    - 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.

11. Document any unexpected events that occurred during the previous run.
    - See "Documentation Instructions."

12. Prepare for the first VES.
    - Make sure you are in the correct vehicle, using your VES order.
    - Select the proper VES and Order on the computer using the commands listed in step 10.
    - Let the valet check the headlamps.
    - Wait for the OK from the onroad experimenters.
    - Continue down the road.

13. Start data collection for first VES when you are parallel with the "Do Not Enter" Sign.

14. 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 read out to determine when the vehicle is within 200 feet of cyclist. Tell the cyclist to clear at that time.

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

16. Bring participants back to the building.
    - Have both participants and both experimenters get in the Sedan.

- One experimenter will drive all four back to the building.

Document time on participant's debriefing sheet.

17. Remind participants of their next scheduled drive**.**

Night 2

Protocol is very similar to Night 1.

- Follow Steps 1 through 7.
- Skip the orientation run.
- Skip the practice run.
- Set up the computer at the top of the road at first turn around.
- Wait for Onroad to Radio that they are ready.
- Collect data using the protocol from Night 1.
- Take drivers back to the building in the Sedan.
- Complete the hours/amount paid section of debriefing form.
- Ask drivers to fill out the payment receipt log.
- Pay the driver and thank him/her for his/her participation.

APPENDIX G—SMART ROAD

Figure 37. Photo. Aerial view of the Smart Road.

The Virginia Smart Road (figure 37) 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. ___________________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

1. General Policies

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

- Drive in a safe manner at all times. This means observing the 25 mile-per-hour speed limit on the road.
- Use a spotter when moving vehicles in and out of the Simulator Bay.
- 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.
- Always drive with your lights on.
- If it's broken, tell someone.
- Attend the nightly meeting.
- Minimize communications on Channel 3.
- Acknowledge all messages you receive.

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 someone immediately as it is crucial to the study, or as soon as it's 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 in the Prep Room (put your name next to it in case we might need further details).

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 from the Subject Prep Room 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 by missed by either valet).
- Valets need to get vests from the Asphalt Lab 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 up large bikes, kid bikes, and tire treads into Pickup.
- Load boxes, cones, and tarps into SUVs.
- 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 the road.
- Cover up the Road Closed signs at the end of the road (SUVs).
- Unload large bikes, kid bikes, and tire treads at each station (Pickup).
- Unload boxes at each station (SUVs).
- Each night you will be assigned one of the following locations:
    - Station 1, 5
    - Station 2, 4
    - Station 3
    - Station 6

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, 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 dark and fluorescent bike (except for station #6).

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.
As soon as the participants are on the road, the following radio rules will begin:

- 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.
- 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 down the hill. During this time onroad experimenters are to remain hidden. However, on the way up the hill, the following stations will need to put out objects:

Station 4	*Child's Bike*
Station 5	*Static Pedestrian—White Clothing*
Station 6	*Tire Tread*

All stations are to report to Station 2-4 when they are ready using channel 2. Then Station 2-4 is responsible for telling the in-car experimenters when they can proceed onto the road. Below is a table of the objects along with placement locations.

OBJECT	LOCATION	SPECIAL INSTRUCTIONS
Parallel pedestrian-black clothing	Shoulder side of white line.	Wear black clothing. Walk 10 paces along shoulder line toward oncoming vehicle, then walk backward ten paces. Repeat.
Parallel pedestrian-white clothing	Shoulder side of white line.	Wear white clothing. Walk 10 paces along shoulder line toward oncoming vehicle, then walk backward ten paces. Repeat.
Perpendicular pedestrian-black clothing	Straight (perpendicular) line between white line and center line.	Wear black clothing. Walk to center line, then walk backward to white line. Repeat.
Perpendicular pedestrian-white clothing	Straight (perpendicular) line between white line and center line.	Wear white clothing. Walk to center line, then walk backward to white line. Repeat.
Cyclist-black clothing	Between white lines in front of station	Wear black clothing. Ride bike in circles across the road, from white line to opposite white line.
Cyclist-white clothing	Between white lines in front of station	Wear white clothing. Ride bike in circles across the road, from white line to opposite white line.
Static pedestrian-white clothing	Centered on white line.	Wear white clothing. Stand facing traffic.
Tire tread	Centered on white line.	None.
Child’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 2nd 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 200 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, safety devices will be placed 200 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 shoulder. This will allow the in-vehicle experimenters to record the distances of detection and recognition on the distance measuring devices.
- This methodology will be repeated for all 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.
- Night One: After the participants have completed their Practice Lap and first VES, show them to their next vehicle.
- 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.

- The first parking space on each side of the road is termed a "vehicle drop off" and needs to be available at the end of every lap. The valets will move any vehicle that is left in those locations to the forward most position on either the right or left side of the road.
- Whenever possible, the first driver that returns to the top 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 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 checklist 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 _________.
- Check the gas level of each vehicle. If it is below ¼ of a tank write a note at end of prep sheet.
- Return SUVs to the Simulator Bay.
- Note any vehicle problems on the vehicle preparation sheets, and then write them down on the message board in the prep room once you return to _________.
- Make sure all the doors are locked and the garage door is closed.
- Return the radios (personal and in-vehicle) to the Subject Prep Room.
- Put away scrubs.
- 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 ¼ - 1 ½ hours as a general rule. Alignment times will be greater on days when headlamps must be moved.
- Turn on the ventilation fans in the garage 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&2), BLK HID (1&2)
- WH HLB (1&2), BLK HLB (1&2)
- P/U HOH(HHB) (1&2)

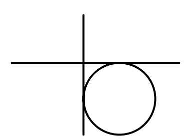
- Pull the vehicle up to the alignment plate mounted onto the ground. This should be located 35 feet from the alignment wall. Make sure the wheels are straight against the plate.
- Use the laser to make sure the screen is centered to the vehicle. Each vehicle has a different line on the screen. The lines 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 <u>do not</u> 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 center line 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 International Light, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a "REG" label, and the sensor for the UV light is marked with a "UV–A" label. Use the sensor marked "REG."

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

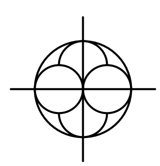
Applies to the following Vehicle/Headlamp combinations*:*

- WH MID/HI UV–A (1-5)
- BLK LO UV–A (1&2)

- Pull the vehicle up to the alignment plate on the ground. This should be located 35 feet 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 International Light, Inc., IL1400A Radiometer/Photometer to measure the area of greatest intensity. There are two sensors for the photometer; the sensor for the visible light is marked with a "REG" label, and the sensor for the UV light is marked with a "UV–A" label. For UV–A light, use the photometer sensor marked "UV–A."

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: You look at this table as you look at the wall for calibration; it’s 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 μW/cm^2	92.0 μW/cm^2

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

HEADLAMP ALIGNMENT FORM

Date:_______________
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: You look at this table as you look at the wall for calibration; it's 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 $\mu W/cm^2$ Actual:	92.0 $\mu W/cm^2$ Actual:

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

APPENDIX K—VALET PROTOCOL

VALET PROTOCOL FOR ENV OBJECTS

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
- 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
- Check that all the materials needed are in the blue boxes and that flashlights all work
- Get vests for all the onroad crew

3. Assist onroad crew with setting up the road and drop them off at their stations.

4. Be sure to be wearing a vest at all times.

5. Park vehicles at the top turnaround.

6. Make sure that radios are on.

7. Valets should have a radio on channel 2 and a radio on channel 3

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

9. Wait for drivers to arrive at the first turnaround.

10. First night: Drivers will do a practice lap.
Second Night: Drivers will stop so Valets can confirm that the proper headlamps are on.
Make sure to wear your safety glasses.

11. Wait at the top turn around and prepare for the vehicles to return.
- The first parking space on each side is termed a "vehicle drop off" and needs to be available at the end of every lap. The valets will move any vehicle that is left in those locations to the forward most parking spots.
- Whenever possible, the first driver that returns to the top 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 vehicle will be used next and which parking spots should be used to ensure that the drivers' wait-time is minimized.

Basic Duties of a Valet

1. Show drivers to their next vehicle as per the experimenter sheet.

- Wait for vehicle to come to a complete stop before approaching it.
- Ask the participant to turn off the vehicle and to hand you keys.
- Turn off lights.
- 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.
- Lead/Guide participant from one vehicle to the next by shining the flashlight on the road in front of them.
- 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.

- See Vehicle Orientation Sheet.
- If they have been in the vehicle before, ask them if they remember the controls. Be sure to offer to answer questions.
- 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 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).
- Pick up Onroad Crew and return to the building for a break
- Change the following radio batteries prior to returning to the road
    - ❑ 2 in-vehicle radios
    - ❑ 2 radios from station 2/4
    - ❑ 1 radio from station 1/5 (the one used for channel 2)
    - ❑ 1 radio from station 3 (the one used for channel 2)

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

7. Shutdown procedures:
- Assist Onroad with gathering all items from the road
- Put away dirty scrubs
- 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

- This one 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.

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.

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.

REFERENCES

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

11. Lunenfeld, H., & Stephens, B.W. (1991). “Human Factors Consideration in the Development of an IVHS System: Night Vision Enhancement.” *ITE 1991 Compendium of Technical Papers*, 120–124.

12. Nilsson, L., & Alm, H. (1996) “Effect of a Vision Enhancement System on Drivers’ Ability to Drive Safely in Fog.” In A.G. Gale (Ed.), *Vision in Vehicles V* (pp. 263–271). Amsterdam: North-Holland/Elsevier.

13. Stahl, A., Oxley, P., Berntman, M., & Lind, L. (1998). “The Use of Vision Enhancements to Assist Elderly Drivers.” Paper presented at Premier Congres Mondial sur les Application Telematiques aux Transports, Paris, France.

14. Calderas, J., personal communication, August 22, 2000.

15. Erion, J., personal communication, June 5, 2000.

16. Dutke, F.F., personal communication, June 20, 2000.

17. Schnell, T., personal communication, August 24, 2000.

18. Winer, B.J., Brown, D.R., & Michels, K.M. (1991). *Statistical Principles in Experimental Design*. New York, NY: McGraw-Hill, Inc., 140–197.

19. Uno, H., & Hiramatsu, K. (2001). “Collision Avoidance Capabilities of Older Drivers and Improvement by Warning Presentations.” *Proceedings—17th International Technical Conference on the Enhanced Safety of Vehicles*. (CD paper # 185).

20. van der Horst, R., & Hogema, J. (1993). “Time-to-Collision and Collision Avoidance Systems.” In proceedings of The 6th Workshop of the International Cooperation on Theories and Concepts in Traffic Safety, 15–22.

21. Jones, E.R., & Childers, R.L. (1993). *Contemporary College Physics* (2nd Edition). New York, NY: Addison-Wesley.

22. American Association of State Highway and Transportation Officials (2001). *A Policy on Geometric Design of Highways and Streets*. Washington, DC: AASHTO.

23. Chang, M.S., Messer, C.J., & Santiago, A.J. (1985). “Timing Traffic Signal Change Interval Based on Driver Behavior.” *Transportation Research Record, 1027,* 20–30.

24. Sivak, M., Olson, P.L., & Farmer, K.M. (1982). “Radar Measured Reaction Time of Unalerted Drivers to Brake Signal.” *Perceptual Motor Skills, 55,* 594.

25. Taoka, G.T. (1989). “Brake Reaction Time of Unalerted Drivers.” *Institute of Transportation Engineers (ITE) Journal, 59*(3), 19–21.

26. Lindeburg, M.R. (1992). *Civil Engineering Reference Manual* (6th edition). Belmont, CA: Professional Publications, Inc.
27. Jost, K. (1995). “High-Intensity Discharge Lamp.” *Automotive Engineering, 11,* 38–42.
28. Mahach, K.R., Knoblauch, R.L., Simmons, C.J., Nitzburg, M., Arens, J., & Tignor, S.C. (1997). *A Preliminary Field Evaluation of Ultraviolet-Activated Fluorescent Roadway Delineation* (Technical Report FHWA-RD-97-082). Washington, DC: U.S. Department of Transportation, Federal Highway Administration.
29. Nitzburg, M., Seifert, R., Knoblauch, R., & Turner, D. (1998). *A Safety Evaluation of UVA Vehicle Headlights* (Tech. Report DTFH61-95-00093). McLean, VA: Federal Highway Administration.
30. Czaja, S. (1988). “Microcomputers and the Elderly.” In M. Halender (Ed.), *Handbook of Human Computer Interaction* (pp. 581–598). Amsterdam: North-Holland.
31. Welford, A.T. (1981). “Signal, Noise, Performance, and Age.” *Human Factors, 31*(1), 97–109.
32. Gish, K.W., & Staplin, L. (1995). *Human Factors Aspects of Using Head-Up Displays in Automobiles: A Review of the Literature* (Report DOT HS 808 320). Washington, DC: National Highway Traffic Safety Administration.
33. Tufano, D.R. (1997). “Automotive HUDs: The Overlooked Safety Issues.” *Human Factors, 39*(2), 303–311.