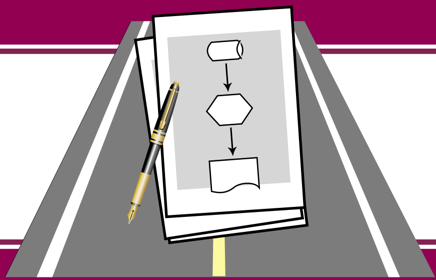

Volume XVIII

Enhanced Night Visibility Series: Overview of Phase III

PUBLICATION NO. FHWA-HRT-04-149

DECEMBER 2005

U.S. Department of Transportation

Federal Highway Administration

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

FOREWORD

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

The following document provides an overview of the series of studies conducted under Phase III of the Enhanced Night Visibility (ENV) project. The ENV project provided a comprehensive evaluation of evolving and proposed headlamp technologies in 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 XVIII. It is anticipated that the reader will select those volumes that provide information of specific interest.

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

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

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-04-149	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Enhanced Night Visibility Series Volume XVIII: Overview of Phase III		5. Report Date December 2005 6. Performing Organization Code:
7. Author(s) Jonathan M. Hankey, Shane B. McLaughlin, Ronald B. Gibbons, Vicki H. Williams, Jason Clark, Thomas A. Dingus		8. Performing Organization Report No.
9. Performing Organization Name and Address Virginia Tech Transportation Institute 3500 Transportation Research Plaza Blacksburg, VA 24061		10. Work Unit No. 11. Contract or Grant No. DTFH61-98-C-00049
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code HRDS-05
15. Supplementary Notes Contracting Officer's Technical Representative (COTR): Carl Andersen, HRDS-05		

16. Abstract

This volume provides an overview of the three studies that compose Phase III of the Enhanced Night Visibility project. The first study compared two prototype near infrared (NIR) vision enhancement systems (VESs), an infrared thermal imaging system (IR–TIS), and three headlamp-only systems in terms of drivers' nighttime detection and recognition of 17 objects. The objects included pedestrians on both sides of straight and curved sections of the road, roadway signs, and obstacles. A subset of the VESs and objects also were tested in rain conditions. The results indicated that both NIR and IR–TIS, if correctly implemented, provided additional detection benefit over headlamps alone for pedestrians in clear conditions. In rain conditions, the NIR also benefited object detection. A disability and discomfort glare study was also conducted with four high intensity discharge lamps and one halogen low-beam lamp. The results indicated that maximum illumination was the best predictor of driver discomfort and disability.

17. Key Words Detection, Disability Glare, Discomfort Glare, Halogen, Headlamp, High Intensity Discharge, Illuminance, Infrared, Night Vision, Pedestrian, Rain, Recognition, Visibility, Vision Enhancement System	18. Distribution Statement No restrictions. This document is available through the National Technical Information Service; Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 27	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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

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

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LIST OF ACRONYMS AND ABBREVIATIONS

General Terms

ENV ....Enhanced Night Visibility
FOV..................................field of view
HHD.................................high head down
HUD.................................heads-up display
IR.......................................infrared
RRPM ....raised retroreflective pavement marking
SUV..................................sport utility vehicle
VES..................................vision enhancement system
UV–A...............................ultraviolet A (wavelength 315 to 400 nanometers)

Vision Enhancement Systems

IR–TIS..............................infrared thermal imaging system
HLB..................................halogen (i.e., tungsten-halogen) low-beam
HID ....high intensity discharge
NIR...................................near infrared vision system

Measurements

ft.......................................feet
km/h ....kilometers per hour
lx ....lux
m ....meters
mi/h ....miles per hour

CHAPTER 1—INTRODUCTION TO PHASE III

Phase III was the final part of the three-phase Enhanced Night Visibility (ENV) project, whose initial goal was to study supplemental ultraviolet band A (UV–A) headlamps and supporting infrastructure to improve night visibility. The results of ENV Phase II indicated that UV–A is not a viable technology for automotive implementation in the foreseeable future. Infrared (IR) technology, however, did show some promise in Phase II as a viable supplemental vision enhancement system (VES) for automobiles. Given these two findings, the Phase III effort was refocused from testing UV–A headlamps on public roads to testing other promising alternative vision enhancement systems, including IR technology, on the Virginia Smart Road. The refocused Phase III effort was driven by the fundamental objective to evaluate methods with the potential to improve visibility of the road environment.

The Phase III effort included two studies that evaluated the performance of near IR (NIR) systems, an IR thermal imaging system (IR–TIS), high intensity discharge (HID) headlamps, and halogen headlamps at night in clear weather and rain, respectively. The primary dependent measures for these visual performance studies were detection and recognition distances of signs, pavement arrows, road debris, and pedestrians in multiple locations on the road. Some pedestrians were positioned away from the edge of the road to determine potential benefit of the additional roadside illumination provided by some HIDs. A third study assessed discomfort and disability glare for the halogen baseline and HID baseline VESs used in Phase II and three HID VESs. A subsequent analysis was performed to characterize the luminance of the objects with each VES included in the visual performance studies. The following four volumes fully detail Phase III:

- Volume XIII: Enhanced Night Visibility Series: Phase III—Study 1: Comparison of Near Infrared, Far Infrared, High Intensity Discharge, and Halogen Headlamps on Object Detection in Nighttime Clear Weather (FHWA-HRT-04-144).
- Volume 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).

- Volume XV: Enhanced Night Visibility Series: Phase III—Study 3: Influence of Beam Characteristics on Discomfort and Disability Glare (FHWA-HRT-04-146).
- Volume XVI: Enhanced Night Visibility Series: Phase III—Characterization of Experimental Objects (FHWA-HRT-04-147).

In addition, Volume XVII—*Characterization of Experimental Vision Enhancement Systems* (FHWA-HRT-04-148)—details the characterization of the vision enhancement systems used in this phase.

This report summarizes the independent variables, dependent variables, and key findings for the visual performance studies and the disability glare study in Phase III.

CHAPTER 2—PHASE III VISUAL PERFORMANCE STUDIES

This portion of the Phase III effort included two studies, one in clear weather and one in rain, that evaluated two NIR VESs, an IR–TIS, two HID VESs, and a halogen low-beam (HLB) (i.e., tungsten-halogen) VES. The clear study analysis used a 6 (VES) by 3 (Age) by 17 (Object) model; age was the only between-subjects variable. The rain study used 4 of the clear study's 6 VESs, 8 of its 17 objects, and a subset of its participants. Each of these independent variables is discussed in more detail below along with the dependent variables and key findings.

INDEPENDENT VARIABLES

Vision Enhancement Systems

The term "VES" encompasses the combination of headlamps, supplemental lighting, and imaging systems used on each vehicle. The Phase III clear and rain visual performance tests evaluated the same halogen low-beam VES and far infrared VES tested in Phase II. New to the ENV project in Phase III were two prototype NIR VESs and two HID VESs. The NIR systems used IR emitters in combination with a camera sensitive to the near IR spectrum; the IR–TIS used a camera sensitive to thermal contrast between objects and surroundings. Images from these systems were displayed in front of the driver just above the instrument panel. All three IR systems were accompanied by halogen headlamps. All VESs were installed on sport utility vehicle (SUV) platforms, including the IR–TIS, which was factory-installed original equipment on a sedan in Phase II. The rain study excluded the HIDs; the clear study used all six VESs listed below:

- IR–TIS: infrared thermal imaging system.
- NIR 1: prototype near infrared vision system.
- NIR 2: prototype near infrared vision system.
- HLB: halogen (i.e., tungsten-halogen) low beam.
- HID 1: high intensity discharge 1.
- HID 2: high intensity discharge 2.

Age

Eighteen drivers participated in the clear study. There were six participants in each of the three age groups: 18 to 25 years, 40 to 50 years, and 65 years and older. Each age group had three males and three females. The rain study used 15 of the 18 clear study participants and included 2 males and 3 females in each age category.

Objects

Table 1 shows the 17 objects used in the clear study. The 12 static pedestrian scenarios included pedestrians appearing just outside of the right or left edgeline in straight sections or turns of 1,250-m radius, appearing off-axis (9.4 m (31 ft) to the left or right of the centerline), and appearing in bloom scenarios (just outside either edgeline and adjacent to a vehicle with its headlamps on parked in the oncoming lane). Ten of the pedestrians wore blue clothing, and two of the pedestrians appearing in straight sections wore black clothing. The retroreflective group included three types of retroreflective infrastructure objects: a raised retroreflective pavement marking (RRPM), traffic signs (yield, stop, and speed limit) positioned roadside, and painted traffic arrows positioned on the pavement as in a turn lane. The two remaining objects—a terrier-sized, internally heated, stuffed dog model positioned on the centerline and a tire tread positioned on the right edgeline—made up the obstacle group. Each object was presented for every VES in a counterbalanced order. Volume XVI provides detailed characterization of each of these objects.

The subset of objects used in the rain study is indicated by an “X” in table 1. A blue-clothed pedestrian crossing the road perpendicular to the driver was added to the rain study. This was the only pedestrian that moved in either the clear or rain study. The pedestrian crossed the vehicle’s path back and forth between the centerline and the edgeline. This scenario had been included in the Phase II studies with pedestrians in white and sometimes black clothing. The tire tread was also included as an object of low contrast in the rain condition.

Table 1. The 17 objects used in the clear study.

	Object	Used in Clear Study	Used in Rain Study
Pedestrian Group	Pedestrian, Black Clothing, Left	X	
	Pedestrian, Black Clothing, Right	X	
	Pedestrian, Blue Clothing, Left	X	X
	Pedestrian, Blue Clothing, Right	X	X
	Pedestrian in Left Turn, Left Side (Blue Clothing)	X	X
	Pedestrian in Left Turn, Right Side (Blue Clothing)	X	X
	Pedestrian in Right Turn, Left Side (Blue Clothing)	X	X
	Pedestrian in Right Turn, Right Side (Blue Clothing)	X	X
	Far Off Axis Left (Blue Clothing)	X	
	Far Off Axis Right (Blue Clothing)	X	
	Bloom Object, Left (Blue Clothing)	X	
	Bloom Object, Right (Blue Clothing)	X	
	Pedestrian in Blue Clothing Crossing Perpendicular		X
Retroreflective Group	Raised Retroreflective Pavement Marking	X	
	Sign	X	
	Turn Arrow	X	
Obstacle Group	Dog	X	
	Tire Tread	X	X

DEPENDENT VARIABLES

The primary performance variables used in both studies were detection and recognition distance. 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."

Measurements of object detection and recognition distances were collected as follows. When a participant detected an object, he or she would say the word "something." Then, when the participant could recognize the object, he or she would provide a verbal recognition. At each of these utterances, the in-vehicle experimenter would flag the data. The in-vehicle experimenter also flagged the data when the front bumper of the vehicle passed the object. The data points were later verified in the laboratory from in-vehicle videotape. Detection and recognition distances were calculated from distance data collected at each of these three points in time.

The dependent variables also included subjective ratings. 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 each VES with their own vehicle's regular headlights. Following is a list of the statements on the questionnaire:

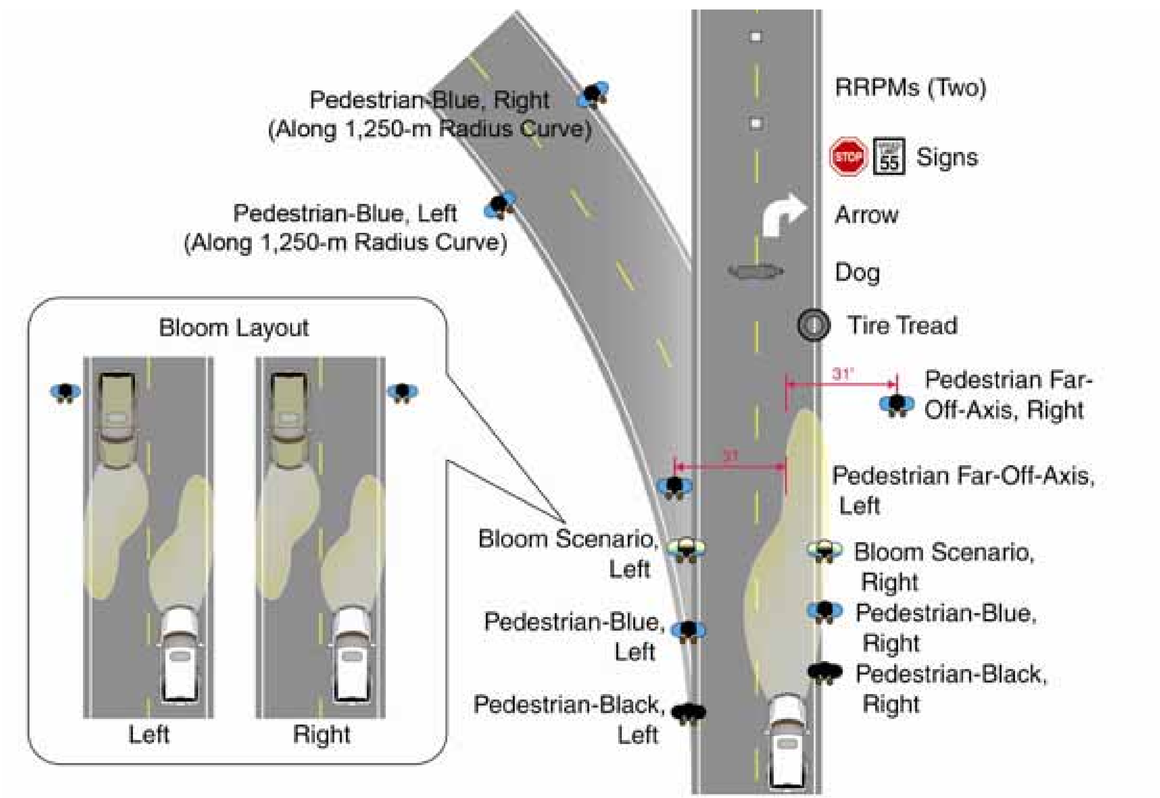
- This VES allowed me to detect objects sooner than my regular headlights.
- This VES allowed me to recognize objects sooner than my regular headlights.
- This VES helped me to stay on the road (not go over the lines) better than my regular headlights.
- This VES allowed me to see which direction the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

The following two questions were added to the Phase III visual performance studies to collect data that was of interest to the VES manufacturers:

- If you could provide any advice to the manufacturer of this vision system, what would it be?
- Anything else?

KEY FINDINGS

Following are the key findings in the clear and rain studies. The reports for each study, ENV Volumes XIII and XIV, contain more detailed information on these and additional findings. Because of the large number of objects that were presented in this study, a graphical representation that shows the relative detection distance of each object used for each VES was developed. Figure 1 is a key that shows the objects that were included in the study and their representations in the following diagrams.



31 ft = 9.5 m

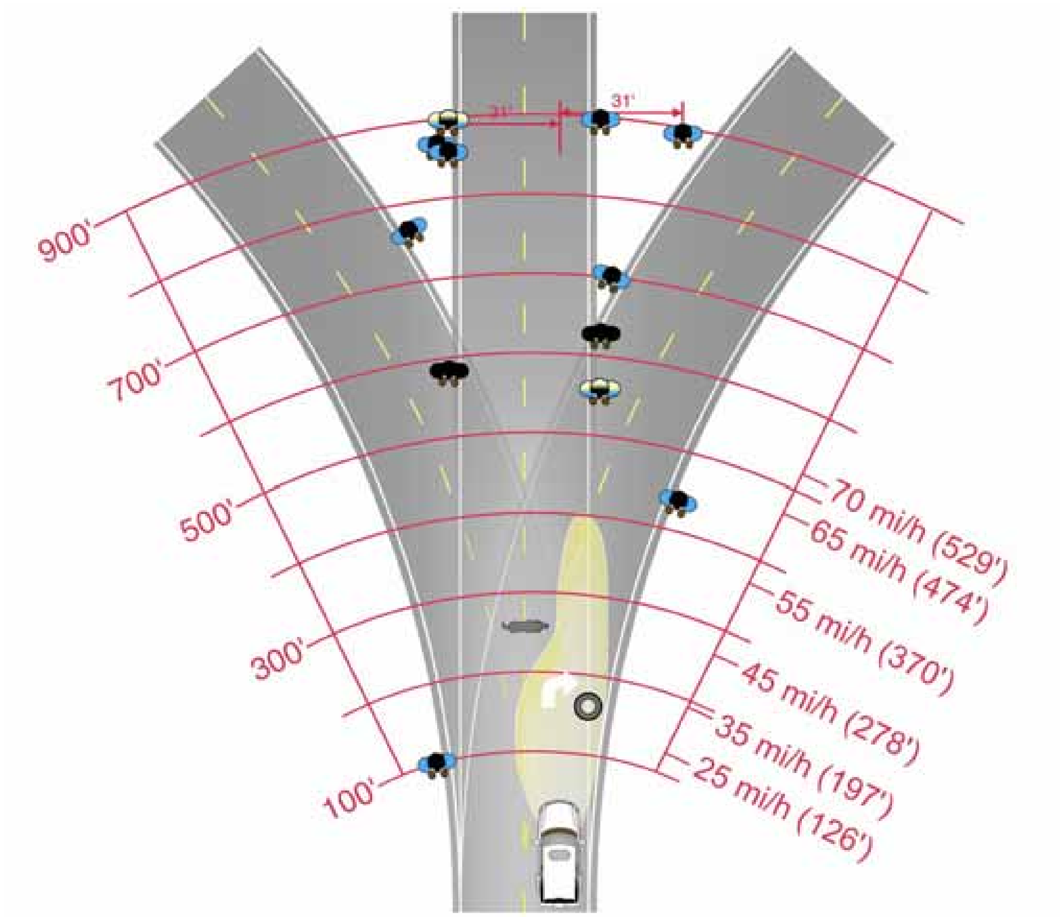
Figure 1. Diagram. Detection distance diagram key.

The figures for each VES provide a graphical representation of visibility using both detection distance, indicated on the left side of the figure, and stopping distance at various speeds, indicated on the right side of the figure. Stopping distance is the distance required to bring the vehicle to a complete stop, and it takes into account both driver reaction time and braking ability of a vehicle in clear weather conditions. Its equation is described in more detail in ENV

Volume XIII. Note that figure 2 and figure 3 do not include the signs' detection distances because they were more than 274 m (900 ft).

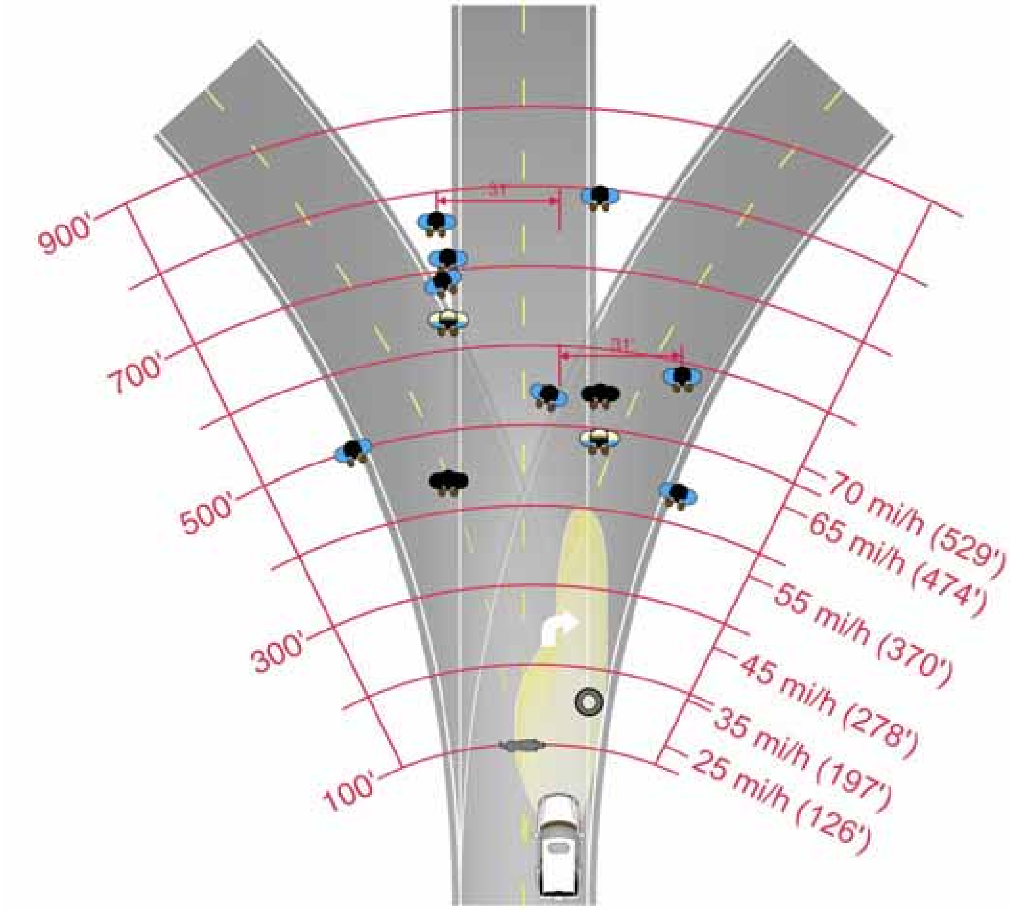
Supplemental Infrared System in Clear Conditions

The study tested three supplemental IR systems, two prototype near IR systems (NIR 1 and NIR 2) and an IR thermal imaging system (i.e., IR–TIS). The NIR 2 system did not perform as well as the other two IR systems or some of the headlamps, illustrating that implementation, not technology, is a key to a successful enhanced night vision system. The remaining two systems, IR–TIS and NIR 1, provided pedestrian detection benefit in clear weather over headlamps. In all but one pedestrian scenario, detection distance was acceptable for 89-km/h (55-mi/h) driving with these two systems. That is, drivers would have had sufficient time to detect the pedestrian, react, and stop at that speed. For most of the pedestrian scenarios, the IR–TIS implementation provided a 20- to 30-m (66- to 98-ft) detection advantage over the NIR 1 implementation. These differences can be seen in figure 2 and figure 3.



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

Figure 2. Diagram. IR–TIS mean detection distances.



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

Figure 3. Diagram. NIR 1 mean detection distances.

Although the IR systems generally enhanced drivers' ability to detect objects, there was some indication of reduced detection distances for objects not shown in the system display. The IR−TIS had the shortest detection of pedestrians on the left in a left turn scenario (see figure 2) and retroreflective objects. This poor performance probably results from these objects being outside that system's field of view, and therefore, not being shown in the display. This decrement could have been caused by oversampling of the IR–TIS system because of the large number of thermal objects in this study, the system novelty, or the experimental situation. The decrement could have also been partly caused by poorer performance of the headlamps on the IR–TIS SUV.

The wider field of view (FOV) (18°) of the NIR 1 system appeared sufficient for presenting pedestrians on the curve tested (radius of 1,250 m), for pedestrians located 9.4 m (31 ft) from the lane's center, and for pedestrians along the sides of road. The narrower FOV (11.7°) of the IR−TIS and NIR 2 systems may not present objects on curves with radii of 1,250 m or less.

Age in Clear Conditions

Although all participants appeared to benefit from the supplemental IR, the older participants appeared to benefit more from the NIR 1 than the IR–TIS in some scenarios. The opposite was true for the younger and middle age groups; in many pedestrian detection scenarios, they had longer detection distances with IR–TIS than the NIR 1. Not surprisingly, when using headlamps alone, older participants had shorter detection distances than younger participants. A detailed analysis of the data was conducted to determine if supplemental IR could offset the detection performance decrement of the older age group. The results indicated that this performance decrement could indeed be offset. That is, the older participants using either the IR–TIS or the NIR 1 systems performed similarly to the younger participants using the best of the three headlamp systems.

Pedestrian Clothing Color in Clear Conditions

In the clear study, the scenarios conducted on straight road segments with a pedestrian on the right or left side allowed a comparison of the effect of blue clothing versus black clothing on detection distances (table 2). All of the VESs demonstrated longer detection distances of pedestrians dressed in blue clothing than of pedestrians dressed in black clothing: 13 to 83 m (42 to 272 ft) longer on the left side and 38 to 83 m (125 to 272 ft) longer on the right. On average blue clothing increased detection distance over black clothing by 60 percent. Not surprisingly, the NIR systems, which are sensitive to differences in the visible spectrum, showed a blue-clothing detection benefit ranging from 38 to 83 m (125 to 272 ft). Perhaps the most surprising result is the 83-m (272-ft) greater detection distance for blue clothing when using an IR–TIS. Recall that IR–TIS is based on thermal differences between the object and the background rather than on differences in the visible spectrum, so there should be no difference in the pedestrian detection because of clothing type. The observed differences could be explained by the thicker blue cloth that may have held more heat than the thinner black cloth. Also, some participants may have waited for visual confirmation (through the windshield) before declaring detection of a pedestrian. For these participants, pedestrians dressed in blue would be seen from farther away than pedestrians dressed in black. Additional research would be required to ascertain the cause behind this difference.

Table 2. Detection distances for pedestrians dressed in black compared to pedestrians dressed in blue.

VES	Black Left Side (m)	Blue Left Side (m)	Black Right Side (m)	Blue Right Side (m)	Overall Blue Longer Percentage
IR–TIS	177	260	189	273	45
NIR 1	133	216	164	240	54
NIR 2	67	125	101	139	62
HLB	82	138	114	183	64
HID 1	35	68	107	158	71
HID 2	27	40	43	82	69

1 ft = 0.305 m

Rain Condition

In general, in rainy driving conditions both NIR systems had longer detection distances than the baseline HLB and IR–TIS systems for nearly all pedestrian detection scenarios. The only exception was the NIR 2 with the pedestrian on the right side of a right curve; it had similar or slightly shorter detection distances for this scenario than both the HLB and the IR–TIS systems, although the differences were not statistically significant. The difference was likely because the pedestrian was outside the FOV of the NIR 2 system. All other pedestrian mean detection distances for both NIR 1 and NIR 2 were longer than those of both the HLB and the IR–TIS. These objective findings do not appear to be differentiated by age and are corroborated by the subjective responses of the drivers in this study. This is a particularly interesting finding because the NIR 2 system consistently performed worse than the other VESs in the clear study.

The IR–TIS, which performed well in the clear condition, did not perform well in rain, and it appears that drivers used the accompanying headlamps to detect objects. This poor performance was also found in the Phase II rain study (ENV Volume IV).

Display Recommendations for Nighttime Visibility

The display should be located as close to the forward road scene as possible, using a high head down (HHD) display or a heads-up display (HUD). Possible objects should be called out clearly in the display to minimize the driver's visual scanning time. Drivers should not think they can drive solely by using the display. The ideal interface would attract the driver's attention when necessary but would not otherwise require glances. This might include HUD technology, auditory warnings when a possible object is present, or display activation only when a possible object is present. Visual interrogation of the display should require minimal glance time. This might be accomplished by presenting objects in high contrast or, as enabling technology becomes feasible, by augmenting the scene with distinctive graphics to call out possible objects.

CHAPTER 3—DISCOMFORT AND DISABILITY GLARE STUDY

Recall that Phase II of the ENV project included a discomfort glare evaluation of 11 different headlamp configurations (ENV Volume VII). The primary focus was on rating the discomfort glare of UV–A as compared to other VESs; however, it is difficult to fully understand the effects of oncoming vehicle safety without a direct disability glare evaluation. The two types of glare have different physiological origins, and factors that affect one type often do not affect the other.[(1)] Therefore, a disability glare evaluation in combination with a discomfort glare evaluation was needed to determine what effect the newer headlight technologies have on oncoming drivers. The study was performed as a 5 (VES) by 2 (Driver's Light Adaptation Level) by 2 (Pedestrian Location) by 3 (Age) mixed-factor design.

This chapter discusses these independent variables, the dependent variables, and the key findings.

INDEPENDENT VARIABLES

Vision Enhancement Systems

For this study, VESs were always two headlamps without supplemental systems. VES was a within-subjects variable. Both baseline headlamps (an HLB and an HID) from the Phase II discomfort glare study were included as VESs. The disability glare study used three additional HID headlamps so that differing intensities and beam patterns could be compared:

- High/narrow: higher intensity with narrow beam pattern (HID).
- High/wide: higher intensity with wide beam pattern (HID).
- Low/wide: lower intensity with wide beam pattern (baseline HID).
- Medium/medium: mid-level intensity with medium beam pattern (HID).
- Low/narrow: low intensity with narrow beam pattern (baseline HLB).

These glare sources were positioned on a static frame in the opposite lane from the participant, simulating an oncoming vehicle.

Age

Driver age was the only between-subjects variable. It included the same three gender-balanced age ranges used in most of the ENV studies: a younger group (18 to 25 years), a middle-aged group (40 to 50 years), and an older group (65 years and older). Ten participants from each age group were involved in the study.

Driver Light Adaptation Level

At night, a driver's eye will adapt to the ambient lighting condition. This adaptation level will change the ability of the driver to perceive objects as well as affect glare sensitivity. For this study, driver light adaptation level was a within-subjects variable that included a low (0.15 lux (lx)) and high level (0.45 lx). The light adaptation level of the driver was varied by using a dimmable light source inside the vehicle, placed across the top of the instrumentation panel.

Pedestrian Location

Pedestrian location was also a within-subjects variable. The locations at which pedestrians walk in the roadway significantly affect their visibility in the presence of glare relative to the driver. Two pedestrian locations were used in this study—one near the centerline and the other near the right edgeline. Both locations were 15.2 m (50 ft) behind the oncoming glare headlamps, and the pedestrians wore white clothing.

DEPENDENT VARIABLES

Three dependent variables were collected during this study: pedestrian detection distance, discomfort glare rating, and driver illumination level in lux.

During the study, the participants drove toward the glare sources. For the disability glare portion, participants indicated when they could see the pedestrian as they approached. For the discomfort glare portion, participants were asked to rate the discomfort of the glare.

During the disability portion of the study, the in-vehicle experimenter flagged the data when the participants verbally reported detecting the pedestrian and flagged the data again when the vehicle passed the pedestrian's location on the road. Calculations of pedestrian detection distances used these data flags. When necessary, videotape from the in-vehicle data collection system was used to verify detection distances using a post hoc video analysis.

During the discomfort glare portion of the study, participants rated the discomfort they experienced from oncoming headlamps. The participant's rating was an overall rating of the approximately 305-m (1,000-ft) approach toward the VES. After stopping past the VES, the participants rated the overall discomfort experienced from the glare by using the deBoer scale, a nine-point scale with verbal anchors for each of the odd numbers as follows: (1) Unbearable, (3) Disturbing, (5) Just Acceptable, (7) Satisfactory, and (9) Just Noticeable.(2)

Illuminance readings were collected at approximately the driver's eye level every tenth of a second throughout both the disability and the discomfort portions of this study, allowing illuminance data to be collected at the point of detection as well as during the discomfort ratings.

KEY FINDINGS

The primary focus of this research effort was to evaluate the discomfort and disability glare associated with headlamps of different intensities and beam patterns. The results indicated that beam intensity (i.e., maximum light output) affected disability and discomfort glare more than beam pattern. Specifically, VESs with higher maximum output had shorter pedestrian detection distances and were rated as more discomforting. In general, the results showed that discomfort glare corresponded to disability glare; oncoming VESs that were rated as more discomforting were the same VESs that restricted detection distances.

The participant's age did not indicate a significant difference in discomfort glare ratings, but the detection distance for pedestrians did decrease significantly as participant age increased. The driver light adaptation level appeared to have no effect on the glare rating and the detection distance for pedestrians. Finally, the pedestrian location near the right edgeline was detected from almost twice as far away as the pedestrian location near the centerline.

CHAPTER 4—CONCLUSIONS

The Phase III research indicated that supplemental IR shows promise for significantly increasing detection of pedestrians; however, for the system to be successful, the implementation of the technology is extremely important. The NIR systems showed promise for increasing visibility in rain conditions. This technology potentially could improve visibility in other inclement weather conditions, although such scenarios were not specifically tested. Both types of IR systems also showed promise in overcoming age-related decrements in visibility.

The disability glare study indicated that headlamps that were rated as discomforting were also associated with more disability glare. It also showed that beam intensity is a better predictor of both disability glare and discomfort glare than beam pattern.

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