Relationship Between Driver Characteristics, Nighttime Driving Risk Perception, and Visual Performance under Adverse and Clear Weather Conditions and Different Vision Enhancement Systems

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(ABSTRACT)

Vehicle crashes remain the leading cause of accidental death and injuries in the United States, claiming tens of thousands of lives and injuring millions of people each year. Many of these crashes occur during nighttime, where a variety of modifiers affect the risk of a crash, primarily through the reduction of object visibility. Furthermore, many of these modifiers also affect the nighttime mobility of older drivers, who avoid driving during the nighttime. Thus, a two-fold need exists for new technologies that enhance night visibility.

Two separate studies were completed as part of this research. Study 1 served as a baseline by evaluating visual performance during nighttime driving under clear weather conditions. Visual performance was evaluated in terms of the detection and recognition distances obtained when different vision enhancement systems were used at the Smart Road testing facility. Study 2, also using detection and recognition distances, compared the visual performance of drivers during low visibility conditions (i.e., due to rain) to the risk perception of driving during nighttime under low visibility conditions. These comparisons were made as a function of various vision enhancement systems. The age of the driver and the characteristics of the object presented (e.g., contrast, motion) were variables of interest in both studies.

The pivotal contribution of this investigation is the generation of a model describing the relationships between driver characteristics, risk perception, and visual performance in nighttime driving in the context of a variety of standard and prototype vision enhancement systems. Improvement of mobility, especially for older individuals, can be achieved through better understanding of the factors that increase risk perception, identification of systems that improve detection and recognition distances, and consideration of drivers' opinions on possible solutions that improve nighttime driving safety. In addition, this research effort empirically described the night vision enhancement capabilities of 12 different vision enhancement systems during clear and adverse weather environments.

DEDICATION

To my husband, Miguel A. Pérez, you are the most important person in my life. Thanks for all you have done to make this venture a success.

To my parents, Alicia Rodríguez and Ismael Blanco, this is just a small token for all that you have given me in life. You encouraged me to study and to be a professional. I think this is part of your harvest and a demonstration of your success as parents.

To God, you gave me the strength to be able to reach this point in my life, without you I would have never been able to do it.

We made it… again.

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1 INTRODUCTION

1.1 Motivation

1.1.1 Mobility

Some drivers, particularly older drivers, avoid driving under conditions of reduced visibility, such as nighttime and poor weather conditions. The American Association of Retired Persons (AARP) surveyed 1,400 of its members, and over half of the respondents indicated that they drive less at night due to reduced visibility and problems with glare (Knoblauch, Nitzburg, and Seifert, 1997). However, the AARP's 2001 Understanding Senior Transportation Survey (Straight, 2001), a nationwide survey of 2,422 respondents, revealed that 89 percent of the respondents between ages 50 and 74 were still driving and 75 percent of the respondents age 75 and older used driving as their key mode of transportation. In addition, licensed drivers in the survey identified nighttime driving as their top perceived problem area. These data indicate that older people might voluntarily limit their mobility at night due to a perception that they can no longer see adequately.

Several important questions surround this voluntary limitation in mobility. First, to what degree is the self-limitation due to an actual decrement in functional visual performance? That is, what is the actual decrement in older driver performance, in terms of ability to see objects and pedestrians under roadway lighting conditions at night and in adverse weather, relative to their younger counterparts? Second, assuming that visual performance is such that older drivers can still effectively remain mobile during reduced visibility conditions, why do they choose not to? One hypothesized reason for older drivers' avoidance of driving under low visibility conditions is that such situations represent a higher perceived risk for them due to increased fear of getting in a crash.

Older driver mobility is affected by a number of perceptual aspects in addition to the physiological effects of aging. For example, Winter (1988) found that older drivers perceive greater risks associated with driving than their younger counterparts. Winter suggests that older drivers are "running scared," frightened away from traffic situations they can probably handle as well as from those they cannot. Psychologically, some older drivers experience fear and anxiety about their vulnerability in today's complex driving environment in relation to citations, insurance, and licensing examinations. According to Winter, older drivers may develop compensatory attitudes and behaviors, some of which are positive and contribute to safety and some of which are negative and promote unsafe practices.

In a study determining why older drivers make the decision to stop driving, Persson (1993) participated in discussions and submitted questionnaires to members in 10 focus groups of older ex-drivers. When queried about why they stopped driving, most individuals (80 percent) stated that after gradually accumulating more and more compensatory driving behaviors (e.g., avoiding night driving or heavy traffic) and driving fewer and fewer miles, they eventually determined it was time to stop.

The decision to stop driving has a large impact on persons living in rural areas where alternative transportation is not available. Even when public transportation is available in urban areas, fear for personal safety can deter older individuals from making use of available services (Levine and Wachs, 1986). Isolation from family and friends and loss of independence can be devastating to the quality of life that older people experience. Often, the loss of personal mobility comes at a time when the need to make trips of greater importance, such as to receive medical care, is increasing. Thus, there is a need to explore the reasons behind nighttime driving risk perception so that mobility can be improved through the design of vehicles or other infrastructure systems that may enhance nighttime driving.

1.1.2 Driving Safety

Vehicle crashes remain the leading cause of accidental death and injuries in the United States, claiming tens of thousands of lives and injuring millions of people each year. Most of these transportation deaths and injuries occur on the nation's highways (Bureau of Transportation Statistics, 1999). When fatality rates are analyzed, nighttime driving is associated with the highest fatality rates across various weather conditions (Blanco, Hankey, and Dingus, 2001; Table 1.1).

Table 1.1 Fatality rate per 100 Million VMT: Weather/ time of day for 1998 (Adapted from Blanco et al., 2001).

	Weather			
	Normal	**Rain**	**Fog**	**Snow**
Day	3.6940	0.3906	0.2246	0.8665
Night	6.0202	0.5503	0.7618	1.0856

Night driving is generally accepted to be two to three times more hazardous than daylight driving per mile driven (Rumar, 1990b; Vanstrum and Lander, 1984). This result, together with the high rate of crashes involving pedestrians at night (Brown, 1980; Evans, 1991b; Hall, 1983), encourages the investigation of fatalities during nighttime driving. Previous research has confirmed that visibility under night driving conditions is severely restricted (Olson and Sivak, 1983b). Night driving tends to be riskier when illumination is provided exclusively by the vehicle's headlamps, since the illumination available is limited and drivers tend to overrun their headlamps. Furthermore, Olson (1993) states that vehicle speeds at night tend to differ very little from those measured during the day. This conclusion leads to a safety and human factors concern, because there are a variety of nighttime driving limitations that reduce the ability to detect and recognize objects when compared to daytime driving. If vehicle speeds are not adjusted accordingly the driver's reaction time to objects in the roadway is reduced.

Driving is a task that mainly depends on the driver's visual system. The vast majority of information required for driving is obtained through the visual system (Mourant and Rockwell, 1972; Olson, 1993), and this information can be severely degraded at night or in inclement weather. The problem is not only due to a lack of visual information; available information may also be misleading (Rheinhardt-Rutland, 1986). Visual perception problems arise at night for a number of reasons. Major visual functions such as acuity, contrast sensitivity, and depth perception are reduced substantially at lower illumination levels (Bullimore, Fulton, and Howard, 1990; Olson, 1993). The glare of opposing headlights can also reduce the visibility of low contrast objects such as pedestrians (Rumar, 1990a). Furthermore, pedestrians tend to overestimate how visible they are to motorists who are facing opposing headlights (Allen, Hazlett, Tracker, and Graham, 1970). These problems may be even worse for older drivers, a growing portion of the driving population (Olson, 1988, 1993). The decreased retinal illumination and increased light scattering in the eye experienced by older drivers also decrease their visual performance and could increase the time and distance required to see and react to potential obstacles (Olson, 1988; Olson and Sivak, 1983a). Despite these impairments, motorists tend to drive at speeds for which the stopping distance is greater than the visibility distance to objects such as pedestrians (Olson and Sivak, 1983a).

In their latest annual report (NHTSA, 1999), the National Highway Traffic Safety Administration (NHTSA) indicated that more than 30 percent of all fatal motor vehicle crashes in the past nine years occurred at night (Table 1.2), even though only 20 percent of vehicle miles traveled (VMT) occur during nighttime (Festin, 1996). Although there is no evidence that the fatalities shown in the table were due to diminished vision, a considerable number of fatalities were not linked to intoxication (e.g., for the 1998 report 35,523 of the fatalities did not involve alcohol). Thus, many of these fatalities could be due to other causes (e.g. reduced visibility, driver drowsiness) and potentially avoided by the use of various devices (e.g., steering wheel vibration when lane excursions are detected, enhancing nighttime visibility).

Table 1.2 Motor vehicle fatal crashes by time of day (units: percent).

		1990	1991	1992	1993	1994	1995	1996	1997	1998
	Fatal crashes	**39,836**	**36,937**	**34,942**	**35,780**	**36,254**	**37,241**	**37,494**	**37,324**	**37,081**
Time of day	Day (6:00 am - 8:59 pm)	59.7	60.2	62.2	63.3	64.4	64.2	64.5	65.6	65.7
	Night (9:00 pm - 5:59 am)	39.3	39.0	37.0	35.8	34.7	34.9	34.6	33.5	33.4
	Unknown	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9

SOURCE: U.S. Department of Transportation, National Highway Traffic Safety Administration, *Traffic Safety Facts (Washington, DC: Annual issues)*

The fatal crashes presented in Table 1.2 include not only vehicle driver and passenger fatalities, but also pedestrians and cyclist fatalities, which represent another principal concern during nighttime driving. Walking and bicycling are means of transportation for many people; unfortunately, many of these individuals are involved in motor vehicle crashes. In 1997, there were more than 6,100 pedestrians and bicyclists killed in crashes with motor vehicles.

About half of the motor vehicle deaths occur at night; furthermore, it has been shown that death rates based on mileage traveled are about four times higher at night than during the day (National Safety Council, 1995). Consequently, pedestrian and bicyclist safety on the roadways at nighttime remains a major concern. Pedestrians are particularly vulnerable in collisions with motor vehicles; in 1997 they accounted for only 77,000 (2 percent) of the 3.3 million highway injuries, but for 5,321 (13 percent) of the 42,013 highway fatalities (NHTSA, 1999). Poor nighttime visibility has been shown to play a significant role in a high percentage of the nearly 6,000 pedestrian fatalities that occur each year (Owens and Sivak, 1993).

1.2 Literature Review

Nighttime driving research in the human factors field is motivated from both the mobility perspective and the driving safety perspective. Before the objectives of this investigation are presented, however, it is important to examine in detail several important areas that are closely related to human factors research in nighttime driving. These areas include vision, age, nighttime driving, object detection and recognition, different types of vision enhancement systems, and driving under adverse weather conditions.

1.2.1 Vision

Vision begins with light, but before this light is seen, it must be transformed into electrical energy by the receptors of the eye. This electrical energy must travel a long and complex path to the visual cortex and beyond (Goldstein, 1989). Visible light, the band of electromagnetic energy with a wavelength between 380 and 720 nm, is the stimulus for vision. Light can be perceived by looking directly at the source that emits these wavelengths, such as the sun or a light bulb. However, most of the perceived light is reflected into the eyes from objects in the environment; this reflection provides information about the nature of these objects.

As light enters the eye, the process of vision begins. The first step is the focusing of light by the cornea and lens onto the receptors of the retina. The retina is the first neural network through which electrical signals generated in the receptors pass on their way to the brain. The two basic receptors types are rods and cones. In essence, these receptors create a "mosaic" on the retina. Rods (responsible for scotopic vision) and cones (responsible for photopic vision) differ in a number of areas (Table 1.3).

Table 1.3 Properties of photopic (cones) and scotopic (rods) vision of humans (adapted from Schiffman, 1990).

	Photopic	**Scotopic**
Receptor	Cones (~7 million)	Rods (~125 million)
Retinal Location	Concentration in Fovea	Peripheral Retina
Functional Luminance Level	Daylight	Night Light
Peak Wavelength	555 nm	505 nm
Color Vision	Trichromatic	Achromatic
Dark Adaptation	Rapid (~5 min)	Slow (~30 min)
Temporal Resolution	Fast Reacting	Slow Reacting
Spatial Resolution	High Acuity, Low Sensitivity	Low Acuity, High Sensitivity

Only all-cone foveal vision enables the detection of small details, which explains why people driving at night might not be able to identify details from a scene. Scotopic vision tends to allow object detection, until the object is illuminated by the vehicle's headlamps and the identification of more details is possible through photopic vision.

1.2.1.1 Visual Acuity and Contrast Sensitivity Testing

Visual acuity, which is typically measured using high-contrast stimuli, indicates the visual system's capacity to resolve fine detail under optimum conditions. Contrast sensitivity testing, however, measures detection abilities under different contrast levels and corresponds to how well the person can perform common, everyday visual tasks such as detecting and identifying a road sign at dusk. Many people have good, even "20/20," acuity but still have problems seeing under conditions of decreased contrast, such as rain or at night. An analogy of quantity and quality can be used to compare acuity testing and contrast sensitivity testing. The Snellen (acuity) test is used to evaluate vision quantity and the Contrast Sensitivity test is used to evaluate vision quality. When the contrast between an object and its background is low (i.e. low quality), the object must be larger (i.e. increased quantity) for it to be discriminated equivalently as a smaller object with greater contrast (i.e. high quality).

Many definitions of contrasts exist, among these definitions are: (1) modulation contrast, (2) luminous contrast, and (3) contrast or luminance ratio. The formulas for these three definitions are shown in the following equations.

(1) Modulation Contrast = $(L_{max} - L_{min}) / (L_{max} + L_{min})$
(2) Luminous Contrast = $(L_{max} - L_{min}) / L_{max}$
(3) Contrast or Luminance Ratio = L_{max} / L_{min}

Where:

L_{max} = maximum luminance
L_{min} = minimum luminance

Luminous contrast has been used previously to measure objects for object detection and discrimination in transportation related research (Vincent and Lemay, 1997; Zwahlen and Schnell, in press).

Various characteristics of the environment and the individual are known to affect acuity and contrast sensitivity. Increased levels of light or background luminance increase acuity and contrast sensitivity. Higher levels of light activate the cones, resulting in higher acuity and sensitivity (Sanders and McCormick, 1993). However, visual acuity and contrast sensitivity decline with age. The movement of an object or the observer (or both) decreases visual acuity. The ability to visually discriminate under these circumstances (e.g. looking at objects on the side of the road while driving) is called dynamic visual acuity. Burg (1966) states that acuity deteriorates with increased relative motion. Scialfa et al. (1988) suggest that static and dynamic visual acuity may be moderately correlated. Therefore, testing a driver's static acuity might provide an indication of their dynamic acuity.

1.2.2 Age

As mentioned previously, visual acuity and contrast sensitivity decline with age. The decline generally begins slowly after 40, followed by an accelerated decline after the age of 60 (Richards, 1966, 1972; Weymouth, 1960). With age lens opacity increases, and the pupil diameter decreases. The maximum area of the iris in eyes of people aged 60 is about half that of those aged 20. These factors result in less light reaching the retina of older persons (Mortimer, 1989). Weale (1961) determined that there is a 50 percent reduction in retinal illumination at age 50 compared to age 20, and this reduction increases to 66 percent at age 60. Hills and Burg (1977) indicated no significant correlation between vision measures and crash data for participants under the age of 54, but for those 54 and older, acuity showed significant correlations with crash data.

By the year 2020, it is anticipated that 17 percent of the U.S. population will be 65 or older, resulting in more than 50 million eligible older drivers (Bishu, Foster, and McCoy, 1991). These drivers may be more likely to suffer a crash. Many studies have been conducted concerning traffic crashes that involve drivers aged 65 and older, researching these drivers' physical, mental, and psychomotor skills as a potential cause of crashes (Brendemuhl, Schmidt, and Schenk, 1988; Ichikawa, 1996; Mtsui, 1995; Schlag, 1993; Wouters and Welleman, 1988). Accident analyses have shown that crash patterns and older drivers' accident maneuvers are similar in many motorized countries, regardless of the different traffic environments and rules (Hakamies-Blomqvist, 1993; Ichikawa, 1996; Simoes, 1996). Deficiencies in physical/mental functions of older drivers are said to play a major role in crash occurrence. However, an exact cause and effect relationship between crash occurrence and the possible deficiencies of older drivers has not been determined.

When calculating crash rates based on the number of licensed drivers, crash rates for older drivers are lower than for younger drivers (Mortimer and Fell, 1988). However, if crash rates are computed using an estimated distance traveled, overall crash rates are higher for older drivers age 65 and up with a steep rise at age 75 (Evans, 1991a; Oxley, 1996; Stutts and Marteli, 1992; Wouters and Welleman, 1988).

1.2.3 Nighttime Driving

Dependent upon the complexity of the required tasks, the ability to see is degraded when illumination is reduced below certain levels. Night driving is one such task in which the ability to see is often inadequate and frequently exposes road users to high levels of risk.

The traffic volume at night is much lower than during daytime (20 percent and 80 percent, respectively). However, the fatality rate for nighttime driving in the U.S. is about two to four times the daytime rate when VMT is considered (Mortimer, 1986). In an interesting analysis of traffic crashes, Vanstrum and Landen (1984) showed that, after removing the effects of alcohol in drivers, there were 1.21 and 2.79 fatalities per hundred million miles of exposure in the day and night, respectively. Thus, the risk of a fatality at night among drivers not impaired by alcohol is about 2.3 times higher than in daytime.

It is difficult to properly account for all of the variables that can affect traffic fatalities, but clearly the most dramatic difference between day and night driving is the large reduction in visibility due to: (1) the decreased levels of illumination, particularly when drivers are dependent solely on headlamps; and (2) the increased glare from other illumination sources, including other vehicles.

Past analyses point to the continued need to improve the visibility of salient objects at night by using fixed lighting, better and consistent roadway delineations, reflective traffic signs, and increased reflectivity of pedestrian and cyclist clothing. Such improvements are not only necessary in clear atmospheric conditions, but are essential in rain or wet road conditions, given that fatality rates for adverse weather conditions during nighttime driving are more than 25 percent higher than for daytime driving (Blanco et al., 2001). While vehicle headlights can improve, it will be difficult to make significant advances in their effectiveness unless radically new concepts are developed. Furthermore, current automobile designs reduce the visibility of drivers because of lower eye heights, lower headlamp mounting, and more raked windshields. The introduction of sport utility vehicles (SUVs) represents an alternative for higher eye height and headlamp mounting, but these vehicles tend to create a glare problem for drivers of oncoming regular vehicles.

Reduced visibility poses a serious problem to car driving since both longitudinal and lateral control are based on environmental references (Harms, 1993). Most car drivers reduce their speed when confronted with sight restrictions, but these speed reductions are usually insufficient in preventing braking distance from exceeding sight distance (Hills, 1980; Hawkins, 1988). Reduced visibility may also disturb drivers' lateral control by forcing them to adjust their lateral position based on few, close, and rapidly changing visual cues. Thus, under conditions of reduced sight, lateral control will probably be more erratic without speed reductions. Tenkink (1988) demonstrated that the amount of lateral variation in lane position increased with decreasing sight distance when the speed level was held constant, whereas in free-speed conditions the increase in lateral variation was apparently compensated by speed reductions. However, the speed difference between a straight road and a curved road was found to be smaller for short sight distances than for longer ones, and drivers' lateral stability in curves differed between sight conditions. Both findings indicate that drivers' lateral control was affected by restricted sight.

1.2.4 Object Detection

The results of Chrysler, Danielson, and Kirby (1997) show that when regular low-beam headlamps are used under clear conditions, younger drivers are able to detect "small road hazards" at longer distances than are older drivers. The younger group detected a static object (7 in high and 13 in wide static target) at an average of 295 ft, and the older group did so at an average of 230 ft. When a 42 in tall mannequin (simulating a children/static pedestrian) was presented to the participants, age was also a significant factor. The older group's mean detection distance for the mannequin was 265 ft and the younger group's mean was 360 ft. This research effort simulated adverse weather conditions by having participants wear plastic visors that blurred and reduced the contrast of the scene. During simulated adverse weather conditions, the same age trend continued, but the detection distance for the static objects had an average reduction of 51 percent when compared to the clear condition. A detection distance reduction of 37 percent occurred for the small pedestrian targets during the adverse weather simulation.

Other researchers have focused on the potential of vision enhancement systems (VESs) in automotive applications to improve peripheral detection (Bossi, 1997). Bossi's research utilized a combination of infrared sensor and heads-up display (HUD) technologies. The focus of the research was the effect of VES on driver peripheral visual performance.

In order to determine how to evaluate the potential benefits or limitations of VESs, Gish, Staplin, and Perel (1999) performed a small-scale investigation of driver performance and behavior using a mockup VES. Four younger (26-36) and four older (56-70) participants drove an instrumented vehicle and verbally reported the detection and recognition of targets placed along a predefined route while performing speed monitoring and navigation tasks. Although the mockup VES provided object detection at longer preview distances than low-beam headlights alone, results suggested that the VES enhancements were not always detected by drivers due to the visual, scanning, and cognitive demands of the driving tasks. Also, older drivers were less willing to use the mockup VES. Based on verbal reports, however, the consensus among all observers was that the VES increased curve detection distances relative to low-beam headlights alone.

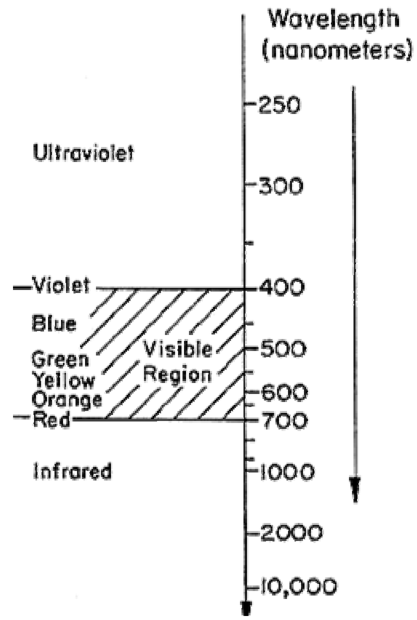
There is general agreement that automobile low-beam headlights provide, at best, marginal visibility for low-contrast objects such as pedestrians (Sivak and Olson, 1984). Furthermore, it is well known that pedestrians tend to overestimate their own nighttime visibility (Allen et al., 1970). This combination of poor visibility and overestimation of one's own visibility is especially critical for older drivers with their impaired vision.

1.2.5 Vision Enhancement Systems (VESs)

Timely detection of traffic control devices and hazards on the roadway is an essential part of safe driving. As mentioned previously, most drivers tend to over-drive their low-beam headlights and operate at very short preview times at night, which could possibly explain the high rates of nighttime crashes (Zwahlen and Schnell, 1997). Therefore, alternative systems that enhance night vision are needed.

If reduced visibility is one of the primary direct causes of increased crash risk at night, are there technologies that can reduce crash risk by providing enhanced visual cues to drivers? Various VESs that claim to accomplish this are currently being developed by various manufacturers. Some of the VESs that are discussed in this section are currently commercially available, while others remain under prototype testing. These various systems differ in various aspects, including their cost and spectral distribution (Figure 1.1).

VES	Cost	Spectral Power [nm]	Visible External Light	Description
Ultraviolet	Prototypes [approximately $1600 per experimental headlamp]	320-380	No	The short wavelength light emitted by the UV headlamps reacts with the fluorescent properties of objects with which it comes into contact to produce visible light. High-beam performance without glare.
High Intensity Discharge	$800-$2000 per vehicle	400-700 [multiple spikes - see graph below]	Yes	Available vehicle headlamps. Provides 80-90 lumens per watt. Available in high end models.
Halogen	$40-$100 per vehicle	400-700 [peak at the end of the visible spectrum -see graph below]	Yes	Available vehicle headlamps. Provides 20-25 lumens per watt. Most common.
Infrared Thermal Imaging	$1,600-$2,500 per vehicle	8,000-12,000	No	IR cameras sense infrared energy (proportionally to the temperature of an object). The image seen through an IR camera provides a thermal signature of the scene, which is displayed on a Heads Up Display. Available in vehicles.



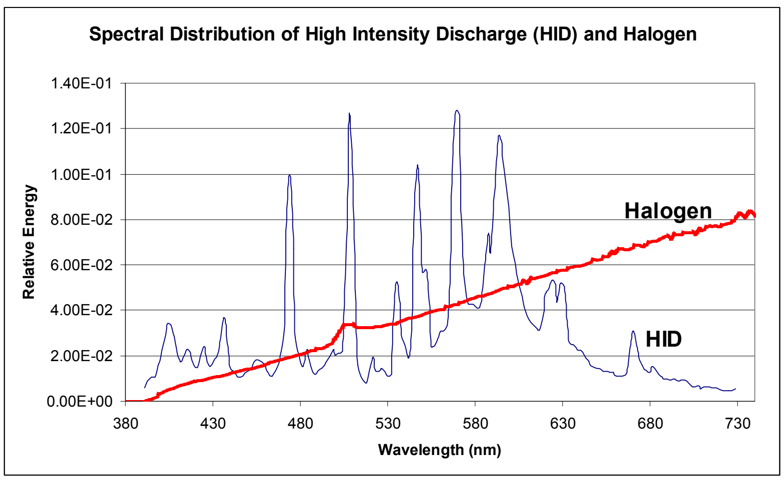


Figure 1.1 Characteristics of available and prototype vision enhancement systems (a reference electromagnetic spectrum is provided).

1.2.5.1 Halogen Headlamps

Although the development of lighting technology was quite advanced in the 1970s, government restrictions prohibited halogen headlights in the U.S. until the early 1980s. Until that time, traditional headlights were incandescent sealed beams. These headlights gave off heat and required a lot of power, drawbacks that were diminished with halogen headlamps. Currently, halogens are the standard headlamps for vehicles in the U.S. A conventional incandescent bulb generates 16-18 lumens of light per watt compared to 20-22 or more lumens per watt for a standard halogen bulb, or 28-33 lumens per watt for some high output halogen bulbs.

Halogen systems provide illumination by routing electricity through a high-resistance tungsten filament in a halogen bulb. The glowing tungsten filament produces light in the visible spectrum that is better in terms of luminance than the conventional filament. Luminous flux measures of 200-300 lumens are typical of halogen bulbs. Combined with sophisticated reflectors and lenses, today's halogen bulbs can provide a low-beam output of 500 lumens, or even up to 1,000 lumens (Hogrefe, Neuman, and Huhn, 1997) in some cases. Halogen lighting systems usually cost between \$40 and \$100 per vehicle (Zino, 1996).

Unfortunately, about 80 percent of the output of halogen headlamp systems is wasted as heat in the infrared spectrum (McCosh, 1990; Zino, 1996). Furthermore, the filament oxidizes and erodes over time, resulting in light with a yellowish hue. The filament is also susceptible to damage from shock, vibration, or impact, limiting its useful life span.

1.2.5.2 High Intensity Discharge (HID) Lamps

HID systems represent a major breakthrough in headlamp technology. Unlike halogen lamps, HID systems produce light in a gas discharge lamp by ionization rather than by a glowing tungsten filament. The arc tube used in the system is composed of a quartz glass envelope that surrounds two electrodes. Inside the tube there are pressurized (at 800 - 900 kPa) xenon and mercury gases and metal-halide salts. A very high voltage (as high as 25 kV) is applied between the electrodes that results in an arc, which in turn creates visible light (Zino, 1996; Jost, 1995). This process usually takes a few minutes to stabilize, although current designs allow the process to be sufficiently complete within seconds. The HID lamp can provide an output varying between 1,000 and 3,000 lumens at the bulb.

HID lighting systems are more efficient than standard halogen headlamps, producing about 75 lumens per watt. They also produce at least 70 percent more light than traditional halogen lamps, require less power, and produce less heat. In contrast to a conventional bulb, an HID bulb produces a brighter blue-white hue, which improves distance visibility by more than 50 percent (Jost, 1995) compared to traditional headlamps and enhances reflective features of road signs and lane markers (Zino, 1996). Furthermore, the filament-less design allows a system life up to six times longer than the life of a halogen bulb (Siuru, 1991). The system also provides more flexibility in headlamp design and allows breakage-resistant polycarbonate plastic to be used as the cover lens material.

Despite its promising features, HID technology has not been implemented widely for several reasons. The system is relatively expensive (roughly $800 - $2,000 per car), therefore it is currently available in only a few luxury car models. Furthermore, a complex sensor system is required in the vehicle to maintain proper aiming of the light. Poorly aimed HID light will result in glare for the oncoming driver (McCosh, 1990). NHTSA requires complete replacement of the system in the event of a component failure (Jost, 1995), increasing service costs. In addition, as is often the case with new technology, the increased viewing distance provided by HID headlamps may create a false sense of security when driving at night.

Another major drawback of HID headlamps is that they offer relatively low color rendering capabilities. The perceived color of an object depends on the spectral power distribution of the light source used to illuminate the object and the spectral reflectance of the object. Unlike the continuous spectral power distributions of daylight or halogen lamps, HID lamps have high concentrations of energy at several narrow-band wavelength regions, while at other regions they have little or no energy. Thus, not all spectral frequencies will be reflected back to the driver, affecting the driver's color perception. The primary concern with this low color rendering has been with the color perception of traffic signs, especially red signs (such as stop signs), because most HID lamps are deficient in the long-wavelength end of the visible spectrum. Sivak and Flannagan (1993) present an extensive summary of research that relates to this matter. These authors state that there are two fundamental issues that have not yet been addressed in past HID research. These two issues are: (1) How important is color (in addition to other dimensions such as shape and legend content) in achieving conspicuity and comprehension of traffic signs in general and red signs in particular; and (2) If color is important, how large a decrement in color rendition is acceptable from a safety point of view? Empirical evidence addressing these two issues does not yet exist.

1.2.5.3 Ultraviolet (UV) Headlamps

Researchers have investigated various methods of making objects and pedestrians more visible at night, thus increasing the reaction time for drivers. One of these methods uses UV light as an auxiliary technology to a more traditional headlamp system (e.g. halogen or HID). Although the concept of UV headlamps has been in existence for some time, a new UV lamp technology developed in Sweden has given researchers fresh insights into the possibilities of its use. These prototype UV headlamps are configured similarly to high-beam headlamps and are intended for use with fluorescent traffic control devices. The headlamps emit UV radiation in the spectral range of 320-380 nm, which is invisible to the human eye. The short wavelength light emitted by the UV headlamps reacts with the fluorescent properties of objects that it contacts to produce visible light. These UV headlamps could potentially offer high-beam performance without glare to oncoming drivers. Since the majority of objects in roadways are not fluorescent, however, UV headlamps would always be used with the existing low-beam headlights and, very likely, existing high-beam headlights.

To date, a number of European and U.S. studies have provided the groundwork for establishing the technical feasibility of the Swedish approach. Field studies show that prototype UV-A (the A stands for the UV band portion used for this particular headlamp design) headlights significantly improve visibility for fluorescent traffic control devices (TCDs) and for pedestrians (Fast, 1994; Fast and Ricksand, 1993; Mahach et al., 1997; Stahl, Oxley, Berntman, and Lind, 1998). Analysis of the spectrophotometric output of the UV-A headlights also shows them to be safe and suitable (Sliney, Fast, and Ricksand, 1995).

Mahach et al., (1997) and Nitzburg, Seifert, Knoblauch, and Turner (1998) suggest in their research that UV-A headlights could improve visibility distances. Nitzburg's pedestrian visibility study was performed in a static environment (i.e., the car's transmission was in the "park" position) and the participant was in the passenger side of the vehicle. Between detection and recognition trials, the vehicle moved in increments of 100 ft. A windshield shutter was used to limit the time available for visual search: a two-second stimulus exposure time was given each time the vehicle moved 100 ft. Results suggested an improvement on visibility distances by more than 200 percent when the detection distances of UV-A headlights were compared to those of halogen headlamps.

Several issues about UV headlights remain unaddressed, however, and it is essential to identify any unintended adverse effects of UV technology that could block implementation, even if these systems improve object detection distances. First, the appearance of UV headlights to oncoming drivers might be considered unacceptable. Studies conducted to date have, for the most part, evaluated only the appearance of the roadway and pedestrians as seen by the driver of the UV-equipped car. While it is true that the eye is insensitive to optical radiation below 400 nm, it is not completely accurate to say that UV-A headlights are invisible to the normal eye. The UV-A lamps cause some fluorescence to occur within the ocular media, particularly the lens, and thus observers (e.g. oncoming drivers) experience the headlights as shimmering, purplish-blue light. When viewed through a windshield, this fluorescence is lessened due to absorption of much of the UV-A radiation, but pedestrians and motorcyclists would not have this advantage.

The second UV headlight issue that has to be addressed prior to implementation is the possibility for driver adaptation or overconfidence. UV-A headlights can increase the visibility distance for fluorescent roadway delineation and for other fluorescent objects, such as pedestrians wearing light-colored or fluorescent clothing. However, visibility of dark, non-fluorescent objects does not increase under UV-A illumination. Will drivers adapt to improved roadway visibility by driving faster, therefore detecting dark roadway hazards or pedestrians at shorter distances? Such an argument could be made by opponents of this technology, and while a counterargument exists in principle (e.g. reliance on retroreflective TCDs involves a similar risk), the issue needs to be evaluated empirically. If indeed there is an increased risk of crashes caused by roadway objects or an increased risk to darkly-clad pedestrians, these issues need to be considered in a detailed human factors analysis.

Lastly, there is also a need to accurately assess the benefits of this technology in adverse weather conditions, as this could be an area where UV headlights offer substantial performance advantage compared to other systems. While the potential for increasing pedestrian safety certainly exists for this VES, the system remains untested under adverse weather conditions.

1.2.5.4 Infrared Thermal Imaging Systems (IR-TIS)

Infrared Thermal Imaging Systems are already in production and are optional in several high-end luxury cars as additions to halogen headlamps. This type of system is composed of an infrared (IR) camera and a HUD. IR cameras sense infrared energy to “see in the dark.” Since IR energy is emitted proportionally to the temperature of an object, the warmer the object, the more energy it emits and the more visible it is. The image obtained from an IR camera provides a thermal signature of the scene. This image can be stored or displayed on a standard video monitor (Figure 1.2). The IR system helps the driver see objects that exhibit temperature differentials when compared to the environment (e.g., pedestrians, cyclists, animals) as an image in different shades of gray. IR systems do not enhance the environment as seen by the driver, but display an alternative version of the environment that contains additional information not available from the areas illuminated by the traditional headlamp system.

Figure 1.2 Infrared-Thermal Imaging System (Source: Raytheon Commercial Infrared). Infrared energy from objects in the scene (A) is focused by optics (B) onto an infrared detector (C). The information from the infrared detector is passed to sensor electronics (D) for image processing. The signal processing circuitry translates the infrared detector data into an image that can be viewed on a standard video monitor (E).

The research of Barham, Oxley, and Ayala (1998b) on a prototype IR system found that participants using the prototype were able to spot pedestrians 295–328 ft away, providing the driver with five seconds to react if driving at 45 mph (66 ft/sec). This research was performed statically, however, and motion will very likely decrease these detection distances. IR systems also impose a secondary task to the driver: monitoring the images on the HUD while driving, since the systems display information on a HUD. Secondary tasks while driving can be considered as causes of driver distraction, which can lead to driving performance degradation.

1.2.5.4.1 Heads-Up Display (HUD)

HUDs are logical alternatives for presenting the type of information that IR-TIS can provide. While the use of IR-TIS HUDs in passenger cars is relatively new, these systems have been used for more than a decade to present drivers with other types of information. Since 1988, passenger car manufacturers have introduced automobiles capable of presenting visual information to the driver through the windshield by way of a HUD (Weihrauch, Meloeny, and Goesch, 1989). The HUD allows the driver the ability to access visually displayed information in closer proximity to forward scene events relative to a conventional head-down (HD), instrument panel display. Heads-up information has traditionally included digital speed, high-beam indicator, and master and/or specific telltale warnings. Under most driving conditions, only the speedometer is shown on the HUD, which is translucent and either blue- or yellow-green (depending on the manufacturer). In addition, the HUD information has been redundantly displayed at conventional HD locations, and the driver has been able to dim the HUD or turn it off.

GM production HUDs are positioned at a nominal four-degree look-down angle, centerline to the driver, and at front bumper distance (or about 7.8 ft). The Nissan and Toyota production HUDs are positioned at a nominal seven-degree look-down angle, 8 to 11 degrees from driver centerline, and at image distances ranging from about 3 to 7 ft (Kato, Ito, Shima, Imaizumi, and Shibata, 1992; Obayashi et al., 1989). HUD look-down angle settings vary somewhat across drivers, depending on each driver's eye position and preference. Drivers of vehicles equipped with HUDs are advised in the owner's manual to adjust the HUD as low as possible in their field of view, with the entire HUD image remaining fully visible (i.e., so the HUD appears just above the driver's front hood).

The next generation of HUDs may include information not redundantly displayed at traditional HD locations, provided technological advances can be made to ensure HUD image visibility comparable to HD displays under a range of conditions. These advances involve increasing image source luminance and/or HUD optical system efficiency. Assuming this technological challenge can be overcome, automotive HUDs have increased potential to improve the driver-vehicle interface, present information that could not be effectively communicated via a HD display, and increase display space and interface design flexibility. In addition, future HUDs may include more advanced driver content such as navigation/route guidance, headway (car following) aiding, intelligent cruise control/forward collision warning, lane maintenance aiding, infrared night vision displays, and roadway-to-vehicle communication information (Grant, Kiefer, Wierwille, and Beyerlein, 1995). These relatively unexplored areas may yield the greatest potential benefit of a HUD to the driver.

1.2.5.5 VES Research

There are numerous concerns regarding the overall benefit of VESs because of potential adverse effects on driving performance and behavior (Mortimer, 1997). Increased speeds due to increased driving confidence/comfort, degraded depth perception, degraded object recognition, and missed peripheral targets due to attentional tunneling and restricted field-of-view (when a display is used) are among the problems that may be linked to VES use.

There is currently no consensus regarding net VES benefits, because there are certain aspects of performance/behavior that are improved and others that are degraded when using particular VESs (Barham, Oxley, and Alexander, 1998a; Bossi, Ward, and Parkes, 1994; Nilsson and Alm, 1996; Stahl et al., 1998; Ward, Stapleton and Parkes, 1994). Using a prototype VES with a conformal HUD, Barham et al. (1998a) determined that the detection distance to pedestrian and child dummy targets increased by 128 ft and 59 ft, respectively, when compared to existing halogen headlamps. There was no benefit of the system with respect to the legibility of road signs. This study is particularly noteworthy because it used a sample of older drivers (65-80).

Replicating the Barham et al. (1998a) findings using a prototype VES in a controlled field experiment, Stahl et al. (1998) demonstrated enhanced visibility of pedestrian (157 ft increase) and child targets (207 ft increase) compared to conventional headlamps, but no benefit for legibility of road signs. Nilsson and Alm (1996) reported improvements in detection performance under simulated fog conditions in a driving simulator; however, lane deviations and speed choice increased. Despite generalization concerns due to the use of a simulator, the Nilsson and Alm findings suggest that studies must include multiple dependent variables in order to obtain a more complete picture of the overall effectiveness of VESs. Incorporating measures of mental workload, speed choice, and pedestrian detections, Ward et al. (1994) showed speed reductions had no effect on pedestrian detections in the presence of VESs among drivers using a prototype VES on a closed test track. The authors attributed the effect on speed choice to increased workload imposed by the VES. The lack of an effect on pedestrian detection was not explained; although it is plausible that workload could explain the lack of a detection distance benefit in this study.

Although it seems that VESs may increase the detection/recognition distances of certain targets under certain conditions, there may be unwanted effects on peripheral detection performance. To investigate this concern, Bossi et al. (1994) studied the effect of a simulated VES on detection performance under dark and dusk viewing conditions. The authors reported some degradation in peripheral target detection/recognition performance. Although this can be attributed to the presence of the simulated VES, it can also be attributed to sensory factors, eye scanning patterns, and/or attentional factors. It is important to determine the reason for the peripheral performance degradation, if it exists, in order to recommend a VES design to overcome this problem.

Comparisons among these studies are complicated by the fact that the technical approaches ranged from using simulated VESs (e.g., a monochrome monitor displaying the same road scene as the forward screen) in a laboratory-setting, to actual dynamic viewing conditions using prototype VESs along a closed test track. Although enhanced performance is certainly a necessary condition for a net VES benefit, the effectiveness of VES as a night driving crash countermeasure cannot be determined from previous research.

1.2.5.6 Driving in Adverse Weather Conditions

To a large extent, driving is a visual task. Therefore, poor visibility conditions like rain, fog, or snow may impose severe demands on drivers, as their ability to collect necessary information is markedly degraded. The driving task involves performing a number of functions, the most important of which is guiding the vehicle within the roadway geometrics and traffic control devices while detecting other vehicles and non-motorists and judging their speed, position, and possible behavior. This task becomes more complex when conditions of reduced visibility, which may be accompanied by wet surfaces and darkness, arise. The effect of these conditions on driver behavior has been a matter of concern for many years, and the subject of past research.

Collins, Neale, and Dingus (1999) studied several factors that can affect the visibility and conspicuity of road signs, taking into consideration participant age (younger and older), weather (clear and rain), time of day (day and night), and in-vehicle signing information system (ISIS) use (ISIS and no ISIS). Khattak, Kantor, and Council (1998) analyzed the impacts of adverse weather interactions with driver and roadway characteristics on occurrence and injury severity of selected crash types. Another example of adverse weather research is the DRIVE II project ROSES (Vos, 1994), which dealt with improving traffic safety in adverse weather conditions. The ROSES system consists of in-vehicle safety monitoring and driver support equipment and an infrastructure-based central monitoring system that combines inputs on road and weather conditions from various sources to derive the current and predicted safety level and recommended maximum speed (Vos, 1994). Khattak, Koppelman, and Schofer (1993) developed a conceptual framework to assess the impact of adverse weather on travel behavior. The framework was used to evaluate the effects of weather and traffic information, individual attributes, and situational factors on drivers' willingness to change normal travel patterns. Similarly, Vos (1992) presented a traffic simulation model based on literature sources and model analysis. This model incorporates the influences of reduced friction and visibility. Simulation of a sudden visibility reduction shows that road capacity and traffic safety are both decreased. The gamut of these research topics represents the variety of situations or conditions that adverse weather may lead to while driving.

The next chapter discusses the objectives of this study. A large portion of the study effort was directed towards the analysis of adverse weather conditions, specifically rain, and how risk perception during this type of weather affects mobility for older drivers.

2 RESEARCH OBJECTIVES

2.1 Rationale for the Study

Based on the discussion presented in Chapter 1 (such as the various factors associated with crashes during nighttime driving and factors affecting the nighttime mobility of older drivers) there seems to be a need for the identification and testing of new technologies that enhance night visibility. The research described here represents an effort to: (1) measure the performance of various new night vision enhancement technologies currently available to assist driver perception of the driving environment, and (2) measure how the use of these technologies affects driver risk perception.

The research consisted of two separate studies. Study 1 served as a baseline for nighttime visual performance. Visual performance during nighttime driving was evaluated under clear weather conditions in terms of detection and recognition distances when different vision enhancement systems were used. Study 2 compared the visual performance of drivers, also using detection and recognition distances, during low visibility conditions (i.e., rain) to the risk perception of driving during nighttime under low visibility conditions. These comparisons were also made as a function of various VESs.

The pivotal result of this investigation was the generation of a model describing the relationships between driver characteristics, risk perception, and visual performance in nighttime driving. This model was based on the context of a variety of standard and prototype VESs.

2.2 Background

It has been established that mobility for older drivers is restricted during nighttime due to a variety of reasons, including low visibility. Several recent advances in technology offer potential enhancement of nighttime driving visibility and may offer a partial solution to this mobility impairment. Previous estimates for the visibility improvement offered by these technologies are presented in this section.

Research investigating the use of UV-A headlamps and fluorescent TCDs to enhance nighttime driving has been conducted in Sweden and to some extent in the U.S. These studies found that nighttime driving visibility distance increased as much as 30 to 200 percent when using these devices (Nitzburg, Seifert, Knoblauch, and Turner, 1998). Furthermore, pedestrian visibility increased as much as 117 percent (Turner, Nitzburg, and Knoblauch, 1998). These researchers concluded that the UV-A system had the potential to increase visibility during periods of adverse weather (i.e. fog, rain, haze, and snow). Unfortunately, much of this past research was preliminary and many confounding variables were not controlled. For example, there were no photometric measurements taken of the objects used in the studies. Weather conditions were generally ideal (i.e. clear) nighttime viewing conditions. In addition, the UV-A light sources used for those studies are no longer in production, and the UV-A light sources now in production have different spectral characteristics.

In addition to UV technology, IR-TIS has been implemented in vehicles in the U.S. This technology detects temperature differences in the roadway and uses this differential to display objects in the forward environment on a HUD. Studies have found that drivers are able to detect pedestrian mock-ups 128 ft farther with this new system when compared to conventional headlamps (Barham et al., 1998a). In addition, IR-TIS is thought to improve visibility even in adverse weather conditions.

HID lamps are also now available. HID lights utilize a gas-discharge lamp design to emit light. Manufacturers state that these lights are advantageous in that they have increased lamp life. HID lights are also more efficient than halogen lamps, making them good candidates for vehicular applications. In addition, manufacturers suggest that this type of headlamp increases the visibility of objects in the roadway by up to 50 percent (Siuru, 1991).

2.3 Experimental Goal

The main experimental goal for this research was to identify whether a relationship existed between the perceived risk that leads to low visibility driving avoidance and several visual performance measurements. These measurements are: (1) detection and recognition distances of objects and pedestrians on a roadway during low visibility conditions, (2) standard visual acuity, and (3) contrast sensitivity.

Several constructs were measured during this research to identify how drivers' mobility can be improved. Visual performance was measured in the laboratory and during actual driving conditions in the form of detection and recognition distances. Subjective quantitative measures of risk were employed (i.e., rating scales) in study 2 to measure the likelihood of drivers engaging in a given scenario using a VES. In addition, risk perception of nighttime driving scenarios was directly addressed utilizing interview techniques at the end of the objective data collection. The operational definitions of the different measurements and concepts that were used throughout this research are listed below:

- ***Detection*** is the distance at which the driver can notice an object even though the object is not recognized.
- ***Recognition*** is the distance at which the object can be seen and correctly identified.
- ***Risk*** is commonly defined by a dictionary as "the possibility of suffering harm or loss." However, more technical definitions refer to risk as an expression of the possibility of a mishap in terms of severity and likelihood (Roland and Moriarty, 1990; Yates and Stone, 1992; Young, Brelsford, and Wogalter, 1990).
- ***Perceived Risk*** is an intuitive risk judgment (Wogalter, Brems, and Martin, 1993; Slovic, 1987). This judgment represents a subjective assessment regarding the severity and likelihood of an undesirable event (Slovic, Fischhoff, and Lichtenstein, 1979; Slovic, Fischhoff, and Lichtenstein, 1980; Wogalter, Desaulniers, and Brelsford, 1986).

In Study 2, only subjective quantifiable risk was measured. Risk can typically be quantified using subjective methods (e.g., rating scales) or objective methods, such as risk assessment models. For the latter, data is needed considering the type of loss, probability of the event, and conditional probabilities of consequence, loss, and cost (Roland and Moriarty, 1990). These entities were outside the scope of this study. The rating scales that addressed the subjective risk in this study evaluated likelihood and carefulness. In previous studies, carefulness has been highly correlated to the severity of a risk, suggesting that precaution intent is a good predictor of severity (Wogalter et al., 1993). In addition, carefulness allows for verification of the construct validity of likelihood if a high negative correlation between the two ratings is found.

2.4 Research Questions

This research effort attempted to obtain empirical evidence that would answer several questions directly related to nighttime visual performance when using a VES. These questions were:

- How will the different VES configurations vary detection and recognition capabilities in clear weather conditions at night?
- How will the different VES configurations vary detection and recognition capabilities in conditions of weather-induced low visibility at night?

- Does age cause a significant difference in terms of detection and recognition distances depending on the VES configuration during clear weather conditions at night?
- Does age cause a significant difference in terms of detection and recognition distances depending on the weather conditions?
- Do systems that show an increase in detection and recognition distances for pedestrians and cyclists also show the same trend for the other objects (e.g., tire tread and children's bicycle)?

In addition to the visual performance research questions above, questions related to the risk perception in nighttime driving were also posed. These questions were:

- Which low visibility scenarios increase the level of perceived risk during nighttime driving?
- How does the level of perceived risk differ for different age groups and genders when driving at night?
- Which characteristic(s) do drivers identify as main generators of risk during nighttime driving?
- What type of relationship exists between nighttime driving risk perception and visual performance measurements?
- What type of relationship exists between the level of risk perceived by drivers and vision enhancement systems?

3 STUDY 1: CLEAR WEATHER

As mentioned in Chapter 2, two studies were performed to achieve the research objectives of this investigation. This chapter focuses on the methods and results for the on-road empirical study and subjective questionnaire performed as part of Study 1.

All experimental tasks for Study 1 consisted of driving during nighttime under clear conditions with 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.

The study took place at the Smart Road testing facility for two consecutive nights per driver. The road was closed off to all traffic except for experimental vehicles. There were at most two experimental vehicles on the road at one time.

3.1 Methods

3.1.1 Participants

Thirty individuals participated in Study 1, which was divided into three different age categories. Ten participants were between the ages of 18 and 25 (younger category of drivers), ten were between the ages of 40 and 50 (middle-age category of drivers), and ten were over 65 (older category of drivers). Five male and five females comprised each age category. Participants received $20 per hour. Participation was allowed after a Screening Questionnaire was completed and only if the selection conditions were fulfilled (Appendix 1). Participants had to successfully comply with the following: (1) sign an Informed Consent form (Appendix 2), (2) present a valid driver's license, (3) successfully pass the visual acuity test (Appendix 3) with a score of 20/40 or better (as required by Virginia State Law), and (4) have no health conditions that made operating the research vehicles a risk.

Two participants performed the experiment simultaneously. Each participant attended one training session and two experimental sessions. In the training session, the study was described and the forms and questionnaires were filled out (Appendices 2-4). A driving practice using the HUD that presents images captured by the IR-TIS and a familiarization process with all the experimental protocols (Appendices 5 and 6) were also included in the training session.

During each of the two experimental sessions, the participant experienced six different VES configurations. The first experimental session included a familiarization lap on the Smart Road and a detection/recognition practice. Each experimental session lasted approximately 3.5

hours. The presentation orders for each VES and object combination were counterbalanced (an example is shown in Table 3.1). A detailed explanation of each of the VES configurations will be presented in Section 3.1.3. The VES configurations were defined as follows:

- Halogen Low Beam [HLB]
- Hybrid UV-A/Visible output together with Halogen Low Beam [Hybrid UV-A + HLB]
- Three UV-A headlamps together with Halogen Low Beam [3 UV-A + HLB]
- Five UV-A headlamps together with Halogen Low Beam [5 UV-A + HLB]
- Halogen Low Beam 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 High Intensity Discharge [Hybrid UV-A + HID]
- Three UV-A headlamps together with High Intensity Discharge [3 UV-A + HID]
- Five UV-A headlamps together with High Intensity Discharge [5 UV-A + HID]
- Infrared Thermal Imaging System [IR-TIS]

All 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.

Table 3.1 Example of the VES configuration order for a pair of participants. The first column, order, indicates the object order that was used for a given configuration. The second column, VES, is the configuration that was performed.

Participant 1, Night 1

Order	VES	Vehicle
13	Practice	
1	5 UV-A + HID	Wht. Explorer
2	HLB	Blk. Explorer
3	HOH	Pick-up
4	3 UV-A + HID	Wht. Explorer
5	IR-TIS	Cadillac
6	Hybrid UV-A + HLB	Blk. Explorer

Participant 2, Night 1

Order	VES	Vehicle
13	Practice	
1	HLB	Blk. Explorer
2	HOH	Pick-up
3	Hybrid UV-A + HLB	Blk. Explorer
4	IR-TIS	Cadillac
5	5 UV-A + HID	Wht. Explorer
6	3 UV-A + HID	Wht. Explorer

Participant 1, Night 2

Order	VES	Vehicle
7	HLB-LP	Cadillac
8	5 UV-A + HLB	Wht. Explorer
9	HHB	Pick-up
10	HID	Blk. Explorer
11	3 UV-A + HLB	Wht. Explorer
12	Hybrid UV-A + HID	Blk. Explorer

Participant 2, Night 2

Order	VES	Vehicle
7	3 UV-A + HLB	Wht. Explorer
8	Hybrid UV-A + HID	Blk. Explorer
9	5 UV-A + HLB	Wht. Explorer
10	HLB-LP	Cadillac
11	HID	Blk. Explorer
12	HHB	Pick-up

3.1.2 Experimental Design

A mixed factor design was used for the data collection of the on-road portion of the study (i.e., different detection and recognition tasks, Table 3.2). 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 3.2 Experimental design: 12 x 3 x 9 mixed factor design (12 VES configurations, 3 age groups, 9 objects)

VES Configuration		Age Groups		
		Young	Middle	Older
1	HLB			
2	Hybrid UV-A + HLB			
3	3 UV-A + HLB			
4	5 UV-A + HLB			
5	HLB-LP			
6	HHB			
7	HOH			
8	HID			
9	Hybrid UV-A + HID			
10	3 UV-A + HID			
11	5 UV-A + HID			
12	IR-TIS			

	Male	Female
Young: 18 to 25	5	5
Middle: 40 to 50	5	5
Older: 65 +	5	5

	Object
DYNAMIC	Parallel Pedestrian-Low Contrast Clothing
	Perpendicular Pedestrian-Low Contrast Clothing
	Parallel Pedestrian-High Contrast Clothing
	Perpendicular Pedestrian-High Contrast Clothing
	Cyclist-Low Contrast Clothing
	Cyclist-Low Contrast Clothing
STATIC	Static Pedestrian-High Contrast Clothing
	Tire Tread
	Children's Bicycle

3.1.3 Independent Variables

VES Configuration, Age, and Type of Object were the independent variables used in the experiment. The Age factor had three levels: younger participants (18 – 25 years), middle-age participants (40 – 50 years) and older participants (65 year or older). These age groups were created based on literature review findings that suggest changes in vision during certain ages (Mortimer, 1989; Richards, 1966; Richards, 1972; Weale, 1961; Weymouth, 1960).

The 12 VES configurations tested (Section 3.1.1) were selected based on several considerations. The HLB and the HID headlamps are currently available on the market and are what most drivers have traditionally used in their vehicles. Therefore, they were added as baseline conditions in order 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 due to 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 employ the UV-A headlamps had to be paired with baseline headlamps, since UV-A headlamps provide minimal visible light. These UV-A headlamps stimulate the fluorescent properties of objects contacted with the UV wave in order to produce visible light. Their purpose is to complement the regular headlamps, not to eliminate their use. These UV-A and baseline pairings resulted in six different UV configurations, three where the pairing was made with HLB lamps and three where HID lamps were used. The three UV conditions inside each pairing category were due to the use of three different forms of UV headlamp configurations: 5 UV-A, 3 UV-A, or UV-A Hybrid. The Hybrid UV-A headlamp is an experimental prototype that has a significant amount of visible light but not enough to drive without low-beam headlamps. The ABM-1 spotlight UV-A headlamps (used for the 5 UV-A and 3 UV-A configurations) have less visible light.

The HHB configuration was included to compare Detection and Recognition distances of any new system with the commonly available halogen headlamp in a high-beam position. Also, 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 very early Detection of pedestrians, cyclists, or animals (i.e., objects generating heat) on the roadway.

The objects selected for this study were pedestrians, cyclists, and static objects. The main reason to include the pedestrians and cyclists was the high crash fatality rates for these non-motorists (NHTSA, 1999). Real pedestrians and cyclists were used to evaluate the effects of object motion on Detection and Recognition distances. Although pedestrian mock-ups have been used in previous research of this type (Chrysler et al., 1997), actual pedestrians and cyclists seemed more appropriate, especially in terms of understanding the effects of motion. Moreover, the use of mock-ups would have improperly restricted the performance capabilities of VESs that use the motion and temperature characteristics of the object of interest, and would have limited the external validity of this study.

Pedestrians and cyclists were presented to the drivers at two different contrast levels: (1) with low contrast clothing, and (2) with high contrast clothing. 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 that is crossing the road; and (2) parallel to the vehicle path, representing a pedestrian that is walking along the shoulder.

Two objects other than pedestrians or cyclists were also used: a Children's Bicycle and Tire Tread. The Children's Bicycle was a 10 in bicycle and the Tire Tread was obtained from a 28 x 9 in steel belted truck radial tire. The Tire Tread was selected due to its potential for very low Detection distances, which often leads to last moment object avoidance maneuvers. The Children's Bicycle was intended to represent the possible presence of a child in the area.

For both static and dynamic objects, participants were required to first detect (e.g. "I see something") and then correctly recognize the objects (e.g. "I see a person," or "I see a cyclist"). A total of nine different objects were presented (Table 3.3 and Figure 3.1).

The reflectivity of the object was calculated using the assumption that the object of interest is a Lambertian (diffuse in all directions) reflector (R. Gibbons, personal communication, February 11, 2001). If this assumption is made, the reflectivity is calculated from the incident illuminance and the object luminance. This is determined through the equation $\boldsymbol{\rho = (L*\pi)/E}$, where ρ is the reflectivity, E is the incident illuminance, L is the object Luminance, and π is a Lambertian constant. The reflectivity of most of the objects was determined using this relationship.

Some objects reflect specularly rather than diffusely. These are shiny objects such as bicycle parts. This means that reflectivity has a directional component and the Lambertian assumption is not valid. For these objects, the specular reflectivity in a given direction is calculated through the equation $\boldsymbol{\rho = L/E}$. In both cases, the reflectivity is a ratio usually expressed in percent and does not have specific units. It is important to note that the reflectivity of the objects can only be established under the non-UV equipped VESs. If the UV-A equipped

VESs are used, the measured luminance contains both the reflected light and the light generated through the fluorescence of the clothing material.

Table 3.3 Description of the objects.

OBJECT	REFLECTANCE AT 200 FT [%]	LOCATION	SPECIAL INSTRUCTIONS
Parallel Pedestrian-Low Contrast Clothing	3.02	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-High Contrast Clothing	50.26	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-Low Contrast Clothing	3.02	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-High Contrast Clothing	50.26	Straight (perpendicular) line between white line and center line.	Wear white clothing. Walk to center line, then walk backward to white line. Repeat.
Cyclist-Low Contrast Clothing	3.02 (Cyclist) 27.00 (Specular – Bike Rims)	Between white lines in front of location.	Wear black clothing. Ride bike in circles across the road, from white line to opposite white line.
Cyclist-High Contrast Clothing	50.26 (Cyclist) 27.00 (Specular – Bike Rims)	Between white lines in front of location.	Wear white clothing. Ride bike in circles across the road, from white line to opposite white line.
Static Pedestrian-High Contrast Clothing	50.26	Centered on white line.	Wear white clothing. Stand facing traffic.
Tire Tread	3.99	Centered on white line.	None.
Children's Bicycle	18.05	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.

(a) Pedestrian
Low Contrast

(b) Cyclist
Low Contrast

(c) Cyclist
High Contrast

(d) Pedestrian
High Contrast

(e) Children's Bicycle

(f) Tire Tread

Figure 3.1 Objects presented on Study 1.

3.1.4 Objective Dependent Variables

Detection and Recognition distances were obtained to analyze the degree to which the different VES configurations enhanced nighttime visibility while driving. These two variables were selected due to their common use and acceptance in the human factors transportation literature (Barham et al., 1998b; Hodge and Rutley, 1978; Lunenfeld and Stephens, 1991; Nilsson and Alm, 1996; Stahl et al., 1998). 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.

3.1.5 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 one (indicating "Strongly Agree") and seven (indicating "Strongly Disagree"). The statements addressed each participant's perception of improved vision, safety, and comfort after experiencing a particular VES. Participants were asked to compare the VES that they were evaluating at a given point in time with their "regular headlights" (i.e. the headlights on their own vehicle). The assumption was made that for each participant, their own vehicle represented what they knew best and, therefore, were most comfortable using. The statements used for the questionnaire were:

- 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.

3.1.6 Safety Procedures

Safety procedures were implemented as part of the instrumented vehicle system. These procedures were employed to minimize possible risks to participants during the experiment. The safety measures required that: (1) all data collection equipment was mounted such that it, to the greatest extent possible, did not pose a hazard to the driver in any foreseeable instance; (2) participants wear the seatbelt restraint system anytime the car was on the road; (3) none of the data collection equipment interfered with any part of the driver's normal field-of-view; (4) a trained in-vehicle experimenter was in the vehicle at all times; and (5) an emergency protocol was established prior to testing.

The pedestrians and cyclists on the road were trained on 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.

3.1.7 Apparatus and Materials

On-road driving was conducted using four vehicles. The experimental vehicles were two Ford Explorers, a GM Pick-up Truck, and a Cadillac DTS. All vehicles were equipped with a NiteStar NS-60 distance measuring device (Figure 3.2). The NiteStar measuring device was connected to a laptop computer, which 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 3.3). The VESs were distributed among the different vehicles. Most vehicles had light-bars that allowed the baseline headlamps (i.e., HLB and HID) to be switched out, thereby maintaining a more consistent horizontal and vertical position among the different VESs (Figure 3.4). The HLB-LP and IR-TIS served as the only exceptions, as these were installed by the factory.

Figure 3.2 NiteStar NS-60 distance measuring instrument.

```
-------------------------- 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 3.3 Data collection display screen – Clear weather.

(a) 5 or 3 UV-A +Halogen Low Beam

(b) High Output Halogen or Halogen High Beam

(c) Hybrid UV-A + High Intensity Discharge

(d) Halogen Low Beam – Low Profile Infrared Thermal Imaging System

Figure 3.4 Examples of VES configurations.

3.1.7.1 Smart Road

The Smart Road was used for the on-road study (Figure 3.5). Six different locations were used on the Smart Road to present the different objects (Figure 3.6). The participants changed vehicles on the turn-around next to the entrance of the Smart Road (Figure 3.6). One on-road experimenter was assigned to each participant; this experimenter was responsible for escorting the participant to the next vehicle, showing them where the different controls were, and verifying that the right VES configuration was being tested. Four other on-road experimenters were positioned at the various locations. One on-road experimenter was assigned to Locations 1 and 5, one to Locations 2 and 5, and one was assigned to cover each of the other two remaining locations, 3 and 6. See Appendix 9 for more details on the protocol for the on-road experimenters.

Figure 3.5 Smart Road.

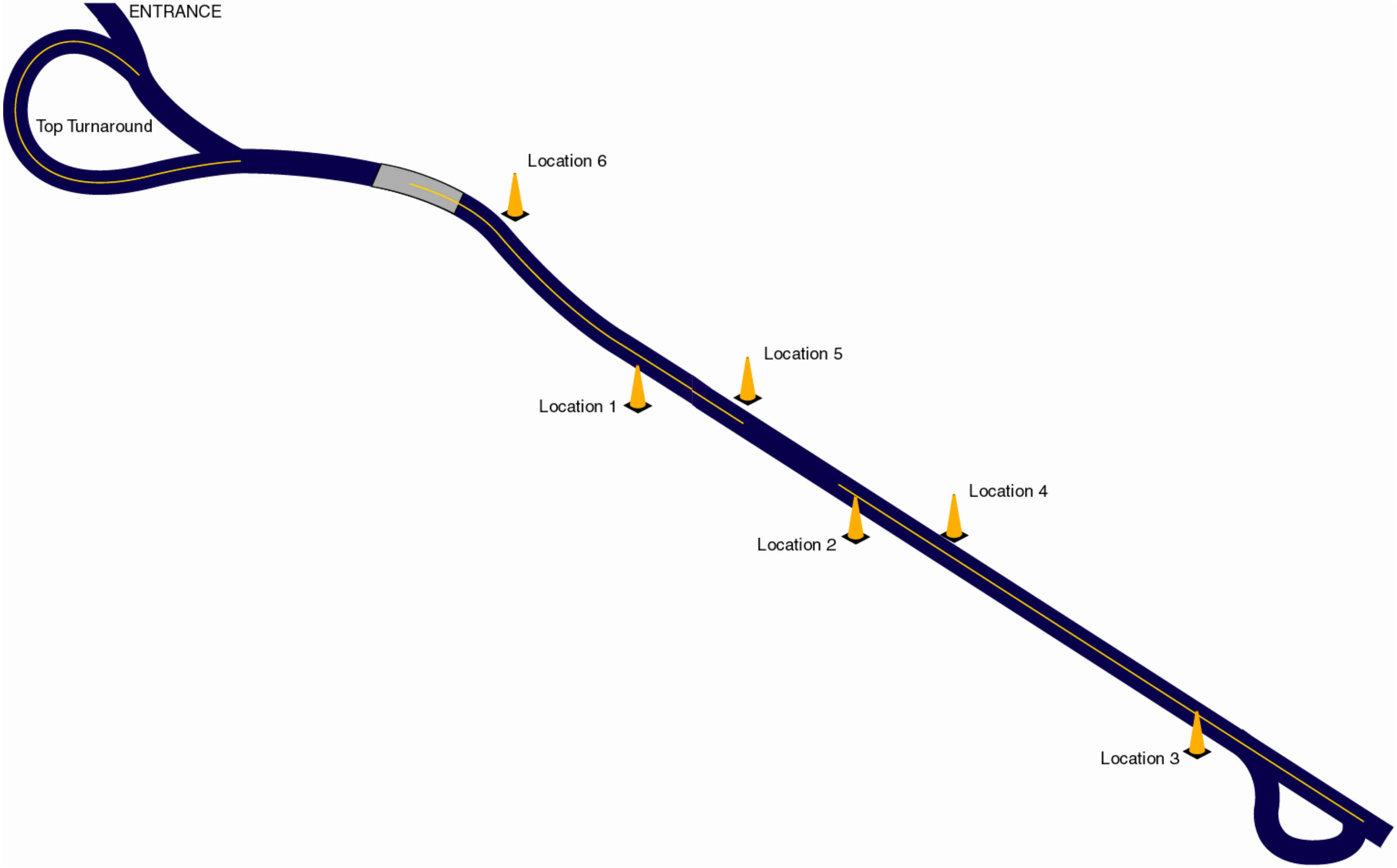


Figure 3.6 Locations where the objects were presented for the clear weather condition.

3.1.7.2 Headlamp Alignment

The headlamps used for several of the VES configurations were located on light-bars that were external to the vehicle. These light-bars were used for the HLB, HID, HOH, and UV-A configurations. To eliminate the possibility of confounding the experimental results with the effects of headlamp misalignment, each light assembly movement required a realignment process. The realignment process took place each night before starting the study. The protocol used for alignment was developed with the help of experts in the field (J. Calderas, personal communication, August 22, 2000; J. Erion, personal communication, June 5, 2000; F. F. Dutke, personal communication, June 20, 2000; T. Schnell, personal communication, August 24, 2000). Prior to this effort, no protocol had been established or published for the alignment of prototype/test headlamps. 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" shape angular 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 center of the headlamp 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 "hot spot" is located in the 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 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.
- Fine or gross adjustment should be performed as needed.

The only difference between the alignment of the UV-A or HHB headlamps and this previous headlamp alignment procedure (HID, HLB, and HOH) is that the "hot spot" must be at the center of the crosshairs. The details of the alignment protocol used for this specific study are described in Appendix 10.

3.1.8 Experimental Procedure

The experiment consisted of three sessions. The first session was a screening, laboratory training, and IR-TIS training. The other two sessions were the two nights of the experiment at the Smart Road. The first night the participant was familiarized with the Smart Road and the experimental objects before starting the experiment. A group of six configurations were presented to the participants during the first night and the remaining six configurations were presented during the second night. The order was counterbalanced. Details of the procedures followed are presented next.

3.1.8.1 Participant Screening

Participants were initially screened over the telephone (Appendix 1), and if a participant qualified for the study, a time was scheduled for testing. Participants were instructed to meet the experimenter at the Virginia Tech Transportation Institute (VTTI), Blacksburg, VA. After arriving at VTTI, an overview of the study was presented to each participant. Subsequently, each participant was asked to complete the Informed Consent Form (Appendix 2), and take an informal vision test for acuity using a Snellen chart and Contrast Sensitivity Test (Appendix 3).

The vision test was performed to ensure that all participants had at least 20/40 vision and to identify any type of vision disparity that might have influenced the results. After these steps were completed, and if no problems were identified, the participant was trained on the experimental tasks to be performed during the drive. A detailed experimenter protocol for vision testing is presented as part of Appendix 5.

3.1.8.2 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 (Appendices 5 and 6). The Detection and Recognition definitions, the use of the push button 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 with the IR-TIS took place, and examples of the objects shown during the experimental sessions were presented as part of the training practice.

3.1.8.3 Familiarization

Given that 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 on-road experimenter/valet reviewed general information concerning the operation of the test vehicle (Appendix 11). Each participant was asked to adjust the vehicle seat and steering wheel position controls for his/her driving comfort. When the participant felt comfortable with the controls of the vehicle, the experiment was ready to start.

3.1.8.4 Driving Instructions

Participants were instructed to remain in the right-hand lane while driving and to place the vehicle in park upon reaching each of the turnarounds. Participants were instructed to drive at 25 mph during the experimental sessions. Participants were required to follow instructions from the in-vehicle experimenter at all times.

3.1.8.5 Driving and Practice Lap

Each participant drove down the road to become familiar with the road and the vehicle; no objects were presented at this point in time. At the bottom turn-around, the experimenter gave the wand with the push button to the participant and instructed the participant that this portion was a practice to familiarize them with the objects. The participant then drove back up the road for a practice run of a detection and recognition task, obtaining feedback from the experimenter as needed. After the practice tasks, the participants drove with the first group of six VESs corresponding to the order assigned to their first night.

3.1.8.6 General On-Road Procedure

Distance data were collected while each VES was evaluated. The in-vehicle experimenter provided the participant with a push button to flag the data collection program when Detection and Recognition were performed. Other than Detection, Recognition, and maintaining 25 mph, no other tasks were performed by the participants while driving. The experimenter was seated in the passenger seat and let the participant know when he/she could start driving and where to park. The in-vehicle experimenter also administered the questionnaires after each VES configuration and controlled the data collection program. For more details on the in-vehicle experimenter protocol, please refer to Appendix 7.

3.1.8.7 Sequence of Data Collection

Each of the participants followed the same sequence of events in order to collect the data for each of the VES configurations. This sequence was as follows:

1. An object was presented at each of the six Locations for the clear condition.
2. While approaching each Location, the participants pressed the push button when they were able to detect an object.
3. When the participants were able to recognize the object, they pressed the push button 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 the two laps were completed, all the objects for a given VES configuration had been presented and the subjective ratings (a questionnaire was answered for each VES configuration) had been collected.
6. Once all VES configurations were completed, the participants were instructed to return to VTTI to be debriefed (Appendix 8).

The study was performed twice every night (i.e., first shift: 7:45 pm – 11 pm; second shift: 11:30 pm – 2:30 am). Participants who worked until late and usually drove late at night ran in the second shift to minimize the possibility of fatigue. Other participants ran during the first shift. Payment for the total number of hours (training, experimental session 1, and experimental session 2) was provided at the end of the second experimental session.

3.1.9 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 driver visual performance under each of the different treatments. An analysis of variance (ANOVA) was performed. "PROC ANOVA" was used in SAS (SAS Institute, Cary, NC) to compute the ANOVA. The full experimental design model was used in the data analysis (Table 3.4).

Table 3.4 Model for the experimental design.

SOURCE
BETWEEN
AGE
SUBJECT(AGE)
WITHIN
VES
AGE*VES
VES*SUBJECT(AGE)
OBJECT
AGE*OBJECT
OBJECT*SUBJECT(AGE)
VES*OBJECT
AGE*VES*OBJECT
VES*OBJECT*SUBJECT(AGE)

ANOVA evaluated 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. The reader interested in a detailed discussion of *post-hoc* tests is referred to Winer, Bram, and Michels (1991).

3.2 Results

3.2.1 Objective Measurements

An ANOVA was performed on the objective measurements taken on the Smart Road portion of the study. The model for this portion of the study was a 12 (VES) x 3 (Age) x 9 (Object) factorial design. ANOVA summary tables were obtained for both objective dependent measurements (Table 3.5 and Table 3.6). A total of 3,229 observations were obtained from the experiment for each objective measurement. Several main effects and interactions were considered significant (Table 3.7).

Table 3.5 ANOVA summary table for the dependent measurement: Detection distance under clear weather conditions.

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*Age	22	1277750.3	58079.6	2.25	0.0014 *
*VES*Subject/Age*	296	7653255.8	25855.6		
Object	8	180324344.1	22540543.0	679.70	<0.0001 *
Object*Age	16	1249341.1	78083.8	2.35	0.0031 *
*Object*Subject/Age*	216	7163085.5	33162.4		
VES*Object	88	9250704.6	105121.6	3.00	<0.0001 *
VES*Object*Age	176	5645156.3	32074.8	0.92	0.7750
*VES*Object*Subject/Age*	2366	82880763.4	35029.9		
TOTAL	3228	319608001.8			

* $p < 0.05$ (significant)

Table 3.6 ANOVA summary table for the dependent measurement: Recognition distance under clear weather conditions.

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*Age	22	577886.9	26267.6	1.03	0.4223	
*VES*Subject/Age*	296	7521854	25411.7			
Object	8	136027251.9	17003406.5	545.65	<0.0001	*
Object*Age	16	1046045.2	65377.8	2.10	0.0094	*
*Object*Subject/Age*	216	6730986.1	31162			
VES*Object	88	5043266.7	57309.8	2.31	<0.0001	*
VES*Object*Age	176	3618771.5	20561.2	0.83	0.9481	
*VES*Object*Subject/Age*	2366	58728710.6	24821.9			
TOTAL	3228	240107325.1				

* $p < 0.05$ (significant)

Table 3.7 Summary of significant main effects and interactions (clear weather).

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

x = $p < 0.05$ (significant)

The main effects and most two-way interactions between age (Age), vision enhancement system (VES), and type of object (Object) were significant ($p < 0.05$) for both visual performance measurements. The VES*Age interaction lacked significance for all of the dependent variables; this interaction was only significant for Detection distance. The *post-hoc* results for the significant main effects and interactions were graphed (Figure 3.7 to Figure 3.14, 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.

On average, the VES*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 (Figure 3.7). Configurations of HLB with UV-A (i.e., 5 UV-A, 3 UV-A, Hybrid) across the three age groups exhibited improvements on Detection distances, but these improvements averaged less than 30 ft. However, performance of the IR-TIS was age dependent. The younger and middle-age drivers had farther Detection distances when using the IR-TIS than when using the HLB. The younger and middle-age participants were able to see objects 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 11 ft farther in the HLB configuration.

A significant separation of results based on object contrast can be observed from the Object*Age interaction for both Detection and Recognition (Figure 3.8 and Figure 3.9). Depending on the age of the driver, a high contrast object such as a pedestrian dressed in high contrast clothing walking across the street (i.e., Perpendicular Pedestrian-High Contrast Clothing) was detected 439 to 490 ft farther away than its counterpart (i.e., Prpendicular Pedestrian-Low Contrast Clothing). Recognition distances followed a fairly similar pattern: Detection distances for the middle-age drivers exposed to high contrast objects were farther than those for older drivers. However, Recognition distances for middle-age drivers were fairly similar to those of the older drivers'. For objects of fairly low contrast and 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.

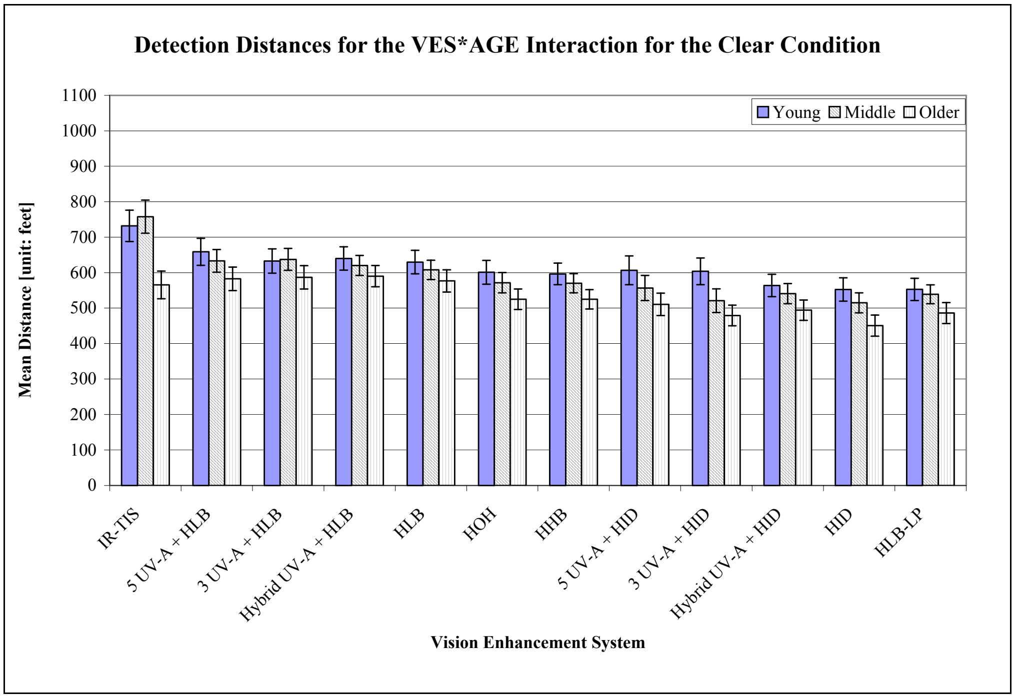


*Figure 3.7 Results on Detection distances for the interaction: VES*Age.*

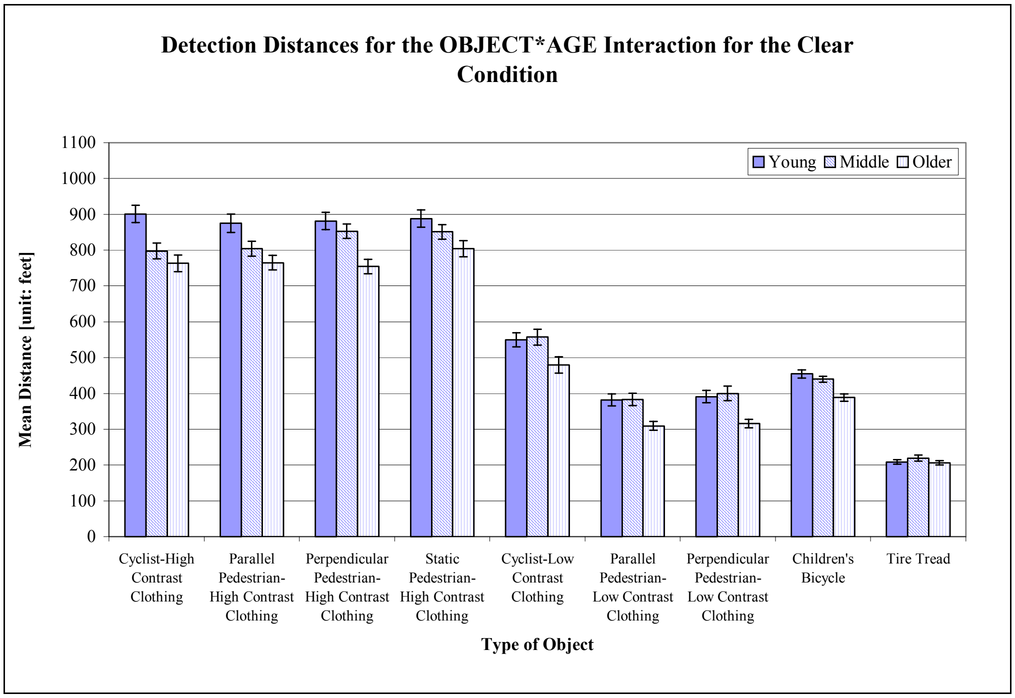


*Figure 3.8 Results on Detection distances for the interaction: Object*Age.*

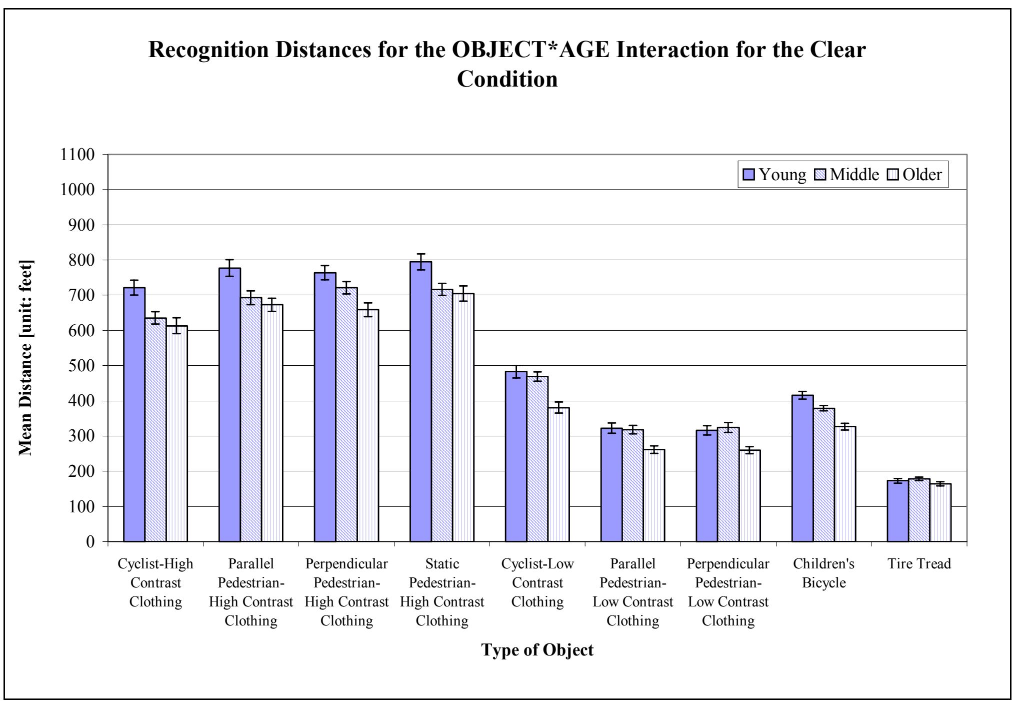


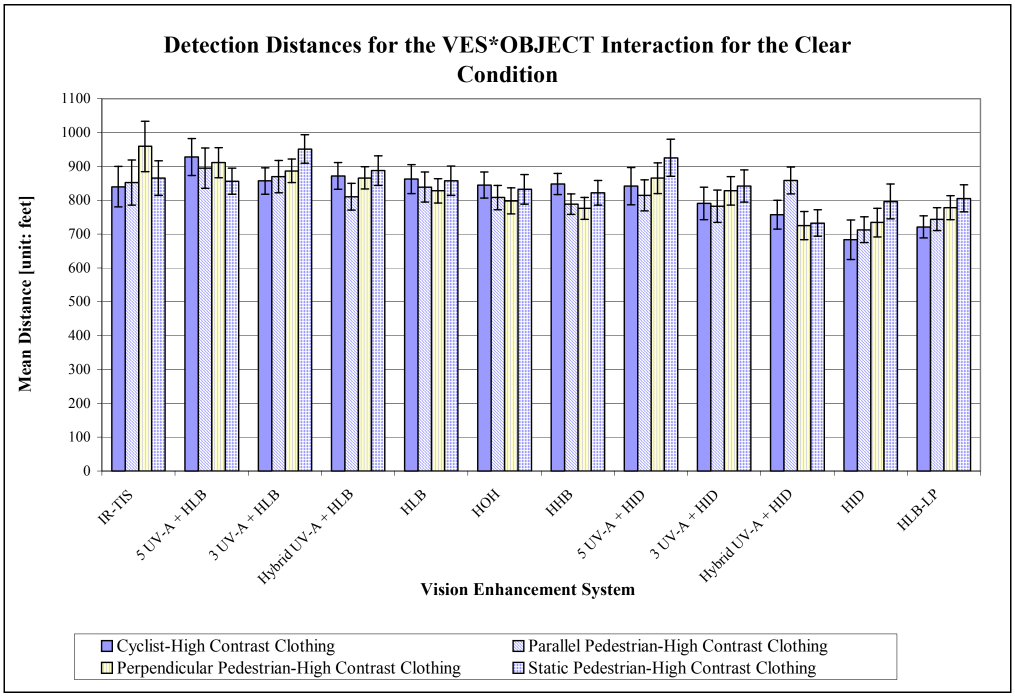
*Figure 3.9 Results on Recognition distances for the interaction: Object*Age.*

The significant difference for VES*Object under both Detection and Recognition distances also appears to be partly the result of the two sets of different objects, low versus high contrast objects (Figure 3.10 and Figure 3.11). The HLB outperformed most of the other VESs for the Cyclist-High Contrast object. The only VES that detected the Cyclist-High Contrast Clothing farther away than the HLB was the HLB supplemented with the 5 UV-A headlamps, with an average Detection distance 65 ft farther than that of the HLB alone. Other VES configurations resulted in distances between 5 and 179 ft closer than the Detection distance obtained with the HLB. For the Parallel Pedestrian-High Contrast Clothing, using the HLB with 5 UV-A, the HLB with 3 UV-A, the HID with 3 UV-A, and the IR-TIS resulted in Detection distances that were farther than HLB distances by 56 ft, 31 ft, 19 ft, and 13 ft, respectively. Fairly similar results were obtained for the Static Pedestrian-High Contrast Clothing.

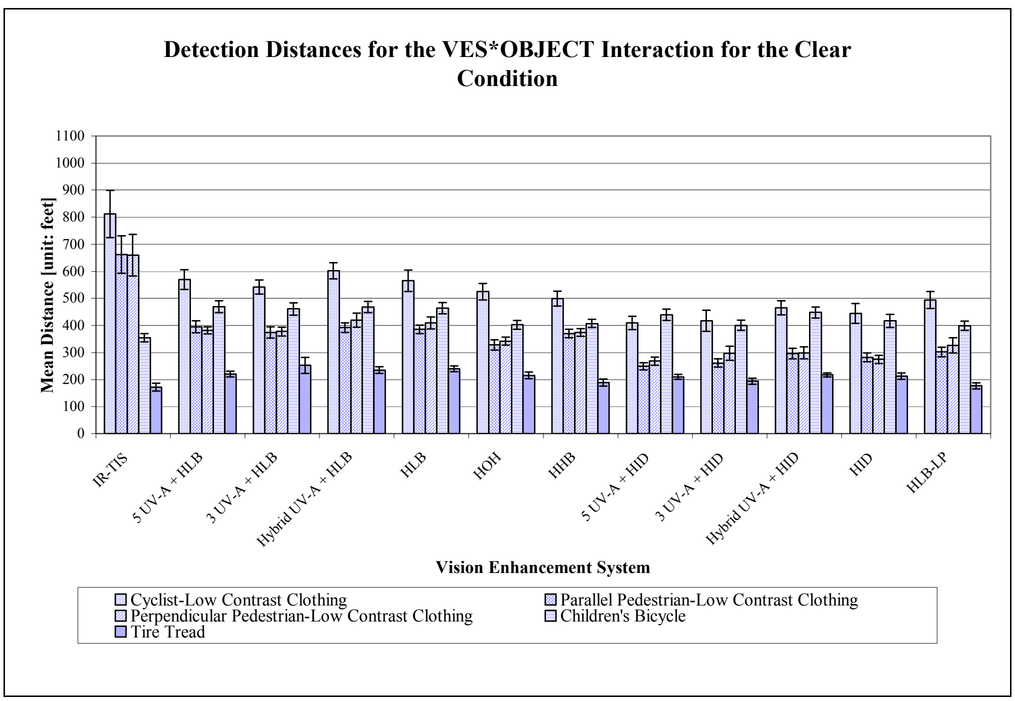
While alternative systems showed some improvements in Detection distances compared to HLB, these improvements were not dramatic. The IR-TIS showed improvements over the HLB in Detection of objects that are in front of the vehicle path, such as the Perpendicular Pedestrian-High Contrast Clothing, and in Detection and Recognition of warm objects with low contrast clothing such as the Cyclist-Low Contrast Clothing, Parallel Pedestrian-Low Contrast Clothing, and the Perpendicular Pedestrian-Low Contrast Clothing. Other dark objects or objects close to the ground level, such as the Children's Bicycle and the Tire Tread, were not detected or recognized as far away as they were by using the HLB. Across all objects, the Halogen baseline condition 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 179 ft (for high contrast objects) to 28 ft (for low contrast objects) farther than the HIDs.

The results from the ANOVA showed a significant difference ($p < 0.05$) among the three age groups in terms of Detection and Recognition distances during clear weather conditions (Figure 3.12). Both Detection and Recognition follow the same pattern with respect to age: distances were not significantly different between younger and middle-age drivers or middle-age 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.

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 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 3 UV-A headlamps added to the HIDs (Figure 3.13). The HLB was able to enhance the Detection of objects an average of 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-LB. Drivers using the HLB were able to recognize objects over 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.

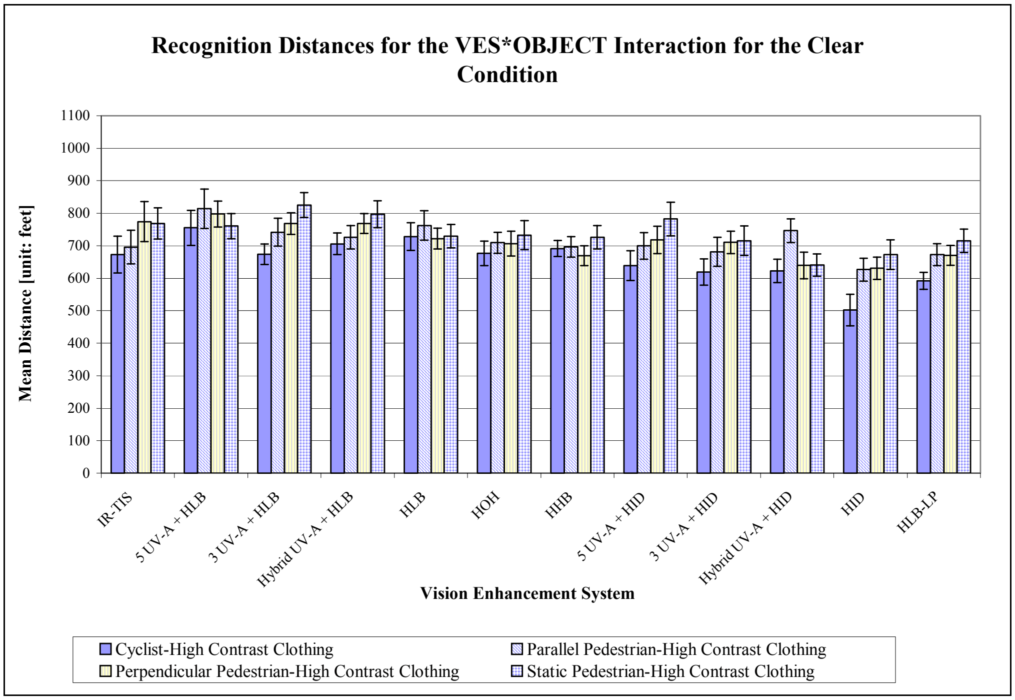


(a) High contrast pedestrians and cyclist

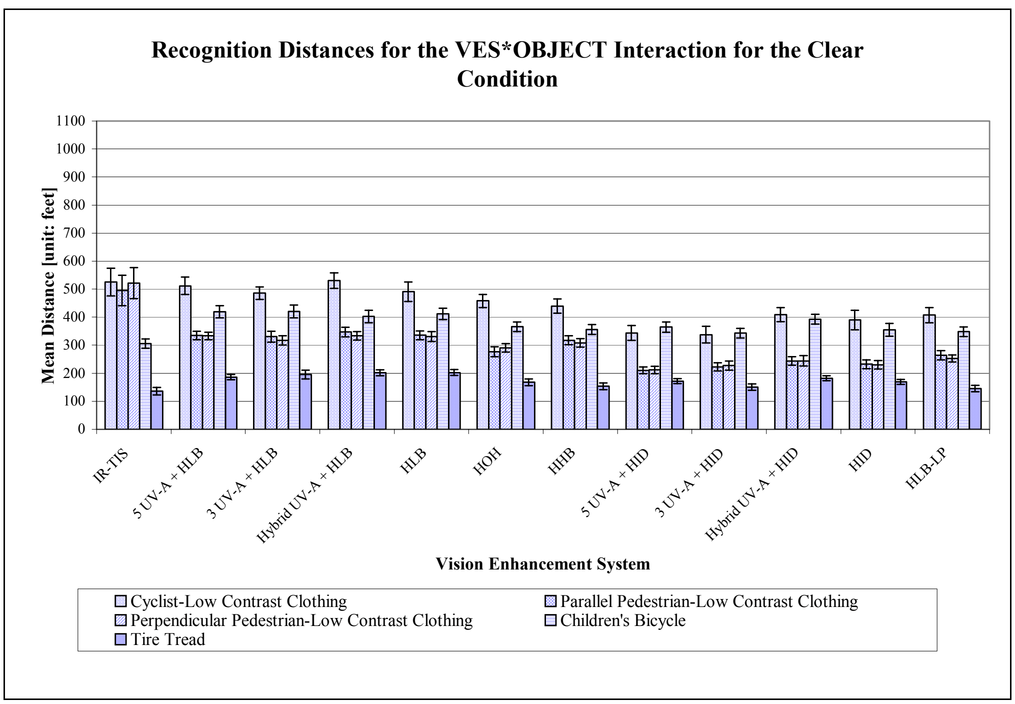


(b) Low contrast pedestrians, cyclist, and other objects

*Figure 3.10 Results on Detection distances for the interaction: VES*Object.*



(a) High contrast pedestrians and cyclist



(b) Low contrast pedestrians, cyclist, and other objects

*Figure 3.11 Results on Recognition distances for the interaction: VES*Object.*

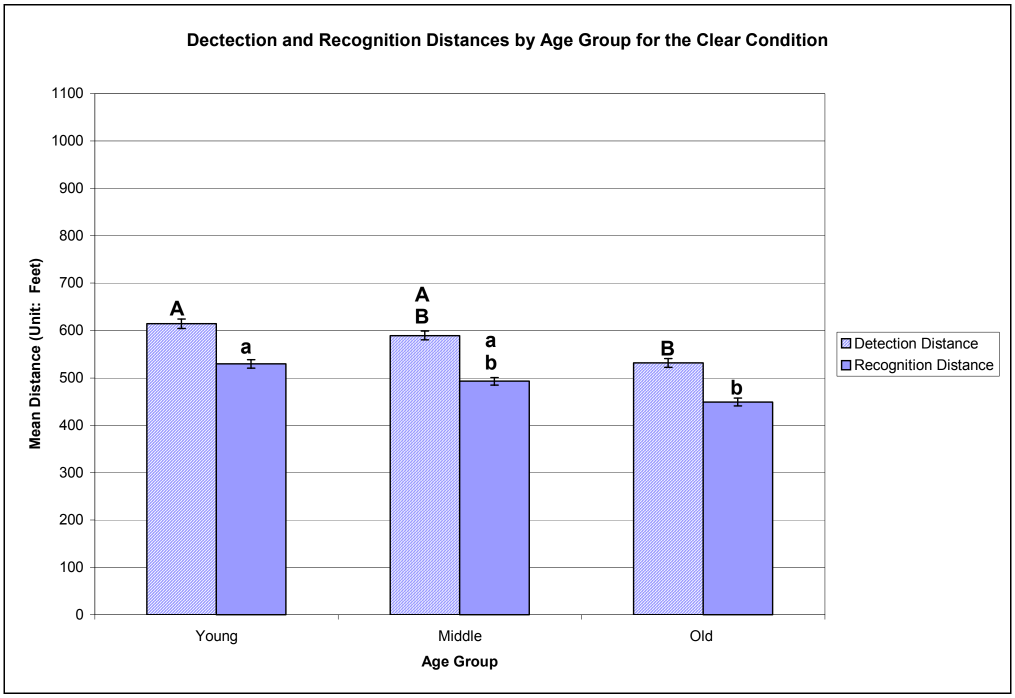


Figure 3.12 Bonferroni post-hoc results on Detection and Recognition distances for the main effect: Age (means with the same letter are not significantly different).

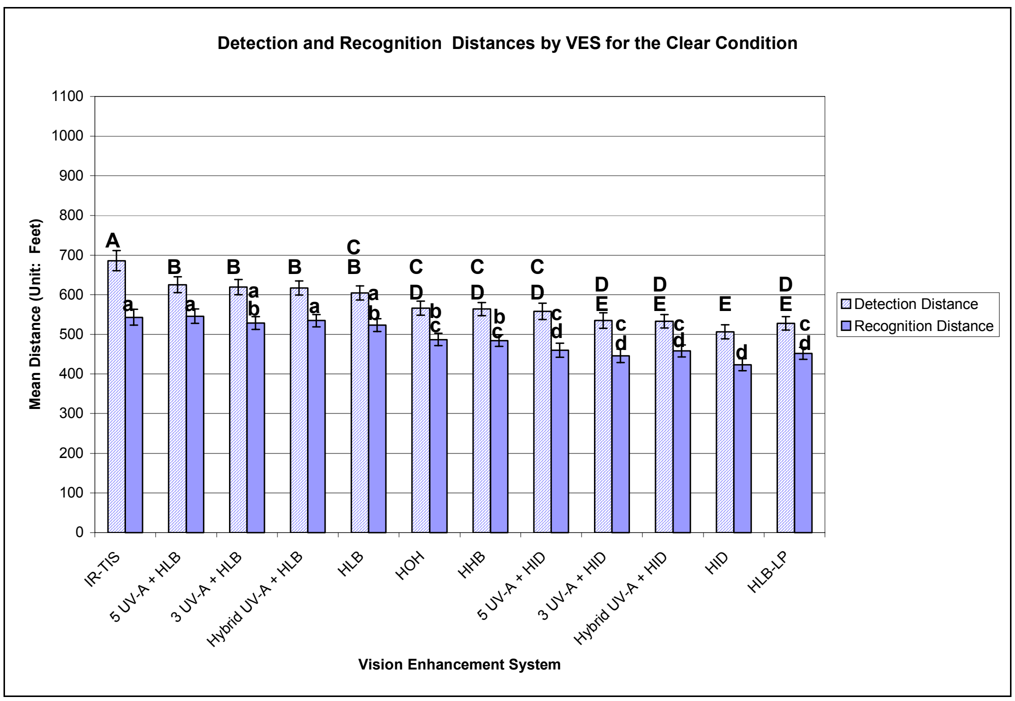


Figure 3.13 Bonferroni post-hoc results on Detection and Recognition distances for the main effect: VES (means with the same letter are not significantly different).

Post-hoc tests for the Type of Object main effect show no significant difference among the Pedestrians-High Contrast Clothing and Cyclist-High Contrast Clothing in terms of Detection. However, the Cyclist-High Contrast Clothing was different from the other three objects in terms of Recognition distance (Figure 3.14). No significant difference was found among the Pedestrians-Low Contrast Clothing in terms of Detection or Recognition. Thus, clothing contrast, rather than object motion, appears to be responsible for the significant differences observed. While there was a significant difference between the Cyclist-Low Contrast Clothing and the Pedestrians-Low Contrast Clothing in terms of Detection and Recognition, it was probable that the increased distances for the Cyclist-Low Contrast Clothing could be attributed to the detection of the bicycle rims rather than detection of the actual cyclist. The Tire Tread and Children'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 Children's Bicycle were shorter than the Cyclist-Low Contrast Clothing but larger than the Pedestrians-Low Contrast Clothing and the Tire Tread.

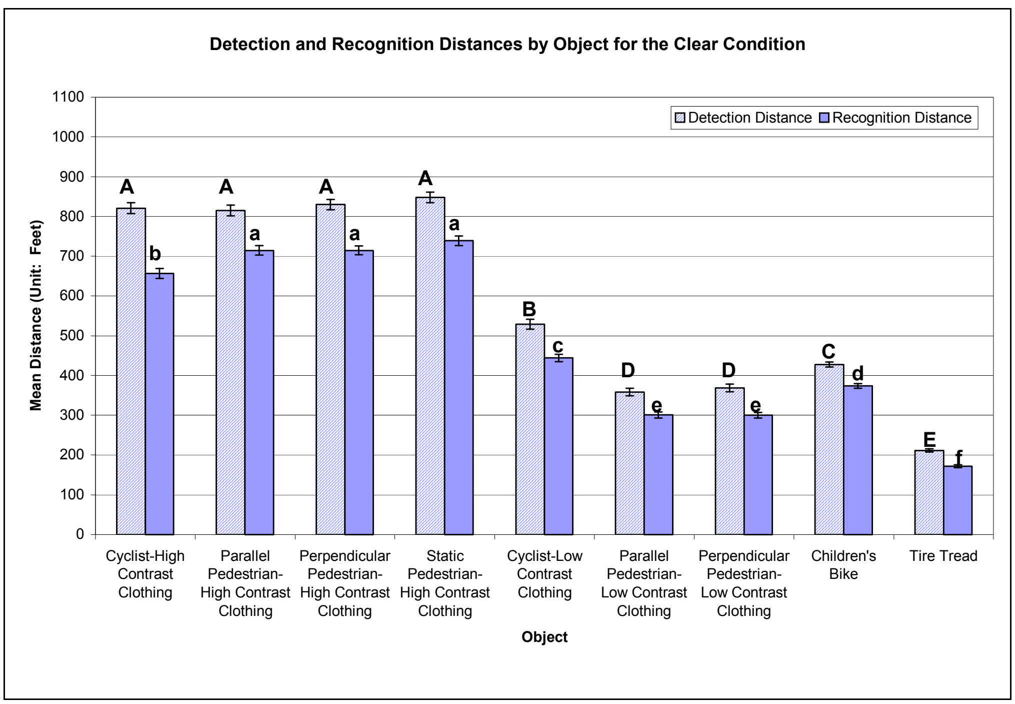


Figure 3.14 Bonferroni post-hoc results on Detection and Recognition distances for the main effect: Object (means with the same letter are not significantly different).

3.2.2 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) x 3 (Age) factorial design. ANOVA summary tables were generated for each of the seven subjective statements (Table 3.8) and the significant main effects and interactions were summarized (Table 3.9).

Table 3.8 ANOVA summary tables for the Likert-type rating scales under clear weather.

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*Age	22	33.1	1.5	1.33	0.1472
*VES*Subject/Age*	296	333.6	1.1		
TOTAL	358	747.8			

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*Age	22	28.6	1.3	1.22	0.2302
*VES*Subject/Age*	296	315.9	1.1		
TOTAL	358	690.7			

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*Age	22	23.2	1.1	1.42	0.1040
*VES*Subject/Age*	296	220.4	0.7		
TOTAL	358	680.6			

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*Age	22	22.9	1.0	1.31	0.1617
*VES*Subject/Age*	296	235.1	0.8		
TOTAL	358	666.7			

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*Age	22	21.0	1.0	0.69	0.8454
*VES*Subject/Age*	296	407.6	1.4		
TOTAL	358	917.2			

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*Age	22	18.5	0.8	0.71	0.8338
*VES*Subject/Age*	296	352.7	1.2		
TOTAL	358	832.0			

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*Age	22	26.4	1.2	0.83	0.6929
*VES*Subject/Age*	296	430.5	1.5		
TOTAL	358	888.9			

* $p < 0.05$ (significant)

Table 3.9 Summary of significant main effects and interactions for the Likert-type rating scales (clear weather).

	Significance Summary per Statement						
Source	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Between							
Age							
Subject/Age							
Within							
VES	x	x			x		
VES*Age							
*VES*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) was the best VES. However, drivers also rated IR-TIS as the lowest (i.e., worst) on effectiveness of the system for lane keeping assistance and highest producer of visual discomfort, when compared to the other VES. The HID, HHB, and HID with 3 UV-A headlamps were lowest in aiding drivers to detect and recognize objects sooner, with a tendency towards 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 faster Detection and Recognition, better lane keeping assistance, less visual discomfort, and a safer perception of the system. A list of all statements is presented next.

- ***Statement 1:*** This Vision Enhancement System allowed me to detect objects sooner than my regular headlights [1=Strongly Agree; 7=Strongly Disagree].

VES	**Mean Rating**
IR-TIS	1.47
5 UV-A + HLB	2.47
Hybrid UV-A + HLB	2.50
Hybrid UV-A + HID	2.83
5 UV-A + HID	2.87
3 UV-A + HLB	2.97
HOH	2.97
HLB-LP	3.14
HLB	3.17
3 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
5 UV-A + HLB	2.50
Hybrid UV-A + HLB	2.57
Hybrid UV-A + HID	2.83
3 UV-A + HLB	2.90
HOH	2.97
5 UV-A + HID	3.00
HLB	3.07
HLB-LP	3.10
HHB	3.30
HID	3.37
3 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
5 UV-A + HID	3.10
HLB-LP	3.14
5 UV-A + HLB	3.17
Hybrid UV-A + HLB	3.17
HOH	3.17
HID	3.17
3 UV-A + HID	3.30
3 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
5 UV-A + HLB	3.00
HOH	3.07
Hybrid UV-A + HLB	3.17
5 UV-A + HID	3.20
HHB	3.23
Hybrid UV-A + HID	3.23
HLB	3.33
IR-TIS	3.40
3 UV-A + HLB	3.40
HID	3.47
HLB-LP	3.48
3 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
5 UV-A + HLB	2.20
HLB	2.23
HOH	2.23
Hybrid UV-A + HLB	2.30
3 UV-A + HLB	2.37
Hybrid UV-A + HID	2.40
HLB-LP	2.48
5 UV-A + HID	2.57
HHB	2.60
HID	2.77
3 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
5 UV-A + HLB	2.87
Hybrid UV-A + HLB	2.97
Hybrid UV-A + HID	2.97
HOH	3.03
HLB-LP	3.10
3 UV-A + HID	3.13
HLB	3.17
3 UV-A + HLB	3.20
HHB	3.27
5 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
5 UV-A + HLB	2.57
Hybrid UV-A + HLB	2.73
HOH	2.87
Hybrid UV-A + HID	2.87
HLB	3.07
3 UV-A + HLB	3.13
3 UV-A + HID	3.13
HHB	3.17
5 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 3.9). 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 3.15). 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 lowest mean rating (Figure 3.16). The Recognition rating was not as low 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 (5 UV-A, 3 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 towards neutral for that statement, but all other VESs align along the center of the agree region (Figure 3.17).

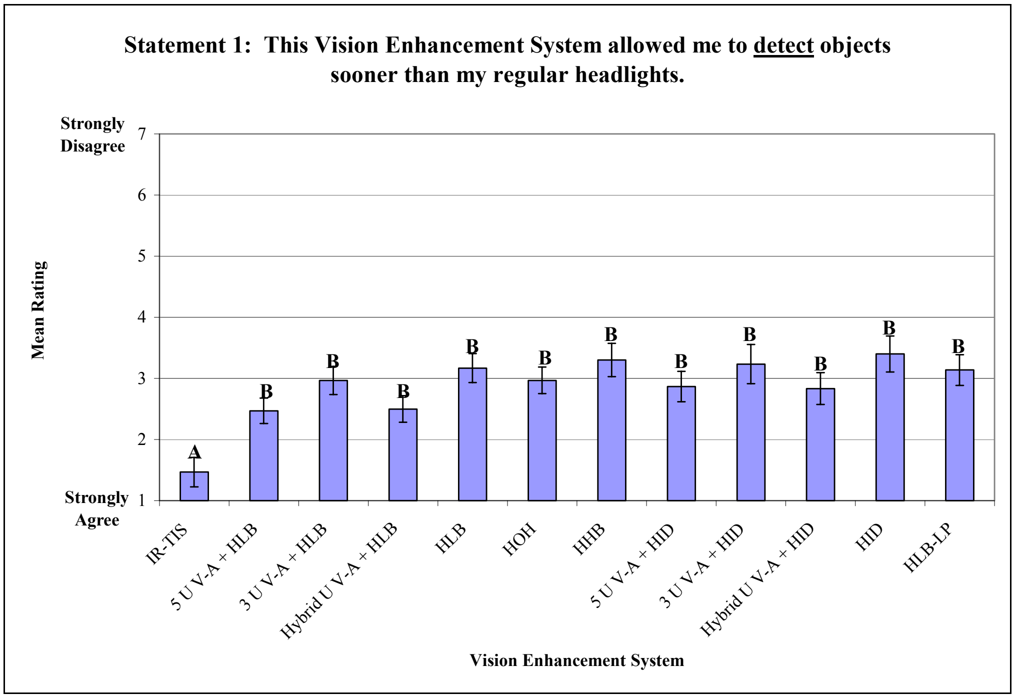


Figure 3.15 Bonferroni post-hoc results on the ratings evaluating Detection for the main effect: VES (means with the same letter are not significantly different).

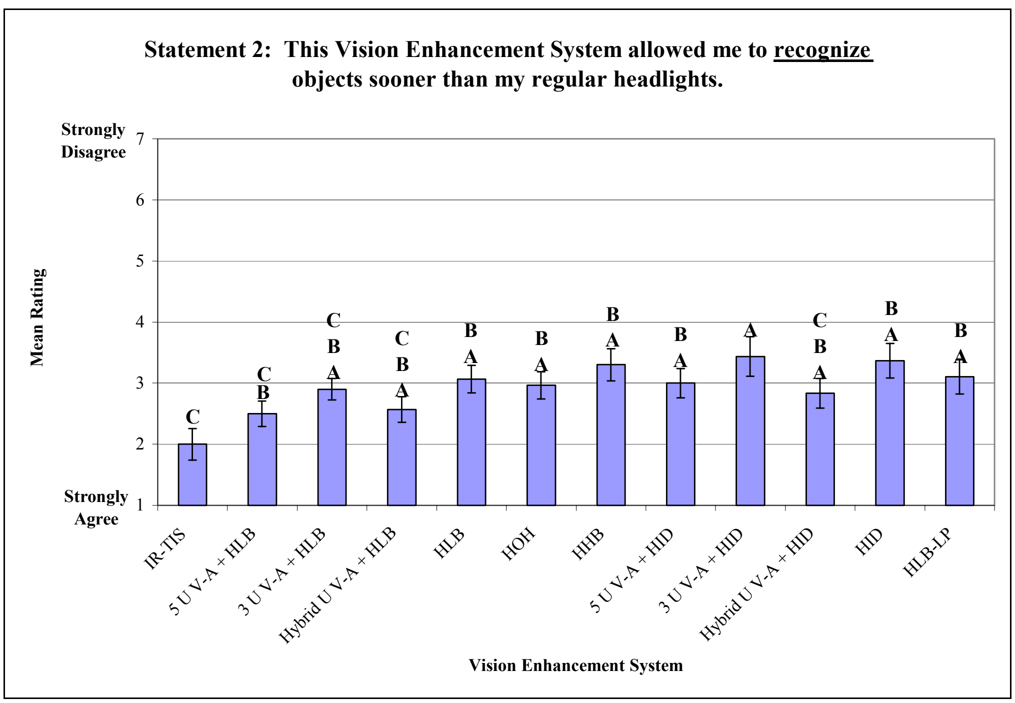


Figure 3.16 Bonferroni post-hoc results on the ratings evaluating Recognition for the main effect: VES (means with the same letter are not significantly different).

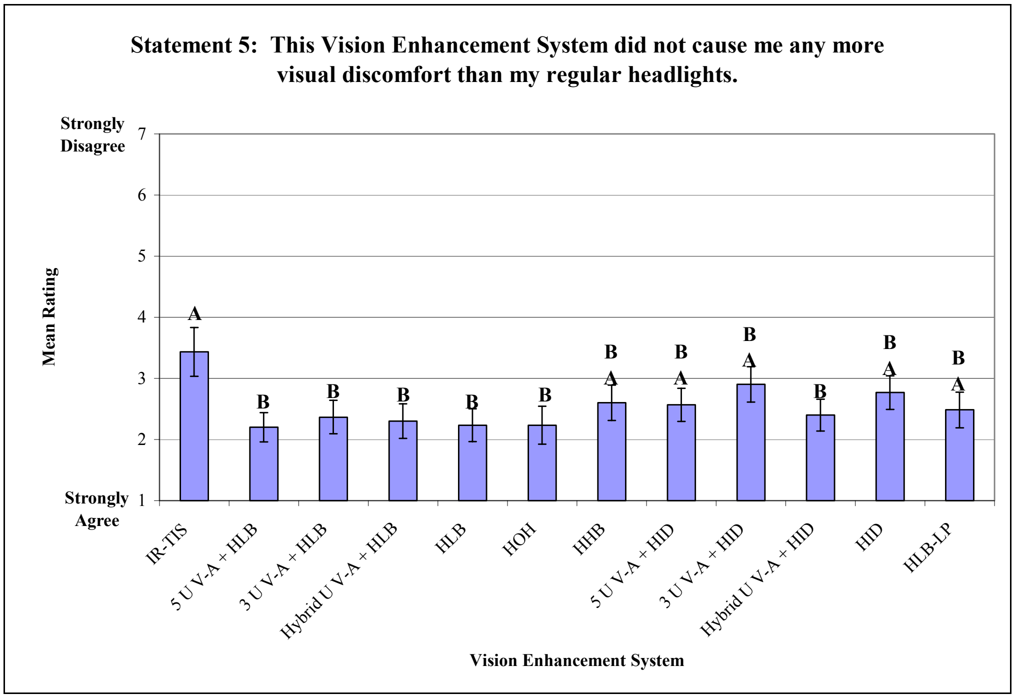


Figure 3.17 Bonferroni post-hoc results on the ratings evaluating visual discomfort for the main effect: VES (means with the same letter are not significantly different).

4 STUDY 2: ADVERSE WEATHER AND RISK PERCEPTION

The experimental tasks for Study 2 consisted of driving during nighttime with the assistance of 12 different VES configurations under rainy atmospheric conditions (as opposed to clear conditions in Study 1) followed by an interview process to evaluate driver risk perception. Detection and Recognition distances assessed visual performance during nighttime driving. The interview process occurred at the end of the second night after all the performance data were collected.

The performance portion of the study took place at the Smart Road testing facility on two consecutive nights. The road was closed off to all traffic except for experimental vehicles. There were no more than two experimental vehicles on the road at one time. The interviews took place at VTTI. The following details characterized Study 2.

4.1 Methods

4.1.1 Participants

Thirty individuals different from the individuals in Study 1 participated in Study 2. This study was divided into three different age categories. Ten participants were between the ages of 18 and 25 (younger category of drivers), ten were between the ages of 40 and 50 (middle-age category of drivers), and ten were over 65 (older category of drivers). Five male and five females comprised each age category. Participants received $20 per hour. Participation was allowed after a Screening Questionnaire was completed and only if the selection conditions were fulfilled (Appendix 1). Participants had to successfully comply with the following: (1) sign an Informed Consent form (Appendix 2), (2) present a valid driver's license, (3) successfully pass the visual acuity test (Appendix 3) with a score of 20/40 or better (as required by Virginia State Law), and (4) have no health conditions that made operating the research vehicles a risk.

Two participants performed the experiment simultaneously. Each participant attended one training session and two experimental sessions. In the training session, the study was described and the forms and questionnaires were filled out (Appendices 2-4). A driving practice using the HUD that presents images captured by the IR-TIS and a familiarization process with all the experimental protocols (Appendices 5 and 6) were also included in the training session.

During each of the two experimental sessions, the participant experienced six different VES configurations. The first experimental session included a familiarization lap on the Smart Road and a detection/recognition practice. Each experimental session lasted approximately 3.5

hours. The presentation orders for each VES and object combination were counterbalanced (an example is shown in Table 4.1). A detailed explanation of each of the VES configurations will be presented in Section 4.1.3. The VES configurations were defined as follows:

- Halogen Low Beam [HLB]
- Hybrid UV-A/Visible output together with Halogen Low Beam [Hybrid UV-A + HLB]
- Three UV-A headlamps together with Halogen Low Beam [3 UV-A + HLB]
- Five UV-A headlamps together with Halogen Low Beam [5 UV-A + HLB]
- Halogen Low Beam 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 High Intensity Discharge [Hybrid UV-A + HID]
- Three UV-A headlamps together with High Intensity Discharge [3 UV-A + HID]
- Five UV-A headlamps together with High Intensity Discharge [5 UV-A + HID]
- Infrared Thermal Imaging System [IR-TIS]

All 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.

Table 4.1 Example of the VES configuration order for a pair of participants

Participant 1, Night 1

Order	VES	Vehicle
13	Practice	
1	5 UV-A + HID	Wht. Explorer
2	HLB	Blk. Explorer
3	HOH	Pick-up
4	3 UV-A + HID	Wht. Explorer
5	IR-TIS	Cadillac
6	Hybrid UV-A + HLB	Blk. Explorer

Participant 2, Night 1

Order	VES	Vehicle
13	Practice	
1	HLB	Blk. Explorer
2	HOH	Pick-up
3	Hybrid UV-A + HLB	Blk. Explorer
4	IR-TIS	Cadillac
5	5 UV-A + HID	Wht. Explorer
6	3 UV-A + HID	Wht. Explorer

Participant 1, Night 2

Order	VES	Vehicle
7	HLB-LP	Cadillac
8	5 UV-A + HLB	Wht. Explorer
9	HHB	Pick-up
10	HID	Blk. Explorer
11	3 UV-A + HLB	Wht. Explorer
12	Hybrid UV-A + HID	Blk. Explorer

Participant 2, Night 2

Order	VES	Vehicle
7	3 UV-A + HLB	Wht. Explorer
8	Hybrid UV-A + HID	Blk. Explorer
9	5 UV-A + HLB	Wht. Explorer
10	HLB-LP	Cadillac
11	HID	Blk. Explorer
12	HHB	Pick-up

4.1.2 Experimental Design

A mixed factor design was used for the data collection of the on-road portion of the study (i.e., different detection and recognition tasks, Table 4.2). 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 4.2 Experimental design: 12 x 3 x 7 mixed factor design (12 VES configurations, 3 age groups, 7 objects)

		Age Groups		
VES Configuration		Young	Middle	Older
1	HLB			
2	Hybrid UV-A + HLB			
3	3 UV-A + HLB			
4	5 UV-A + HLB			
5	HLB-LP			
6	HHB			
7	HOH			
8	HID			
9	Hybrid UV-A + HID			
10	3 UV-A + HID			
11	5 UV-A + HID			
12	IR-TIS			

	Male	Female
Young: 18 to 25	5	5
Middle: 40 to 50	5	5
Older: 65 +	5	5

	Object
DYNAMIC	Parallel Pedestrian-Low Contrast Clothing
	Perpendicular Pedestrian-Low Contrast Clothing
	Parallel Pedestrian-High Contrast Clothing
	Perpendicular Pedestrian-High Contrast Clothing
	Cyclist-High Contrast Clothing
STATIC	Tire Tread
	Children's Bicycle

4.1.3 Independent Variables

VES Configuration, Age, and Type of Object were the independent variables used in the experiment. The Age factor had three levels: younger participants (18 – 25 years), middle-age participants (40 – 50 years) and older participants (65 year or older). These age groups were created based on literature review findings that suggest changes in vision during certain ages (Mortimer, 1989; Richards, 1966; Richards, 1972; Weale, 1961; Weymouth, 1960).

These 12 VES configurations tested (Section 4.1.1) were selected based on several considerations. The HLB and the HID headlamps are currently available on the market and are what most drivers have traditionally used in their vehicles. Therefore, they were added as baseline conditions in order 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 due to 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 employ the UV-A headlamps had to be paired with baseline headlamps, since UV-A headlamps provide minimal visible light. These UV-A headlamps stimulate the fluorescent properties of objects contacted with the UV wave in order to produce visible light. Their purpose is to complement the regular headlamps, not to eliminate their use. These UV-A and baseline pairings resulted in six different UV configurations, three where the pairing was made with HLB lamps and three where HID lamps were used. The three UV conditions inside each pairing category were due to the use of three different forms of UV headlamp configurations: 5 UV-A, 3 UV-A, or UV-A Hybrid. The Hybrid UV-A headlamp is an experimental prototype that has a significant amount of visible light but not enough to drive without low-beam headlamps. The ABM-1 spotlight UV-A headlamps (used for the 5 UV-A and 3 UV-A configurations) have less visible light.

The HHB configuration was included to compare Detection and Recognition distances of any new system with the commonly available halogen headlamp in a high-beam position. Also, 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 very early Detection of pedestrians, cyclists, or animals (i.e., objects generating heat) on the roadway.

The objects selected for this study were pedestrians, cyclists, and static objects. The main reason to include the pedestrians and cyclists was the high crash fatality rates for these non-motorists (NHTSA, 1999). Real pedestrians and cyclists were used to evaluate the effects of object motion on Detection and Recognition distances. Although pedestrian mock-ups have been used in previous research of this type (Chrysler et al., 1997), actual pedestrians and cyclists seemed more appropriate, especially in terms of understanding the effects of motion. Moreover, the use of mock-ups would have improperly restricted the performance capabilities of VESs that use the motion and temperature characteristics of the object of interest, and would have limited the external validity of this study.

Pedestrians and cyclists were presented to the participants at two different contrast levels: (1) with low contrast clothing, and (2) with high contrast clothing. The dynamic pedestrians were walking in two different directions: (1) perpendicular to the vehicle path, representing a pedestrian that is crossing the road; and (2) parallel to the vehicle path, representing a pedestrian that is walking along the shoulder.

Two objects other than pedestrians or cyclists were also used: a Children's Bicycle and Tire Tread. The Children's Bicycle was a 10 in bicycle and the Tire Tread was obtained from a 28 x 9 in steel belted truck radial tire. The Tire Tread was selected due to its potential for very low Detection distances, which often leads to last moment object avoidance maneuvers. The Children's Bicycle was intended to represent the possible presence of a child in the area.

For both static and dynamic objects, participants were required to first detect (e.g. "I see something") and then correctly recognize the objects (e.g. "I see a person," or "I see a cyclist"). A total of seven different objects were presented (Table 4.3 and Figure 4.1).

The reflectivity of the object was calculated using the assumption that the object of interest is a Lambertian (diffuse in all directions) reflector (R. Gibbons, personal communication, February 11, 2001). If this assumption is made, the reflectivity is calculated from the incident illuminance and the object luminance. This is determined through the equation $\rho = (L*\pi)/E$, where ρ is the reflectivity, E is the incident illuminance, L is the object Luminance, and π is a Lambertian constant. The reflectivity of most of the objects was determined using this relationship.

Some objects reflect specularly rather than diffusely. These are shiny objects such as bicycle parts. This means that reflectivity has a directional component and the Lambertian assumption is not valid. For these objects, the specular reflectivity in a given direction is calculated through the equation $\rho = L/E$. In both cases, the reflectivity is a ratio usually expressed in percent and does not have specific units. It is important to note that the reflectivity of the objects can only be established under the non-UV equipped VESs. If the UV-A equipped

VESs are used, the measured luminance contains both the reflected light and the light generated through the fluorescence of the clothing material.

Table 4.3 Description of the objects.

OBJECT	REFLECTANCE AT 50 FT [%]	LOCATION	SPECIAL INSTRUCTIONS
Parallel Pedestrian-Low Contrast Clothing	3.83	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-High Contrast Clothing	21.80	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-Low Contrast Clothing	3.83	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-High Contrast Clothing	21.80	Straight (perpendicular) line between white line and center line.	Wear white clothing. Walk to center line, then walk backward to white line. Repeat.
Cyclist-High Contrast Clothing	21.80 (Cyclist) 27.00 (Specular – Bicycle Rims)	Between white lines in front of location.	Wear white clothing. Ride bike in circles across the road, from white line to opposite white line.
Tire Tread	6.00	Centered on white line.	None.
Children’s Bicycle	18.05	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.

In Study 2 the rain was generated by the All-Weather Testing Facility on the Smart Road. The use of controlled precipitation ensured a constant amount of precipitation throughout the data collection effort. The precipitation rate selected was 4 in per hour, which forced most of the participants to use the vehicles’ windshield wipers at a high speed.

(a) Pedestrian
Low Contrast

(b) Cyclist
High Contrast

(c) Pedestrian
High Contrast

(d) Children's Bicycle

(e) Tire Tread

Figure 4.1 Objects presented on Study 2.

4.1.4 Objective Dependent Variables

Detection and Recognition distances were obtained to analyze the degree to which the different VES configurations enhanced nighttime visibility while driving. These two variables were selected due to their common use and acceptance in the human factors transportation literature (Barham et al., 1998b; Hodge and Rutley, 1978; Lunenfeld and Stephens, 1991; Nilsson and Alm, 1996; Stahl et al., 1998). 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 participant 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.

4.1.5 Subjective Ratings

4.1.5.1 Safety and Comfort Questionnaire

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 one (indicating "Strongly Agree") and seven (indicating "Strongly Disagree"). The statements addressed each participant's perception of improved vision, safety, and comfort after experiencing a particular VES. Participants were asked to compare the VES that they were evaluating at a given point in time with their "regular headlights" (i.e. the headlights on their own vehicle). The assumption was made that for each participant, their own vehicle represented what they knew best and, therefore, were most comfortable using. The statements used for the questionnaire were:

- 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.

4.1.5.2 Likelihood and Carefulness Questionnaire

Two additional subjective ratings were included in Study 2. The 12 different VESs were compared based on how they affected each driver's likelihood of driving at night, given adverse weather conditions. Driver's mobility at night can be improved by identifying VESs that make drivers more comfortable and safe when driving at night. The systems were also compared based on their effect on the driver carefulness while using the system, again given adverse weather conditions. Carefulness has been highly correlated to risk severity in previous studies, suggesting that precaution intent is a good predictor of severity (Wogalter, Brems, and Martin, 1993). In addition, carefulness allows for verification of the construct validity of likelihood (i.e., supported if a high negative correlation between the two ratings is found). The rating scales were phrased as follows:

- Please rate the likelihood of you driving at night in rainy conditions with this Vision Enhancement System.

1	2	3	4	5	6	7
Extremely Likely						***Not at all Likely***

- How carefully would you drive in rainy conditions at night with this Vision Enhancement System?

1	2	3	4	5	6	7
Extremely Careful						***Not at all Careful***

4.1.6 Safety Procedures

Safety procedures were implemented as part of the instrumented vehicle system. These procedures were implemented to minimize possible risks to participants during the experiment. The safety measures required that: (1) all data collection equipment was mounted such that it, to the greatest extent possible, did not pose a hazard to the driver in any foreseeable instance; (2) participants wear the seatbelt restraint system anytime the car was on the road; (3) none of the data collection equipment interfered with any part of the driver's normal field-of-view; (4) a trained in-vehicle experimenter was in the vehicle at all times; and (5) an emergency protocol was established prior to testing.

The pedestrians and cyclists on the road were trained on 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.

4.1.7 Apparatus and Materials

On-road driving was conducted using four vehicles. The experimental vehicles were two Ford Explorers, a GM Pick-up Truck, and a Cadillac DTS. All vehicles were equipped with a NiteStar NS-60 distance measuring device (Figure 4.2). The NiteStar measuring device was connected to a laptop computer, which 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 4.3). The VESs were distributed among the different vehicles. Most vehicles had light-bars that allowed the baseline headlamps (i.e., HLB and HID) to be switched out, thereby maintaining a more consistent horizontal and vertical position among the different VESs (Figure 4.4). The HLB-LP and IR-TIS served as the only exceptions, as these were installed by the factory.

Figure 4.2 NiteStar NS-60 distance measuring instrument.

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

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

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

Figure 4.3 Data collection display screen – Adverse weather.

(a) 5 or 3 UV-A +Halogen Low Beam

(b) High Output Halogen or Halogen High Beam

(c) Hybrid UV-A + High Intensity Discharge

(d) Halogen Low Beam – Low Profile Infrared Thermal Imaging System

Figure 4.4 Examples of VES configurations.

4.1.7.1 Smart Road

The All-Weather Testing Facility on the Smart Road was utilized in this study (Figure 4.5). Six different locations were used on the Smart Road to present the different objects (Figure 4.6). The participants changed vehicles on the turn-around next to the entrance of the Smart Road (Figure 4.6). One on-road experimenter was assigned to each participant; this experimenter was responsible for escorting the participant to the next vehicle, showing them where the different controls were, and verifying that the right VES configuration was being tested. Four other on-road experimenters were positioned at the various locations. Two on-road experimenters were assigned to Locations 1 and 5, and two were assigned to Locations 2 and 5. See Appendix 9 for more details on the protocol for the on-road experimenters.

(a) Road facilities

(b) All-Weather testing equipment on the Smart Road

Figure 4.5 Smart Road.

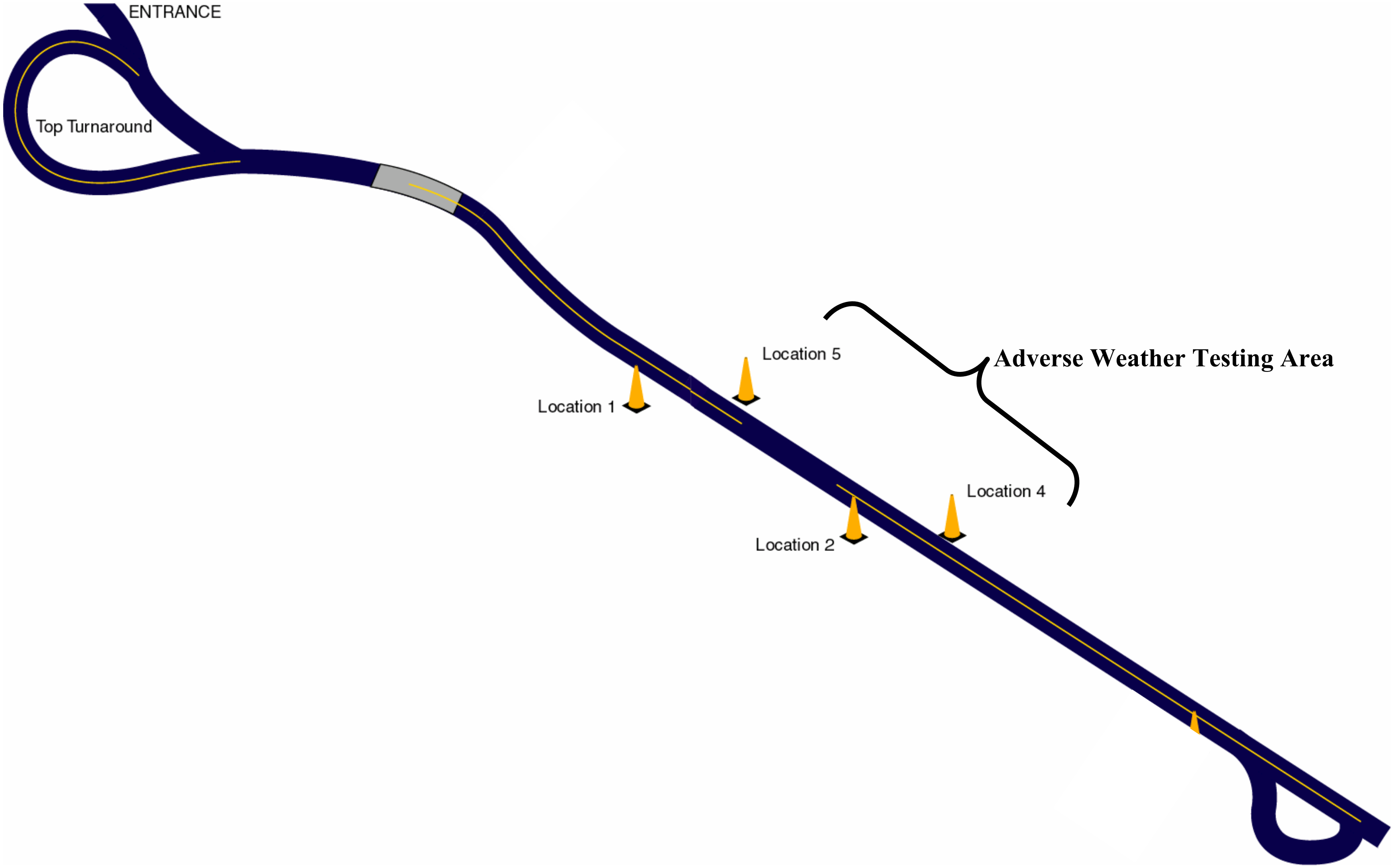


Figure 4.6 Locations where the objects were presented for the adverse weather condition (note the area where rain was generated).

4.1.7.2 Headlamp Alignment

The headlamps used for several of the VES configurations were located on light-bars that were external to the vehicle. These light-bars were used for the HLB, HID, HOH, and UV-A configurations. To eliminate the possibility of confounding the experimental results with the effects of headlamp misalignment, each light assembly movement required a realignment process. The realignment process took place each night before starting the study. The protocol used for alignment was developed with the help of experts in the field (J. Calderas, personal communication, August 22, 2000; J. Erion, personal communication, June 5, 2000; F. F. Dutke, personal communication, June 20, 2000; T. Schnell, personal communication, August 24, 2000). Prior to this effort, no protocol had been established or published for the alignment of prototype/test headlamps. 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" shape angular 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 center of the headlamp 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 "hot spot" is located in the 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 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.
- Fine or gross adjustment should be performed as needed.

The only difference between the alignment of the UV-A or HHB headlamps and this previous headlamp alignment procedure (HID, HLB, and HOH) is that the "hot spot" must be at the center of the crosshairs. The details of the alignment protocol used for this specific study are described in Appendix 10.

4.1.8 Experimental Procedure

The experiment consisted of three sessions. The first session was a screening, laboratory training, and IR-TIS training. The other two sessions were the two nights of the experiment at the Smart Road. The first night the participant was familiarized with the Smart Road and the experimental objects before starting the experiment. A group of six configurations were presented to the participants during the first night and the remaining six configurations were presented during the second night. The order was counterbalanced. Details of the procedures followed are presented next.

4.1.8.1 Participant Screening

Participants were initially screened over the telephone (Appendix 1), and if a participant qualified for the study, a time was scheduled for testing. Participants were instructed to meet the experimenter at VTTI. After arriving at VTTI, an overview of the study was presented to each participant. Subsequently, each participant was asked to complete the Informed Consent Form (Appendix 2), and take an informal vision test for acuity using a Snellen chart and Contrast Sensitivity Test (Appendix 3). The vision test was performed to ensure that all participants had at least 20/40 vision and to identify any type of vision disparity that might have influenced the results. After these steps were completed, and if no problems were identified, the participant was trained on the experimental tasks to be performed during the drive. A detailed experimenter protocol for vision testing is presented as part of Appendix 5.

4.1.8.2 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 (Appendices 5 and 6). The Detection and Recognition definitions, the use of the push button 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 with the IR-TIS took place, and examples of the objects shown during the experimental sessions were presented as part of the training practice.

4.1.8.3 Familiarization

Given that 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 on-road experimenter/valet reviewed general information concerning the operation of the test vehicle (Appendix 11). Each participant was asked to adjust the vehicle seat and steering wheel position controls for his/her driving comfort. When the participant felt comfortable with the controls of the vehicle, the experiment was ready to start.

4.1.8.4 Driving Instructions

Participants were instructed to remain on the center of the road while driving and to place the vehicle in park upon reaching each of the turnarounds. Due to the rain, participants were instructed to drive at 10 mph during the experimental sessions. Participants were required to follow instructions from the in-vehicle experimenter at all times.

4.1.8.5 Driving and Practice Lap

Each participant drove down the road to become familiar with the road and the vehicle; no objects were presented at this point in time. At the bottom turn-around, the experimenter gave the wand with the push button to the participant and instructed the participant that this portion was a practice to familiarize them with the objects. The participant then drove back up the road for a practice run of a detection and recognition task, obtaining feedback from the experimenter as needed. After the practice tasks, the participants drove with the first group of six VESs corresponding to the order assigned to their first night.

4.1.8.6 General On-Road Procedure

Distance data were collected while each VES was evaluated. The in-vehicle experimenter provided the participant with a push button to flag the data collection program when Detection and Recognition were performed. Other than Detection, Recognition, and maintaining 10 mph, no other tasks were performed by the participants while driving. The experimenter was seated in the passenger seat and let the participant know when he/she could start driving and where to park. The in-vehicle experimenter also administered the questionnaires after each VES configuration and controlled the data collection program. For more details on the in-vehicle experimenter protocol, please refer to Appendix 7.

4.1.8.7 Sequence of Data Collection

Each of the participants followed the same sequence of events in order to collect the data for each of the VES configurations. This sequence was as follows:

1. An object was presented at each of the four Locations for the adverse weather condition.
2. While approaching each Location, the participants pressed the push button when they were able to detect an object.
3. When the participants were able to recognize the object, they pressed the push button 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 the two laps were completed, all the objects for a given VES configuration had been presented and the subjective ratings (a questionnaire was answered for each VES configuration) had been collected.
6. Once all VES configurations were completed, the participants were instructed to return to VTTI to be interviewed (if this was the end of their second experimental session) and debriefed (Appendix 8).

The study was performed twice every night (i.e., first shift: 7:45 pm – 11 pm; second shift: 11:30 pm – 2:30 am). Participants who worked until late and usually drove late at night ran in the second shift to minimize the possibility of fatigue. Other participants ran during the first shift. Payment for the total number of hours (training, experimental session 1, and experimental session 2) was provided after the interview at the end of the second experimental session.

4.1.8.8 Risk Perception Questionnaire and Interview

The nighttime driving risk perception questionnaire (Appendix 12) and elicitation process was administered at the end of the second experimental session. The in-vehicle experimenter escorted each participant to the location used for the private interviews. The driving risk perception questionnaire was administered first, and the participant's ratings on this questionnaire were used as a starting point for the interviews. Verbal responses from the interviews were tape-recorded.

Elicitation is a systematic approach used for data gathering when details are needed about a specific process in a system under study. In the matter at hand, nighttime driving can be considered the process of interest. Although transportation related research traditionally emphasizes performance measurements, the goals of this specific research effort required the gathering of information on perceived risks during nighttime driving, in addition to objective performance data. Therefore, traditional performance measurements were augmented by the use of elicitation methods (Kleiner and Drury, 1998), specifically, the semi-structured interview method. Semi-structured interviews allow the participants (i.e. drivers, in this particular situation) to "fill in the gaps" based on their own perceptions of the information needed about the topics of interest (Shadbolt and Burton, 1995). Thus, the participant expresses his or her own mental model on the topic. With unstructured interviews there is a possibility of failing to discuss specific topics with the participants. To prevent this error, the interviewer in this investigation was guided through the semi-structured interview process by a list of topics that had to be covered before the interview could end (Appendix 12).

The elicitation process explored the perceived risk associated with having several different nighttime scenarios, with the intention of examining the potential effects of vision enhancement on risk perception and mobility during nighttime driving. To establish a baseline to compare against nighttime, equivalent daytime scenarios were presented during the elicitation process (Appendix 12).

4.1.9 Data Analysis

Data for this research were contained in one data file per VES configuration, questionnaire, interview, and participant. All the performance data collected for the 30 participants were merged into a single database that included objective and subjective data. The performance data were evaluated to examine driver visual performance under each of the different treatments. "PROC ANOVA" was used in SAS (SAS Institute, Cary, NC) to compute the ANOVA. The full experimental design model was used in the performance data analysis (Table 4.4).

Table 4.4 Model for the experimental design.

SOURCE
BETWEEN
AGE
SUBJECT(AGE)
WITHIN
VES
AGE*VES
VES*SUBJECT(AGE)
OBJECT
AGE*OBJECT
OBJECT*SUBJECT(AGE)
VES*OBJECT
AGE*VES*OBJECT
VES*OBJECT*SUBJECT(AGE)

ANOVA evaluated whether there were significant differences among the different VESs in terms of dependent variables. The main effects that characterized this study are 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. The reader interested in a detailed discussion of *post-hoc* tests is referred to Winer, et al. (1991).

After all the 30 interviews were transcribed, a Content Analysis (CA) was performed using the HyperRESEARCH (Scolari, CA) software. HyperRESEARCH allows the coding and retrieval of data, the development of theories, and data analyses within an integrated data environment. This software package has been successfully used in the past by many researchers in the social sciences and other fields for similar purposes. The software transforms the interview data into frequency of comments for each of the codes of interest. These frequency data were analyzed using both Chi-Square and ANOVA procedures. While it seems unorthodox to employ ratio data analysis techniques (e.g. ANOVA, regression) on frequency data from the CA, these techniques have been suggested in the literature as valid data analysis methods for CA-generated frequencies (Barley, Meyer, and Gash, 1988; Bettman and Weitz, 1983; Ericsson and Simon, 1984; Gibson, Fiedler, and Barrett, 1993; Kleiner and Drury, 1998; Sims, Jr. and Manz, 1984).

4.2 Results

4.2.1 Objective Measurements

An ANOVA was performed on the objective measurements taken on the Smart Road portion of the study. The model for this portion of the study was a 12 (VES) x 3 (Age) x 7 (Object) factorial design. ANOVA summary tables were obtained for both objective dependent measurements (Table 4.5 and Table 4.6). A total of 2,509 observations were obtained from the experiment for each objective measurement. Several main effects and interactions were considered significant (Table 4.7).

ANOVA results showed no significant differences between the three age groups in terms of Detection (Mean (SE) - Young: 197.7 (2.73) ft, Middle-age: 193.4 (2.66) ft; Older: 193.0 (2.92) ft) and Recognition (Mean (SE) - Young: 174.1 (2.49) ft; Middle-age: 171.4 (2.49) ft; Older: 168.3 (2.71) ft) distances during adverse weather conditions.

Table 4.5 ANOVA summary table for the dependent measurement: Detection distance under adverse weather.

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

* $p < 0.05$ (significant)

Table 4.6 ANOVA summary table for the dependent measurement: Recognition distance under adverse weather.

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

* $p < 0.05$ (significant)

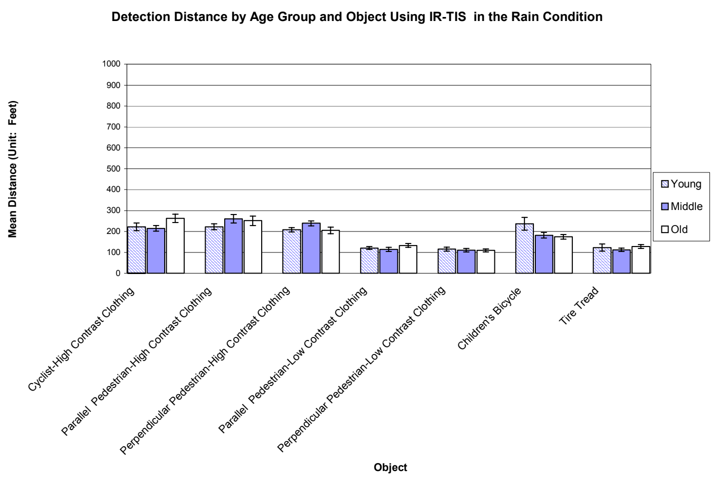
Table 4.7 Summary of significant main effects and interactions (adverse weather).

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

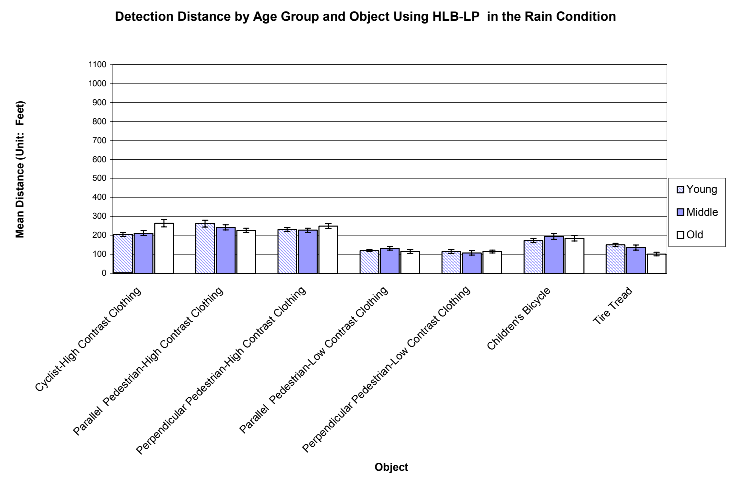
x = $p < 0.05$ (significant)

The main effects of and interactions between VES configuration and Type of Object (Object) were significant ($p < 0.05$) for both visual performance measurements. The VES*Object*Age interaction was significant ($p < 0.05$) only in terms of Detection distances. The results of *post-hoc* tests based on these significant effects were graphed for ease of interpretation (Figure 4.7 to Figure 4.13).

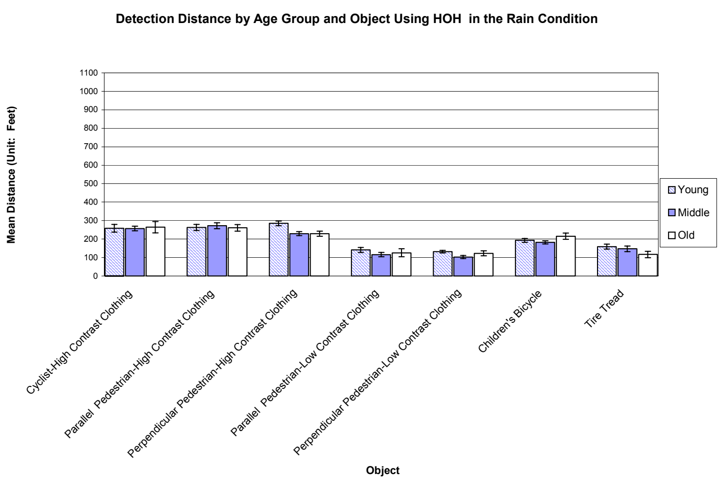
For the three-way interaction VES*Object*Age (Figure 4.7 to Figure 4.9), Detection distances for low contrast objects (i.e., Parallel Pedestrian-Low Contrast Clothing, Perpendicular Pedestrian-Low Contrast Clothing, Tire Tread) under all Age*VES combinations were less than 170 ft. The high contrast objects, on the other hand, were detected at farther distances, ranging from 310 ft to 328 ft. Age did not seem to follow any trends on this three-way interaction. The different Halogen + UV-A configurations resulted in the best Detection distances for all objects. However, the Halogen + UV-A Detection distances represented only an improvement between 20 ft (low contrast or ground level objects) and 90 ft (high contrast objects) over the Halogen (i.e., baseline) configuration.



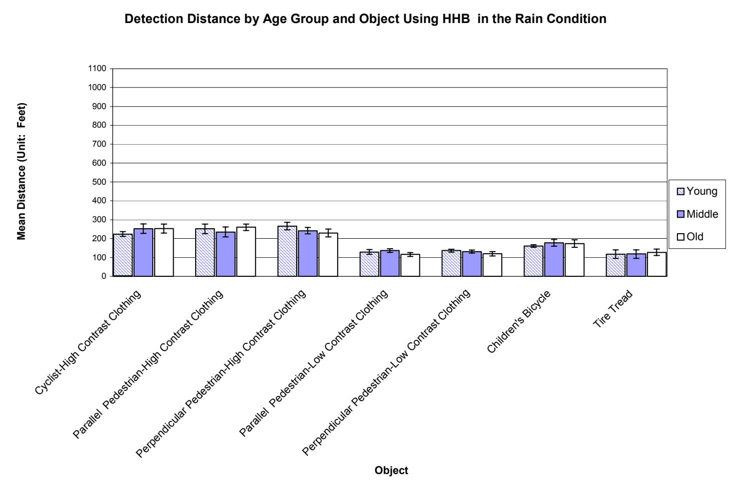
(a) Infrared-Thermal Imaging System



(b) Halogen Low Beam –Low Profile

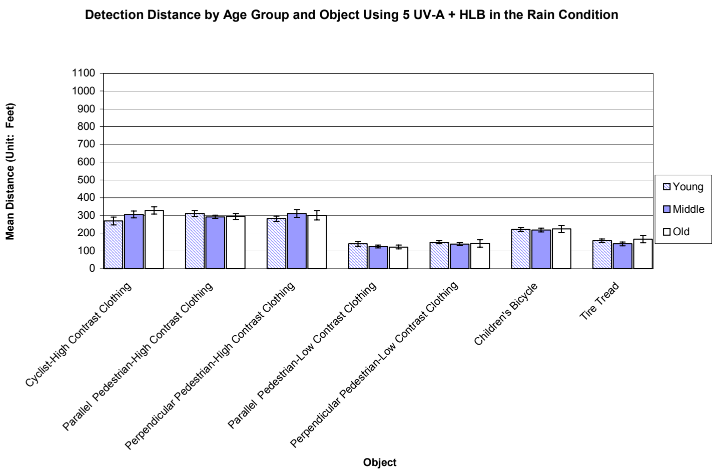


(c) High Output Halogen

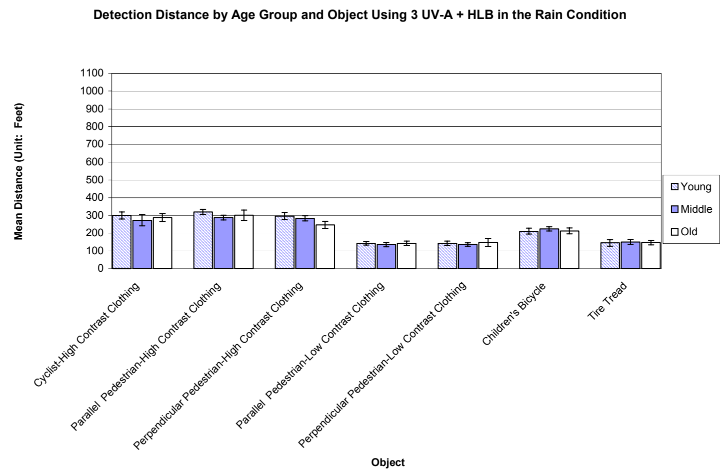


(d) Halogen High Beam

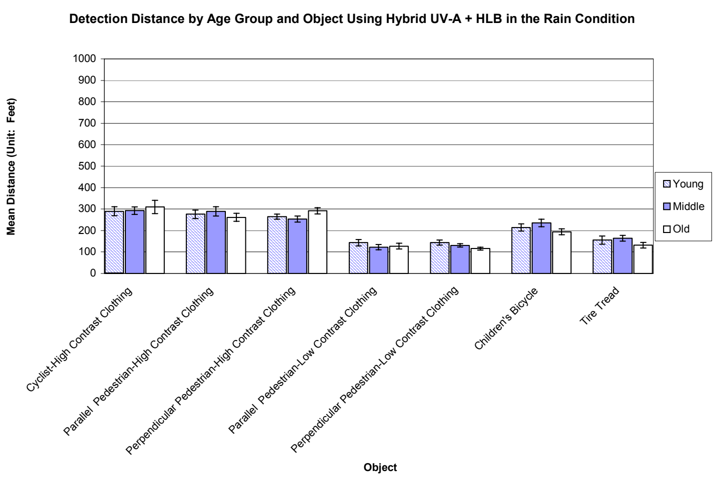
*Figure 4.7 Results for the interaction: VES*Object*Age (Includes: IR-TIS, HLB-LP, HOH, HHB).*



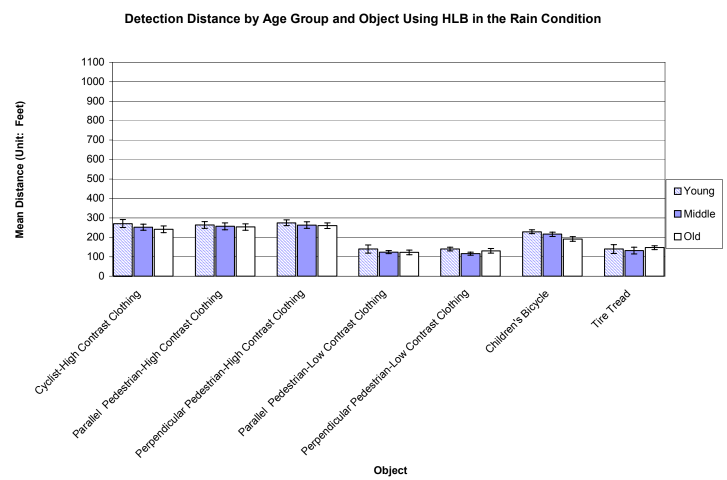
(a) 5 UV-A + Halogen Low Beam



(b) 3 UV-A + Halogen Low Beam

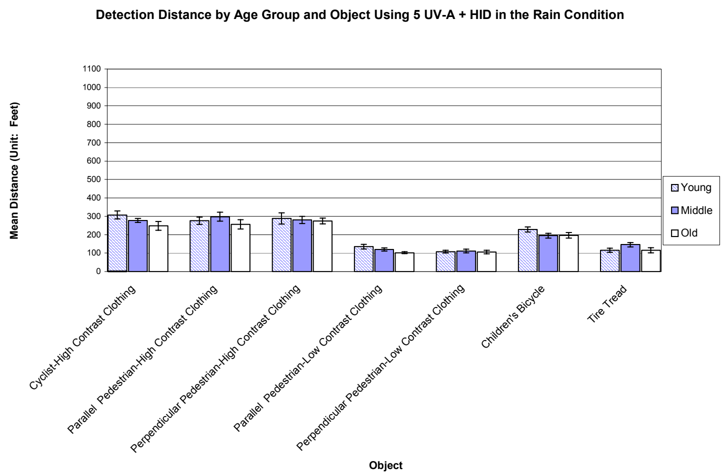


(c) Hybrid UV-A + Halogen Low Beam

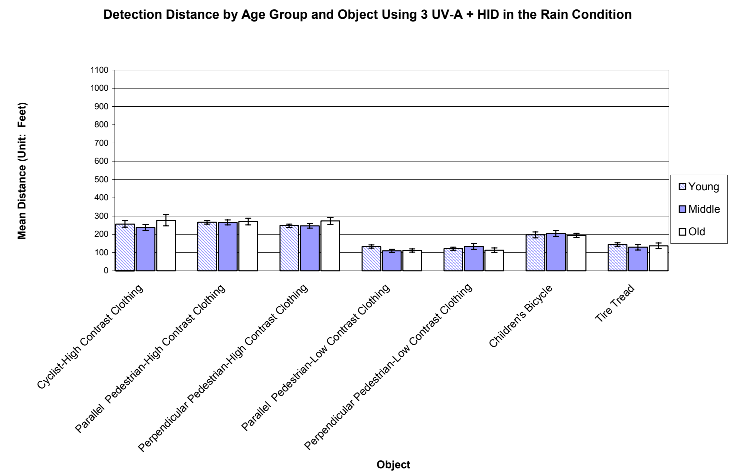


(d) Halogen Low Beam

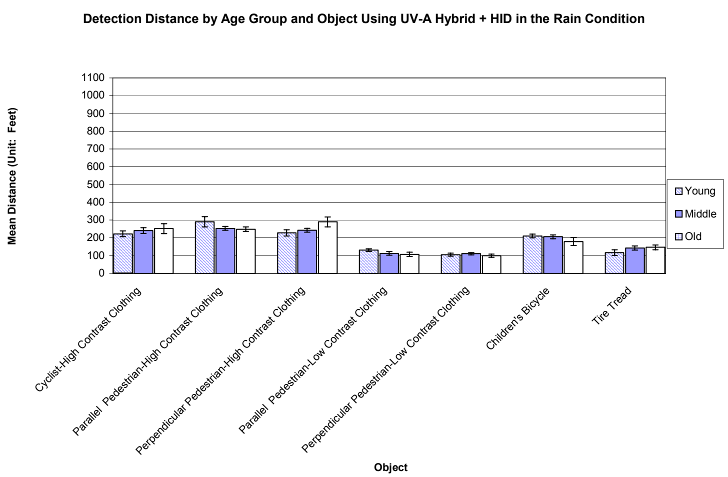
*Figure 4.8 Results for the interaction: VES*Object*Age (Includes: 5 UV-A + HLB, 3 UV-A + HLB, Hybrid + HLB, HLB).*



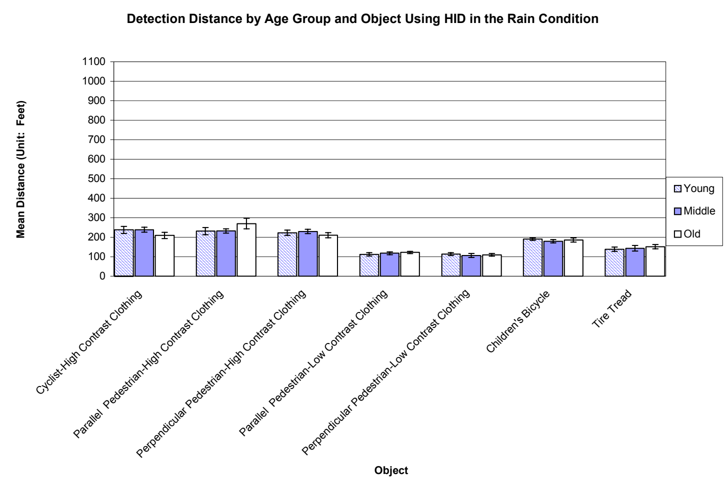
(a) 5 UV-A + High Intensity Discharge



(b) 3 UV-A + High Intensity Discharge

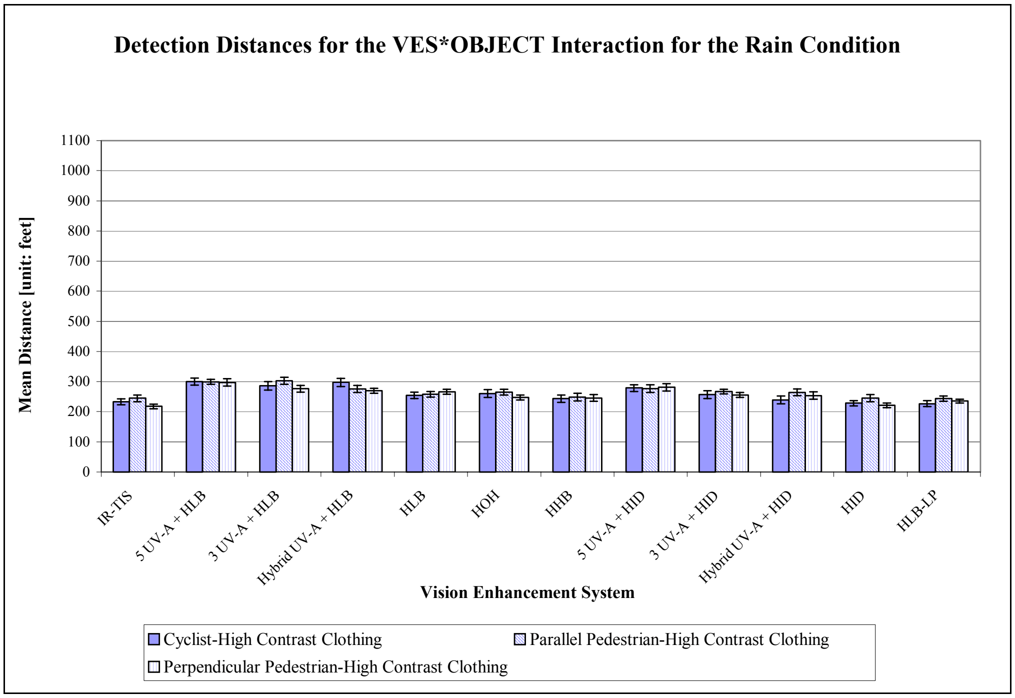


(c) Hybrid UV-A + High Intensity Discharge

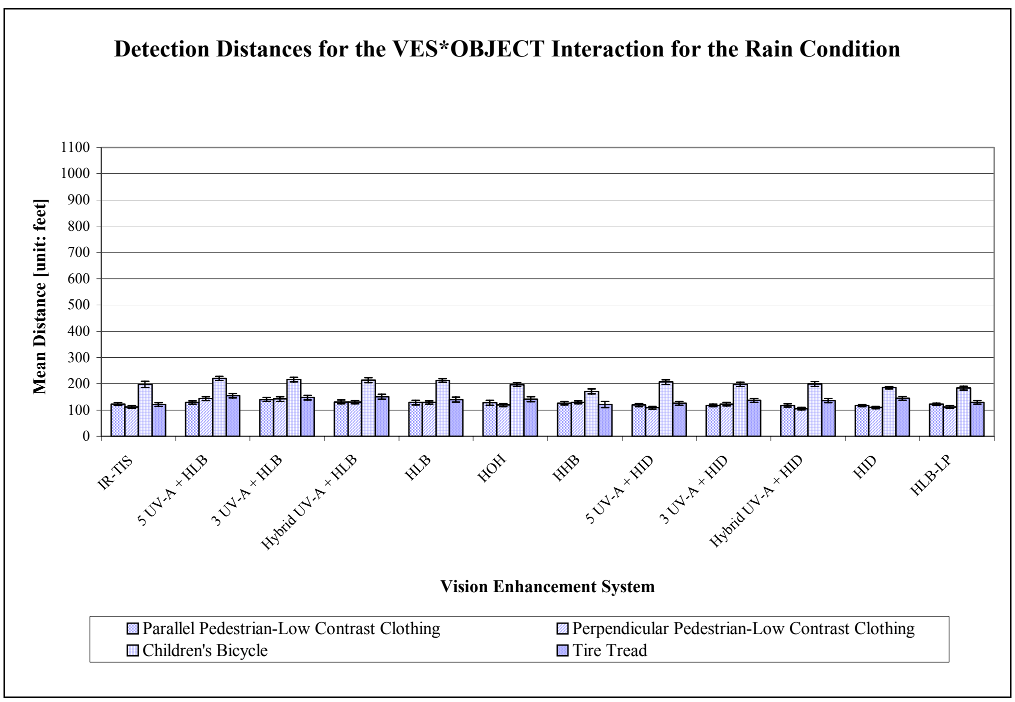


(d) High Intensity Discharge

*Figure 4.9 Results for the interaction: VES*Object*Age (Includes: 5 UV-A + HID, 3 UV-A + HID, Hybrid + HID, HID).*

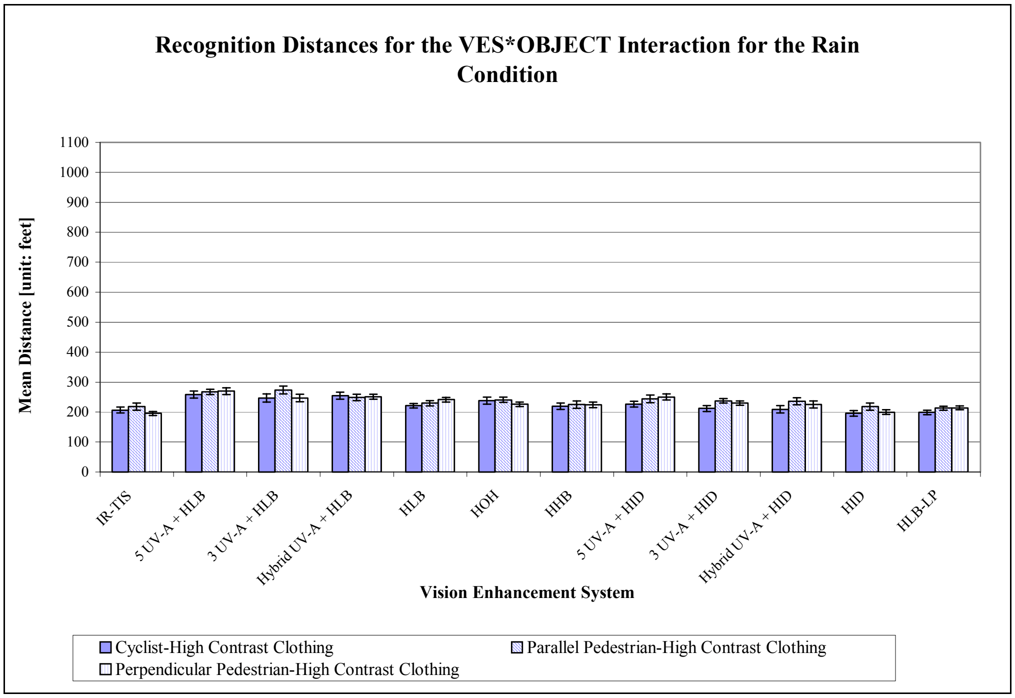


(a) High Contrast Pedestrians and Cyclist

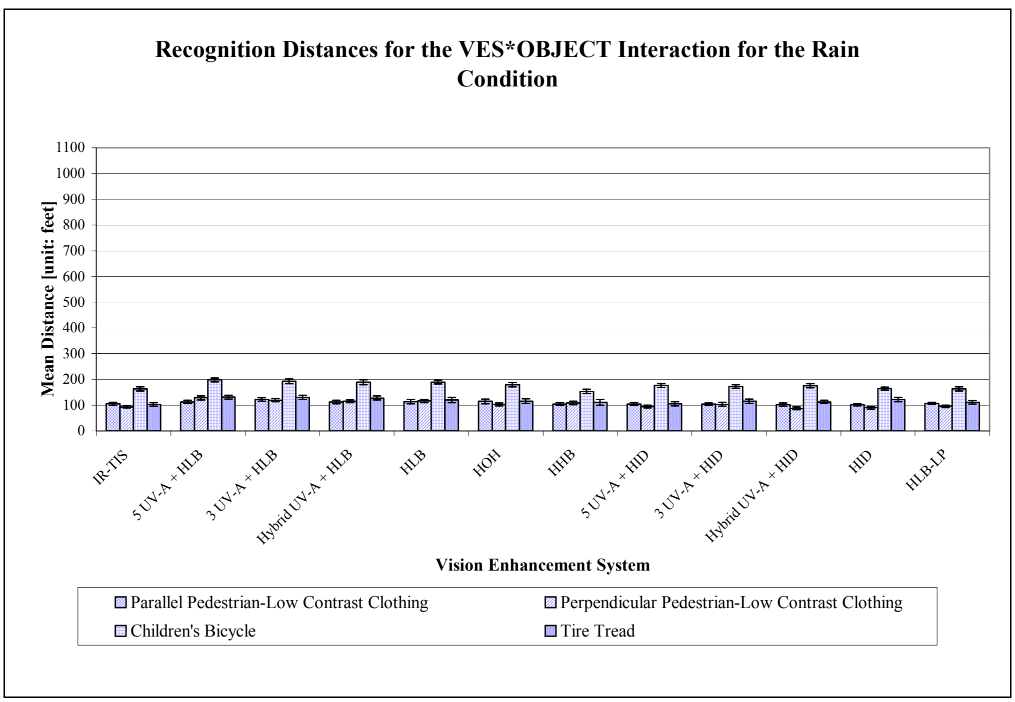


(b) Low Contrast Pedestrians, Cyclist, and other objects

*Figure 4.10 Results on Detection distances for the interaction: VES*Object.*



(a) High Contrast Pedestrians and Cyclist



(b) Low Contrast Pedestrians, Cyclist, and other objects

*Figure 4.11 Results on Recognition distances for the interaction: VES*Object.*

The two sets of objects (i.e., low contrast vs. high contrast) seem to be responsible for the significant VES*Object interaction (Figure 4.10 and Figure 4.11). The type of VES made a considerably smaller contribution than Object to the Detection and Recognition distances. The maximum difference between the mean Detection and Recognition distances for low contrast objects was less than 26 ft across all VESs, and 32 ft for Pedestrians-High Contrast Clothing. Across Objects, the Halogen baseline condition allowed drivers to detect and recognize objects sooner than the HID system. The Halogen system allowed Detection distances between 129 ft (low contrast objects) and 266 ft (high contrast objects), that is 11-45 ft farther away than HID systems. The UV-A assisted HID system had smaller Detection distances that the Halogen baseline for low contrast objects, although a marginal improvement over the baseline (~25 ft) was observed for high contrast objects.

VESs were significantly different ($p < 0.05$) in terms of Detection and Recognition distances obtained from their use. *Post-hoc* analyses showed that the HLB baseline differed from the IR-TIS, HID, HLB-LP, and 5 UV-A + HLB systems (Figure 4.12). However, the magnitude of these differences was relatively small, approximately ±23 ft on average. The Detection and Recognition distances for IR-TIS, HID, and HLB-LP were closer to the object and for the 5 UV-A + HLB configuration were farther away than HLB.

Type of Object was also significant for both Detection and Recognition distances (Figure 4.13). *Post-hoc* test results showed three distinct groups: high contrast clothing, low contrast clothing, and ground objects. This suggests that, overall, the contrast rather than the motion of the object (or lack thereof) caused the observed differences. The high contrast objects were detected and recognized farther away than the other objects. The Detection distance for the Tire Tread and Children's Bicycle were statistically different ($p < 0.05$) from the other objects. The Detection distances for Pedestrians-Low Contrast Clothing were the closest, and their Recognition distances were either as close (i.e., Parallel Pedestrian-Low Contrast Clothing) or closer (i.e., Perpendicular Pedestrian-Low Contrast Clothing) than a Tire Tread. The Children's Bicycle was detected and recognized farther than the Pedestrians-Low Contrast Clothing and the Tire Tread.

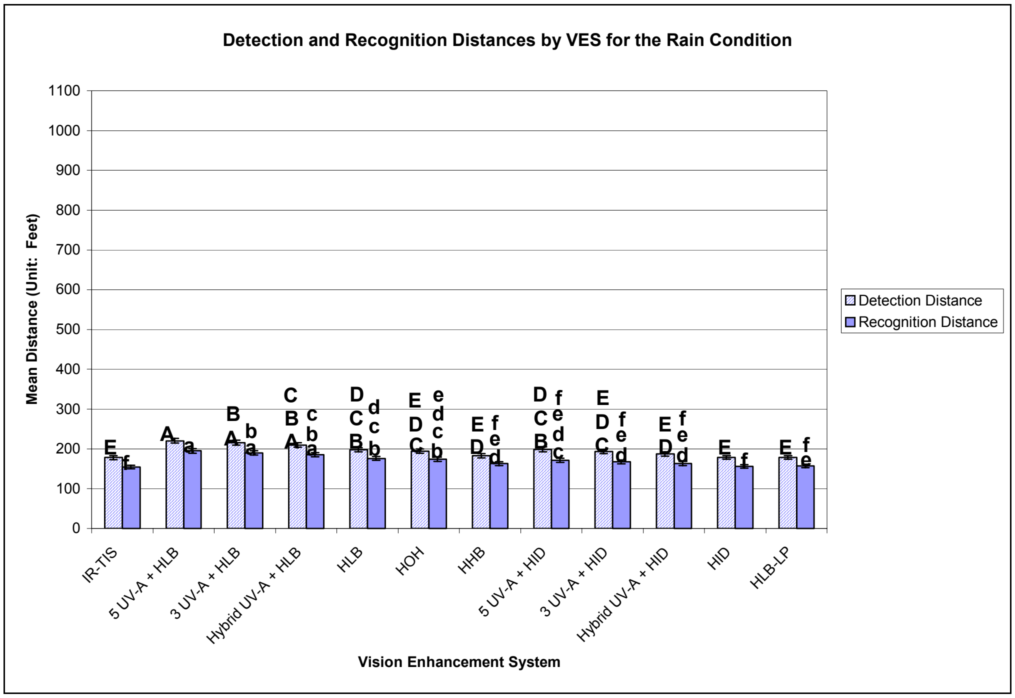


Figure 4.12 Bonferroni post-hoc results for the main effect: VES (means with the same letter are not significantly different).

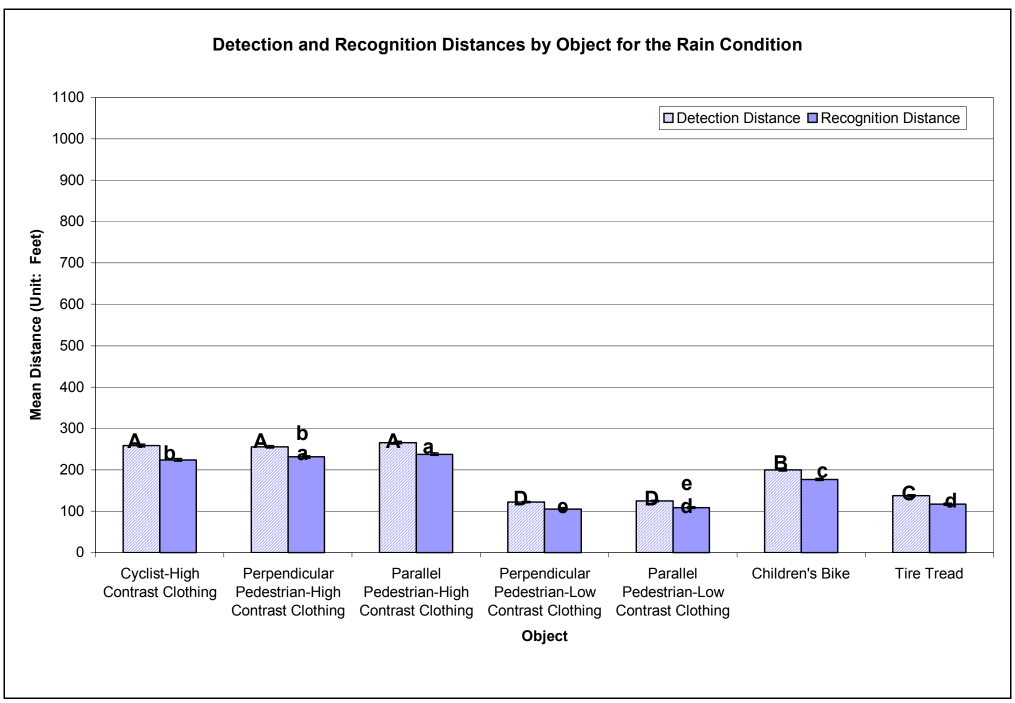


Figure 4.13 Bonferroni post-hoc results for main effect: Object (means with the same letter are not significantly different).

4.2.2 Subjective Measurements

4.2.2.1 Questionnaire Performed After each VES

An ANOVA was performed to analyze the subjective measurements taken on the Smart Road portion of the study. A 12 (VES) x 3 (Age) factorial design was used as a model for this portion of the study. ANOVA summary tables were generated for each of the nine subjective statements (Table 4.8), and significant main effects and interactions were summarized (Table 4.9).

Table 4.8 ANOVA summary tables for Likert-type rating scales (adverse weather).

Statement 1: Detection

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

Statement 2: Recognition

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

Statement 3: Lane keeping assistance

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

Statement 4: Roadway direction

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

Statement 5: Visual discomfort

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

Statement 6: Overall safety rating

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

Statement 7: Overall VES evaluation

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

Statement 8: Likelihood

Source	DF	SS	MS	F value	P value	
Between						
Age	2	1.9	0.9	0.06	0.9458	
Subject/Age	27	447.6	16.6			
Within						
VES	11	207.8	18.9	14.38	<0.0001	*
VES*Age	22	55.6	2.5	1.92	0.0085	*
*VES*Subject/Age*	297	390.2	1.3			
TOTAL	359	1103.1				

Statement 9: Carefulness

Source	DF	SS	MS	F value	P value	
Between						
Age	2	311.3	155.7	16.24	<0.0001	*
Subject/Age	27	258.8	9.6			
Within						
VES	11	30.2	2.7	3.35	0.0002	*
VES*Age	22	34.3	1.6	1.91	0.0093	*
*VES*Subject/Age*	297	242.9	0.8			
TOTAL	359	877.5				

* $p < 0.05$ (significant)

Table 4.9 Summary of significant main effects and interactions for the Likert-type rating scales (adverse weather).

	Significance Summary per Statement								
Source	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Between									
Age									x
Subject/Age									
Within									
VES	x	x	x	x	x	x	x	x	x
VES*Age								x	x
*VES*Subject/Age*									

x = $p < 0.05$ (significant)

All nine statements are presented with the VES systems sorted by their mean rating for each statement. Based on the mean ratings, drivers rated the 5 UV-A + HID configuration as the most likely to help them detect and recognize objects sooner. The IR-TIS was last on these same statements, obtaining only a neutral rating. In general, HIDs received higher (i.e., better) rankings than HLB on statements dealing with farther Detection and Recognition distances, effectiveness in assisting with lane keeping, less visual discomfort, and overall safety perception.

- ***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**
5 UV-A + HID	1.93
3 UV-A + HID	2.10
Hybrid UV-A + HID	2.27
Hybrid UV-A + HLB	2.37
HOH	2.37
HID	2.47
5 UV-A + HLB	2.53
3 UV-A + HLB	2.60
HLB	2.77
HLB-LP	3.27
HHB	4.03
IR-TIS	4.87

- ***Statement 2:*** This Vision Enhancement System allowed me to recognize objects sooner than my regular headlights [1=Strongly Agree; 7=Strongly Disagree].

VES	Mean Rating
5 UV-A + HID	1.90
3 UV-A + HID	2.07
Hybrid UV-A + HLB	2.37
HOH	2.47
Hybrid UV-A + HID	2.47
HID	2.50
3 UV-A + HLB	2.63
5 UV-A + HLB	2.67
HLB	2.73
HLB-LP	3.30
HHB	3.97
IR-TIS	4.73

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

VES	Mean Rating
5 UV-A + HID	2.03
3 UV-A + HID	2.07
HOH	2.30
Hybrid UV-A + HID	2.33
HID	2.33
Hybrid UV-A + HLB	2.63
3 UV-A + HLB	2.77
5 UV-A + HLB	2.87
HLB	3.00
HLB-LP	3.53
HHB	4.37
IR-TIS	5.10

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

VES	Mean Rating
5 UV-A + HID	2.07
Hybrid UV-A + HID	2.37
HID	2.37
3 UV-A + HID	2.43
3 UV-A + HLB	2.70
Hybrid UV-A + HLB	2.70
HOH	2.70
5 UV-A + HLB	2.83
HLB	3.07
HLB-LP	3.23
HHB	4.17
IR-TIS	4.93

* ***Statement 5:*** This Vision Enhancement System did not cause me any more visual discomfort than my regular headlights [1=Strongly Agree; 7=Strongly Disagree].

VES	**Mean Rating**
5 UV-A + HID	1.53
HOH	1.73
3 UV-A + HID	1.80
HID	1.80
3 UV-A + HLB	1.97
HLB	2.03
5 UV-A + HLB	2.20
HLB-LP	2.30
Hybrid UV-A + HLB	2.40
Hybrid UV-A + HID	2.40
HHB	3.70
IR-TIS	4.33

* ***Statement 6:*** This Vision Enhancement System makes me feel safer when driving on the roadways at night than my regular headlights [1=Strongly Agree; 7=Strongly Disagree].

VES	**Mean Rating**
5 UV-A + HID	1.90
3 UV-A + HID	1.93
HOH	2.30
Hybrid UV-A + HID	2.30
Hybrid UV-A + HLB	2.40
HID	2.43
3 UV-A + HLB	2.53
HLB	2.67
5 UV-A + HLB	2.87
HLB-LP	3.17
HHB	4.07
IR-TIS	4.93

* ***Statement 7:*** This is a better Vision Enhancement System than my regular headlights [1=Strongly Agree; 7=Strongly Disagree].

VES	**Mean Rating**
5 UV-A + HID	1.73
3 UV-A + HID	1.90
HOH	2.20
Hybrid UV-A + HID	2.20
HID	2.27
Hybrid UV-A + HLB	2.33
3 UV-A + HLB	2.43
HLB	2.60
5 UV-A + HLB	2.67
HLB-LP	2.80
HHB	3.90
IR-TIS	4.77

- ***Statement 8***: Please rate the likelihood of you driving at night in rainy conditions with this Vision Enhancement System [1=Extremely Likely; 7=Not at all Likely].

VES	Mean Rating
5 UV-A + HID	1.70
3 UV-A + HID	1.70
HOH	1.80
5 UV-A + HLB	2.00
HID	2.00
3 UV-A + HLB	2.17
Hybrid UV-A + HID	2.20
HLB	2.27
Hybrid UV-A + HLB	2.30
HLB-LP	2.53
HHB	3.63
IR-TIS	4.30

- ***Statement 9:*** How carefully would you drive in rainy conditions at night with this Vision Enhancement System? [1=Extremely Careful; 7=Not at all Careful]

VES	Mean Rating
IR-TIS	1.73
HHB	1.77
3 UV-A + HLB	2.17
HLB-LP	2.20
Hybrid UV-A + HID	2.23
HID	2.27
5 UV-A + HLB	2.33
HLB	2.33
Hybrid UV-A + HLB	2.53
HOH	2.60
5 UV-A + HID	2.63
3 UV-A + HID	2.63

Likelihood and Carefulness (Statements 8 and 9, respectively) were inversely correlated (*Pearson* $r = -0.90$, $p < 0.0001$). Previous research has shown high correlations between carefulness and risk severity, suggesting that precaution intent is a good predictor of severity (Wogalter et al., 1993). The high negative correlation between Likelihood and Carefulness also supports the construct validity of Likelihood. With respect to specific VESs, participants stated that they were more likely to use HIDs with 5 or 3 UV-A headlights than any of the other systems, and remain neutral with respect to the IR-TIS. Participants also felt that they should be careful while driving under adverse weather conditions, regardless of the system in use.

Post-hoc test results were graphed for ease of interpretation (Figure 4.14 to Figure 4.25). Type of VES had the only significant effect on Statements 1 through 7; both VES and the

VES*Age interaction showed significant effects on Statement 8; and VES, Age, and the VES*Age interaction were significant effects for Statement 9 (Table 4.9).

In Statement 1 (this Vision Enhancement System allowed me to detect objects sooner than my regular headlights), a significant difference was observed between the IR-TIS configuration and all other configurations except HHB. IR-TIS received a mean rating of 4.87 (i.e., above Neutral with a tendency towards Disagree), while the HLB baseline received a mean rating of 2.77 (Figure 4.14). Statements 2 through 8 followed the same pattern of groupings (Figure 4.15 to Figure 4.21). The results for Statement 9 (how carefully would you drive in rainy conditions at night with this Vision Enhancement System?), however, showed no significant differences between the HLB baseline and the other 11 VESs (Figure 4.24).

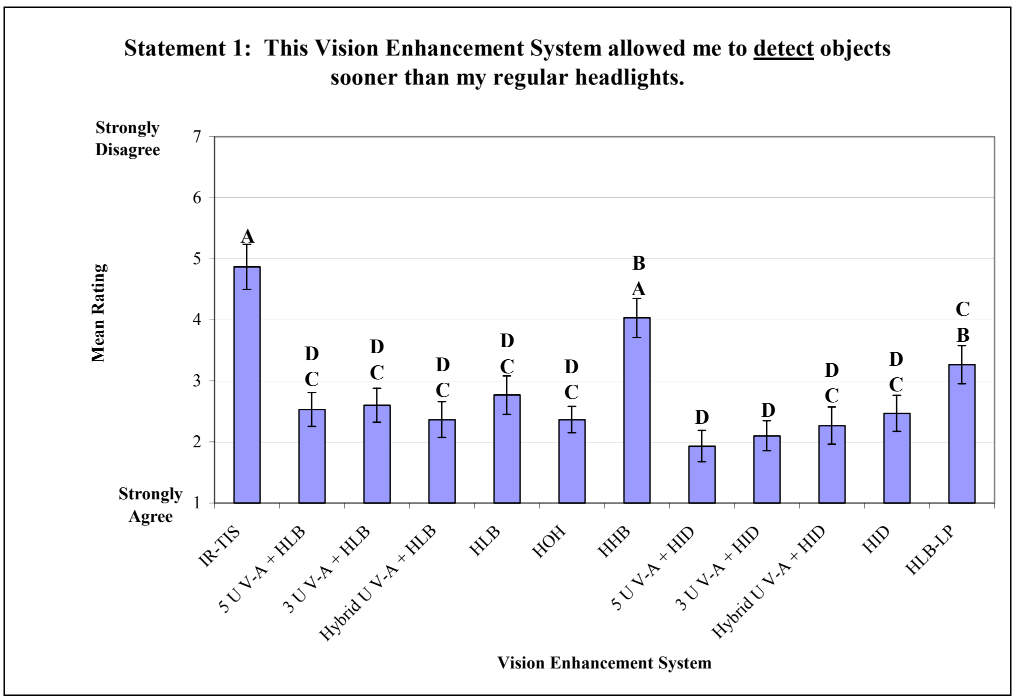


Figure 4.14 Bonferroni post-hoc results on the ratings evaluating detection for the main effect: VES (means with the same letter are not significantly different).

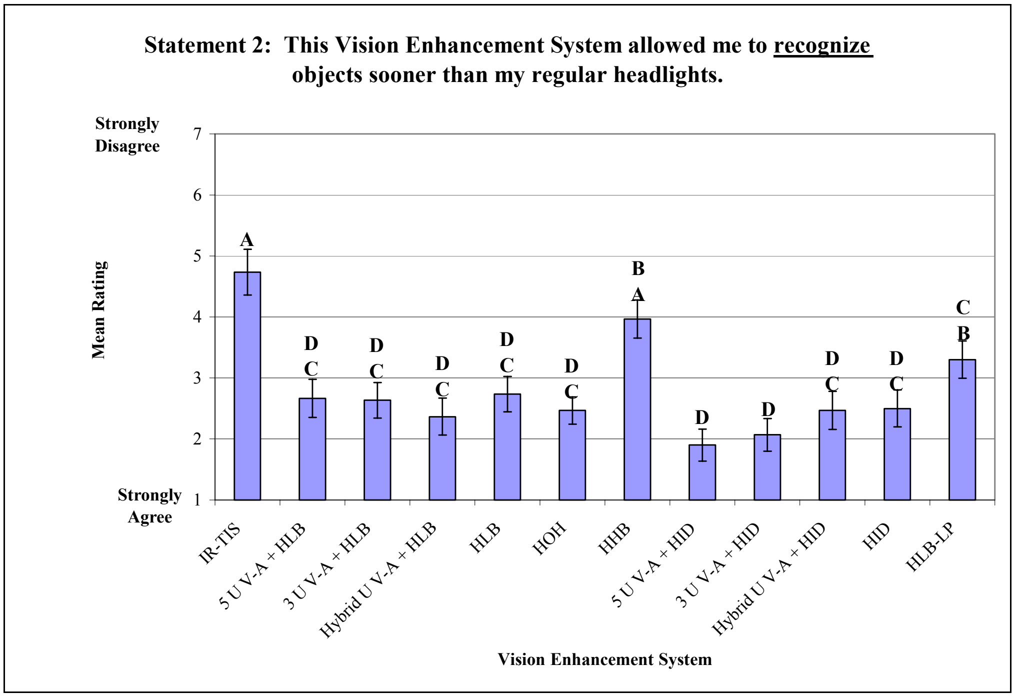


Figure 4.15 Bonferroni post-hoc results on the ratings evaluating recognition for the main effect: VES (means with the same letter are not significantly different).

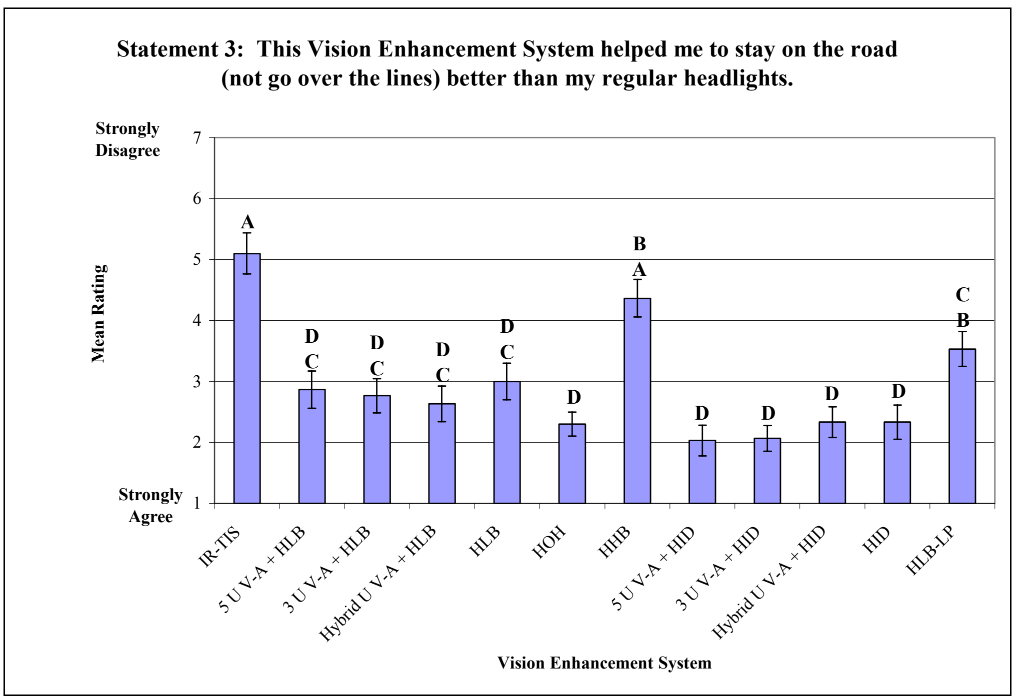


Figure 4.16 Bonferroni post-hoc results on the ratings evaluating lane keeping assistance for the main effect: VES (means with the same letter are not significantly different).

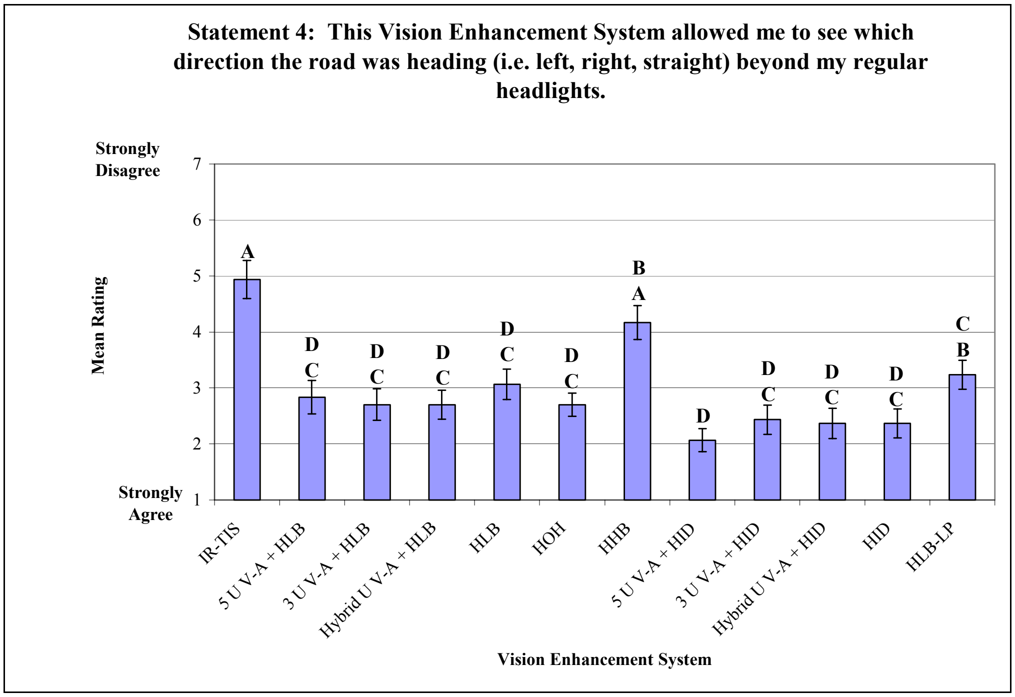


Figure 4.17 Bonferroni post-hoc results on the ratings evaluating roadway direction for the main effect: VES (means with the same letter are not significantly different).

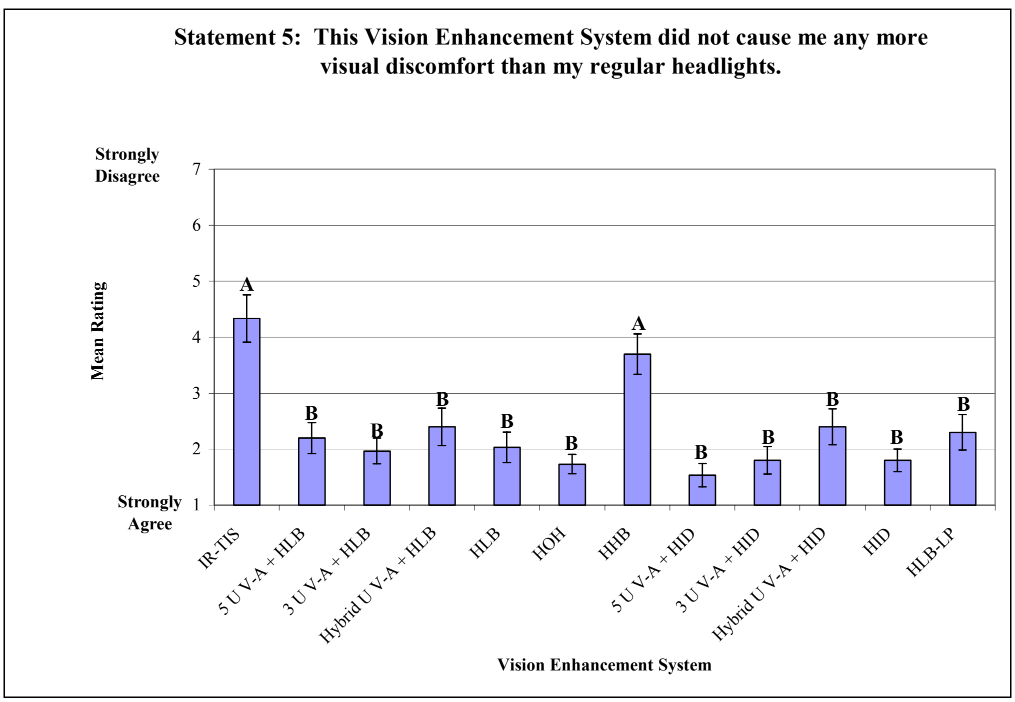


Figure 4.18 Bonferroni post-hoc results on the ratings evaluating visual discomfort for the main effect: VES (means with the same letter are not significantly different).

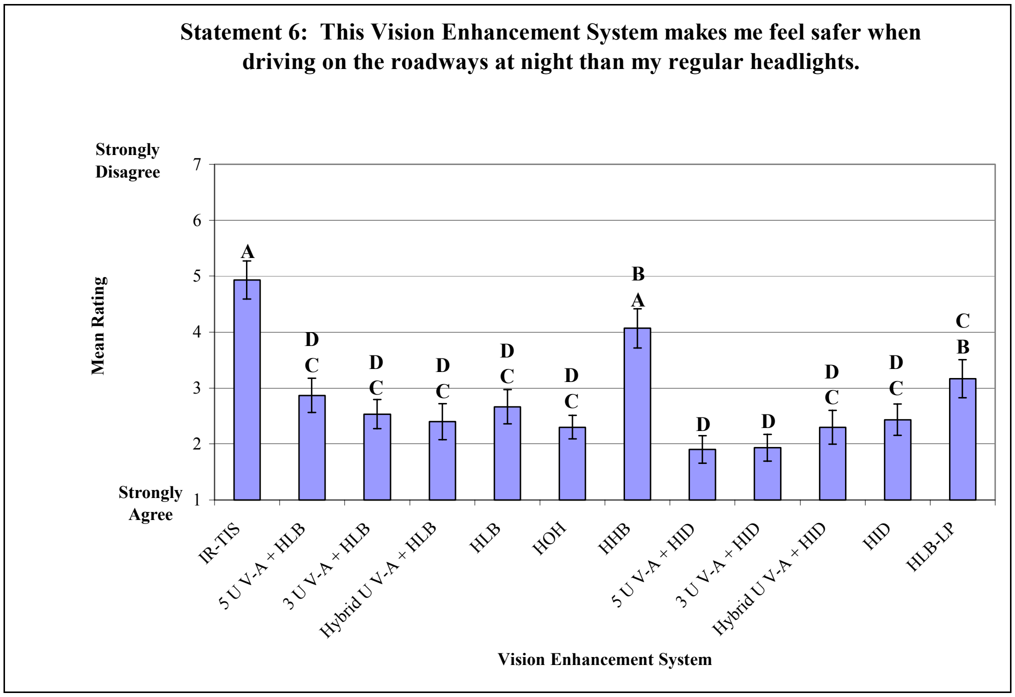


Figure 4.19 Bonferroni post-hoc results on the ratings evaluating overall safety for the main effect: VES (means with the same letter are not significantly different).

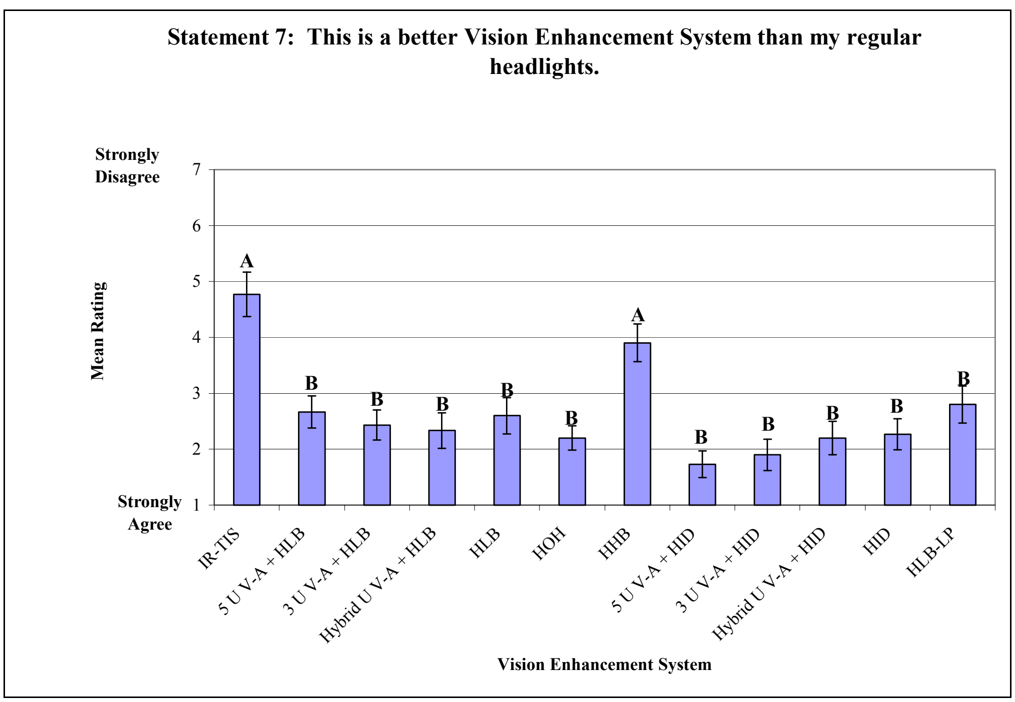


Figure 4.20 Bonferroni post-hoc results on the overall rating for the main effect: VES (means with the same letter are not significantly different).

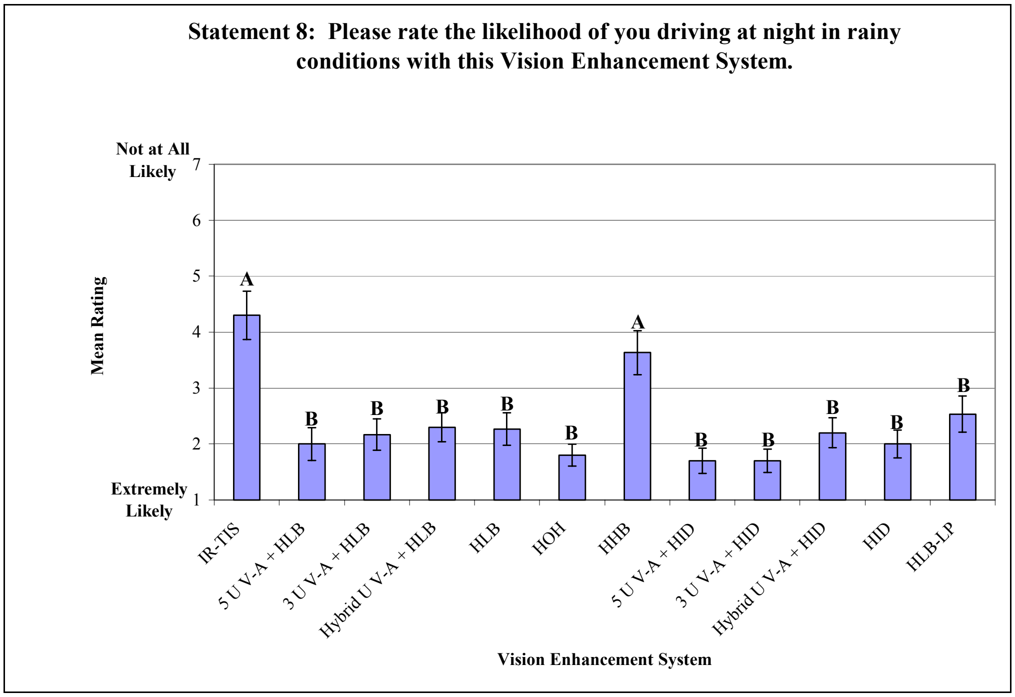


Figure 4.21 Bonferroni post-hoc results on the ratings evaluating likelihood for the main effect: VES (means with the same letter are not significantly different).

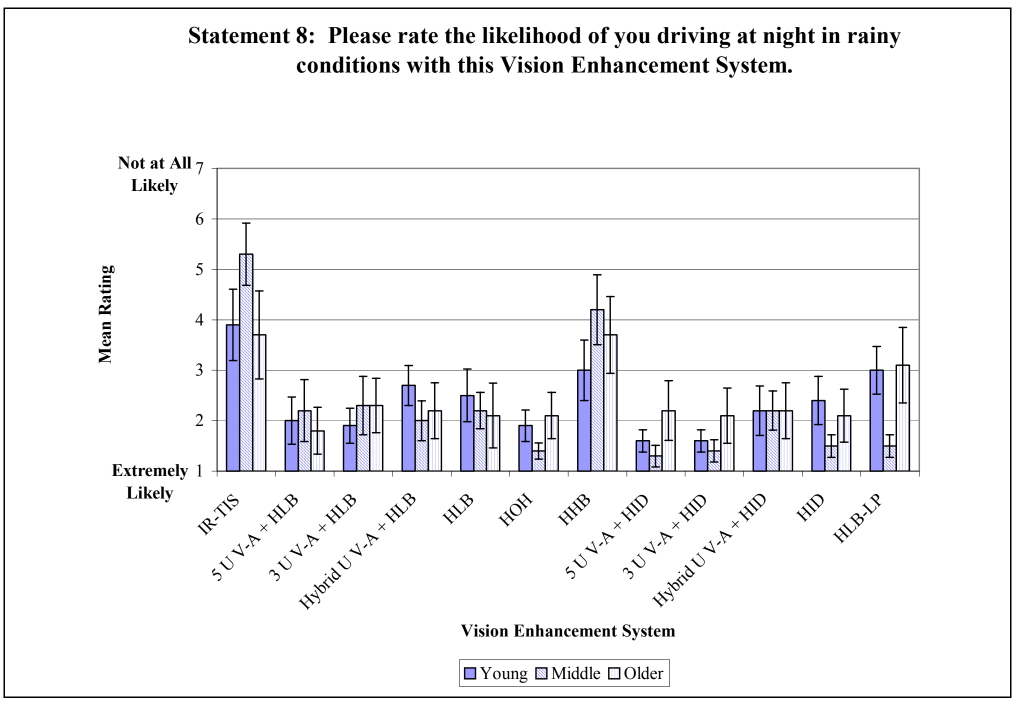


*Figure 4.22 Results on the ratings evaluating of likelihood for the interaction: VES*Age.*

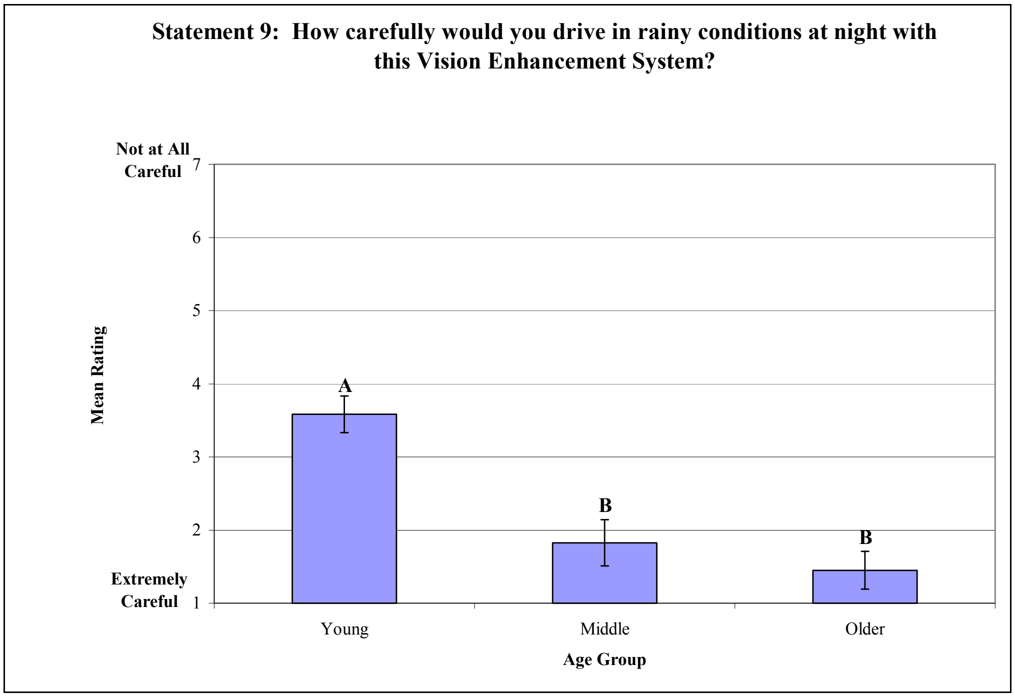


Figure 4.23 Bonferroni post-hoc results on the ratings evaluating carefulness for the main effect: Age (means with the same letter are not significantly different).

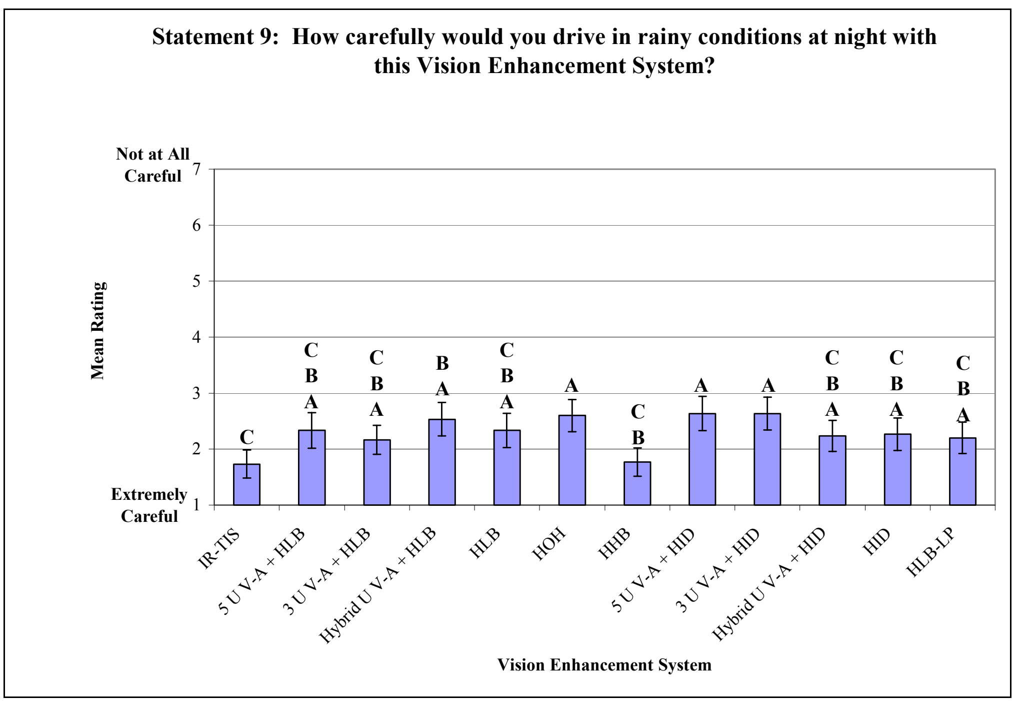


Figure 4.24 Bonferroni post-hoc results on the ratings evaluating carefulness for the main effect: VES (means with the same letter are not significantly different).

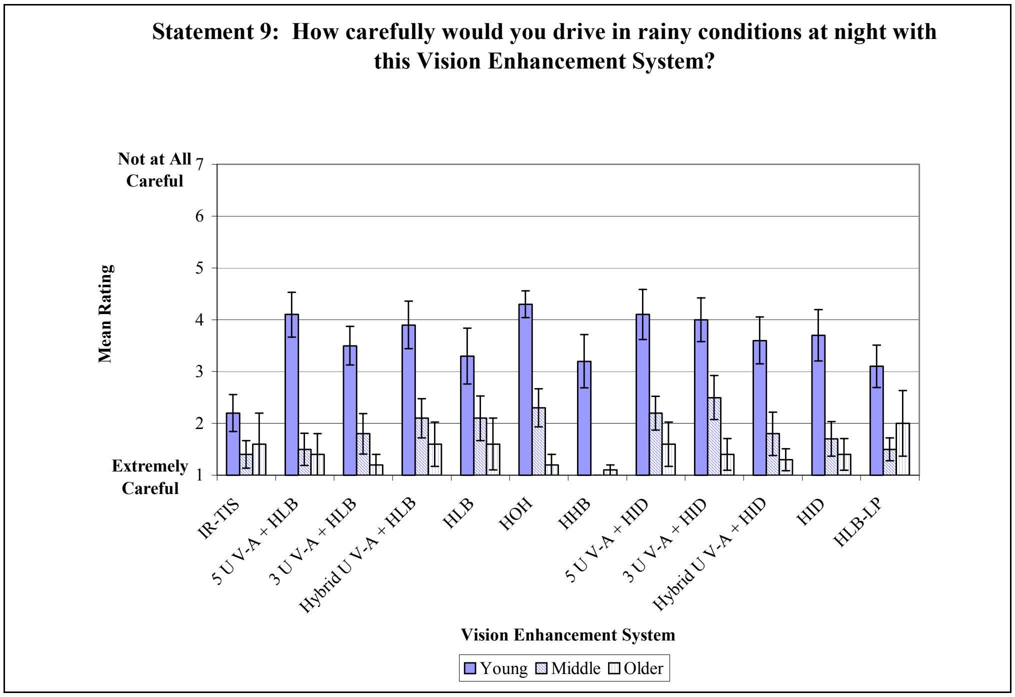


*Figure 4.25 Results on the ratings evaluating carefulness for the interaction: VES*Age.*

The VES*Age interaction for Statement 8 (please rate the likelihood of you driving at night in rainy conditions with this Vision Enhancement System), shows that the middle-age drivers tend to be drastic in most of their likelihood ratings (Figure 4.22). These drivers were either Extremely Likely to use a system or were Neutral (with a tendency towards Not Likely). The 5 UV-A + HLB configuration was the system most likely to be used by older drivers, whereas these older drivers are less likely to use the IR-TIS and HHB systems. Younger drivers are more likely to use the 5 UV-A + HID or the 3 UV-A + HID systems and less likely to use the IR-TIS, HLB-LP, and HHB systems. Similarly, middle-age drivers are more likely to use the 5 UV-A + HID system and less likely to use the IR-TIS and HHB systems.

Post-hoc tests for the significant Age main effect in Statement 9 (How carefully would you drive in rainy conditions at night with this VES?) suggested no significant difference between older and middle-age drivers, who tended to be extremely careful (Figure 4.23). Younger drivers, however, were significantly different from the other two age groups, with a tendency towards a Neutral rating. Similarly, the VES*Age interaction showed that younger drivers did not feel the need to be Extremely Careful with any of the systems (Figure 4.25). While the answers for these drivers remained relatively neutral across VESs, older drivers tended to be more careful when using any of the HLB or HID configurations (with or without UV-A), while middle-age drivers rated IR-TIS, HHB, and HLB-LP as configurations that required the most carefulness.

4.2.2.2 Final Questionnaire

The seven point Likert-type rating scales used for the final questionnaire (Appendix 12) identified nighttime driving scenarios that represented, across drivers, a large decrease in the likelihood of driving when compared to the same scenario during daytime driving. Paired t-tests were used to determine significant differences ($p < 0.05$; Table 4.10).

Table 4.10 Paired t-test results for the final questionnaire.

		Mean Difference	p-value	
	Type of Roadway:			
1	Driving during daytime on a roadway with high volume traffic.	1.13	0.0001	*
2	Driving during nighttime on a roadway with high volume traffic.			
3	Driving during daytime on a roadway with low volume traffic.	0.07	0.7019	
4	Driving during nighttime on a roadway with low volume traffic.			
	Passengers:			
5	Driving during daytime alone (no passengers).	0.37	0.0190	*
6	Driving during nighttime alone (no passengers).			
7	Driving during daytime with another adult.	-0.07	0.6772	
8	Driving during nighttime with another adult.			
9	Driving during daytime with children.	0.53	0.0055	*
10	Driving during nighttime with children.			
	Weather:			
11	Driving during daytime with clear weather.	0.30	0.1070	
12	Driving during nighttime with clear weather.			
13	Driving during daytime with rain.	0.43	0.0131	*
14	Driving during nighttime with rain.			
	Type of Place (Assumption: It is a safe place):			
15	Driving during daytime on a known roadway.	0.33	0.1520	
16	Driving during nighttime on a known roadway.			
17	Driving during daytime on an unknown roadway.	0.93	0.0005	*
18	Driving during nighttime on an unknown roadway.			

* significan ($p < 0.05$)

Notes:
Difference = Nighttime Likelihood Rating - Daytime Likelihood Rating
A positive mean difference means that the drivers are less likely to be involved in that scenario at night.

Several driving scenarios significantly ($p < 0.05$) decreased the likelihood of driving during nighttime: high volume traffic, driving alone, driving with children, rainy/adverse weather, and driving over unknown roadways. An experimental model (Table 4.11) was used to evaluate the 18 statements from the final questionnaire as well as the likelihood rating differences between driving at night under a given scenario versus driving during daytime with the same scenario. ANOVAs based on this model found no significant effects for any of the statements.

Table 4.11 Model for the final questionnaire.

SOURCE	DF
BETWEEN	
AGE	**2**
GENDER	**1**
AGE*GENDER	**2**
SUBJECT(AGE GENDER)	**24**

4.2.2.3 Interviews

After developing a coding scheme, a CA was performed on the interviews (Table 4.12). The unit of analysis used was a phrase or sentence. A set of frequencies for each of the coding units emerged as a result of the CA (Table 4.12). Without using independent raters, the test-retest method was used to verify consistency of the coding method. The results of the CA coding process are presented in Appendix 13. After the codes were developed the answers were divided into units and classified based on their composite content of the characteristics presented below:

- **Daytime:** the unit relates to daytime events.
- **Nighttime:** the unit relates to nighttime events.
- **Negative:** the unit demonstrates a perception of risk in that event.
- **Positive:** the unit demonstrates no perception of risk in that event.
- **Passenger-Adult:** the unit refers to having an adult as a passenger while driving.
- **Passenger-Alone:** the unit refers to driving alone.

- **Passenger-Children:** the unit refers to having children as passengers while driving.
- **Place-Known:** the unit refers to going to a place the driver is familiar with.
- **Place-Unknown:** the unit refers to going to a place the driver is not familiar with.
- **Roadway-High Volume Traffic:** the unit refers to going through a congested roadway.
- **Roadway-Low Volume Traffic:** the unit refers to going through a roadway without congestion.
- **Weather-Clear:** the unit refers to driving during clear weather conditions.
- **Weather-Adverse:** the unit refers to driving during adverse weather conditions.
- **Speed:** the unit refers to driving under a condition that is affected by the speed limit.
- **Vision:** the unit refers to driving under a condition that is affected by the driver's vision.

Table 4.12 Coding scheme for content analysis of the interviews and the frequencies obtained for each code.

Daytime:	Freq	Nighttime:	Freq
• Daytime-Neg-Passenger-Adult	1	• Nighttime-Neg-Passenger-Adult	24
• Daytime-Neg-Passenger-Alone	0	• Nighttime-Neg-Passenger-Alone	18
• Daytime-Neg-Passenger-Children	1	• Nighttime-Neg-Passenger-Children	40
• Daytime-Neg-Place-Known	0	• Nighttime-Neg-Place-Known	7
• Daytime-Neg-Place-Unknown	3	• Nighttime-Neg-Place-Unknown	58
• Daytime-Neg-Roadway-High Volume Traffic	3	• Nighttime-Neg-Roadway-High Volume Traffic	66
• Daytime-Neg-Roadway-Low Volume Traffic	1	• Nighttime-Neg-Roadway-Low Volume Traffic	12
• Daytime-Neg-Speed	4	• Nighttime-Neg-Speed	56
• Daytime-Neg-Vision	1	• Nighttime-Neg-Vision	59
• Daytime-Neg-Weather-Clear	1	• Nighttime-Neg-Weather-Clear	0
• Daytime-Neg-Weather-Adverse	5	• Nighttime-Neg-Weather-Adverse	105
• Daytime-Pos-Passenger-Adult	2	• Nighttime-Pos-Passenger-Adult	31
• Daytime-Pos-Passenger-Alone	4	• Nighttime-Pos-Passenger-Alone	11
• Daytime-Pos-Passenger-Children	7	• Nighttime-Pos-Passenger-Children	4
• Daytime-Pos-Place-Known	7	• Nighttime-Pos-Place-Known	15
• Daytime-Pos-Place-Unknown	13	• Nighttime-Pos-Place-Unknown	13
• Daytime-Pos-Roadway-High Volume Traffic	5	• Nighttime-Pos-Roadway-High Volume Traffic	9
• Daytime-Pos-Roadway-Low Volume Traffic	8	• Nighttime-Pos-Roadway-Low Volume Traffic	19
• Daytime-Pos-Speed	0	• Nighttime-Pos-Speed	20
• Daytime-Pos-Vision	12	• Nighttime-Pos-Vision	27
• Daytime-Pos-Weather-Clear	3	• Nighttime-Pos-Weather-Clear	7
• Daytime-Pos-Weather-Adverse	4	• Nighttime-Pos-Weather-Adverse	9
		Other:	
		• No driving at night under this conditions	*
		• Eliminating or reducing night driving risks	*
		• Pro-Driving at night increases risk of accident	50
		• Con-Driving at night increases risk of accident	16

** Data used for discussion purposes and not for frequency analysis.*

An experimental model was then created to evaluate the frequencies of each individual code (Table 4.13). In addition, four composite measurements were created: Daytime-Positive (DP), Daytime-Negative (DN), Nighttime-Positive (NP), and Nighttime-Negative (NN). The frequencies for each of these composite variables were created by adding up the individual frequencies for the codes belonging to each of the categories (e.g., frequency of DP was the sum of all codes that positively described daytime events). The only significant main effect obtained using this experimental model was Gender, obtained for the "Nighttime-Negative-Place-Unknown" code (Table 4.14)

Table 4.13 Model for the content analysis.

SOURCE
BETWEEN
AGE
GENDER
AGE*GENDER
SUBJECT(AGE GENDER)

Table 4.14 ANOVA summary table for the "Nighttime-Negative-Place-Unknown" code.

Source	DF	SS	MS	F value	P value	
Between						
Age	2	2.5	1.2	0.49	0.6166	
Gender	1	13.3	13.3	5.33	0.0298	*
Age*Gender	2	2.1	10.3	0.41	0.6661	
Subject/Age Gender	24	60.0	2.5			
TOTAL	29	77.9				

* $p < 0.05$ (significant)

A *Post-hoc* analysis revealed that the significant difference was due to female participants perceiving as risky twice the number of conditions, on average, that male participants perceived under situations of nighttime driving to an unknown place.

Correspondence Analysis was performed on the set of code frequencies to identify a structure that reasonably represented all of the variables in a reduced dimensionality space. If successful, the resultant structure can be used to easily represent the data in further statistical analyses. Correspondence Analysis revealed that the individual codes had importance in and of themselves. Only weak relationships existed among the codes, which hindered any effort to re-express the data in simplified dimensions while explaining a reasonable amount of the total variance.

Pearson Chi-Square frequency tests were also performed as a function of Age and Gender. Some cells counts were smaller than five, which is typically considered to invalidate the results of the test. Consequently, some codes were not analyzed with a Chi-Square test. Most of the analyses performed resulted in *p-values > 0.05*, indicating no significant evidence of an association between Age and Gender for the various codes. Only the overall frequencies presented a significant effect (Table 4.15). The NP composite code was the only code close to being significant (Table 4.15).

Table 4.15 Chi-Square test results: Overall and Nighttime-Positive [NP] frequencies.

		Gender		
		F	M	Total
Age	Y	95	129	224
	M	132	128	260
	O	117	94	211
	Total	344	351	695

	DF	Value	p-value
Chi-Square	2	7.6596	0.0217

(a) Overall frequencies

		Gender		
		F	M	Total
Age	Y	20	33	53
	M	29	28	57
	O	33	22	55
	Total	82	83	165

	DF	Value	p-value
Chi-Square	2	5.4004	0.0672

(b) Nighttime-Positive frequencies

From the information gathered from the interviews, a list of driving situations that tend to be avoided by drivers was generated (Table 4.16). Each of the conditions is accompanied by the frequency with which it was mentioned. An additional list was generated with suggestions that the participants felt could eliminate or reduce nighttime driving risks (Table 4.17).

Table 4.16 Interview-summary of results: no driving at night under these conditions and the frequencies obtained for each condition.

Conditions		Frequency	
Weather related			**62**
	icy	14	
	snow	14	
	rain	11	
	bad weather in general	4	
	fog	4	
	hail	4	
	thunderstorm	4	
	blizzard	3	
	hurricanes	2	
	flood	1	
	windy	1	
Drunk: time of year or areas with drunk drivers			**5**
Vehicle related			**4**
	headlamp problems	3	
	vehicle conditions	1	
Animals			**3**
Roadway conditions (e.g. illumination)			**3**
Night vision problems			**2**
Prefer not to drive at night at all at night			**2**
Tired			**2**
Life style (males and younger people will drive)			**1**
Depending on the area			**1**
Sickness			**1**
Traffic			**1**

Table 4.17 Interview-summary of results: Aspects that can eliminate or reduce the nighttime driving risks and the frequencies obtained for each recommendation.

Recommendation	Frequency
Improve Night Vision Enhancements	**27**
Improve headlamps: general improvement	12
Improve headlamps: minimize glare	5
Improve headlamps: see farther away and more off to the side of the road	2
Improve headlamps: see farther away during adverse weather	2
Eliminate glare	2
Improve taillights	1
Develop alternative night vision	1
Intelligent headlamps: will know if you are on a curve or a hill and adjust themselves	1
Intelligent night vision: will tell you what the object in front of you is	1
Improve overhead illumination	**16**
Improve overhead illumination: general improvement	14
Improve overhead illumination: revisit areas that need them every so often	1
Improve overhead illumination: especially at intersections	1
Improve roadway markings	**14**
Improve roadway markings: general improvement	12
Improve roadway markings: improve wet marking visibility	1
Improve roadway markings: reflectors	1
Improve roadway materials	**6**
Improve roadway materials: general improvement	2
Improve roadway materials: auto de-icer in the pavement	2
Improve roadway materials: color of the roadway sometimes affects visibility	1
Improve roadway materials: less maintenance required	1
Wearing clothing that can be easily detected	**6**
Wearing clothing that can be easily detected	5
Wearing clothing that can be easily detected: give tickets to people wearing dark color clothing at night	1
Improve signs	**5**
Improve signs: general improvement	2
Improve signs: advice on exits and streets with enough time	1
Improve signs: update signs when changes occur	1
Improve signs: update signs when they are damaged or worn out	1
Improve windshield wipers	**4**
Changeable speed limit at night	**3**
Changeable speed limit at night	2
Changeable speed limit at night: according to weather	1
Improve roadway construction area	**3**
Roadway construction area: Improve housekeeping of the construction area	1
Roadway construction area: notify and define better the lane changes	2
Special lanes	**3**
Special lanes: for heavy vehicles and other service vehicles	2
Special lanes: to reduce traffic volume	1
Intelligent ignition	**3**
Intelligent ignition: detects alcohol level of driver and will not let the vehicle start	2
Intelligent ignition: detects day or night vision problems and will not let the vehicle start	1
Virtual Co-Pilot	**2**
Virtual co-pilot: detects fatigue and will not let the driver fall asleep	1
Virtual co-pilot: lets the driver know the proximity to other vehicles even if he/she cannot see them due to adverse weather	1
Proper use/care of headlamps	**2**
Dashboard redesign: interior illumination affects dark adaptation	**1**
Disable cell phones for drivers	**1**
External airbag system: activates before rear-end collision occurs	**1**
Revise requirements for driving: include nighttime driving related vision tests	**1**
Curfews	**1**
	99

5 MODELING RISK PERCEPTION AND VISUAL PERFORMANCE

A main goal of this research effort was to quantitatively describe the relationship between risk perception during nighttime driving and object Detection and Recognition capabilities during nighttime driving in adverse weather conditions for a variety of VESs. This chapter describes the development of an empirical model that serves this quantification purpose.

5.1 Methods

5.1.1 Variables

The subjective and objective measurements obtained from Study 1 and Study 2 were used to generate the different polynomial regression models used in the creation of the overall model. Since the names of some variables are lengthy, a list of alternative variable names used for the equations was created (Table 5.1). Refer back to Chapters 2, 3 and 4 for more information on these variables.

5.1.2 Data Analysis

The coefficient of determination (R^2), the Adjusted R^2 (to guard against model overfitting), and Mallow's C_p were used to determine the predictive performance of the various model sub-components. In most cases, the number of possible regressors exceeded the number of degrees-of-freedom available, thus, a stepwise variable selection algorithm was used to generate the regression models (PROC STEPWISE in SAS [SAS Institute, Cary, NC]). The stepwise approach also reduces the possibility of multicolinearity between the variables selected for model inclusion, which can lead to regression instability.

Table 5.1 Summary of the variables used to generate the empirical model.

Variable	Description
Age	Age of the driver [unit: years]
Gender	Female or Male
Acuity	Visual Acuity
PCLA	Lowest percentage of contrast perceived with the left eye for VCTS line A, at 1.5 cpd
PCLB	Lowest percentage of contrast perceived with the left eye for VCTS line B, at 3 cpd
PCLC	Lowest percentage of contrast perceived with the left eye for VCTS line C, at 6 cpd
PCLD	Lowest percentage of contrast perceived with the left eye for VCTS line D, at 12 cpd
PCLE	Lowest percentage of contrast perceived with the left eye for VCTS line E, at 18 cpd
PCRA	Lowest percentage of contrast perceived with the right eye for VCTS line A, at 1.5 cpd
PCRB	Lowest percentage of contrast perceived with the right eye for VCTS line B, at 3 cpd
PCRC	Lowest percentage of contrast perceived with the right eye for VCTS line C, at 6 cpd
PCRD	Lowest percentage of contrast perceived with the right eye for VCTS line D, at 12 cpd
PCRE	Lowest percentage of contrast perceived with the right eye for VCTS line E, at 18 cpd
VES1	Halogen Low Beam (HLB) [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES2	High Intensity Discharge (HID) [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES3	Hybrid UV-A headlamps with HLB [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES4	3 UV-A headlamps with HLB [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES5	5 UV-A headlamps with HLB [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES6	Hybrid UV-A headlamps with HID [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES7	3 UV-A headlamps with HID [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES8	5 UV-A headlamps with HID [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES9	High Output Halogen (HOH) [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES10	Halogen High Beam (HHB) [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES11	Halogen Low Beam at a Lower Profile (HLB-LP) [used as a 1 or 0 to indicate presence or absence of the characteristic]
VES12	Infrared-Thermal Imaging System [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ2	Perpendicular Pedestrian-Low Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ3	Perpendicular Pedestrian-High Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ4	Cyclist-High Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ5	Children's Bicycle [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ6	Parallel Pedestrian-High Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ7	Tire Tread [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ8	Static Pedestrian-High Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ9	Cyclist-Low Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
OBJ10	Parallel Pedestrian-Low Contrast Clothing [used as a 1 or 0 to indicate presence or absence of the characteristic]
Detection	Detection distance [units: feet]
Recogntion	Recognition distance [units: feet]
$RP_{overall}$	It is an indicator or global measurement of nighttime risk perception created as a proportion of nighttime risk perceived units over the total number of coding units for nighttime obtained from the Content Analysis

5.2 Results

The risk perception and visual performance model is comprised of several relationships. These relationships are divided into the following eight areas:

- Driver Characteristics and Risk Perception.
- Driver Characteristics and Visual Performance during Adverse Weather.
- Driver Characteristics and Subjective Evaluations during Adverse Weather.
- Visual Performance and Subjective Evaluations during Adverse Weather.
- Risk Perception and Subjective Evaluations during Adverse Weather.
- Driver Characteristics and Visual Performance during Clear Weather.
- Driver Characteristics and Subjective Evaluations during Clear Weather.
- Visual Performance and Subjective Evaluations during Clear Weather.

These eight areas were combined to create a hypothesized model structure (Figure 5.1). Each of the areas was analyzed and the resulting relationships are discussed in the following sections.

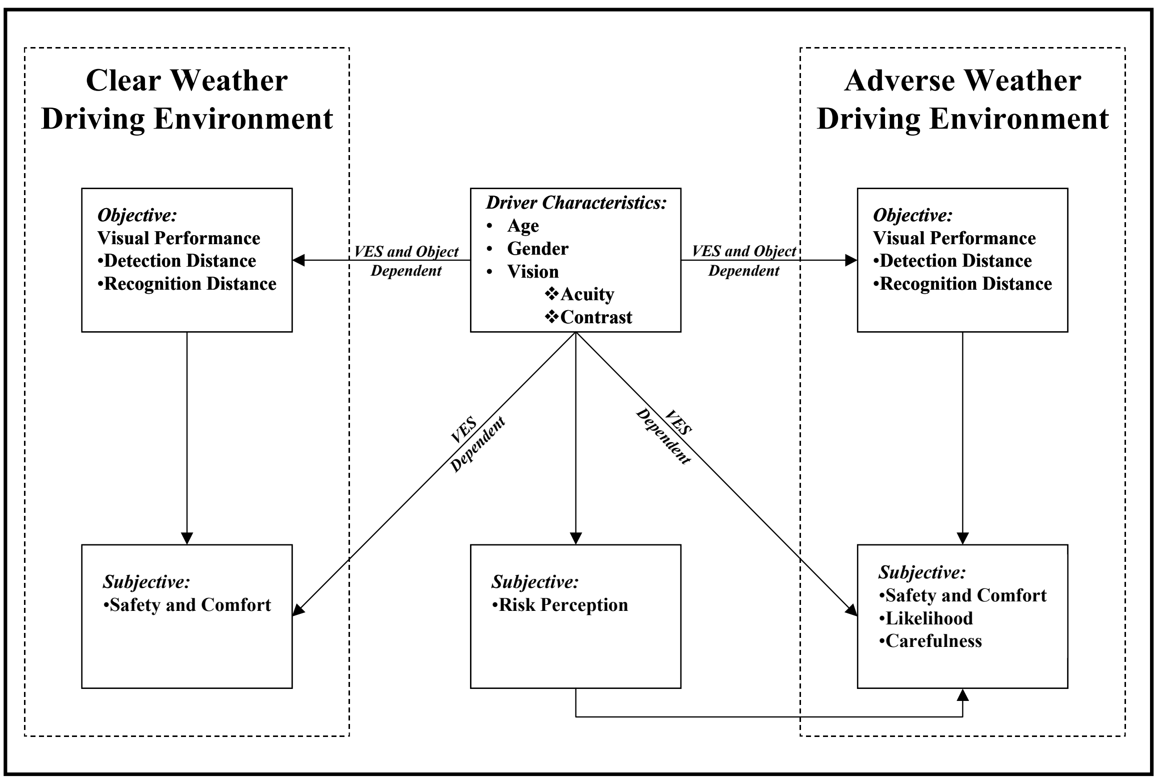


Figure 5.1 Hypothesized empirical model describing the relationship of risk perception and visual performance to the driver's characteristics.

Several simplifications have been made in the development of this model. First, since Age was a significant effect in only some of the measurements obtained under adverse weather (see Chapter 4), it will be considered as a regressor only for those portions of the modeling effort for which an ANOVA demonstrated the significance of the effect. Second, the results of a Principal Components Analysis (PCA) on the variables obtained from the contrast sensitivity test (Vision Contrast Test System 6500 Type C) suggested that the tests of spatial frequencies at 12 and 18 cycles per degree contributed the majority (>75%) of the overall variance contained in this set of dependent measures. Therefore, only these two portions of the test (four total components, two per eye) were used for modeling purposes.

5.2.1 Driver Characteristics and Risk Perception

This area of the model evaluated whether driver characteristics (i.e., age, gender, visual acuity, and visual contrast sensitivity) predicted the risk perception for different scenarios (Figure 5.2).

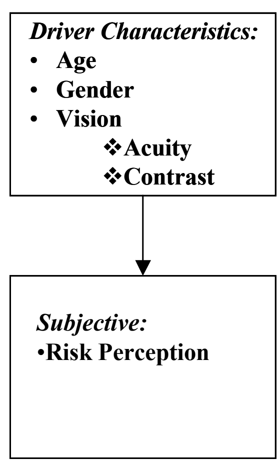


Figure 5.2 Representation of the relationship between driver characteristics and risk perception.

Risk perception proportions were generated using the results from the nighttime codes of the CA from Study 2 (see Chapter 4 for more details). These proportions represent the amount of risk perceived under each scenario. Two different proportion types were generated: proportions for a given CA code (RP_i), and proportions for the overall measurement of risk perception during nighttime driving ($RP_{overall}$). Equation 1 (EQ. 1) represents the global proportion, which considered all the codes. Equation 2 (EQ. 2) was used to generate each of the other 11 proportions by considering one code at a time. For both equations, values near zero represent low perceived risk and values close to one represent a high perceived risk.

[EQ. 1]

$$\mathbf{RP_{overall}} = \frac{\sum Nighttime\_Negative\_Frequencies}{\sum Nighttime\_Negative\_Frequencies + \sum Nighttime\_Positive\_Frequencies}$$

[EQ. 2]

$$\mathbf{RP_i} = \frac{Nighttime\_Negative\_Code_i\_Frequency}{Nighttime\_Negative\_Code_i\_Frequency + Nighttime\_Positive\_Code_i\_Frequency}$$

Where, i = 1 through 11

1 = Passenger-Adult
2 = Passenger-Alone
3 = Passenger-Children
4 = Place-Known
5 = Place-Unknown
6 = Roadway-High Volume Traffic
7 = Roadway-Low Volume Traffic
8 = Speed
9 = Vision
10 = Weather-Clear
11 = Weather-Adverse

The regression analysis used $RP_{overall}$ and RP_i as dependent (e.g., predicted) variables. The independent variables were Gender, the five vision-related variables (i.e., Acuity, PCLD, PCLE, PCRD, PCRE), and the interactions between Acuity and the four contrast sensitivity variables. Age was not included given that the results of a previous ANOVA revealed that Age was not a significant effect for any of the CA codes predicted.

Driver characteristics moderately predicted the overall risk perception (EQ. 3; $R^2 = 0.54$) and the risk perceived for driving during nighttime during adverse weather conditions (EQ. 4; $R^2 = 0.86$). Gender was not significant in any of the models. The individual model equations (EQ. 3 and EQ. 4) are valid for the following range of independent variable values:

- ***Acuity:*** 20/30 through 20/13
- ***PCLD:*** 0.59 through 12.5
- ***PCLE:*** 1.54 through 25.0
- ***PCRD:*** 0.80 through 6.67
- ***PCRE:*** 1.11 through 25.00

[EQ. 3]

$$RP_{overall} = 0.877 - 0.017*PCLE - 0.153*PCRD + 0.002*Acuity*PCLD + 0.004*Acuity*PCRD$$

[EQ. 4]

$$\begin{aligned} RP_{adverse\ weather} = {} & 0.445 + 0.029*Acuity - 0.207*PCLD + 0.144*PCLE + 0.068*PCRE \\ & + 0.013*Acuity*PCLD - 0.008*Acuity*PCLE + 0.002*Acuity*PCRD \\ & - 0.005*Acuity*PCRD \end{aligned}$$

5.2.2 Driver Characteristics and Visual Performance during Adverse Weather

This section of the model determined whether driver characteristics (i.e., age, gender, vision acuity, vision contrast sensitivity) predicted Detection and Recognition distances under adverse weather across various VESs and experimental object types (Figure 5.3).

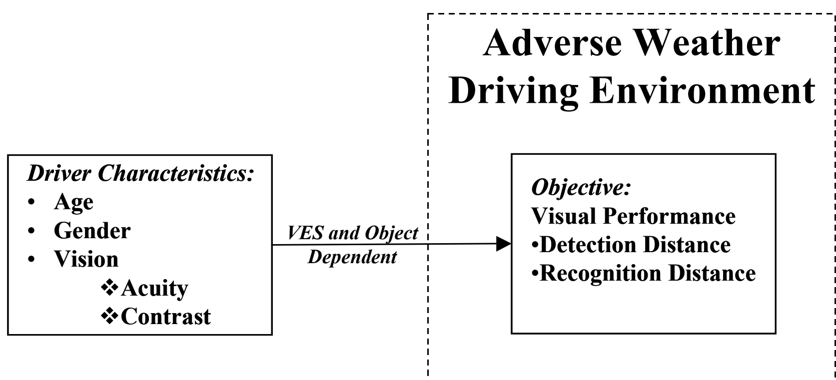


Figure 5.3 Representation of the relationship of driver characteristics and visual performance during adverse weather.

The regression analysis used the Detection and Recognition distances from Study 2 (Chapter 4) as dependent variables. Gender, the five vision-related variables (i.e., Acuity, PCLD, PCLE, PCRD, PCRE), the interaction between Acuity and the four contrast sensitivity variables, the type of VES (i.e., VES1 through VES12), and the Type of Object (i.e., OBJ2, OBJ3, OBJ4, OBJ5, OBJ6, OBJ7, OBJ10) were used as the independent variables. VES and Type of Object were represented in the regression as dummy variables. Age was not included as a regressor since the results of a previous ANOVA revealed that Age was not a significant effect for any of the visual performance measurements under adverse weather.

Driver characteristics moderately predicted the Detection (EQ. 5; $R^2 = 0.64$) and Recognition distances (EQ. 6; $R^2 = 0.63$). Gender was not a significant effect for any of the models. Model equations (EQ. 5 and EQ. 6) are valid for the following range of independent variable values:

- ***Acuity:*** 20/30 through 20/13
- ***PCLD:*** 0.59 through 12.5
- ***PCLE:*** 1.54 through 25.0
- ***PCRD:*** 0.80 through 6.67
- ***PCRE:*** 1.11 through 25.00

Examination of the standardized parameter estimates for equations 5 and 6 indicated that vision variables, specifically the Contrast Sensitivity and the Acuity*Contrast Sensitivity interactions, had large effects on the equations.

[EQ. 5]

$$
\begin{aligned}
\text{Detection Distance} = {} & 359.11 - 5.72*\text{Acuity} - 5.32*\text{PCLD} - 1.47*\text{PCRD} - 16.41*\text{PCRE} \\
& + 0.13*\text{Acuity}*\text{PCLE} + 0.74*\text{Acuity}*\text{PCRE} + 18.30*\text{VES1} \\
& + 29.98*\text{VES3} + 36.43*\text{VES4} + 40.64*\text{VES5} + 8.31*\text{VES6} \\
& + 13.72*\text{VES7} + 19.56*\text{VES8} + 14.15*\text{VES9} - 135.47*\text{OBJ2} \\
& - 57.29*\text{OBJ5} + 8.57*\text{OBJ6} - 120.14*\text{OBJ7} - 132.46*\text{OBJ10}
\end{aligned}
$$

[EQ. 6]

$$
\begin{aligned}
\text{Recognition Distance} = {} & 318.41 - 4.72*\text{Acuity} - 6.24*\text{PCLD} + 3.18*\text{PCLE} - 15.84*\text{PCRE} \\
& + 0.70*\text{Acuity}*\text{PCRE} + 19.91*\text{VES1} + 29.53*\text{VES3} + 34.28*\text{VES4} \\
& + 38.94*\text{VES5} + 8.30*\text{VES6} + 11.64*\text{VES7} + 15.62*\text{VES8} \\
& + 17.82*\text{VES9} + 7.36*\text{VES10} - 133.04*\text{OBJ2} - 6.45*\text{OBJ3} - 13.66*\text{OBJ4} \\
& - 61.02*\text{OBJ5} - 120.59*\text{OBJ7} - 128.90*\text{OBJ10}
\end{aligned}
$$

5.2.3 Driver Characteristics and Subjective Evaluations during Adverse Weather

This subsection of the model determined whether driver characteristics (i.e., age, gender, vision acuity, vision contrast sensitivity) could predict the subjective ratings of Safety, Comfort, Likelihood of Using a Given VES, and Carefulness while Using a Given VES under adverse weather (Figure 5.4).

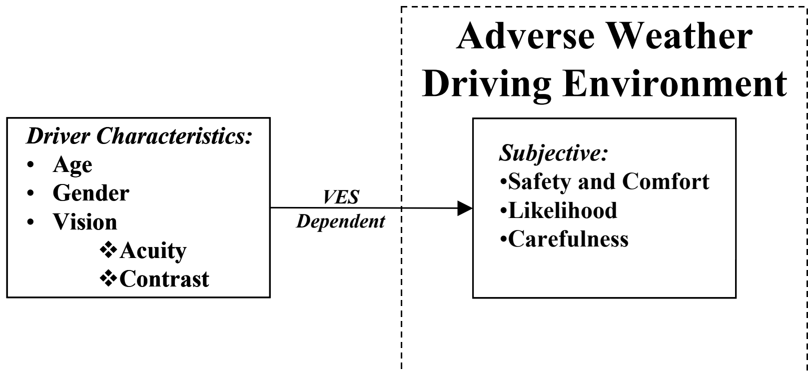


Figure 5.4 Representation of the relationship between driver characteristics and the subjective evaluation of safety, comfort, and risk perception during adverse weather.

The regression analysis used as dependent variables the subjective ratings from nine Likert-type statements, which were obtained after each VES was evaluated during Study 2 (Chapter 4). Age, Gender, the five vision related variables (i.e., Acuity, PCLD, PCLE, PCRD, PCRE), the interaction of Acuity with the four contrast sensitivity variables, the interaction of Age with the four contrast sensitivity variables, and the Type of VES (i.e., VES1 through VES12) were used as the independent variables.

Driver characteristics moderately predicted how carefully a person might drive at night during adverse weather conditions for a given VES (EQ. 7; $R^2 = 0.51$). Gender was not a significant variable for the model. The model equation (EQ. 7) is valid for the following range of independent variable values:

- ***Age:*** 19 through 79 years
- ***Acuity:*** 20/30 through 20/13
- ***PCLD:*** 0.59 through 12.5
- ***PCLE:*** 1.54 through 25.0
- ***PCRD:*** 0.80 through 6.67
- ***PCRE:*** 1.11 through 25.00

Standardized parameter estimates showed that Age and Vision variables, specifically the Contrast Sensitivity and the terms interacting Age with Contrast Sensitivity, had large effects on the equation.

[EQ. 7]

$$
\begin{aligned}
\text{Carefulness} = {} & 5.57 - 0.07*\text{Age} - 0.12*\text{PCLE} - 1.09*\text{PCRD} + 0.46*\text{PCRE} + 0.01*\text{AGE}*\text{PCRD} \\
& + 0.01*\text{Acuity}*\text{PCLD} + 0.03*\text{Acuity}*\text{PCRD} - 0.02*\text{Acuity}*\text{PCRE} - 0.63*\text{VES10} \\
& - 0.66*\text{VES12}
\end{aligned}
$$

Because most regression models failed to reach significance, a correlation analysis was performed to examine the relationships, if any, between vision-related driver characteristics and the various subjective ratings. The analysis revealed very low correlations; even significant ($p < 0.05$) Pearson Correlations were less than $|0.11|$ (Table 5.2).

Table 5.2 Results from correlation analysis for driver characteristics and subjective ratings under adverse weather conditions.

	Acuity	**PCLD**	**PCLE**	**PCRD**	**PCRE**
Statement 1	-0.03	0.02	-0.05	0.09	0.05
p-value	0.53	0.65	0.36	0.09	0.36
Statement 2	-0.04	0.03	-0.055	0.11	0.04
p-value	0.409	0.62	0.30	0.04	0.427
Statement 3	-0.08	0.0004	-0.07	0.10	0.03
p-value	0.12	0.99	0.16	0.06	0.60
Statement 4	-0.05	0.002	-0.04	0.10	0.05
p-value	0.32	0.97	0.43	0.06	0.31
Statement 5	0.02	-0.02	-0.05	0.06	-0.02
p-value	0.72	0.70	0.35	0.27	0.74
Statement 6	-0.04	0.03	-0.05	0.10	0.03
p-value	0.44	0.59	0.33	0.05	0.53
Statement 7	-0.01	0.04	-0.04	0.09	0.04
p-value	0.83	0.45	0.49	0.08	0.43
Statement 8	0.02	-0.05	-0.10	0.00	-0.10
p-value	0.66	0.31	0.05	0.98	0.07

5.2.4 Visual Performance and Subjective Evaluations during Adverse Weather

This section determined whether visual performance (in terms of Detection and Recognition distances) predicted drivers' subjective evaluations of safety, comfort, likelihood of using a given VES, and their carefulness while using a given VES under adverse weather (Figure 5.5).

The regression analysis used the subjective ratings from the nine Likert-type statements, which were obtained after each VES was evaluated during Study 2 (Chapter 4), as the dependent variables. Detection and Recognition distances of the 12 VESs were used as independent variables.

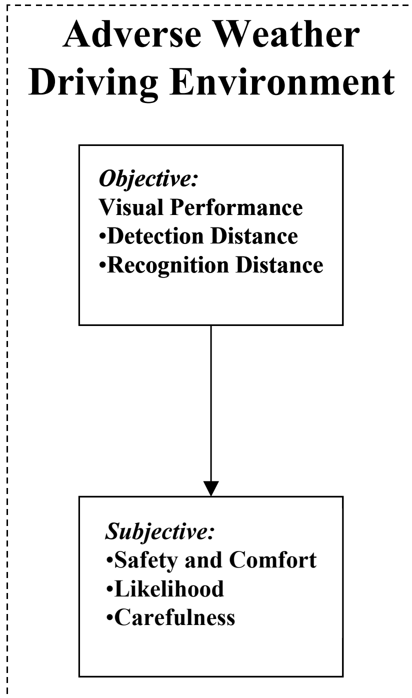


Figure 5.5 Representation of the relationship of visual performance with the subjective evaluation of safety and risk perception during adverse weather.

None of the nine subjective measurements could be predicted using Detection and Recognition distances obtained during clear weather conditions. Consequently, a correlation analysis was performed to examine possible relationships between both distances and the subjective ratings. The analysis revealed very low correlations; even significant ($p < 0.05$) Pearson Correlations were less than $|0.15|$ (Table 5.3), although the direction of the relationships behaved as expected.

Table 5.3 Results from correlation analysis for subjective ratings and visual performance for adverse weather conditions.

	Statement								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Detection	-0.13	-0.11	-0.08	-0.08	-0.09	-0.09	-0.08	-0.10	0.13
p-value	0.01	0.04	0.11	0.13	0.09	0.08	0.11	0.05	0.01
Recognition	-0.14	-0.12	-0.10	-0.09	-0.08	-0.10	-0.10	-0.10	0.14
p-value	0.01	0.03	0.06	0.10	0.11	0.06	0.06	0.07	0.01

5.2.5 Risk Perception and Subjective Evaluations during Adverse Weather

This portion of the model determined whether the perceived risk predicted the subjective evaluation of different scenarios under adverse weather (Figure 5.6).

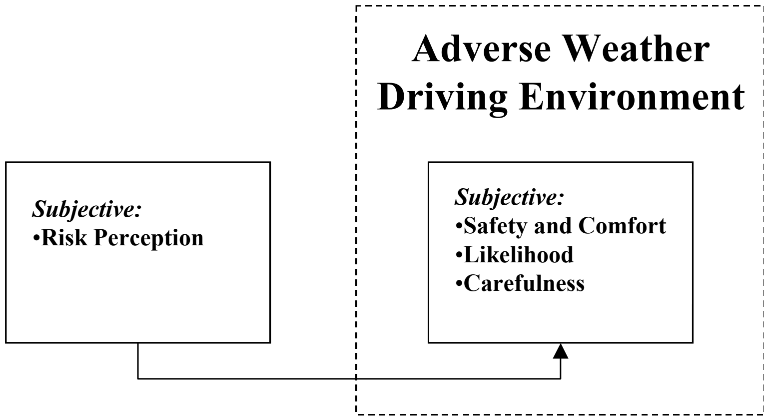


Figure 5.6 Representation of the relationship of the level of risk perception of the driver and the subjective evaluation of safety and risk perception during adverse weather.

Frequencies from the nighttime codes of the CA from Study 2 (Chapter 4) were used to generate proportions. These proportions represent the amount of risk perceived for each different nighttime-driving scenario. Proportions for each CA code (RP_i) and an overall measurement of risk perception during nighttime driving ($RP_{overall}$) were generated previously (EQ. 1 and EQ. 2, respectively).

The regression analysis used the mean subjective rating from each of the nine Likert-type statements, which were obtained after each VES was evaluated during Study 2, as the dependent variables. The independent variables were the Detection and Recognition distances for the 12 VESs. The regression analysis used $RP_{overall}$ and RP_i as the independent variables.

None of the nine subjective measurements could be meaningfully predicted using the subjective risk perception measurements. Consequently, a correlation analysis was performed to examine the possible relationships between different risk perception measurements and the subjective Likert-type statements. The analysis revealed only one significant ($p < 0.05$) correlation (Table 5.4). This correlation moderately ($r = 0.52$) linked the perception of risk in a nighttime scenario where the driver is alone and the subjective evaluation of safety in a nighttime scenario where the driver needs to evaluate the direction of the road.

Table 5.4 Results from correlation analysis for subjective ratings and risk perception.

	Statement								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
$RP_{overall}$	0.02	0.02	-0.10	-0.04	0.12	0.05	0.15	0.08	0.03
p-value	0.90	0.92	0.59	0.82	0.54	0.78	0.42	0.67	0.88
Passenger-Adult	-0.33	-0.30	-0.44	-0.42	-0.33	-0.33	-0.30	-0.20	0.15
p-value	0.09	0.13	0.02	0.03	0.09	0.09	0.13	0.31	0.46
Passenger-Alone	0.45	0.40	0.47	0.52	0.43	0.48	0.47	0.39	-0.05
p-value	0.08	0.12	0.07	0.04	0.09	0.06	0.07	0.14	0.86
Passenger-Children	0.21	0.21	0.14	0.07	0.11	0.19	0.22	0.24	0.19
p-value	0.35	0.34	0.52	0.77	0.64	0.40	0.33	0.29	0.40
Place-Known	-0.34	-0.33	-0.32	-0.37	-0.07	-0.34	-0.22	-0.31	-0.18
p-value	0.21	0.23	0.25	0.17	0.80	0.21	0.43	0.26	0.52
Place-Unknown	-0.02	-0.02	-0.12	-0.12	-0.19	-0.10	-0.09	0.08	-0.06
p-value	0.91	0.92	0.55	0.55	0.33	0.61	0.64	0.69	0.76
High Volume Traffic	0.09	0.07	-0.06	-0.03	0.10	0.08	0.17	-0.14	0.22
p-value	0.64	0.75	0.78	0.90	0.61	0.68	0.40	0.49	0.27
Low Volume Traffic	-0.14	-0.10	-0.24	-0.24	-0.13	-0.13	-0.11	-0.02	-0.22
p-value	0.62	0.73	0.40	0.39	0.65	0.64	0.69	0.94	0.43
Speed	0.00	0.00	0.01	-0.06	0.23	0.05	0.13	0.16	-0.32
p-value	1.00	0.99	0.96	0.77	0.25	0.81	0.50	0.41	0.10
Vision	-0.18	-0.18	-0.19	-0.09	-0.13	-0.09	-0.10	0.07	0.22
p-value	0.36	0.37	0.34	0.66	0.51	0.65	0.60	0.73	0.26
Adverse Weather	0.09	0.07	0.09	-0.06	0.01	0.08	0.08	-0.01	0.13
p-value	0.65	0.72	0.64	0.78	0.96	0.70	0.68	0.96	0.51

5.2.6 Driver Characteristics and Visual Performance during Clear Weather

Depending on the VES used and the Type of Object presented this subsection of the model determined whether driver characteristics (i.e., Age, Gender, Vision Acuity, Vision Contrast Sensitivity) predicted Detection and Recognition distances for clear weather (Figure 5.7).

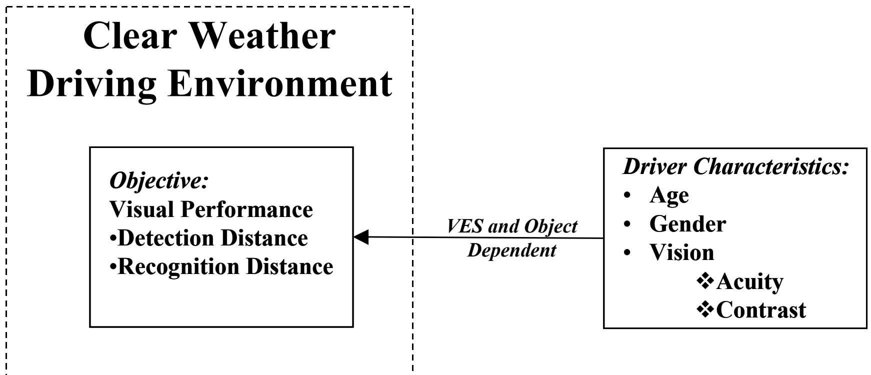


Figure 5.7 Representation of the relationship between driver characteristics and visual performance during clear weather.

The regression analysis used the Detection and Recognition distances from Study 1 (see Chapter 3 for more details) as dependent variables. Age, Gender, the five vision related variables (i.e., Acuity, PCLD, PCLE, PCRD, PCRE), the interaction of Acuity with the four contrast sensitivity variables, the interaction of Age with the four contrast sensitivity variables, the Type of VES (i.e., VES1 through VES12), and the Type of Object (i.e., OBJ2, OBJ3, OBJ4, OBJ5, OBJ6, OBJ7, OBJ8, OBJ9, OBJ10) were used as the independent variables. VES and Type of Object were implemented as dummy variables in the regression model.

Driver characteristics moderately predicted both Detection (EQ. 8; $R^2 = 0.57$) and Recognition distances (EQ. 9; $R^2 = 0.57$). Gender was not a significant regressor in any of the models. Model equations (EQ. 8 and EQ. 9) are valid for the following range of independent variable values:

- ***Age:*** 19 through 76 years
- ***Acuity:*** 20/40 through 20/13
- ***PCLD:*** 0.59 through 12.5
- ***PCLE:*** 1.54 through 25.0
- ***PCRD:*** 0.59 through 12.5
- ***PCRE:*** 1.54 through 25.00

Standardized parameter estimates showed that vision variables had large effects on the equations' predictions, specifically the Contrast Sensitivity and the terms interacting with Contrast Sensitivity.

[EQ. 8]

$$
\begin{aligned}
\text{Detection Distance} = {} & 757.64 - 2.71*\text{Age} + 0.08*\text{Acuity}*\text{Age} + 29.87*\text{PCRD} \\
& + 1.03*\text{Age}*\text{PCLD} - 0.63*\text{Age}*\text{PCLE} + 0.26*\text{Age}*\text{PCRD} \\
& - 2.51*\text{Acuity}*\text{PCLD} + 1.26*\text{Acuity}*\text{PCLE} - 1.47*\text{Acuity}*\text{PCRD} \\
& + 43.10*\text{VES1} - 56.56*\text{VES2} + 54.18*\text{VES3} + 56.40*\text{VES4} \\
& + 62.24*\text{VES5} - 29.67*\text{VES6} - 28.06*\text{VES7} - 36.70*\text{VES11} \\
& + 123.08*\text{VES12} - 319.15*\text{OBJ2} + 141.52*\text{OBJ3} + 132.59*\text{OBJ4} \\
& - 260.66*\text{OBJ5} + 126.60*\text{OBJ6} - 476.94*\text{OBJ7} - 329.95*\text{OBJ10}
\end{aligned}
$$

[EQ. 9]

$$
\begin{aligned}
\text{Recognition Distance} = {} & 738.94 - 1.92*\text{Age} - 26.48*\text{PCLD} + 16.19*\text{PCLE} + 59.66*\text{PCRD} \\
& - 29.81*\text{PCRE} + 0.56*\text{Age}*\text{PCLD} - 0.37*\text{Age}*\text{PCLE} + 0.19*\text{Age}*\text{PCRE} \\
& -3.09*\text{Acuity}*\text{PCRD} + 1.11*\text{Acuity}*\text{PCRE} - 112.14*\text{VES2} - 77.46*\text{VES6} \\
& - 89.86*\text{VES7} - 75.19*\text{VES8} - 48.21*\text{VES9} - 51.06*\text{VES10} \\
& - 84.37*\text{VES11} - 291.13*\text{OBJ2} + 123.45*\text{OBJ3} + 65.43*\text{OBJ4} \\
& - 217.39*\text{OBJ5} + 123.19*\text{OBJ6} - 419.48*\text{OBJ7} - 290.45*\text{OBJ10}
\end{aligned}
$$

5.2.7 Driver Characteristics and Subjective Evaluations during Clear Weather

This portion of the model determined whether driver characteristics (i.e., age, gender, vision acuity, vision contrast sensitivity) predicted the subjective evaluations of Safety and Comfort for a given VES under clear weather (Figure 5.8).

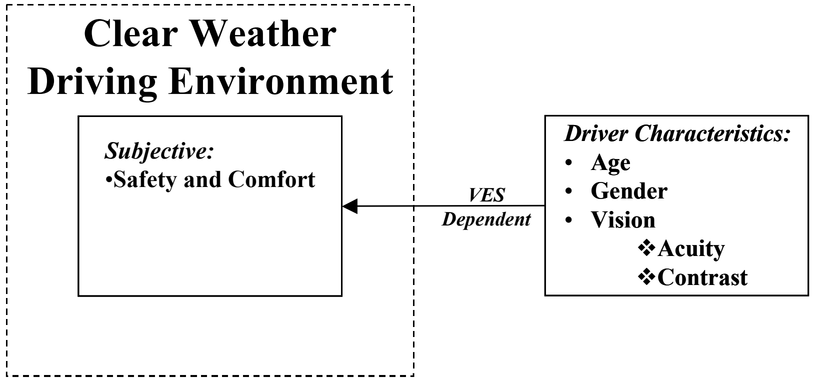


Figure 5.8 Representation of the relationship between driver characteristics and the subjective evaluation of safety and comfort during clear weather.

The regression analysis used the subjective ratings obtained for the seven Likert-Type statements, which were obtained after each VES was evaluated during Study 1 (Chapter 3), as the dependent variables. The independent vairaibles used were Gender, the five vision related variables (i.e., Acuity, PCLD, PCLE, PCRD, PCRE), the interaction of Acuity with the four Contrast Sensitivity variables, and the Type of VES (i.e., VES1 through VES12).

None of the seven subjective measurements is significantly predicted by driver characteristics during clear weather conditions. Consequently, a correlation analysis was performed to examine the relationships, if any, between driver visual characteristics and the subjective ratings. The analysis revealed very low correlations; significant ($p < 0.05$) Pearson Correlations were less than $|0.32|$ (Table 5.5).

Table 5.5 Results from correlation analysis for driver characteristics and subjective for clear weather conditions.

	Acuity	PCLD	PCLE	PCRD	PCRE
Statement 1	-0.07	0.00	0.10	-0.21	-0.09
p-value	0.17	0.94	0.05	<.0001	0.09
Statement 2	-0.15	-0.11	0.005	-0.28	-0.16
p-value	0.004	0.03	0.93	<.0001	0.002
Statement 3	-0.21	-0.03	0.09	-0.31	-0.20
p-value	<.0001	0.58	0.11	<.0001	0.00
Statement 4	-0.18	0.02	0.16	-0.29	-0.19
p-value	0.00	0.65	0.00	<.0001	0.00
Statement 5	-0.11	-0.12	0.01	-0.24	-0.10
p-value	0.04	0.02	0.91	<.0001	0.06
Statement 6	-0.16	-0.09	0.05	-0.30	-0.15
p-value	0.00	0.09	0.35	<.0001	0.00
Statement 7	-0.15	-0.05	0.06	-0.26	-0.16
p-value	0.00	0.32	0.28	<.0001	0.00

5.2.8 Visual Performance and Subjective Evaluations during Clear Weather

This section of the model determined whether visual performance in terms of Detection and Recognition distances predicted the subjective evaluations of Safety and Comfort under clear weather conditions (Figure 5.9).

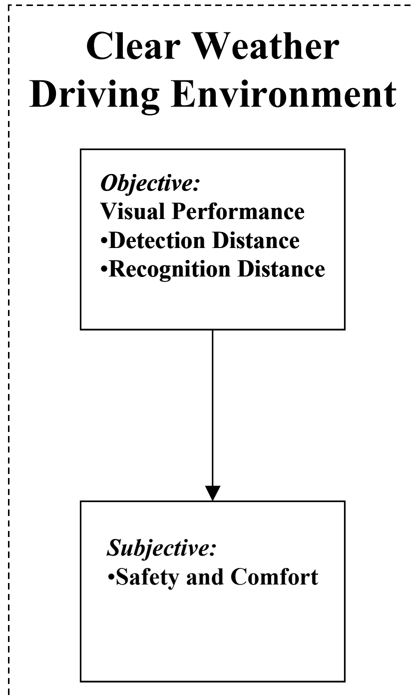


Figure 5.9 Representation of the relationship of visual performance and the subjective evaluation of safety and risk perception during clear weather.

The regression analysis used the subjective ratings from the seven Likert-type statements, which were obtained after each VES was evaluated during Study 1 (Chapter 3), as the dependent variables. The Detection and Recognition distances for the 12 VESs were used as independent variables.

Detection and Recognition distances during clear weather conditions failed to significantly predict any of the seven subjective measurements. Consequently, a correlation analysis was performed to examine possible relationships between the distances and the subjective ratings. The analysis revealed very low correlations, and significant ($p < 0.05$) Pearson Correlations were less than $|0.27|$ (Table 5.6). The direction of the significant relationships did not behave as expected.

Table 5.6 Results from correlation analysis for subjective ratings and visual performance for clear weather conditions.

	Statement						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Detection	-0.10	-0.05	0.26	0.13	0.17	0.06	0.01
p-value	0.06	0.38	<.0001	0.01	0.00	0.24	0.90
Recognition	-0.08	-0.07	0.22	0.08	0.14	0.01	-0.04
p-value	0.13	0.16	<.0001	0.11	0.01	0.81	0.47

5.3 Summary

Taken as a whole, these individual analyses suggest a complex interplay between the dimensions of interest. While some dimensions are weakly correlated, others are partial functions of other dimension(s). An updated diagram (Figure 5.10) shows the revised model as it evolved from the hypothesized model (Figure 5.1) based on the quantitative relationships discussed in this chapter.

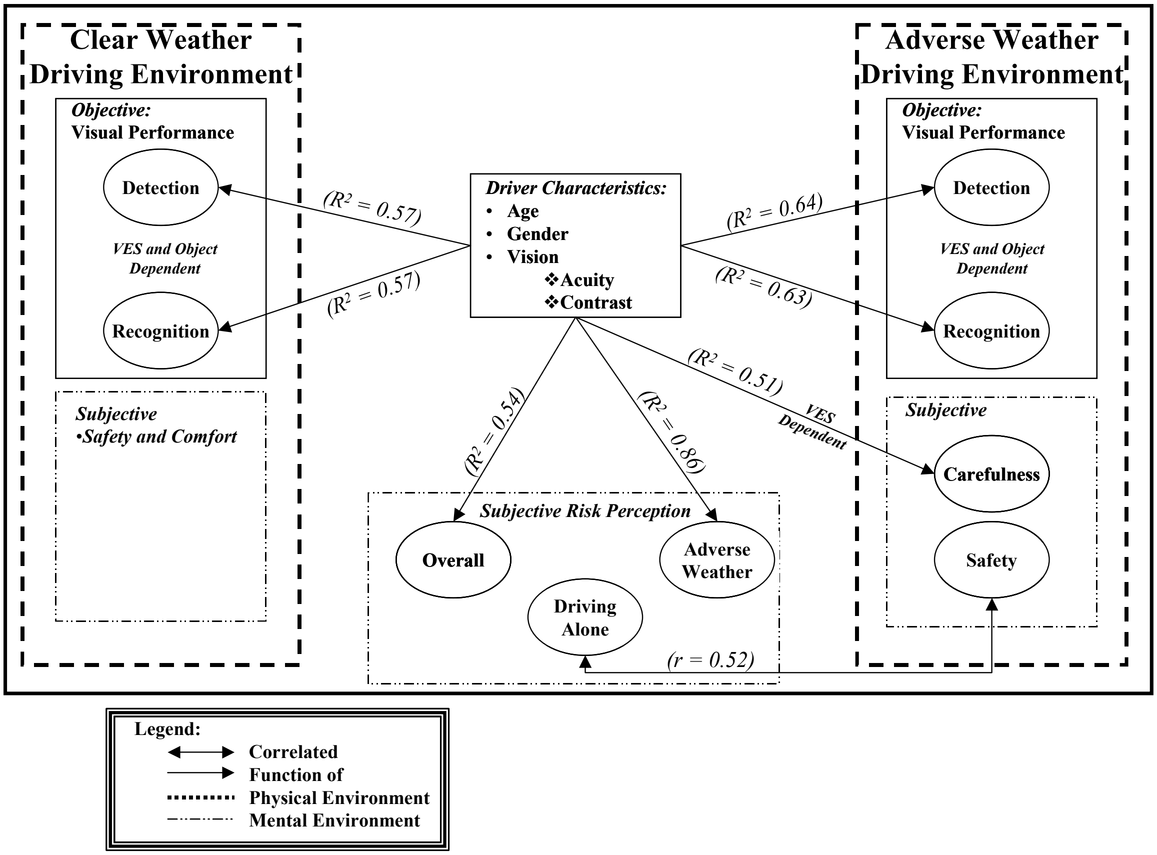


Figure 5.10 Empirical model describing the relationship of risk perception and visual performance depending on the driver characteristics.

6 DISCUSSION

The restrictions in visibility and mobility due to nighttime driving remain a primary concern for transportation human factors engineers. Since several advances in night vision technology offer potential solutions to these problems, a principal objective of this research was to study the relationships between driver characteristics, nighttime driving risk perception, and visual performance under clear and adverse weather conditions as a function of various VESs. A comprehensive, quantitative description of these relationships would assist designers in testing their creations based not only on the possibility of enhancing night vision, but also on the possibility of diminishing driver risk perception to manageable and realistic levels, especially for older drivers.

This chapter links the two studies performed by detailing answers to the 10 research questions that helped shape this research effort. The discussion of the different studies presented in the previous three chapters will be shaped by these research questions.

6.1 Answers to the Research Questions

6.1.1 Research Question 1: How will the different VES configurations vary Detection and Recognition capabilities in clear weather conditions at night?

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 a baseline, due to its widespread availability. In this particular study, several systems under- or over-performed the HLB system by as much as 100 ft (Table 6.1), representing a 19 percent difference. These differences in distance can be translated to gains or losses in reaction time (Table 6.2). Reaction time has been used in the past to evaluate time margins for crash avoidance behavior when encountering obstacles in the driving path (Uno and Hiramatsu, 2001). Overall, use of the IR-TIS resulted in significant Detection improvements over other systems. Specifically, participants were able to detect objects 81 ft farther (i.e., 13 percent increase in distance) with the IR-TIS than with the HLB. On average, the HID configuration provided the closest Detection and Recognition distances. When compared to the HLB, the HID headlamps resulted in object Detection distances that were 99 ft closer (i.e., 16 percent decrease in distance).

Table 6.1 Mean Detection and Recognition distances (unit: feet) during nighttime clear weather environment.

			Comparison to HLB	
VES	Mean Detection	Mean Recognition	Detection	Recognition
IR-TIS	685.6	543.1	80.9	20.0
5 UV-A + HLB	624.9	545.9	20.2	22.8
3 UV-A + HLB	619.1	528.7	14.4	5.6
Hybrid UV-A + HLB	616.9	534.7	12.2	11.7
HLB	604.7	523.1	0.0	0.0
HOH	566.1	487.1	-38.6	-36.0
HHB	563.9	484.2	-40.8	-38.9
5 UV-A + HID	558.1	460.1	-46.6	-63.0
3 UV-A + HID	534.6	445.4	-70.1	-77.7
Hybrid UV-A + HID	533.0	457.8	-71.7	-65.2
HID	506.1	423.1	-98.6	-99.9
HLB-LP	527.4	452.0	-77.3	-71.1

Table 6.2 Difference of reaction time (units: seconds) available depending on vehicle speed (based on the difference of detection time from HLB under clear weather).

VES	Detection	25 mph	35 mph	45 mph	55 mph	65 mph
IR-TIS	80.9	2.2	1.6	1.2	1.0	0.8
5 UV-A + HLB	20.2	0.6	0.4	0.3	0.3	0.2
3 UV-A + HLB	14.4	0.4	0.3	0.2	0.2	0.2
Hybrid UV-A + HLB	12.2	0.3	0.2	0.2	0.2	0.1
HLB	0.0	0.0	0.0	0.0	0.0	0.0
HOH	-38.6	-1.1	-0.8	-0.6	-0.5	-0.4
HHB	-40.8	-1.1	-0.8	-0.6	-0.5	-0.4
5 UV-A + HID	-46.6	-1.3	-0.9	-0.7	-0.6	-0.5
3 UV-A + HID	-70.1	-1.9	-1.4	-1.1	-0.9	-0.7
Hybrid UV-A + HID	-71.7	-2.0	-1.4	-1.1	-0.9	-0.8
HID	-98.6	-2.7	-1.9	-1.5	-1.2	-1.0
HLB-LP	-77.3	-2.1	-1.5	-1.2	-1.0	-0.8

While these distances and reaction times provide an indication of the advantages of one system over another, they fail to completely describe any potential safety benefits or concerns based 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. This comparison can help determine the ease with which a system may be "over-driven;" that is, the advantages of a particular system in terms of increased Detection distances are overridden by increases in vehicle speed due to an unfounded sense of security. Collision avoidance research dealing with different visibility aspects suggests that time-to-collision is an important parameter in the enhancement of driving safety (Van Der Horst and Hogema, 1993). For consistency purposes, time-to-collision will be presented as "distance-to-collision" (or stopping distance) in order 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 6.3). Braking distance is the distance that a vehicle travels while slowing to a complete stop (Jones and Childers, 1993). The results from driver braking performance studies suggest that the 95th percentile BRT to an unexpected object scenario under open road conditions is about 2.5 seconds (American Association of State Highway and Transportation Officials, 1984; Chang, Messer, and Santiago, 1985; Sivak, Olson, and Farmer, 1982; Taoka, 1989). The braking distance calculated below, $d=V^2/(2g(f + G))$, assumes an acceleration (g) of 32.2 ft/sec^2, a final speed of zero, a coefficient of friction (f) between the tire and the pavement of 0.5, and a straight, level roadway (gradient, G=0 percent).

Table 6.3 Stopping distances needed for a dry roadway.

Speed (mph)	25	35	45	55	65	70
Speed (ft/sec)	36.7	51.3	66.0	80.7	95.3	102.7
BRT in terms of Distance (feet)	91.7	128.3	165.0	201.7	238.3	256.7
Braking Distance(feet)	23.7	46.5	76.9	114.8	160.4	186.0
Stopping Distance (feet)	115.4	174.8	241.9	316.5	398.7	442.7

The calculations above represent a simple and ideal condition, but allow for some visualization of the VESs capabilities. Based on these calculations, the average Detection distances for each VES (Table 6.1) provide enough time to react and brake, even at speeds as high as 70 mph. However, some caveats apply. First, these distances were obtained while drivers were moving at approximately 25 mph, and their ability to detect objects will not necessarily remain the same as speeds increase. Second, systems that are currently close to the stopping distance (e.g., HID, HLB-LP) might quickly become ineffective when conditions worsen (e.g., wet pavement, worn tires, down hill condition). Third, and most importantly, when Detection distances are analyzed in more detail by examining the significant ($p < 0.05$) VES*Object interaction, different conclusions can be reached (Table 6.4 to Table 6.15). Several combinations of VES and Object resulted in Detection distances that might compromise stopping distances.

Table 6.4 Detection distances by Types of Object and potential detection problems: IR-TIS (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	171.8		X	X	X	X	X
Children's Bicycle	354.6					*	*
Perpendicular Pedestrian-Low Contrast Clothing	659.7						
Parallel Pedestrian-Low Contrast Clothing	662.2						
Cyclist-Low Contrast Clothing	811.8						
Cyclist-High Contrast Clothing	840.1						
Parallel Pedestrian-High Contrast Clothing	852.0						
Static Pedestrian-High Contrast Clothing	865.6						
Perpendicular Pedestrian-High Contrast Clothing	958.9						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.5 Detection distances by Types of Object and potential detection problems: 5 UV-A + HLB (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	220.0			X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	381.5					X	X
Parallel Pedestrian-Low Contrast Clothing	394.6					X	X
Children's Bicycle	469.1						
Cyclist-Low Contrast Clothing	569.3						
Static Pedestrian-High Contrast Clothing	856.0						
Parallel Pedestrian-High Contrast Clothing	894.8						
Perpendicular Pedestrian-High Contrast Clothing	911.3						
Cyclist-High Contrast Clothing	927.7						

X = stopping distance might be compromised

Table 6.6 Detection distances by Types of Object and potential detection problems: 3 UV-A + HLB (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	252.6				X	X	X
Parallel Pedestrian-Low Contrast Clothing	373.9					X	X
Perpendicular Pedestrian-Low Contrast Clothing	377.4					X	X
Children's Bicycle	460.8						
Cyclist-Low Contrast Clothing	542.4						
Cyclist-High Contrast Clothing	856.9						
Parallel Pedestrian-High Contrast Clothing	869.6						
Perpendicular Pedestrian-High Contrast Clothing	886.7						
Static Pedestrian-High Contrast Clothing	951.5						

X = stopping distance might be compromised

Table 6.7 Detection distances by Types of Object and potential detection problems: Hybrid UV-A + HLB (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	235.2			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	391.9					X	X
Perpendicular Pedestrian-Low Contrast Clothing	419.4						X
Children's Bicycle	467.9						
Cyclist-Low Contrast Clothing	601.7						
Parallel Pedestrian-High Contrast Clothing	810.6						
Perpendicular Pedestrian-High Contrast Clothing	866.1						
Cyclist-High Contrast Clothing	871.6						
Static Pedestrian-High Contrast Clothing	887.6						

X = stopping distance might be compromised

Table 6.8 Detection distances by Types of Object and potential detection problems: HLB (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	239.8			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	385.7					X	X
Perpendicular Pedestrian-Low Contrast Clothing	409.0						X
Children's Bicycle	464.0						
Cyclist-Low Contrast Clothing	565.6						
Perpendicular Pedestrian-High Contrast Clothing	827.8						
Parallel Pedestrian-High Contrast Clothing	839.0						
Static Pedestrian-High Contrast Clothing	857.8						
Cyclist-High Contrast Clothing	862.3						

X = stopping distance might be compromised

Table 6.9 Detection distances by Types of Object and potential detection problems: HOH (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	215.3			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	328.0					X	X
Perpendicular Pedestrian-Low Contrast Clothing	341.7					X	X
Children's Bicycle	402.2						*
Cyclist-Low Contrast Clothing	524.7						
Perpendicular Pedestrian-High Contrast Clothing	797.7						
Parallel Pedestrian-High Contrast Clothing	807.9						
Static Pedestrian-High Contrast Clothing	832.1						
Cyclist-High Contrast Clothing	844.8						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.10 Detection distances by Types of Object and potential detection problems: HHB (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	189.3			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	370.3					X	X
Perpendicular Pedestrian-Low Contrast Clothing	374.2					X	X
Children's Bicycle	407.3						*
Cyclist-Low Contrast Clothing	499.6						
Perpendicular Pedestrian-High Contrast Clothing	776.2						
Parallel Pedestrian-High Contrast Clothing	788.6						
Static Pedestrian-High Contrast Clothing	822.2						
Cyclist-High Contrast Clothing	847.9						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.11 Detection distances by Types of Object and potential detection problems: 5 UV-A + HID (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	209.9			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	249.2				X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	268.0				X	X	X
Cyclist-Low Contrast Clothing	409.1						X
Children's Bicycle	439.6						*
Parallel Pedestrian-High Contrast Clothing	814.5						
Cyclist-High Contrast Clothing	841.6						
Perpendicular Pedestrian-High Contrast Clothing	865.5						
Static Pedestrian-High Contrast Clothing	925.4						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.12 Detection distances by Types of Object and potential detection problems: 3 UV-A + HID (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	193.6			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	260.9				X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	296.8				X	X	X
Children's Bicycle	400.4						*
Cyclist-Low Contrast Clothing	417.1						X
Parallel Pedestrian-High Contrast Clothing	782.6						
Cyclist-High Contrast Clothing	790.5						
Perpendicular Pedestrian-High Contrast Clothing	827.8						
Static Pedestrian-High Contrast Clothing	842.0						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.13 Detection distances by Types of Object and potential detection problems: Hybrid UV-A + HID (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	217.0			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	296.2				X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	298.3				X	X	X
Children's Bicycle	447.7						
Cyclist-Low Contrast Clothing	465.0						
Perpendicular Pedestrian-High Contrast Clothing	724.8						
Static Pedestrian-High Contrast Clothing	732.8						
Cyclist-High Contrast Clothing	757.1						
Parallel Pedestrian-High Contrast Clothing	858.5						

X = stopping distance might be compromised

Table 6.14 Detection distances by Types of Object and potential detection problems: HID (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	212.2			X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	274.7				X	X	X
Parallel Pedestrian-Low Contrast Clothing	282.1				X	X	X
Children's Bicycle	416.6						*
Cyclist-Low Contrast Clothing	444.0						
Cyclist-High Contrast Clothing	683.0						
Parallel Pedestrian-High Contrast Clothing	712.7						
Perpendicular Pedestrian-High Contrast Clothing	733.9						
Static Pedestrian-High Contrast Clothing	796.1						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.15 Detection distances by Types of Object and potential detection problems: HLB-LP (Clear Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**115.4**	**174.8**	**241.9**	**316.5**	**398.7**	**442.7**
Tire Tread	176.9			X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	301.8				X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	326.2					X	X
Children's Bicycle	399.2						*
Cyclist-Low Contrast Clothing	494.0						
Cyclist-High Contrast Clothing	721.2						
Parallel Pedestrian-High Contrast Clothing	744.0						
Perpendicular Pedestrian-High Contrast Clothing	778.0						
Static Pedestrian-High Contrast Clothing	805.4						

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

The literature review in Chapter 1 suggested that new VESs (such as HIDs, configurations supplemented by UV-A Headlamps, and IR-TISs) could be expected to outperform Halogen headlamps. These expectations were not completely fulfilled.

As expected, the infrared technology allowed the Detection of warm objects (i.e., pedestrians and cyclists) from 660 to 959 ft, an improvement of more than 250 ft over the Halogen headlamps for dark color perpendicular pedestrians. This improvement over HLB is consistent with results obtained by Barham et al. (1998b). 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 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," when referring to the image on the IR-TIS.

Jost (1995) suggested that HID systems should improve visibility distance by more than 50 percent compared to standard HLB systems. The HID system used for this study (i.e., HID headlamp system for a 2000 Mercedes Benz S class) did not perform up to this expectation. In fact, Detection distances for the individual objects with this HID system were 28 to 180 ft closer than 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 agrees with Jost (1995) in the fact that HIDs provided more illumination than regular tungsten headlamps, the problem with the current HID system lies in the location the illumination is directed. The large amount of visible light generated by these systems requires a dramatic cutoff angle to comply with glare standards. While this creates good foreground illumination, less illumination is provided as the distance from the vehicle increases. This foreground illumination might also be affecting driver performance by increasing the driver's light adaptation, thus decreasing the driver's capability to detect objects in dark environments.

Mahach et al. (1997) and Nitzburg et al. (1998) 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 100 ft. A windshield shutter was used to limit the time available for visual search, and a 2-second stimulus exposure time was given each time the vehicle moved 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. Comparison of similar trials between both studies, however, can provide some information on the reasons for the apparent performance decrease 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 Mahach's study (Figure 6.1). For example, the static pedestrian was a common object in Mahach et al. (1997) and the current investigation. Note that static pedestrian Detection distances obtained for Mahach's "HLB-May 97" were 628 and 578 ft smaller for the HLB and HLB-LP systems, respectively, that were tested in this study. While a dramatic improvement occurred on UV-A technology, it was not large enough for this technology to maintain the advantage that it once had over HLB systems. Another possibility is that, given the limited amount of environment exposure time in the Mahach et al. study (2-second window exposure every 100 ft), those distances represent less of an absolute threshold. Absolute thresholds were the focus of the current investigation.

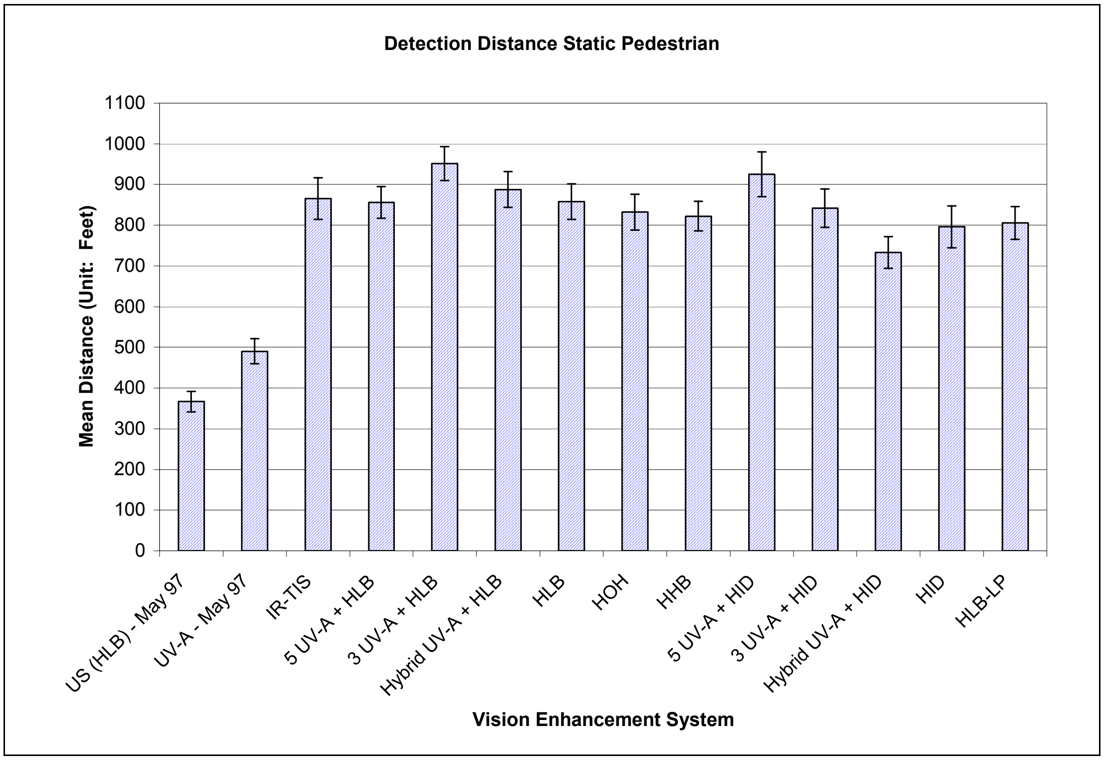


Figure 6.1 Comparison of the results obtained for UV-A headlamps with previous research.

6.1.2 Research Question 2: Does age cause a significant difference in terms of Detection and Recognition distances depending on the VES configuration during clear weather conditions at night?

Depending on the VES, Age was responsible for some of the variability in Detection distances. However, this was not the case for Recognition distances. On average, Detection distances by VES for the younger drivers ranged from 553 to 732 ft, whereas Detection distances for older drivers ranged from 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-age drivers was similar to distances for the younger drivers, 515 to 758 ft. These differences can be quantified in terms of a VES baseline (HLB, Table 6.16), and in terms of the pair-wise differences between the three groups (Table 6.17).

Table 6.16 Detection distances (units: feet) by age and VES: A comparison to HLB by age (Clear Weather).

VES	Young	Middle	Older	Comparison to HLB		
				Young	Middle	Older
IR-TIS	732.1	758.0	565.5	102.2	150.2	-11.2
High UV-A + HLB	658.8	633.3	582.7	28.9	25.5	6.0
3 UV-A + HLB	632.9	637.4	587.0	3.0	29.6	10.3
Hybrid UV-A + HLB	640.1	620.4	590.2	10.2	12.6	13.5
HLB	629.9	607.8	576.7	0.0	0.0	0.0
HOH	601.1	571.8	525.3	-28.8	-36.0	-51.4
HHB	596.5	570.3	525.0	-33.4	-37.4	-51.8
5 UV-A + HID	606.7	557.0	510.6	-23.2	-50.8	-66.1
3 UV-A + HID	603.8	521.0	479.2	-26.1	-86.8	-97.5
Hybrid UV-A + HID	563.9	540.9	494.2	-66.0	-66.9	-82.5
HID	552.7	515.1	450.7	-77.2	-92.7	-126.0
HLB-LP	552.9	539.1	486.1	-77.0	-68.7	-90.6

Table 6.17 Detection distances (units: feet) by age and VES: A comparison between age groups (Clear Weather).

VES	Young	Middle	Older	Comparison by Age per VES		
				Young - Middle	Young - Older	Middle - Older
IR-TIS	732.1	758.0	565.5	-25.9	166.5	192.4
High UV-A + HLB	658.8	633.3	582.7	25.5	76.1	50.6
3 UV-A + HLB	632.9	637.4	587.0	-4.5	45.9	50.4
Hybrid UV-A + HLB	640.1	620.4	590.2	19.8	50.0	30.2
HLB	629.9	607.8	576.7	22.1	53.2	31.1
HOH	601.1	571.8	525.3	29.3	75.8	46.5
HHB	596.5	570.3	525.0	26.2	71.6	45.4
5 UV-A + HID	606.7	557.0	510.6	49.7	96.1	46.3
3 UV-A + HID	603.8	521.0	479.2	82.8	124.6	41.8
Hybrid UV-A + HID	563.9	540.9	494.2	23.1	69.7	46.6
HID	552.7	515.1	450.7	37.6	102.0	64.4
HLB-LP	552.9	539.1	486.1	13.8	66.8	52.9

The IR-TIS resulted in Detection distances of over 100 ft longer than those obtained with the HLB for the younger and middle-age groups. However, the Detection distances for older drivers using the IR-TIS were the same as the distances obtained by this group using HLBs, and only 79 ft longer than the distances that this group obtained using HLB-LP. This difference between age groups might be due to 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 (Czaja, 1988; Welford, 1981). In addition, HUD users risk cognitive capture, which might occur when there is inefficient switching of attention between the HUD and the external environment (Gish and Staplin, 1995; Tufano, 1997). Inefficient switching is of paramount importance as it may result in missed external objects and/or 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. 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-VES).*
- *"…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-VES).*

When the average Detection distances for the three groups by VES configuration are compared to the stopping distances needed (Table 6.3) for a highway type environment (i.e., 65 mph), the maximum stopping distance is close to the Detection distance observed for older drivers when HIDs or HLB-LPs were used.

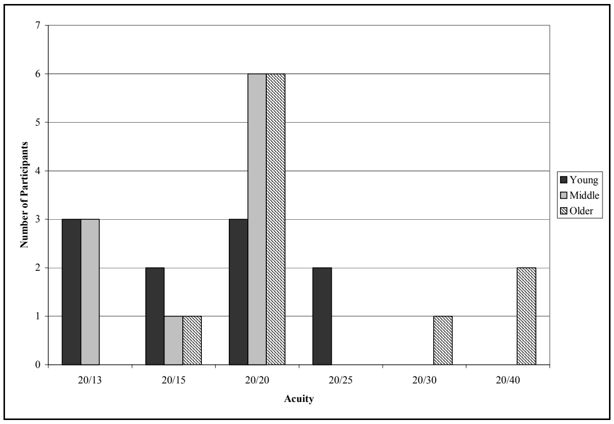
Age also caused significant differences on Detection and Recognition distances depending on the Type of Object (Table 6.18). Older drivers appeared less capable of detecting and recognizing low contrast objects than their younger counterparts. In fact, the ability of older drivers to detect and recognize pedestrians and cyclists with low contrast clothing was reduced from 13 to 21 percent when compared to the abilities of the younger drivers. This difference in performance is likely due to 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

(Richards, 1966, 1972; Weymouth, 1960). This trend was observed between the various age groups in this investigation (Figure 6.2).

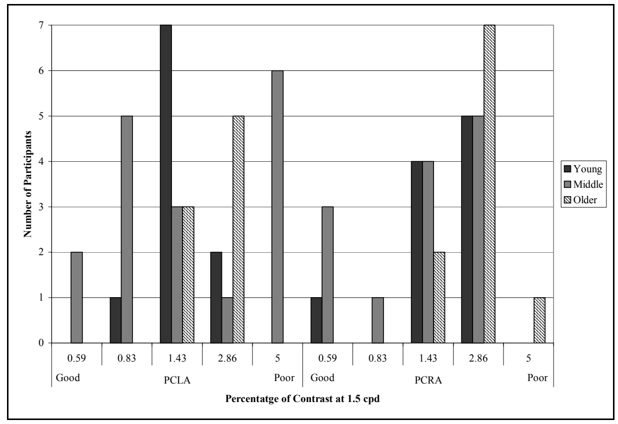
Table 6.18 Detection and Recognition distances by age and type of object (Clear Weather).

	Detection Distance [feet]			Comparison by Age per Object		
Type of Object	**Young**	**Middle**	**Older**	**Young - Middle**	**Young - Older**	**Middle - Older**
Cyclist-High Contrast Clothing	901.1	797.3	763.5	103.7	137.6	33.8
Parallel Pedestrian-High Contrast Clothing	874.8	804.2	764.9	70.6	109.9	39.2
Perpendicular Pedestrian-High Contrast Clothing	881.4	852.6	754.4	28.8	127.0	98.2
Static Pedestrian-High Contrast Clothing	888.2	851.0	803.9	37.2	84.2	47.0
Cyclist-Low Contrast Clothing	549.7	557.0	479.3	-7.3	70.4	77.7
Parallel Pedestrian-Low Contrast Clothing	381.8	383.2	309.2	-1.4	72.6	74.0
Perpendicular Pedestrian-Low Contrast Clothing	391.1	399.9	315.6	-8.7	75.5	84.2
Children's Bicycle	454.4	439.5	388.3	14.9	66.2	51.2
Tire Tread	208.3	219.3	206.1	-10.9	2.2	13.2

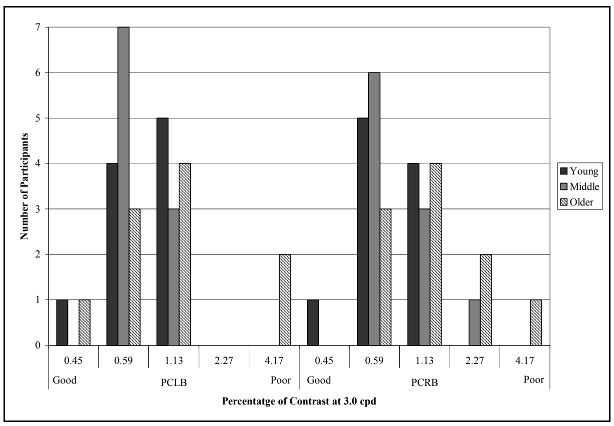
	Recognition Distance [feet]			Comparison by Age per Object		
Type of Object	**Young**	**Middle**	**Older**	**Young - Middle**	**Young - Older**	**Middle - Older**
Cyclist-High Contrast Clothing	721.2	635.4	613.0	85.8	108.1	22.3
Parallel Pedestrian-High Contrast Clothing	777.2	693.0	673.0	84.1	104.2	20.1
Perpendicular Pedestrian-High Contrast Clothing	763.7	721.2	659.0	42.5	104.8	62.2
Static Pedestrian-High Contrast Clothing	794.8	716.3	704.9	78.4	89.9	11.5
Cyclist-Low Contrast Clothing	482.7	469.0	380.7	13.6	102.0	88.4
Parallel Pedestrian-Low Contrast Clothing	322.5	318.3	261.5	4.2	61.1	56.8
Perpendicular Pedestrian-Low Contrast Clothing	316.0	324.2	260.0	-8.2	56.0	64.2
Children's Bicycle	415.5	378.8	327.0	36.7	88.5	51.8
Tire Tread	172.9	178.3	164.3	-5.4	8.6	14.0



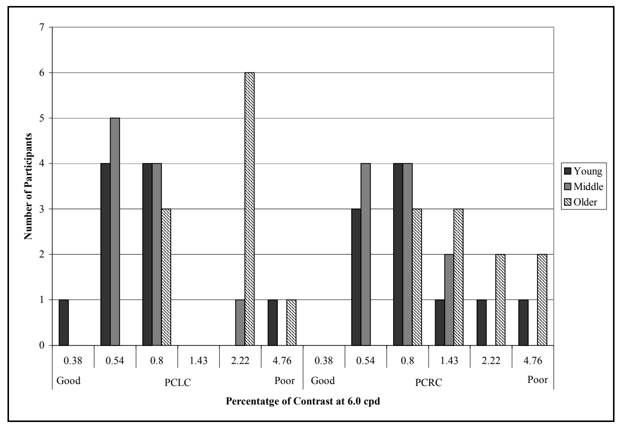
(a) Visual Acuity



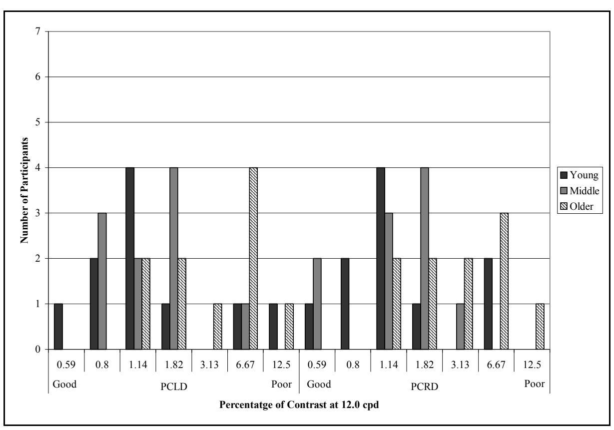
(b) Percentage of Contrast at 1.5 cpd



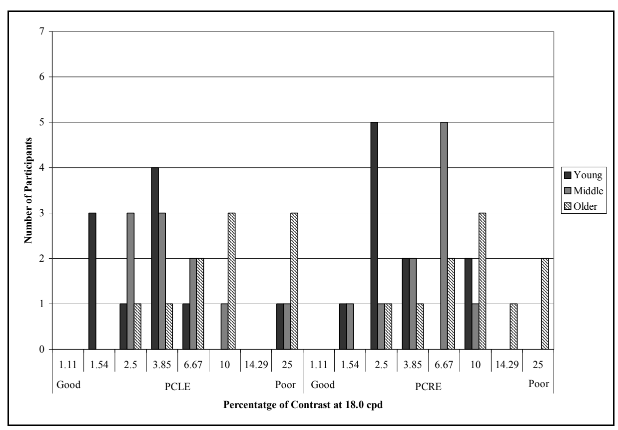
(c) Percentage of Contrast at 3.0 cpd



(d) Percentage of Contrast at 6.0 cpd



(e) Percentage of Contrast at 12.0 cpd



(d) Percentage of Contrast at 18.0 cpd

Figure 6.2 Participant's visual acuity and contrast sensitivity divided by age group (Clear Weather).

6.1.3 Research Question 3: How will the different VES configurations vary Detection and Recognition capabilities in conditions of weather-induced low visibility at night?

Different VESs significantly affected Detection and Recognition distances during nighttime driving under weather-induced low visibility conditions. The average effects per VES can be expressed as the difference from a particular baseline. The HLB system was selected as a baseline in the current investigation due to its widespread availability (Table 6.19).

Table 6.19 Mean Detection and Recognition distances (unit: feet) during nighttime adverse weather environment.

			Comparison to HLB	
VES	**Mean Detection**	**Mean Recognition**	**Detection**	**Recognition**
IR-TIS	178.1	154.8	-20.1	-21.3
5 UV-A + HLB	220.5	195.1	22.3	19.0
3 UV-A + HLB	215.8	190.0	17.6	13.9
Hybrid UV-A + HLB	209.8	185.7	11.7	9.6
HLB	198.2	176.1	0.0	0.0
HOH	194.0	174.0	-4.2	-2.1
HHB	182.8	163.0	-15.4	-13.1
5 UV-A + HID	199.1	171.5	0.9	-4.6
3 UV-A + HID	193.2	167.5	-5.0	-8.6
Hybrid UV-A + HID	187.2	163.7	-11.0	-12.4
HID	178.8	155.9	-19.4	-20.2
HLB-LP	178.5	157.2	-19.6	-18.9

Significant differences between the HLB and other VESs were less than 22 ft, which translates to less than an additional second of reaction time, even at relatively low speeds (i.e., 25 mph; Table 6.20). However, visibility for all the VESs was severely decreased by the adverse weather, as much as 64 to 74 percent depending on the VES (Table 6.21). Therefore, configurations such as the HLB supplemented by UV-A represent up to an 11 percent improvement on Detection distance over the HLB alone (under this adverse weather condition).

Table 6.20 Differences in reaction time (units: seconds) available depending on vehicle speed (based on the difference of detection time from HLB – Adverse Weather).

VES	Detection	25 mph	35 mph	45 mph	55 mph	65 mph
IR-TIS	-20.1	-0.5	-0.4	-0.3	-0.2	-0.2
5 UV-A + HLB	22.3	0.6	0.4	0.3	0.3	0.2
3 UV-A + HLB	17.6	0.5	0.3	0.3	0.2	0.2
Hybrid UV-A + HLB	11.7	0.3	0.2	0.2	0.1	0.1
HLB	0.0	0.0	0.0	0.0	0.0	0.0
HOH	-4.2	-0.1	-0.1	-0.1	-0.1	0.0
HHB	-15.4	-0.4	-0.3	-0.2	-0.2	-0.2
5 UV-A + HID	0.9	0.0	0.0	0.0	0.0	0.0
3 UV-A + HID	-5.0	-0.1	-0.1	-0.1	-0.1	-0.1
Hybrid UV-A + HID	-11.0	-0.3	-0.2	-0.2	-0.1	-0.1
HID	-19.4	-0.5	-0.4	-0.3	-0.2	-0.2
HLB-LP	-19.6	-0.5	-0.4	-0.3	-0.2	-0.2

Table 6.21 Differences in Detection distances (units: feet) between clear and adverse weather environments.

VES	Clear Detection	Rain Detection	Detection Difference	Percent of Reduction
IR-TIS	685.6	178.1	507.6	74%
5 UV-A + HLB	624.9	220.5	404.4	65%
3 UV-A + HLB	619.1	215.8	403.3	65%
Hybrid UV-A + HLB	616.9	209.8	407.0	66%
HLB	604.7	198.2	406.5	67%
HOH	566.1	194.0	372.0	66%
HHB	563.9	182.8	381.1	68%
5 UV-A + HID	558.1	199.1	359.0	64%
3 UV-A + HID	534.6	193.2	341.5	64%
Hybrid UV-A + HID	533.0	187.2	345.8	65%
HID	506.1	178.8	327.4	65%
HLB-LP	527.4	178.5	348.9	66%

Stopping distances under adverse weather tend to increase over dry-pavement distances due to the reduced coefficient of friction between the tires and the pavement. Using the same approach explained in Section 6.1.1, stopping distances were calculated for wet pavement by reducing the coefficient of friction in the formula from 0.5 to 0.3 (Table 6.22).

Table 6.22 Stopping distance needed to complete full braking in a wet roadway.

Speed (mph)	25	35	45	55	65	70
Speed (ft/sec)	36.7	51.3	66.0	80.7	95.3	102.7
BRT in terms of Distance (feet)	91.7	128.3	165.0	201.7	238.3	256.7
Braking Distance(feet)	47.4	93.0	153.7	229.6	320.7	372.0
Stopping Distance (feet)	139.1	221.3	318.7	431.3	559.1	628.7

The calculations above represent a simple condition, but allow some visualization of the VESs' capabilities under wet pavement situations. Based on these calculations, the average Detection distances (Table 6.19) for each VES tested under adverse weather conditions (i.e., rain of 4 inches per hour, windshield wiper on highest speed) are not long enough to provide enough stopping time for vehicle speeds greater than 35 mph.

As in clear weather, adverse weather distances were deeply affected by the characteristics of the object being detected or recognized, but this effect was modulated by the type of VES. The HID and low profile configurations (i.e., HLB-LP and IR-TIS) provided the shortest Detection and Recognition distances for low contrast objects, while the HLB supplemented by UV-A provided the longest distances for high contrast objects. These observations are even more apparent when described in terms of stopping distances (Table 6.23 to Table 6.34).

Table 6.23 Detection distances by Types of Object and potential detection problems: IR-TIS (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	111.7	X	X	X	X	X	X
Tire Tread	121.0	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	122.3	X	X	X	X	X	X
Children's Bicycle	197.6		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	217.6		X	X	X	X	X
Cyclist-High Contrast Clothing	232.8			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	244.7			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.24 Detection distances by Types of Object and potential detection problems:5 UV-A + HLB (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Parallel Pedestrian-Low Contrast Clothing	128.8	X	X	X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	143.3		X	X	X	X	X
Tire Tread	154.3		X	X	X	X	X
Children's Bicycle	221.2		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	297.1			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	298.6			X	X	X	X
Cyclist-High Contrast Clothing	300.4			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.25 Detection distances by Types of Object and potential detection problems: 3 UV-A + HLB (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Parallel Pedestrian-Low Contrast Clothing	140.5		X	X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	142.5		X	X	X	X	X
Tire Tread	147.6		X	X	X	X	X
Children's Bicycle	216.0		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	276.5			X	X	X	X
Cyclist-High Contrast Clothing	286.5			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	303.0			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.26 Detection distances by Types of Object and potential detection problems: Hybrid UV-A + HLB (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	129.9	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	130.9	X	X	X	X	X	X
Tire Tread	150.6		X	X	X	X	X
Children's Bicycle	214.3		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	270.2			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	275.7			X	X	X	X
Cyclist-High Contrast Clothing	297.3			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.27 Detection distances by Types of Object and potential detection problems: HLB (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Parallel Pedestrian-Low Contrast Clothing	128.7	X	X	X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	128.8	X	X	X	X	X	X
Tire Tread	139.5		X	X	X	X	X
Children's Bicycle	211.9		X	X	*	*	*
Cyclist-High Contrast Clothing	254.7			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	257.7			X	X	X	X
Perpendicular Pedestrian-High Contrast Clothing	266.0			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.28 Detection distances by Types of Object and potential detection problems: HOH (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	119.3	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	127.7	X	X	X	X	X	X
Tire Tread	141.0		X	X	X	X	X
Children's Bicycle	196.8		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	247.6			X	X	X	X
Cyclist-High Contrast Clothing	260.1			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	265.4			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.29 Detection distances by Types of Object and potential detection problems: HHB (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Tire Tread	120.8	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	126.4	X	X	X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	128.5	X	X	X	X	X	X
Children's Bicycle	170.5		X	X	*	*	*
Cyclist-High Contrast Clothing	243.5			X	X	X	X
Perpendicular Pedestrian-High Contrast Clothing	245.7			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	248.5			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.30 Detection distances by Types of Object and potential detection problems: 5 UV-A + HID (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	108.4	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	119.2	X	X	X	X	X	X
Tire Tread	125.9	X	X	X	X	X	X
Children's Bicycle	206.7		X	X	*	*	*
Parallel Pedestrian-High Contrast Clothing	276.7			X	X	X	X
Cyclist-High Contrast Clothing	278.7			X	X	X	X
Perpendicular Pedestrian-High Contrast Clothing	280.9			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.31 Detection distances by Types of Object and potential detection problems: 3 UV-A + HID (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Parallel Pedestrian-Low Contrast Clothing	117.7	X	X	X	X	X	X
Perpendicular Pedestrian-Low Contrast Clothing	122.4	X	X	X	X	X	X
Tire Tread	136.8	X	X	X	X	X	X
Children's Bicycle	198.1		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	255.4			X	X	X	X
Cyclist-High Contrast Clothing	256.8			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	267.2			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.32 Detection distances by Types of Object and potential detection problems: Hybrid UV-A + HID (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	105.1	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	117.1	X	X	X	X	X	X
Tire Tread	135.6	X	X	X	X	X	X
Children's Bicycle	198.8		X	X	*	*	*
Cyclist-High Contrast Clothing	239.3			X	X	X	X
Perpendicular Pedestrian-High Contrast Clothing	253.6			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	264.2			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.33 Detection distances by Types of Object and potential detection problems: HID (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	110.0	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	117.4	X	X	X	X	X	X
Tire Tread	144.6		X	X	X	X	X
Children's Bicycle	185.1		X	X	*	*	*
Perpendicular Pedestrian-High Contrast Clothing	221.1		X	X	X	X	X
Cyclist-High Contrast Clothing	228.3			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	244.9			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

Table 6.34 Detection distances by Types of Object and potential detection problems: HLB-LP (Adverse Weather).

		Speed (mph)					
		25	35	45	55	65	70
		Total Distance Needed (feet)					
Type of Object	**Detection**	**139.1**	**221.3**	**318.7**	**431.3**	**559.1**	**628.7**
Perpendicular Pedestrian-Low Contrast Clothing	112.0	X	X	X	X	X	X
Parallel Pedestrian-Low Contrast Clothing	121.9	X	X	X	X	X	X
Tire Tread	128.9	X	X	X	X	X	X
Children's Bicycle	183.8		X	X	*	*	*
Cyclist-High Contrast Clothing	226.6			X	X	X	X
Perpendicular Pedestrian-High Contrast Clothing	235.3			X	X	X	X
Parallel Pedestrian-High Contrast Clothing	243.4			X	X	X	X

X = stopping distance might be compromised

* = exceeds distance, but the scenario is not likely

As discussed in the first research question, the literature review suggested that new VES technologies including HID, configurations supplemented by UV-A headlamps, and IR-TIS would out-perform HLB in the experimental conditions for this study. Although some of these technologies indeed out-performed HLB, not all achieved this goal.

HID systems, in general, followed the same trend discussed in Question 1 (clear conditions): they were out-performed by the rest of the systems. The same issues that were suggested in Question 1 as probable causal agents for this sub-par performance may also negatively affect the performance of this technology under adverse weather.

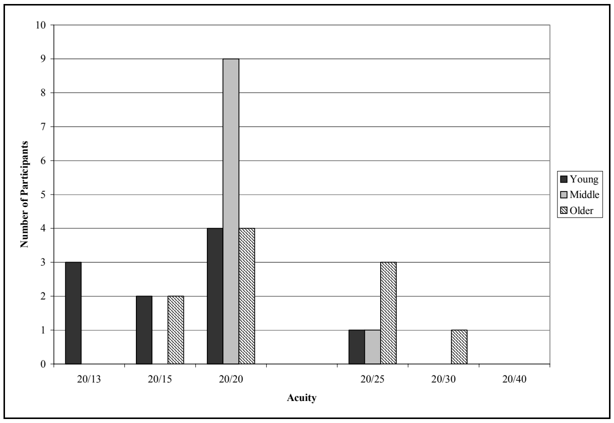
IR-TIS was negatively affected by the adverse weather. While it provided excellent performance levels under clear weather, this system exhibited the shortest Detection and Recognition distances observed in this study. The reason for this performance reversal is attributable to problems with the technology. Since a temperature differential between the rain and the environment usually exists, rain droplets are visible to the IR system. Thus, rain droplets are displayed on the HUD, effectively washing out the display. The resultant display is similar to the picture on a television screen receiving considerable signal interference (i.e., “snow”). Thus, drivers were not able to use the system inside the rain most of the time, thus, they were left with a system of low profile HLB. Indeed, no performance differences were observed between the traditional HLB-LP and the IR-TIS under adverse weather. Detection and Recognition distances when driving with the IR-TIS were reduced by approximately 22 ft (12 percent reduction) when compared to HLB.

UV-A headlamps improved Detection and Recognition of various objects when used as supplements for HLB, especially for pedestrians and non-motorists with high contrast clothing. Potentially, the improvement over HLB might exceed the 18 percent observed in this study (e.g., Detection of the cyclist-high contrast clothing was 46 ft farther away) during less severe weather conditions.

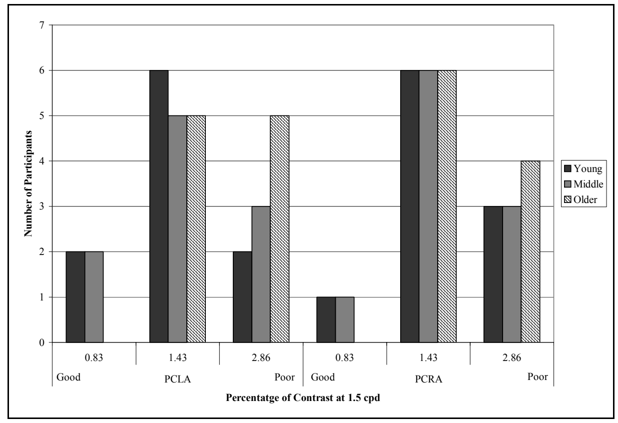
6.1.4 Research Question 4:Does age cause a significant difference in terms of Detection and Recognition distances depending on the weather conditions?

Age trends in clear weather, in which younger and older drivers’ Detection and Recognition distances differed, did not occur in adverse weather conditions. During adverse weather, the visibility was severely restricted across all age groups and no significant difference between age groups was observed in terms of Detection and Recognition distances. The data must be divided by Age Group, Type of Object, and VES (i.e., three-way interaction) before a few significant changes in performance are observed. For example, headlamp systems supplemented with UV-A allowed older drivers to detect and recognize the Pedestrians-High Contrast Clothing considerably farther away than they were able to with HIDs or HLB-LPs for Pedestrians-Low Contrast Clothing. Younger and middle-age drivers, on the other hand, exhibited more consistency in their performance across VES and objects.

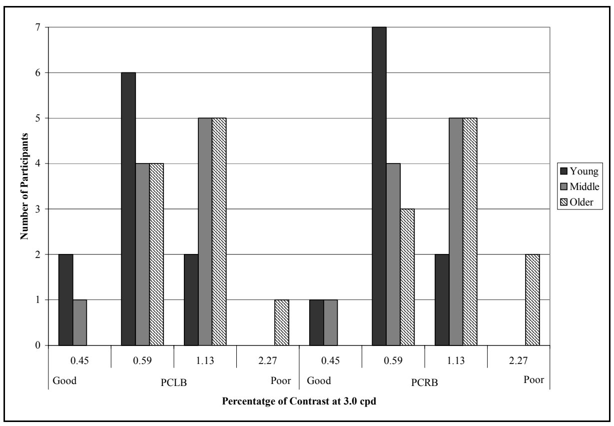
As explained earlier, visual acuity and contrast sensitivity decline with age. It is theorized that, due to decreased contrast sensitivity and the low-visibility conditions of adverse weather, older drivers were able to see farther only those objects that fluoresced because of the UV-A headlamps. The same trends of decreased visual acuity and contrast sensitivity mentioned in the Question 2 discussion were evident for this pool of participants (Figure 6.3).



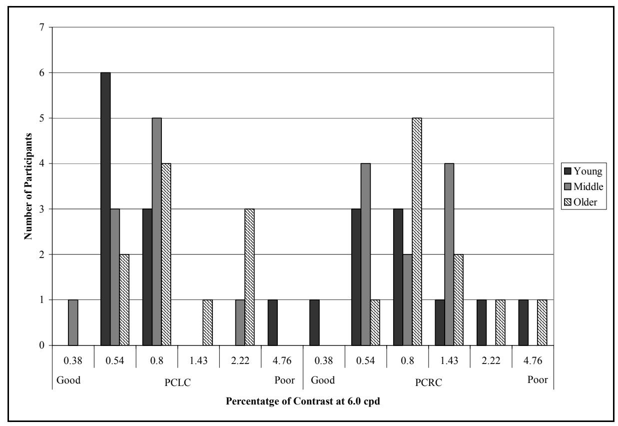
(a) Visual Acuity



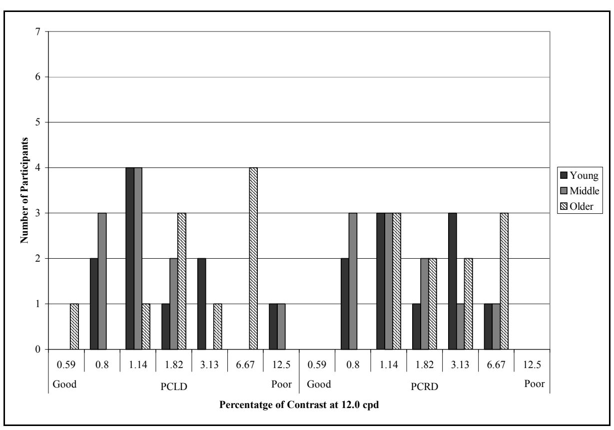
(b) Percentage of Contrast at 1.5 cpd



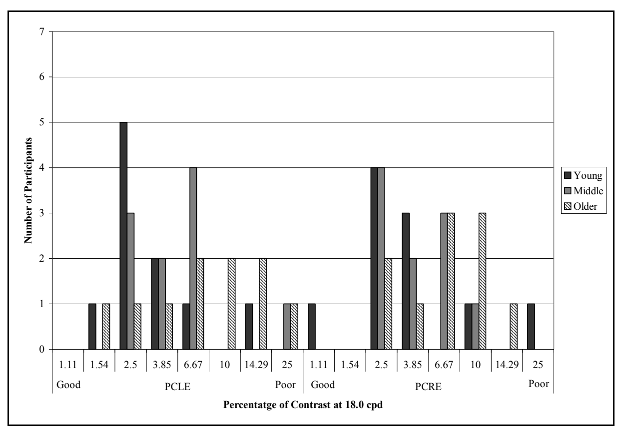
(c) Percentage of Contrast at 3.0 cpd



(d) Percentage of Contrast at 6.0 cpd



(e) Percentage of Contrast at 12.0 cpd



(d) Percentage of Contrast at 18.0 cpd

Figure 6.3 Participant's visual acuity and contrast sensitivity divided by age group (Adverse Weather).

6.1.5 *Research Question 5: Do systems that show an increase in Detection and Recognition distances for pedestrians and cyclists also show the same trend for the other objects (i.e., Tire Tread and Children's Bicycle)?*

Comparisons made in this section use HLB headlamps as a baseline system. Detection and Recognition distances were determined by VES, Object, and Weather Condition (Table 6.35 to Table 6.38). The top three Detection and Recognition distances for each object are highlighted on these tables (1st = green; 2nd = red; 3rd = yellow).

No consistent trend was observed under clear weather conditions. The best VES for the Detection of pedestrians and cyclists with low contrast clothing (i.e., IR-TIS) did not perform as well for objects at ground level (i.e., Tire Tread and the Children's Bicycle). For Pedestrians-High Contrast Clothing, the IR-TIS allowed early Detection of pedestrians in front of the vehicle path (i.e., Perpendicular Pedestrian-High Contrast Clothing), but not those on the side of the road (i.e., Static Pedestrian-High Contrast Clothing and Parallel Pedestrian-High Contrast Clothing). This effect is probably due to 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 non-motorists with low contrast clothing (i.e., < 7 percent Detection increase over HLB). However, HLB supplemented with the UV-A headlamps represented up to an 11 percent (i.e., 94 ft) increase in Detection distance and a 13 percent (i.e., 96 ft) increase in Recognition distances over HLB for pedestrians and non-motorists with high contrast 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 high contrast clothing). This result was not surprising, as the HID headlamp exhibits a sharp cutoff towards the driver's right side, the same spot in the road where these pedestrians aligned. While these technologies always maintained control of the first three positions (best) for both Detection and Recognition, the rankings were modified in some instances. For example, IR-TIS was the best system for detecting the Cyclist-Low Contrast Clothing and Perpendicular Pedestrian-High Contrast Clothing, but it was not the best system for Recognition of these objects. Thus, in clear weather conditions no VES is consistently the best in facilitating long Detection and Recognition distances. However, HLB is remarkably consistent.

Table 6.35 Detection distance differences by VES and Type of Object – Clear Weather.

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	811.8	662.2	659.7	354.6	171.8	840.1	852.0	958.9	865.6
5 UV-A + HLB	569.3	394.6	381.5	469.1	220.0	927.7	894.8	911.3	856.0
3 UV-A + HLB	542.4	373.9	377.4	460.8	252.6	856.9	869.6	886.7	951.5
Hybrid UV-A + HLB	601.7	391.9	419.4	467.9	235.2	871.6	810.6	866.1	887.6
HLB	565.6	385.7	409.0	464.0	239.8	862.3	839.0	827.8	857.8
HOH	524.7	328.0	341.7	402.2	215.3	844.8	807.9	797.7	832.1
HHB	499.6	370.3	374.2	407.3	189.3	847.9	788.6	776.2	822.2
5 UV-A + HID	409.1	249.2	268.0	439.6	209.9	841.6	814.5	865.5	925.4
3 UV-A + HID	417.1	260.9	296.8	400.4	193.6	790.5	782.6	827.8	842.0
Hybrid UV-A + HID	465.0	296.2	298.3	447.7	217.0	757.1	858.5	724.8	732.8
HID	444.0	282.1	274.7	416.6	212.2	683.0	712.7	733.9	796.1
HLB-LP	494.0	301.8	326.2	399.2	176.9	721.2	744.0	778.0	805.4

Type of Object

(a) Mean Detection Distances (units: feet)

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	246.2	276.5	250.7	-109.4	-68.0	-22.2	13.0	131.1	7.8
5 UV-A + HLB	3.8	9.0	-27.5	5.2	-19.8	65.4	55.8	83.5	-1.8
3 UV-A + HLB	-23.1	-11.8	-31.6	-3.1	12.8	-5.4	30.6	59.0	93.7
Hybrid UV-A + HLB	36.1	6.2	10.4	3.9	-4.6	9.2	-28.4	38.3	29.8
HLB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HOH	-40.9	-57.7	-67.3	-61.7	-24.5	-17.5	-31.1	-30.0	-25.7
HHB	-66.0	-15.4	-34.9	-56.7	-50.5	-14.4	-50.5	-51.6	-35.6
5 UV-A + HID	-156.4	-136.5	-141.0	-24.4	-29.9	-20.8	-24.6	37.8	67.6
3 UV-A + HID	-148.5	-124.8	-112.2	-63.5	-46.2	-71.8	-56.4	0.1	-15.8
Hybrid UV-A + HID	-100.6	-89.5	-110.8	-16.2	-22.8	-105.3	19.5	-103.0	-125.0
HID	-121.6	-103.6	-134.3	-47.4	-27.6	-179.3	-126.4	-93.9	-61.7
HLB-LP	-71.6	-83.9	-82.8	-64.8	-62.9	-141.1	-95.0	-49.7	-52.3

Type of Object

(b)Detection Distance difference between the different VES and HLB (units: feet)

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	44%	72%	61%	-24%	-28%	-3%	2%	16%	1%
5 UV-A + HLB	1%	2%	-7%	1%	-8%	8%	7%	10%	0%
3 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%
5 UV-A + HID	-28%	-35%	-34%	-5%	-12%	-2%	-3%	5%	8%
3 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%

(c)Percentage of difference between the different VES and HLB

Table 6.36 Recognition distance differences by VES and Type of Object – Clear Weather.

Type of Object

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	525.6	495.4	521.5	305.1	135.9	672.5	695.9	774.4	768.7
5 UV-A + HLB	512.1	334.8	333.1	419.3	185.9	755.3	814.0	797.9	760.7
3 UV-A + HLB	485.9	330.8	316.7	420.2	195.2	673.9	741.8	768.2	825.4
Hybrid UV-A + HLB	530.6	346.9	333.4	402.6	201.5	705.9	726.0	768.6	797.1
HLB	490.8	335.6	331.3	412.0	202.5	728.2	762.4	722.2	729.3
HOH	457.8	276.5	290.5	366.0	167.5	676.5	709.4	706.5	732.8
HHB	440.0	317.2	308.1	356.1	153.7	691.2	696.6	669.2	725.7
5 UV-A + HID	343.7	210.0	211.6	364.9	171.7	639.1	699.5	718.0	782.3
3 UV-A + HID	337.8	222.6	227.7	343.2	150.5	619.1	681.7	710.4	715.7
Hybrid UV-A + HID	408.8	243.2	244.3	392.9	182.1	622.1	746.5	639.7	640.7
HID	389.9	231.9	229.6	355.4	169.4	502.1	626.3	630.7	672.8
HLB-LP	407.4	264.1	252.9	348.4	145.2	591.9	672.6	670.1	715.2

(a) Mean Recognition Distances (units: feet)

Type of Object

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	**34.8**	**159.8**	**190.2**	-106.9	-66.6	-55.7	-66.5	**52.2**	39.4
5 UV-A + HLB	**21.2**	-0.8	**1.8**	**7.3**	-16.6	**27.1**	**51.6**	**75.7**	31.4
3 UV-A + HLB	-4.9	-4.8	-14.6	**8.2**	**-7.3**	-54.3	-20.6	46.1	**96.1**
Hybrid UV-A + HLB	**39.8**	**11.3**	**2.1**	-9.4	**-1.0**	**-22.3**	-36.4	**46.4**	**67.8**
HLB	0.0	**0.0**	0.0	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0
HOH	-33.0	-59.1	-40.8	-45.9	-35.1	-51.7	-53.0	-15.7	3.5
HHB	-50.8	-18.4	-23.2	-55.9	-48.8	-37.0	-65.9	-53.0	-3.6
5 UV-A + HID	-147.2	-125.6	-119.8	-47.1	-30.9	-89.1	-62.9	-4.2	**53.1**
3 UV-A + HID	-153.0	-113.0	-103.7	-68.7	-52.1	-109.1	-80.7	-11.8	-13.6
Hybrid UV-A + HID	-82.0	-92.4	-87.0	-19.1	-20.4	-106.1	**-15.9**	-82.5	-88.6
HID	-100.9	-103.7	-101.7	-56.6	-33.1	-226.1	-136.1	-91.5	-56.5
HLB-LP	-83.4	-71.5	-78.4	-63.6	-57.4	-136.3	-89.8	-52.1	-14.0

(b)Recognition Distance difference between the different VES and HLB (units: feet)

Type of Object

VES	Cyclist-Low Contrast Clothing	Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing	Static Pedestrian-High Contrast Clothing
IR-TIS	**7%**	**48%**	**57%**	-26%	-33%	-8%	-9%	**7%**	5%
5 UV-A + HLB	**4%**	0%	**1%**	**2%**	-8%	**4%**	**7%**	**10%**	4%
3 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%
5 UV-A + HID	-30%	-37%	-36%	-11%	-15%	-12%	-8%	-1%	**7%**
3 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%

(c)Percentage of difference between the different VES and HLB

Adverse weather considerably modifies the conclusions reached under clear weather. HLB, by itself or supplemented with UV-A, resulted in the top Detection and Recognition distances across all objects. The additional effect of UV-A ranged from a 0.1 to 46 ft (i.e., < 1 to

18 percent) improvement over HLB for Detection distances, and up to a 44 ft (i.e., 19 percent) improvement for Recognition distances.

Table 6.37 Detection distance differences by VES and Type of Object – Adverse Weather.

VES	Type of Object Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing
IR-TIS	122.3	111.7	197.6	121.0	232.8	244.7	217.6
5 UV-A + HLB	128.8	143.3	221.2	154.3	300.4	298.6	297.1
3 UV-A + HLB	140.5	142.5	216.0	147.6	286.5	303.0	276.5
Hybrid UV-A + HLB	130.9	129.9	214.3	150.6	297.3	275.7	270.2
HLB	128.7	128.8	211.9	139.5	254.7	257.7	266.0
HOH	127.7	119.3	196.8	141.0	260.1	265.4	247.6
HHB	126.4	128.5	170.5	120.8	243.5	248.5	245.7
5 UV-A + HID	119.2	108.4	206.7	125.9	278.7	276.7	280.9
3 UV-A + HID	117.7	122.4	198.1	136.8	256.8	267.2	255.4
Hybrid UV-A + HID	117.1	105.1	198.8	135.6	239.3	264.2	253.6
HID	117.4	110.0	185.1	144.6	228.3	244.9	221.1
HLB-LP	121.9	112.0	183.8	128.9	226.6	243.4	235.3

(a) Mean Detection Distances (units: feet)

VES	Type of Object Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing
IR-TIS	-6.4	-17.1	-14.2	-18.5	-21.8	-13.0	-48.4
5 UV-A + HLB	**0.1**	**14.5**	**9.3**	**14.8**	**45.8**	**40.9**	**31.1**
3 UV-A + HLB	**11.8**	**13.7**	**4.1**	**8.1**	**31.9**	**45.3**	**10.5**
Hybrid UV-A + HLB	**2.2**	**1.1**	**2.5**	**11.1**	**42.7**	18.0	4.2
HLB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HOH	-1.0	-9.4	-15.0	1.6	5.5	7.7	-18.4
HHB	-2.3	-0.3	-41.4	-18.6	-11.1	-9.2	-20.3
5 UV-A + HID	-9.5	-20.4	-5.2	-13.6	24.0	**19.0**	**14.9**
3 UV-A + HID	-11.1	-6.3	-13.7	-2.7	2.2	9.5	-10.6
Hybrid UV-A + HID	-11.6	-23.7	-13.1	-3.9	-15.4	6.6	-12.4
HID	-11.3	-18.8	-26.8	5.1	-26.4	-12.8	-44.9
HLB-LP	-6.9	-16.8	-28.1	-10.5	-28.0	-14.2	-30.7

(b)Detection Distance difference between the different VES and HLB (units: feet)

VES	Type of Object Parallel Pedestrian-Low Contrast Clothing	Perp Pedestrian-Low Contrast Clothing	Children's Bicycle	Tire Tread	Cyclist-High Contrast Clothing	Parallel Pedestrian-High Contrast Clothing	Perp Pedestrian-High Contrast Clothing
IR-TIS	-5%	-13%	-7%	-13%	-9%	-5%	-18%
5 UV-A + HLB	**0.08%**	**11%**	**4%**	**11%**	**18%**	**16%**	**12%**
3 UV-A + HLB	**9%**	**11%**	**2%**	**6%**	**13%**	**18%**	**4%**
Hybrid UV-A + HLB	**2%**	**1%**	**1%**	**8%**	**17%**	7%	2%
HLB	0%	0%	0%	0%	0%	0%	0%
HOH	-1%	-7%	-7%	1%	2%	3%	-7%
HHB	-2%	0%	-20%	-13%	-4%	-4%	-8%
5 UV-A + HID	-7%	-16%	-2%	-10%	9%	**7%**	**6%**
3 UV-A + HID	-9%	-5%	-6%	-2%	1%	4%	-4%
Hybrid UV-A + HID	-9%	-18%	-6%	-3%	-6%	3%	-5%
HID	-9%	-15%	-13%	4%	-10%	-5%	-17%
HLB-LP	-5%	-13%	-13%	-8%	-11%	-6%	-12%

(c)Percentage of difference between the different VES and HLB

Table 6.38 Recognition distance differences by VES and Type of Object – Adverse Weather.

	Type of Object						
VES	**Parallel Pedestrian-Low Contrast Clothing**	**Perp Pedestrian-Low Contrast Clothing**	**Children's Bicycle**	**Tire Tread**	**Cyclist-High Contrast Clothing**	**Parallel Pedestrian-High Contrast Clothing**	**Perp Pedestrian-High Contrast Clothing**
IR-TIS	105.6	93.4	163.0	102.6	206.9	218.1	195.2
5 UV-A + HLB	112.6	128.7	198.4	131.1	258.3	267.3	269.5
3 UV-A + HLB	121.9	119.5	193.0	130.2	246.9	273.5	246.9
Hybrid UV-A + HLB	112.6	115.5	189.9	128.2	255.0	248.2	250.7
HLB	114.2	116.2	189.8	120.2	221.3	229.6	241.3
HOH	114.8	103.1	179.4	115.9	238.3	240.8	225.8
HHB	104.3	108.4	153.6	110.9	218.8	224.8	224.1
5 UV-A + HID	104.8	94.4	176.8	105.2	226.3	244.5	250.5
3 UV-A + HID	103.6	103.3	172.7	115.1	211.9	237.4	229.8
Hybrid UV-A + HID	102.1	87.7	176.0	112.9	209.2	235.4	225.4
HID	101.8	89.9	164.5	122.1	195.3	218.1	199.7
HLB-LP	107.4	95.4	163.1	111.0	198.7	213.1	213.5

(a) Mean Recognition Distances (units: feet)

	Type of Object						
VES	**Parallel Pedestrian-Low Contrast Clothing**	**Perp Pedestrian-Low Contrast Clothing**	**Children's Bicycle**	**Tire Tread**	**Cyclist-High Contrast Clothing**	**Parallel Pedestrian-High Contrast Clothing**	**Perp Pedestrian-High Contrast Clothing**
IR-TIS	-8.6	-22.8	-26.9	-17.6	-14.4	-11.5	-46.1
5 UV-A + HLB	-1.6	**12.5**	**8.5**	**10.9**	**37.0**	**37.7**	**28.2**
3 UV-A + HLB	**7.7**	**3.3**	**3.1**	**10.0**	**25.6**	**43.9**	5.6
Hybrid UV-A + HLB	-1.6	-0.7	0.0	**7.9**	**33.7**	**18.6**	**9.4**
HLB	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0
HOH	**0.6**	-13.1	-10.4	-4.3	17.0	11.2	-15.5
HHB	-9.9	-7.8	-36.3	-9.3	-2.4	-4.8	-17.2
5 UV-A + HID	-9.4	-21.8	-13.0	-15.0	5.1	14.8	**9.2**
3 UV-A + HID	-10.6	-12.9	-17.1	-5.1	-9.3	7.7	-11.5
Hybrid UV-A + HID	-12.1	-28.5	-13.9	-7.3	-12.1	5.8	-15.9
HID	-12.4	-26.3	-25.3	1.9	-26.0	-11.5	-41.5
HLB-LP	-6.8	-20.8	-26.7	-9.2	-22.6	-16.6	-27.8

(b)Recognition Distance difference between the different VES and HLB (units: feet)

	Type of Object						
VES	**Parallel Pedestrian-Low Contrast Clothing**	**Perp Pedestrian-Low Contrast Clothing**	**Children's Bicycle**	**Tire Tread**	**Cyclist-High Contrast Clothing**	**Parallel Pedestrian-High Contrast Clothing**	**Perp Pedestrian-High Contrast Clothing**
IR-TIS	-8%	-20%	-14%	-15%	-7%	-5%	-19%
5 UV-A + HLB	-1%	**11%**	**4%**	**9%**	**17%**	**16%**	**12%**
3 UV-A + HLB	**7%**	**3%**	**2%**	**8%**	**12%**	**19%**	2%
Hybrid UV-A + HLB	-1%	-1%	0%	**7%**	**15%**	**8%**	**4%**
HLB	**0%**	**0%**	**0%**	0%	0%	0%	0%
HOH	**1%**	-11%	-5%	-4%	8%	5%	-6%
HHB	-9%	-7%	-19%	-8%	-1%	-2%	-7%
5 UV-A + HID	-8%	-19%	-7%	-12%	2%	6%	**4%**
3 UV-A + HID	-9%	-11%	-9%	-4%	-4%	3%	-5%
Hybrid UV-A + HID	-11%	-25%	-7%	-6%	-5%	3%	-7%
HID	-11%	-23%	-13%	2%	-12%	-5%	-17%
HLB-LP	-6%	-18%	-14%	-8%	-10%	-7%	-12%

(c)Percentage of difference between the different VES and HLB

Under clear weather conditions, the following conclusions can be reached: (1) IR-TIS is the best configuration for pedestrians and cyclists with low contrast clothing, (2) halogen supplemented with UV-A is the best configuration for pedestrians and cyclists with high contrast clothing, and (3) halogen is the best configuration for all other types of objects. Conversely, under adverse weather conditions: (1) halogen supplemented with UV-A is the best configuration for pedestrians and cyclists with high contrast clothing, and (2) halogen is the best configuration for pedestrians and cyclists with low contrast clothing and all other types of objects.

6.1.6 Research Question 6: Which low visibility scenarios increase the level of perceived risk during nighttime driving?

Risk is an expression of the possibility of a mishap in terms of severity and likelihood (Roland and Moriarty, 1990; Yates and Stone, 1992; Young, Brelsford, and Wogalter, 1990). The rating scales that addressed risk in this study evaluated Likelihood and Carefulness. Carefulness has been highly correlated to risk severity in previous studies, which suggest that precaution intent is a good predictor of severity (Wogalter et al., 1993). The subjective rating results for Likelihood and Carefulness confirmed this inverse correlation (*Pearson* $r = 0.90$, $p < 0.0001$), which also verified the Likelihood construct validity.

Subjective ratings of low visibility (i.e., adverse weather) scenarios suggested that drivers are more likely to use HIDs with 5 or 3 UV-A headlights than any of the other systems, and they feel relatively neutral with respect to the IR-TIS. Carefulness ratings indicate that drivers feel they should be careful with all of the systems under adverse weather conditions. Although no significant quantifiable relationship was found between the subjective measurements of Likelihood and Carefulness and the objective measurements, both results indicated that the effects of adverse weather served to equalize the systems. The consistency of subjective ratings across VESs might simply have occurred because, under the type of adverse weather considered, the drivers were not able to perceive that a particular system performed considerably better, or worse, than the others.

During interviews, participants suggested a variety of weather-related scenarios (not all of which were low visibility related) that would increase risk perception during nighttime driving to a point where they would prefer not to drive at all: (1) icy road conditions, (2) snow, (3) rain, (4) bad weather in general, (5) fog, (6) hail, (7) thunderstorm, (8) blizzard, (9) hurricanes, and

(10) floods. Some of the comments obtained during the interview process that concern drivers' perceptions of potential risks during low visibility conditions are as follows:

- *"Rain reflects back, especially if it's coming down real fast" (Participant #30-NN-Weather).*
- *"Snow is the worse, I know, I've been there" (Participant #31-NN-Weather).*
- *[During snow] "The road is all one color and you can't see any lane markings" (Participant #32-NN-Weather).*
- *"If it's raining and you know that it's in a freezing zone, a freezing temperature, then it's going to totally change, it's no longer rain, now you're in the condition where you're going to be sliding because of ice, and then if it's not cold enough to freeze, then you may look at how much it has rained; you may start hydroplaning" (Participant #42-NN-Weather).*
- *[During fog] "You couldn't see the car's tail lights two feet in front of you. Scary" (Participant #47-NN-Weather).*
- *"The rain blocks your vision, and a lot of it has to do with how hard the rain is coming down" (Participant #45-NN-Weather).*
- *"I've had rain come down so hard that you couldn't see hardly anything in front of you" (Participant #46-NN-Weather).*
- *[During rain] "I'd say that raises the risk of accidents because of visibility and reaction time" (Participant #49-NN-Weather).*
- *"Fog at night is probably the worst condition to drive in" (Participant #56-NN-Weather).*
- *"Rain at night is of course worse than daytime" (Participant #57-NN-Weather).*
- *[During rain] "A great risk because you can't see, visibility is a problem" (Participant #33-NN-Weather).*
- *"Rain isn't as bad for me as fog because I can't see very far ahead" (Participant #34-NN-Weather).*
- *"I think one of the hardest and worst types of driving there is in a snowstorm, well you can't see anything. And the snow gets all over you headlights and blocks your light and usually it gets on the low part first and if you put them on low beam, have you ever tried to drive in a snow storm with high beams? You can't see anything because its up in the snow and it all comes back at you. And so, the worst type of driving there is, is in a snowstorm" (Participant #52-NN-Weather).*

6.1.7 Research Question 7:How does the level of perceived risk differ for different age groups and genders when driving at night?

No significant differences in the level of perceived risk were observed due to the difference in Age or Gender for any of the following situations:

- Having an adult as a passenger while driving during nighttime.
- Driving alone during nighttime.
- Having children as a passenger while driving during nighttime.

- Going to a place that the driver is familiar with during nighttime.
- Traveling through a congested roadway during nighttime.
- Traveling through an uncongested roadway during nighttime.
- Driving under clear weather conditions during nighttime.
- Driving under adverse weather conditions during nighttime.
- Driving under a condition that is affected by the speed limit during nighttime.
- Driving under a condition that is affected by the driver's vision during nighttime.

Only the risk perceived when going to a place unfamiliar to the driver was significantly different across genders; males perceived less than half of the risk perceived by females. The overall risk perception for nighttime driving, when all the nighttime risk related categories were collapsed, demonstrated a significant difference due to both Age and Gender. As expected, middle-age and older females perceived higher levels of risk than did younger females. Younger and middle-age males perceived similar levels of risk, while older males had a lower perception. This drop in risk perception for older males was unexpected. Holland (1993) suggested that positive self-bias increases ("bad things can happen, but not to me") might be common for older drivers with greater driving experience. For this specific study, all participants, including older drivers, were fully in control of their mobility and drove themselves to the experimental location. It is possible that these individuals might drive more often than the average person of their same age group and, thus, not be fully representative of the average person in terms of their attitudes toward driving.

In situations where no risk was perceived during nighttime (i.e., Nighttime-Positive), younger males reported more situations in which they did not perceive any risk. Middle-age males fell between younger and older males in these frequencies. Older male drivers were less prone to categorize a condition as a positive (i.e., no risk) nighttime driving scenario. Female drivers showed a distinctly different behavior: older females perceived more conditions as positive during nighttime. This finding, however, might be due to some common characteristics that tend to describe older female research participants. Older females who participate in research studies tend to be more willing to help, and have a greater interest in collaborating with the improvement of issues that might affect them; improving nighttime driving environment is a fairly common concern for older female drivers (Straight, 2001).

Because young males are more likely to consider a scenario as offering "no risk," these individuals may be more prone to misjudge risk situations than older male drivers. This finding agrees with previous research on driving behavior, which suggested that young drivers, especially males, are overconfident (Brown, 1982) and have a lower perception of hazards (Jonah, 1986).

In general, the perception of risk while driving during nighttime is completely subjective, and what one driver might perceive as a dangerous situation, another might simply perceive as a situation where caution is needed, or where no risk is present at all.

6.1.8 Research Question 8: Which characteristic(s) do drivers identify as main generators of risk during nighttime driving?

Based on data from the final questionnaire in Study 2, the following characteristics represent scenarios that significantly decrease the likelihood of driving during nighttime. The scenarios are ranked based on the difference between daytime and nighttime likelihood of driving during a given scenario (the greatest likelihood difference is presented first):

1. High Volume Traffic
2. Unknown Roadways
3. Driving with Children
4. Rainy/Adverse Weather
5. Driving Alone

The results obtained from the unstructured interviews were consistent with the questionnaire findings. Based on interview results, driving during nighttime under adverse weather conditions was the highest perceived risk generator, followed by driving during nighttime on a roadway with high volume traffic (mainly because of oncoming traffic creating a glare discomfort), and the overall reduction of visibility during nighttime (which participants judged to affect their driving). Going to an unknown place during nighttime represented levels of perceived risk similar to those assigned to reduced visibility or visibility problems while driving during nighttime. This generator (going to an unknown place during nighttime) was also perceived as a higher risk by females than by males. An excerpt from the interviews supports this finding:

> *"I just would feel more comfortable if I had someone with me on an unknown roadway. I don't know, maybe women are supposed to be afraid of the night maybe" (Participant #51-NP-Passenger-Adult).*

The results obtained by Coughlin (2001), which are based on focus groups composed of AARP members, coincide with the risk generators identified in this study. In his report, Coughlin suggests that older people who are still driving will curtail their trips during nighttime, adverse weather, or heavy traffic.

6.1.9 Research Question 9: What type of relationship exists between nighttime driving risk perception and visual performance measurements?

The empirical model developed as part of this research effort suggests that both risk perception and Detection and Recognition distances can be moderately predicted as a function of a driver's visual characteristics (Figure 6.4; please refer to Chapter 5 for model development and a graphical representation of the entire empirical model). Specifically, the overall nighttime driving risk perception and the risk perception while driving during nighttime under adverse weather conditions were both developed from the content analysis of the interview data (see equations 1 and 2 in Chapter 5). These risk perception measurements can be moderately predicted using multivariate regression models (equations 3 and 4 in Chapter 5). The regressors in these models included the driver's percentage of contrast at two different sensitivity levels (i.e., 12 cpd and 18 cpd) and the driver's visual acuity. These equations are more easily understood if presented graphically. The risk perception level, for example, increases as the driver's visual acuity and contrast sensitivity decrease (Figure 6.5).

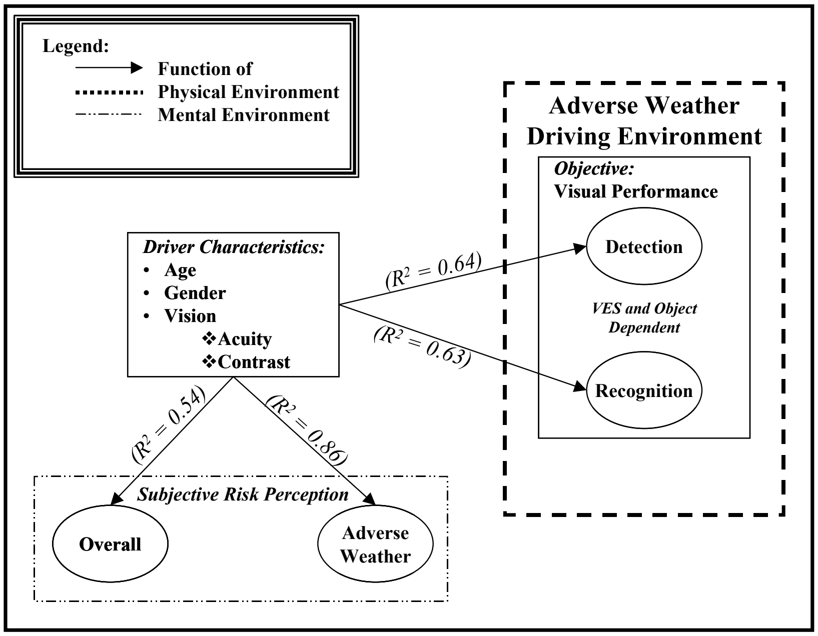


Figure 6.4 Relationship of driver characteristics with risk perception and Detection and Recognition distances under adverse weather.

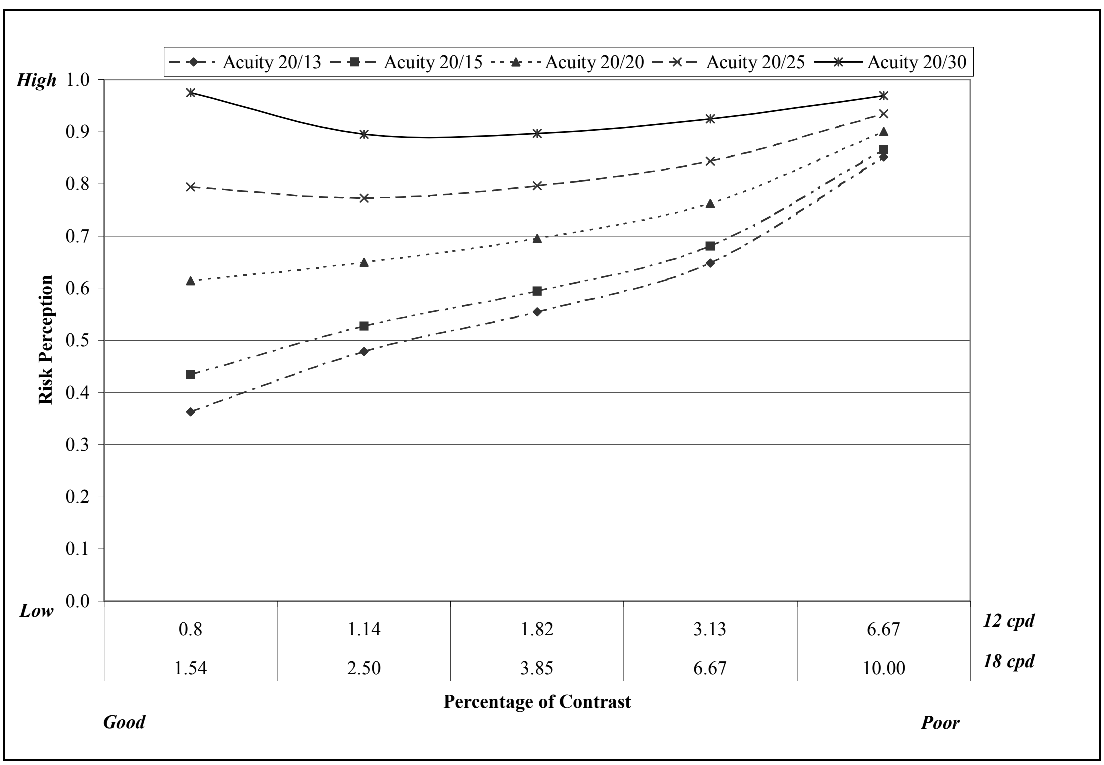


Figure 6.5 Graphical representation of the model that describes the relationship between driver characteristics and risk perception of nighttime driving under adverse weather.

Detection and Recognition distances for nighttime driving under adverse weather conditions can be predicted as a function of a driver's visual acuity, contrast sensitivity, the VES, and the characteristics of the object of interest (equations 5 and 6 in Chapter 5). Since the prediction equations are VES and Object dependent, the graphical examples presented here were calculated for a scenario in which the VES was an HLB and the object of interest was a pedestrian crossing the street dressed in low contrast clothing (Perpendicular Pedestrian-Low Contrast Clothing) (Figure 6.6 and Figure 6.7 for Detection and Recognition distances, respectively). For drivers with good visual acuity (i.e., 20/20, 20/15, 20/13) Detection distances tend to decrease as the ability to perceive contrast decreases. For less than optimal visual acuity (i.e., 20/25, 20/40) the Detection distances tend to increase as the ability to perceive contrast decreases. It is hypothesized that this increase in Detection and Recognition distance for drivers with low acuity and decreased contrast sensitivity is caused by the drivers' overcompensation of their impairment with an increased level of situational awareness. In other words, since these drivers cannot see objects as they used to, they tend to unconsciously be more alert of their surroundings. These reduced acuity and contrast sensitivity levels are mainly representative of older drivers, and it has been suggested that older drivers compensate for impairments not only by adapting their traffic behavior, but also by using the compensatory potential still available to them (Holland, 2001).

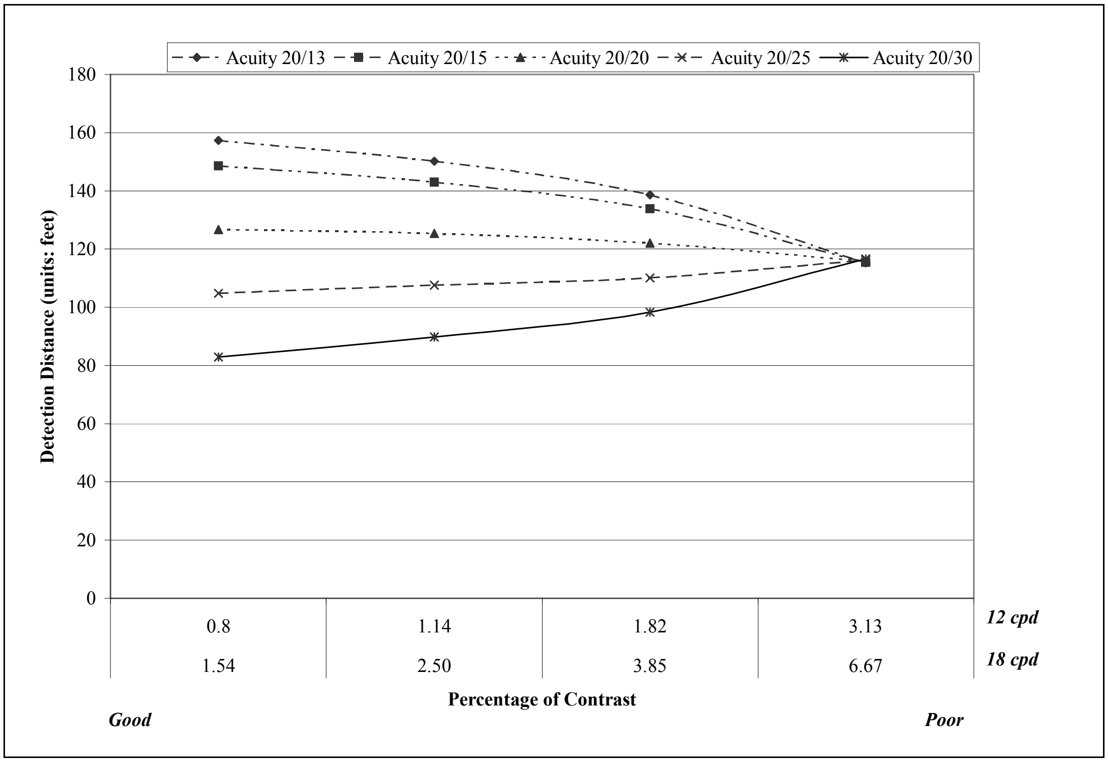


Figure 6.6 Graphical representation of the model that describes the relationship of driver characteristics and Detection distance under adverse weather (graphed for the HLB configuration and the object is a Perpendicular Pedestrian-Low Contrast Clothing).

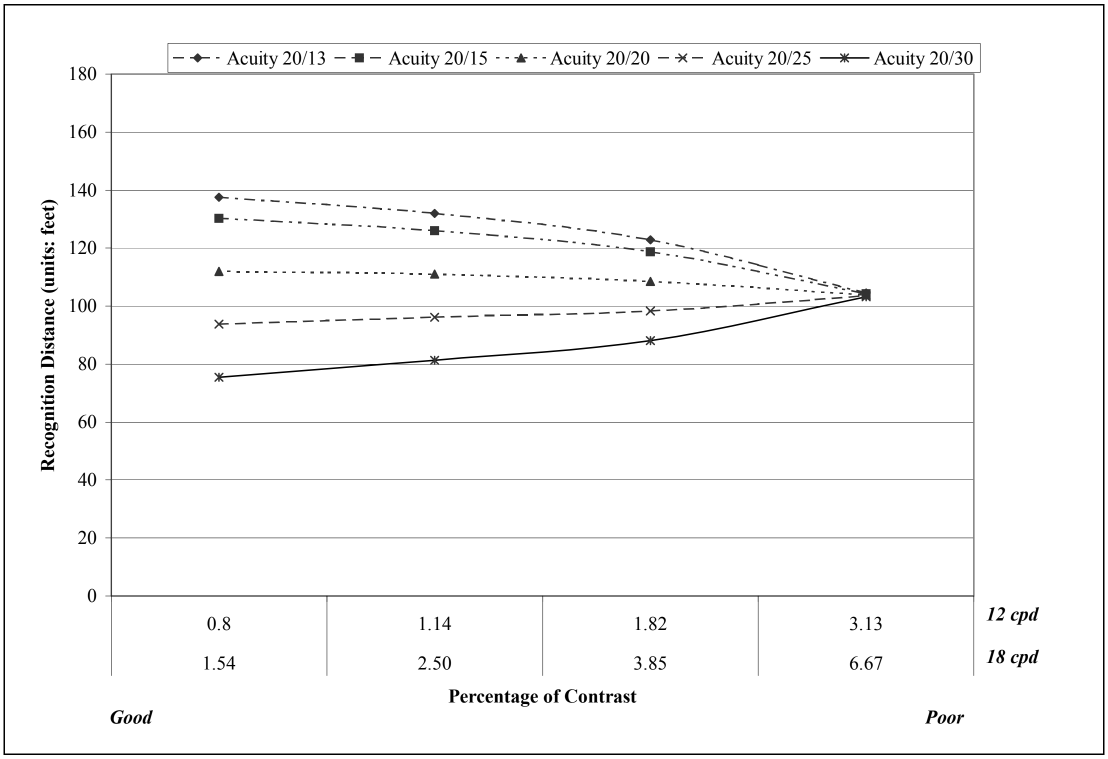


Figure 6.7 Graphical representation of the model that describes the relationship of driver characteristics and Recognition distance under adverse weather (graphed for the HLB configuration and the object is a Perpendicular Pedestrian-Low Contrast Clothing).

6.1.10 Research Question 10:What type of relationship exists between the level of risk perceived by drivers and vision enhancement systems?

As part of the modeling effort a relationship predicting nighttime driving Carefulness under adverse weather conditions as a function of a driver's Age, Visual Acuity, Contrast Sensitivity, and the VES of interest was developed (EQ. 7 in Chapter 5; Figure 6.8; Refer to Chapter 5 for details on the model development and a graphical representation of the full empirical model). Since the prediction equation is VES and Age dependent, the graphical example presented here was calculated for a scenario in which the VES was an IR-TIS and the driver was younger (Figure 6.9). Carefulness increases as the Visual Acuity and the ability to perceive contrast decreases. Although not apparent from this figure, the subjective perception of Carefulness increases with age. Also, as expected from statistical tests on the subjective ratings, IR-TIS and HHB were included as regressors in the model. These VESs exhibited the highest subjective Carefulness levels. For HHB, the high rating could explain perceived levels of reduced visibility from the reflection that a high beam headlamp creates on the roadway when used in adverse weather. IR-TIS might have received high Carefulness ratings because of the problems with the technology in adverse weather conditions (signal interference effect).

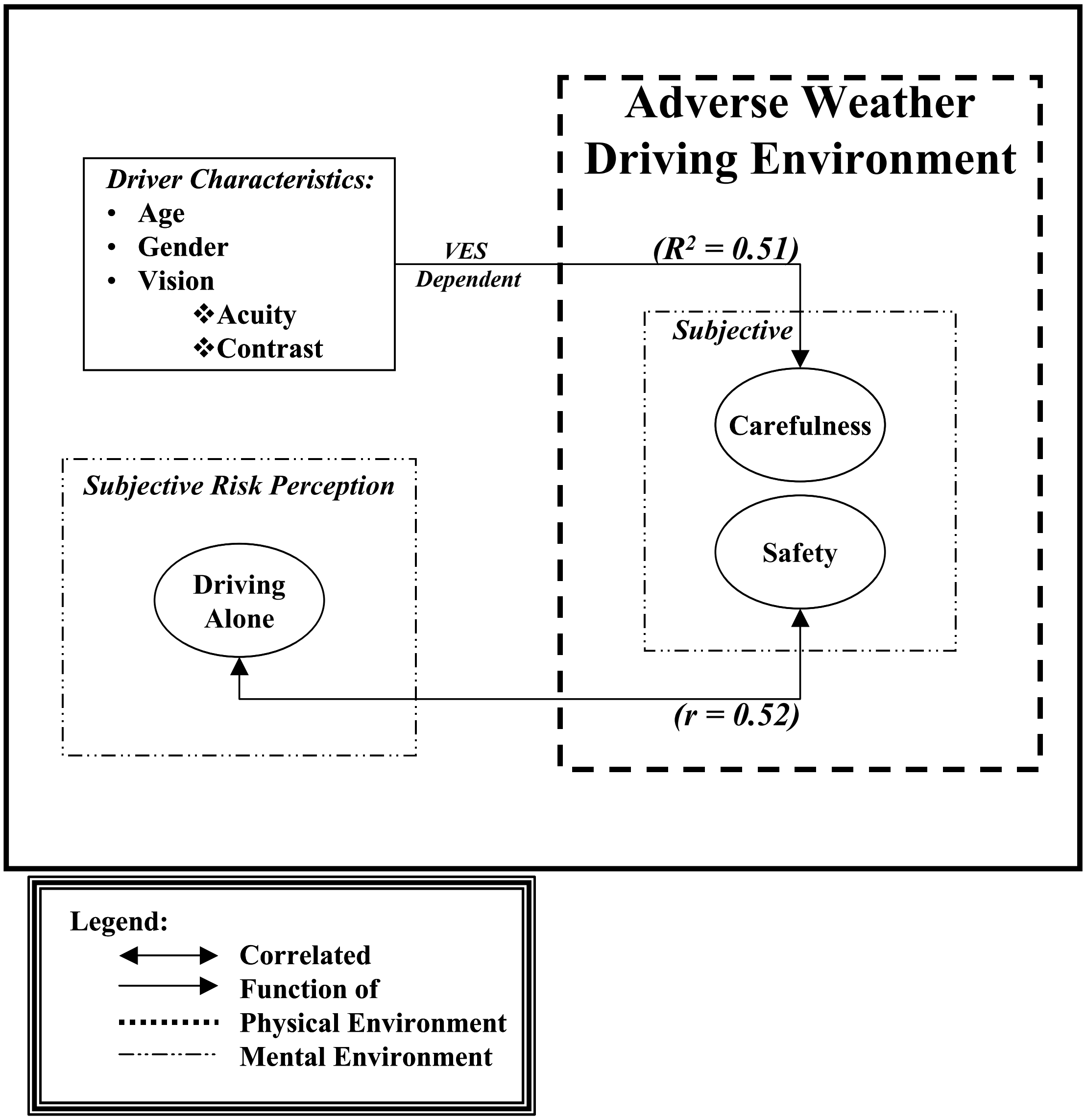


Figure 6.8 Relationship of driver characteristics with risk perception and different VES.

An interesting and positive correlation was observed between the subjective risk perception obtained from the interviews and the subjective rating scale that evaluated each driver's perception of a system's ability in assisting with lane-keeping behavior. One potential explanation for this correlation is that people who perceive a high level of risk when they have to drive by themselves at nighttime do not have much confidence in the systems assisting them. Consequently, these individuals have a tendency to perceive that the systems do not significantly improve guidance for them. Some statements gathered from the interviews support this possibility:

- *"At night, that is a little different… it is just that the concern is more stressful, or sort of dreary alone at night with no one to check our uncertainties of the road" (Participant #54-NN-Alone).*
- *"If there is some decision to be made, of any kind, while driving, if you have someone to talk it over with, 'was that the exit coming up? Or let me see...I wasn't sure of that sign at night,' that sort of thing" (Participant #55-NP-Passenger-Adult).*

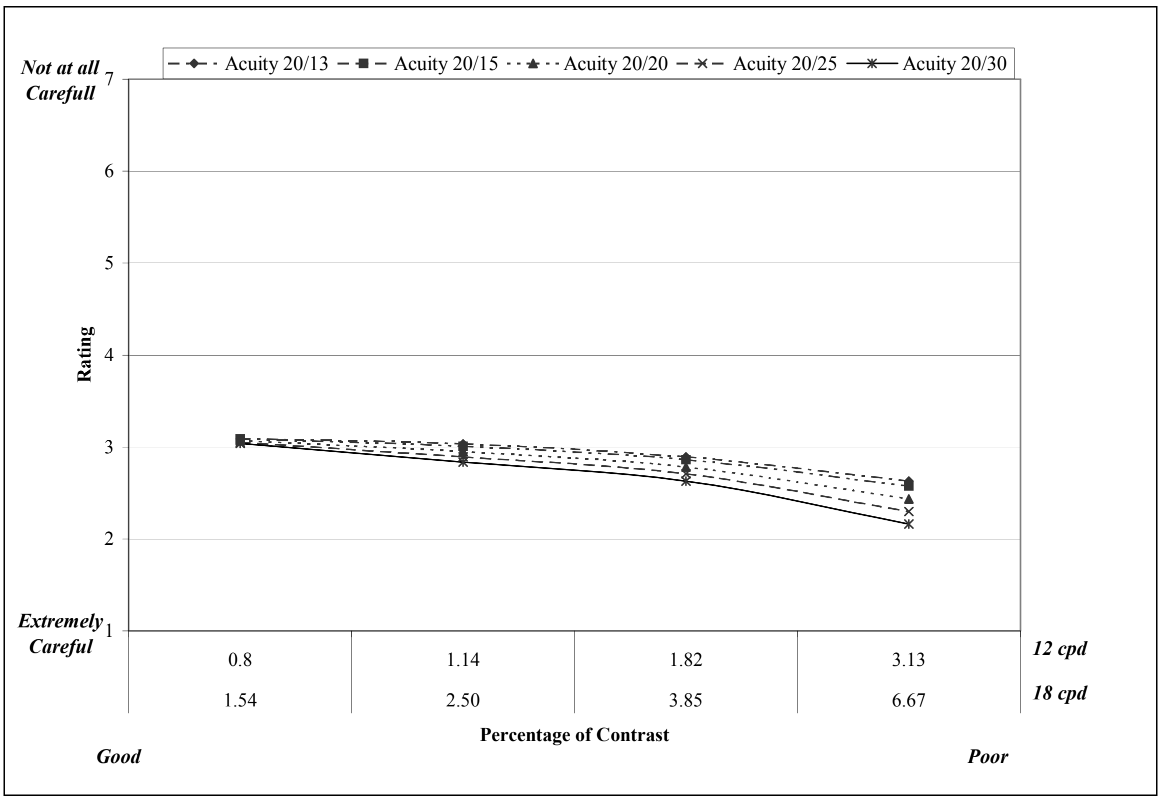


Figure 6.9 Graphical representation of the model that describes the relationship of driver characteristics and the subjective rating of Carefulness under adverse weather (graphed is for the IR-TIS configuration and a young driver).

6.2 Limitations of the study

There are several limitations associated with this study:

- ***Vision Enhancement Systems:*** There are several different types of halogen headlamps and HIDs on the market right now (e.g., different luminous output levels, different cutoff angle). Those used for this study are only a sample of current headlamp designs. Thus, the results of this study cannot necessarily be generalized to all types of HIDs or halogen headlamps.
- ***Expectancy:*** The appearance of objects was not unexpected, and the participants knew the type of objects they would be presented with. A different result might have been obtained if unexpected objects were introduced.
- ***Drivers under Adverse Weather:*** All the drivers who participated in the interview process for Study 2 were willing to drive at night under adverse weather conditions. This in itself shows that, on a risk perception scale, these individuals are not excessively afraid of driving during nighttime. Therefore, levels and types of risk perception different from those presented in this document might be found during interviews with drivers who refuse to drive at all during nighttime. It is suggested that the risk perception findings presented in this document be generalized only for the portion of the driving population that still drives during nighttime.
- ***Balancing by Vision:*** Visual acuities and the contrast sensitivities were not equally present for all age groups and for both genders. Balancing the experimental design by visual characteristics might be helpful in analyzing future research data of a similar nature.
- ***Test for Night Vision Problems:*** Participants were screened in terms of visual acuity (individuals with 20/40 vision or better are allowed to drive according to Virginia State Law), and contrast sensitivity was collected as an additional variable. Formal tests exist to identify night vision problems. Inclusion of these tests as screening criteria (or balancing for their effect) might also be helpful in future data collection efforts.
- ***Model:*** The independent variables in the model are restricted to values within certain limited ranges. That is, not all levels of acuity and contrast sensitivity were represented in the data, and not all VESs, Objects, and Ages were controlled. Therefore, the equations presented in Chapter 5 should be used only for values within the different ranges provided. Model extrapolation may not generate valid results.

7 CONCLUSIONS

The principal goal of this research effort was to study the relationship between driver characteristics, nighttime driving risk perception, and visual performance under adverse weather conditions when different VESs are used. Better understanding of the factors that increase risk perception, which systems improve detection and recognition distances, and drivers' thoughts on methods to improve driving safety during nighttime all lead to the improvement of mobility, especially for older individuals. In addition, this research effort empirically described the night vision enhancement capabilities of 12 different VESs during clear and adverse weather environments.

Limited empirical data existed that could be used to quantify and evaluate the detection and recognition distances when regular halogen headlamps, high intensity discharge, ultraviolet headlamps, and thermal imaging systems were used to perceive different types of objects at night. The results of this study represent the foundation for larger future efforts aimed at improving nighttime driving. It is also hoped that the current findings serve to illustrate the possibility that new VESs may have the potential to adversely affect the driving task and create unsafe circumstances due to possibly supporting driving behaviors unforeseen by designers. Thus, new VESs must be comprehensively tested before they are marketed.

Additional research is also needed in related night vision areas, such as empirical evaluation of low visibility conditions due to other types of adverse weather. During adverse weather conditions in this study, visibility was severely restricted across VESs, a 64 to 74 percent reduction when compared to clear conditions. This number might change dramatically for other weather conditions (e.g., snow) or lighter rain.

An interesting outcome of this research was the necessity to visualize, from a safety standpoint, the importance of considering the objects to be analyzed (e.g., contrast, motion, temperature differential) in experiments of this nature. Not surprisingly, high contrast objects were much easier to detect and recognize than low contrast objects. On average, non-motorists and pedestrians with high contrast clothing exhibited detection distances under clear weather that were more than 400 ft farther than similar low contrast objects. This increase in distance provides drivers with ample time to adjust their driving to the situation at hand and, if necessary, perform evasive maneuvers. By using high contrast clothing, non-motorists and pedestrians would avoid some of the problems of nighttime driving, such as drivers obtaining misleading information from the environment (Rheinhardt-Rutland, 1986) or failing to detect a pedestrian who is approaching (Hall, 1983). On the other hand, static objects such as tire treads or other debris on the roadway are very hard to detect and recognize, and may not allow enough time for an evasive reaction maneuver.

In addition, the results of this research suggest there is still a need for night vision enhancement to reduce fatality rates during nighttime driving. Based on the results of this study, the different types of UV-A configurations tested as alternatives for VESs resulted in no significant enhancement of detection and recognition distances when compared to regular halogen low-beam headlamps in the clear weather environment. Under adverse weather conditions, UV-A demonstrated some enhancement capabilities over halogen headlamps. The HIDs tested achieved the lowest detection and recognition distances, with detection distances 100 ft closer than halogen, on average, during clear weather conditions. On the other hand, during clear weather conditions, the IR-TIS provided the greatest detection and recognition distances, allowing the detection of pedestrians dressed with low contrast clothing over 200 ft farther away than the halogen low-beam headlamps allowed. Its performance quickly deteriorated, however, under the adverse weather condition.

7.1 Design Guidelines

The following guidelines are based on the findings of this study. The results strongly suggest that:

- Under clear weather conditions, the IR-TIS represents the most appropriate vision enhancement for detecting pedestrians and cyclists with low contrast clothing.
- Under clear weather conditions, halogen supplemented with UV-A represents the most appropriate vision enhancement for detecting and recognizing pedestrians and cyclists with high contrast clothing.
- Under clear weather conditions, halogen represents the most appropriate vision enhancement for detecting and recognizing other types of objects not included in the two results listed above.
- Under adverse weather conditions, halogen supplemented with UV-A represents the most appropriate vision enhancement for detecting and recognizing pedestrians and cyclists with high contrast clothing.

- Under adverse weather conditions, halogen supplemented with UV-A allows older drivers to detect pedestrians and cyclists with high contrast clothing sooner.
- Under adverse weather conditions, halogen represents the most appropriate vision enhancement for detecting and recognizing pedestrians and cyclists with low contrast clothing and other types of objects not included in the two results listed above.

Therefore, these results show that no condition is 100 percent dominant for overall detection and recognition of objects.

7.2 Practical Implications

Several practical implications emerge from this research. First, regulatory commissions and technical societies involved in the development of standards and recommended practices should take a more proactive approach and involve themselves with emerging VESs from the development phase. After a VES is deployed, it is too late to make changes, and only regulation remains as a viable alternative. Second, even within a category of headlamps, there are several different illumination patterns and intensities that might or might not enhance night vision. Beam pattern and intensity should be standardized so that they optimize visibility while minimizing glare to oncoming traffic. Third, the image provided by the IR-TIS is severely degraded under adverse weather conditions. This system has a potential to generate distraction during heavy rain conditions, and its operation during adverse weather conditions should be reconsidered. This distraction potential was revealed by the shortest detection distances with the IR-TIS when compared to the detection distances of the halogen low beam at a low profile (i.e., low beams of the vehicle that had the IR-TIS). Technology currently available allows windshield wipers to be automatically activated and adjusted depending on sensors that detect the amount of rain. A similar technology could be used to disable the IR-TIS during adverse weather.

7.3 Future Research

Several possibilities for future research to improve night vision exist. Over the past 10 years, significant improvements have been made in the visibility provided by traditional halogen headlamps. This is evident in the results of Study 1 of this research effort. Newer technologies, while offering advantages over existing equipment, might also suffer from some unknown disadvantages. HIDs, for example, include a greater beam spread, which not only uses the available light more efficiently, but also increases the visibility of objects in the peripheral roadway. However, these systems may have discomfort and disability glare effects on oncoming traffic. Empirical studies designed to investigate possible advantages and disadvantages of headlight technology often do not occur until after the technology appears on U.S. roadways. Therefore, a more proactive approach involving communication between researchers and automotive manufacturers is needed to initiate testing on technologies that may be available in the near future.

Providing additional overhead lighting was an aspect suggested by multiple participants as a way to reduce nighttime driving risks. The use of UV-A technology in the form of overhead lighting, for example, may result in significant advances in terms of non-motorist and pedestrian safety.

Passive IR systems showed significant benefits for detecting pedestrians in clear weather conditions. The evolution of passive IR systems, which is being pursued by several automotive original equipment manufacturers and suppliers, has great potential to improve night driving. Based upon the current findings, these newer systems may either become more sensitive to temperature differences (making it possible to detect and identify more objects), or the information from the IR camera may be passed through noise filtering algorithms (eliminating the rain-induced noise before displaying the information to the driver). The introduction of active IR technology might also significantly improve night visibility. Since IR light does not blind oncoming drivers, active IR systems have the potential to increase visibility distances beyond that of conventional headlights without negatively affecting oncoming traffic. Due to the unique characteristics of the IR technology, it is worthwhile to consider its impact on night driving in two separate ways:

1. Will evolving IR technologies further improve detection and recognition of objects in the roadway?
2. How can the roadway infrastructure work in coordination with IR systems to provide the greatest possible integration and benefit?

Public concern and press coverage about glare associated with new headlamps has been a prevalent topic in recent years, especially since the introduction of HID headlights. HID lamps provide more luminous flux than conventional halogen headlamps. This trait has made them excellent candidates for vehicular applications, and they have been implemented as standard components in some new automobiles. However, this implementation may be premature since limited research exists on the possible deleterious effects that these headlights may have on the visibility of oncoming drivers. Similar research is also lacking for high output halogen headlamps, another feasible alternative to the standard halogen lamp. Public opinion about the glare problem has revolved around a perceived increase in discomfort glare when approaching a vehicle equipped with newer headlight technology. Although driver comfort is very important and may ultimately decide whether a new technology is universally adopted, disability glare is more likely to have greater effects on safety. Disability glare is the result of light scattering in the ocular media. Light from a glare source, such as the headlights of an opposing vehicle, enters the eye and scatters, creating a uniform luminance, or “veiling” luminance, over the retina. Whether an object is brighter or darker than its background, veiling luminance will decrease the contrast of the object. As a result, the object is harder to see.

Some HID headlamps have a wider beam spread than more conventional systems. HID lamps also have a blue spectral component, which is more closely related to the scotopic sensitivity of the human peripheral visual field. These features can effectively increase the visibility of objects that are eccentric to the line of driver observation. This creates a potential safety benefit for detecting pedestrians, animals, and other objects that could enter the roadway. Other lamp types, such as high output halogen lamps, can also be considered for this type of improved visibility.

7.4 Summary

This research effort shows that the overall risk perception of nighttime driving and the risk perception of nighttime driving during adverse weather conditions vary depending on the visual capabilities of the driver. These visual capabilities also influence detection and recognition distances, more prominently so with older drivers. Older drivers obtained the shortest detection and recognition distances under clear and adverse weather conditions across all types of objects. In addition, younger drivers exhibited a sense of overconfidence and potential misjudgment of risk throughout different potential risk scenarios.

The empirical model obtained from this research portrays the influence of driver characteristics on visual performance and subjective evaluations. Driving during nighttime, especially under adverse weather conditions, restricts driver visual performance. Non-motorists represent a very vulnerable portion of the transit population, as it is difficult for oncoming drivers to detect them. Therefore, awareness of the safety hazard represented by wearing low contrast clothing during nighttime should be increased to reduce the number of fatal collisions between vehicles and non-motorists.

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Appendices

DRIVER SCREENING AND DEMOGRAPHIC QUESTIONNAIRE: ENV-OBJECTS

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 as a guideline in the screening interview):

Good morning/afternoon! My name is _____ and I work at the Virginia Tech Transportation Institute in Blacksburg, VA. 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 here in Blacksburg, VA. 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 session 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 Virginia Tech Transportation Institute? 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, LASIK, 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 2 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 three years.***
7. ***Must not have caused an injurious accident in the past two 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, LASIK eye surgery, or any other ophthalmic surgeries.***

****

Accepted: ________ ***Days that will attend to Study:***
(T):_________(N1):_________(N2):________

Rejected: ________ ***Reason:____***

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

Willing to Drive in Snow?   Y   N   Willing to come in 11:00pm or later?   Y   N

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

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

Investigators: Myra Blanco, Jon Hankey, and Tom Dingus

I. 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.

II. Procedures

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

- ❑ 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.

III. Risks

The primary risks that you may come into contact with are the obstacles on the road for Study 3 or sliding on the roadway during the "Rain" or "Snow" conditions (if this apply 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 seat belt at all times in the vehicle, and the vehicle is equipped with anti-lock 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, LASIK 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.

IV. 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.

V. 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.

VI. 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.

VII. 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.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained.

IX. 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, and

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

3. Wear your seat belt.

4. Abide by the 25 mile-per-hour speed limit.

X. 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:

Myra Blanco	231-1500
Jon Hankey	231-1500
Tom Dingus	231-1500
David Moore, Chair, IRB Research Division	231-4991

Participant Number: __________

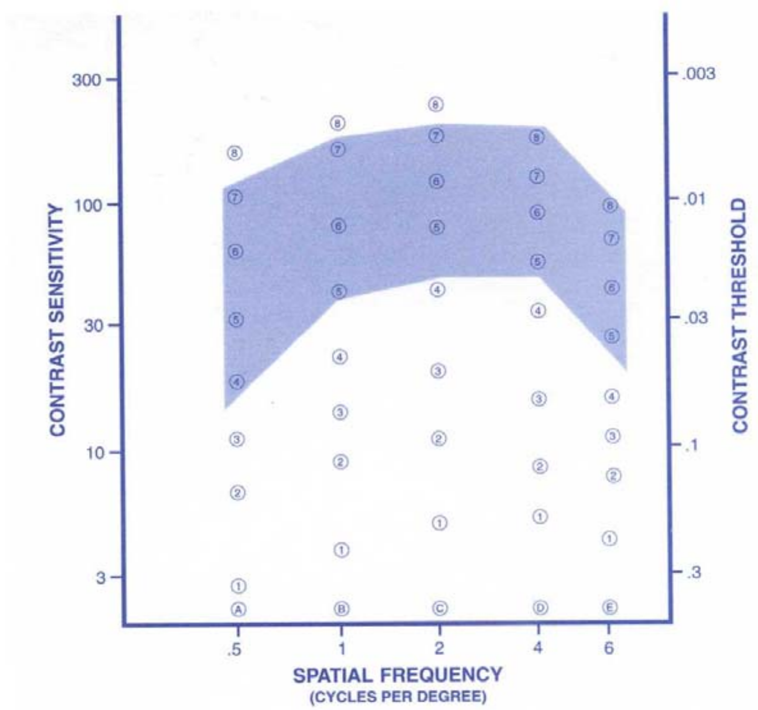
Vision Tests

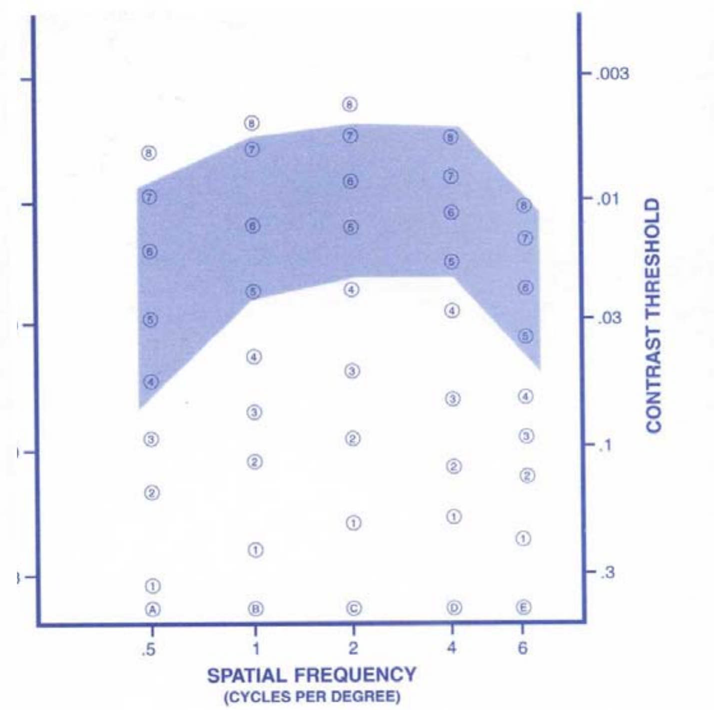
I – Acuity Test

- **Acuity Score:________**

II – Contrast Sensitivity Test

Left **Right**





III –Ishihara Test for Color Blindness

1._____ **4._____** **7.____**

2._____ **5._____**

3._____ **6._____**

NIGHTTIME DRIVING QUESTIONNAIRE

1. Do you drive at night? Yes ______ No ______

   If no, please explain why. ____

   ____

2. (If they drive at night) How often do you drive at night (i.e. past dusk)?

   Every day ____ At least twice a week ____ Less than twice a week ____

3. Do you ever drive in areas that do not have overhead lighting at night?

   Yes ______ No ______

   If no, please explain why. ____

   ____

4. Do you have any vision impairments that restrict your night driving?

   Yes ______ No ______

   If so, please explain. ____

   ____

VIRGINIA TECH TRANSPORTATION INSTITUTE

Protocol for Enhanced Night Visibility - Objects
In-Vehicle Experimenters - Training

1. **Prior to the participants 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. Place chairs or tables around the work light to prevent anyone from being burned.**
   - **Get color vision test, eye occluder, alcohol and cotton balls from prep room.**
   - **Get Participant Schedule Binder 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:

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 car 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 twelve 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 at the Vision Test Form

a) 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.

b) 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 patient 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.

c) The last vision test is the Test for Color Blindness.

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

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

- Record the participants answers on the Vision Tests Form

9. Nighttime Driving Questionnaire.

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

10. ENV Training

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

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

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

- Definition of **detection** versus **recognition**
- Stress safety (i.e. 25 mph, drive safely, etc)
- Again, answer questions

Slide 1: *This study is called the 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 on-road studies. One car with a Thermal Imaging System, a Pick-Up 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 identify 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 Kids 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 children'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 each question, we want you to rank your answer on a* *scale from 1 to 7. One means you strongly agree with the statement. Seven means you strongly disagree with the statement. You can give me any number between one and seven. Your answers may or may not be different for each VES, we just want your opinion on the one you just saw.*

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

Slide 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 mph. 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 mph. You will then drive through two more cones driving* *parallel to the white line on your left. Here you will see one of the objects involved in the experiment and how it appears in the heads up display. Then make a U-turn around the cone at end of white line and leave the gravel lot and proceed to the road section.*

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

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

11. Take the participant to the IR-TIS vehicle. Orient them to the vehicle.

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

12. Turn on the HUD

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

13. 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.

14. 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.

15. Instruct/assist the driver through 3 laps of the training course

Ask driver periodically to describe what they can see using the HUD

16. Take Eye Height Measurements on all vehicles that are available.

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

17. Remind Participant of the day and time they are scheduled to return

This information is found in the participant schedule binder

18. Document the time they leave on the debriefing form

19. SHUT DOWN

1. File the following forms in the appropriate binders (located in the Prep room file cabinet in drawer labeled "Binders")
    - Tax Form
    - Informed Consent

2. Make sure completed envelopes contain the following:
    - Eye height measurement sheet
    - Debriefing/Time in-out form
    - Vision Tests
    - Night Driving Questionnaire

    *the only form with participants name on it is the debriefing form

3. Write the participants name on the outside of the envelope

4. Place completed envelope in the file cabinet in Prep Room
    - File in the drawer labeled "Participant Packets"
    - File according to the date that participant is scheduled to return and drive

5. Return all equipment and binders to Prep room

6. Send Julie C. an email if someone does not show up

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Enhanced Night Visibility

Schedule and Training

Experimenter:
Myra Blanco

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

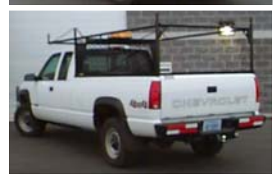
The Smart Road

- 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.

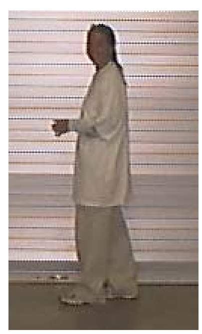
Types of objects

- 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?

IN-VEHICLE PROTOCOL FOR NIGHT 1 &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.
    - If after 10:00 PM the experimenter in the first car will need to get out and punch in the code for the gate.
    - Otherwise 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 on-road 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.***

<u>First vehicle at the bottom of the hill</u>

- ***pull all the way to the first parking space***
- ***put the vehicle in park and have the participant take their foot off the brake***

<u>Second vehicle at the bottom of the hill</u>

- ***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**.

- Turn computer on by pushing round button located on top left of keyboard.
- Type in "Night"
- Press Return

Enter in **Participant Information**. (ID, Age, Gender)

Command	Function
Shift Z	Scrolls up numerically in Participant ID Field
Shift X	Scrolls down numerically in Participant ID Field
Shift A	Scrolls through age categories: Y = 18-25 M = 40-50 O = 65+
Shift G	Toggles through gender categories: M= Male F = Female

Enter **Current Setup** information

Command	Function
Shift H	Scrolls through options in “VES” field **(Use “Practice” for first run up the road)**
Shift N	Scrolls through Number of Participants (should always be “1”)
Shift B	Turns Beep “OFF” and “ON” (should always be “ON”)
Shift O	Scrolls through the Object Order **(Use 13 for Practice)**
Shift D	Toggles between Day “1” and “2”

- Start the computer program:

Command	Function
Shift S	Starts computer program *also saves the set-up information at the top of the screen

- Check that the computer program is reading the correct “CALIBRATION VALUE”:

Vehicle	Correct Calibration Value
Cadillac	1318
Black Explorer	660
White Explorer	660
Pick Up	46

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

Command	Function
Shift T	Starts data collection

*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. **It is VERY important that you do not talk to the drivers when you are collecting data. (this means no talking starting at the bridge on the drive down the hill, and no talking starting at the guardrail when driving up the hill). EMERGENCIES EXCLUDED!!!!**

12. **Monitor the computer while going up the hill:**
- Make sure that the value in the "Current Distance" field is increasing. This ensures the DMI is working.
- When driver presses button the first time, the computer should beep and record the "Detection Dist".
- After they press button the second time, the computer should beep and record the "Recognize Dist"

…and perform the following tasks:
- Press the computer **space bar** again when your body is in line with the object. After space bar is pressed, the arrow will scroll down to the next object.
- Press the **ESC** key if the driver presses the button on accident or states that they made a <u>False Detection</u>.
- Press the **ESC** key if the driver makes an <u>Unsuccessful Recognition</u>

During the practice run, you may need to assist the participant. For example, if they do not indicate the Detection or Recognition points and the object is close to 200-feet, you need to say,

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

- ***<u>First car at the top of the hill</u>***
  Pull up to the cone on the right hand side just before the top of hill
  Wait for headlight glow from 2nd vehicle to appear, before
  going to the top of the turn around and parking on the left side.

- <u>Second car at the top of the hill</u>
  Pull up to the first cone on the right side of the road.
  Wait until the first car is out of sight before you go down road.

13. **Ask Driver the 7 Questions about the VES**
- *You may begin to ask the questions when the driver is past the bridge, if you are comfortable doing so. If not, wait until they are parked.
- Remind subjects of the 1-7 scale, where 1 is strongly agree and 7 is strongly disagree.
- Type in their response .

To change a response that has already been entered:

Command	Function
J/K	Scrolls up/down

Once all the responses are correct Accept the Answers

Command	Function
Shift Q	Accepts Answers to VES questions

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

15. **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 on-road experimenters
    - Continue down the road.

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

Command	Function
Shift T	Starts data collection

17. **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.

17. **Continue the same procedure for the rest of the VES**

18. **Bring Participants Back to the Building**
    - Have both participants and both experimenters get in the Cadillac
    - One experimenter will drive all four back to the building

19. **Document Time on Participant's Debriefing Sheet**

20. **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 On-Road to Radio that they are ready.
Collect data using the protocol from Night 1.
Take drivers back to the building in the Cadillac.
Complete the hours/amount paid section of debriefing form.
Ask drivers to fill out the payment receipt log.
Pay the drivers, and thank them for their participation.

NAME:________________________________

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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. Dr. Jon Hankey and Myra Blanco 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: ________________________________

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ENV Objects Protocol for On-Road 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 whenever you are exposed to headlights.
- 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 (namely Myra or Julie) 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 VTTI **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 headlights are outlined with a diagram and description in each vehicle. Failure to follow the procedures will prevent the headlights from working, and therefore leave gaps in the data. For this reason, you are to review the operations each night for your assigned vehicle.

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

When you do receive a message, please acknowledge the message by saying, "[Your Station Number] Copy." That way, the sender will know whether or not everyone received the message. If you do not hear a message, and it is not relayed to you, you can assume it was not directed towards you and can therefore disregard it. Do not get on the radio and ask them to repeat the message. If it is directed to you then station 2 will relay it to you.

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 on-road and in-vehicle experimenters. Each on-road 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 be either valet).
- ❑ Valets need to get vests from the Asphalt Lab for all the on-road experimenters.
- ❑ Experimenters assigned to the four on-road 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 VTTI 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 on-road 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 pick-up.
- ❑ Load boxes, cones, and tarps into Explorers.
- ❑ **Close the doors of the Simulator Bay.**

- ❑ Set up parking spaces by putting out the cones at the appropriate locations (Explorers).
- ❑ Set up cone at second turn-around (Explorers).
- ❑ 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 (Explorers).
- ❑ Unload large bikes, kid bikes, and tire treads at each station (pick-up).
- ❑ Unload boxes at each station (Explorers).
- ❑ 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. (located in asphalt lab).
- Tire tread (located in asphalt lab).
- Small bicycle (located in the asphalt lab).
- 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 on-road 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:

1. **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 on-road experimenters are expected to know the protocol without confirmation from others. However, you may radio other on-road experimenters for assistance at any time on channel 2.
2. There will be a relay at station 2 to repeat any messages not heard by geographically opposite stations.

3. As soon as you receive a message (providing it pertains to you), you must acknowledge that message immediately by saying, "Station X (and Y) copy." That way the station 2 (relay station) experimenter will know whether they need to repeat the message. If you did not copy, say nothing and wait for the relay station person to repeat it. However, if after several seconds you receive no feedback, you may try to contact the relay station. ONLY THE PERSON WHO DID NOT COPY THE MESSAGE MAY CONTACT THE RELAY STATION USING CHANNEL 2. As soon as you acknowledge the message you are not to respond further unless you believe someone is endangered.
4. If there is an emergency you are to get on the radio IMMEDIATELY and contact the relay station experimenter. The relay station experimenter will make sure the in-vehicle experimenters heard the message.

- 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 on-road experimenters are to remain hidden. However, on the way up the hill, the following stations will need to put out objects:

Station 4	Kid's Bike
Station 5	White Static Pedestrian
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 black pedestrian	Shoulder side of white line.	Wear black clothing. Walk 10 paces along shoulder line toward oncoming vehicle, then walk backward ten paces. Repeat.
Parallel white pedestrian	Shoulder side of white line.	Wear white clothing. Walk 10 paces along shoulder line toward oncoming vehicle, then walk backward ten paces. Repeat.
Perpendicular black pedestrian	Straight (perpendicular) line between white line and center line.	Wear black clothing. Walk to center line, then walk backward to white line. Repeat.
Perpendicular white pedestrian	Straight (perpendicular) line between white line and center line.	Wear white clothing. Walk to center line, then walk backward to white line. Repeat.
Black cyclist	Between white lines in front of station	Wear black clothing. Ride bike in circles across the road, from white line to opposite white line.
White cyclist	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 white pedestrian	Centered on white line.	Wear white clothing. Stand facing traffic.
Tire tread	Centered on white line.	None.
Kid's bicycle	Centered across white line, one wheel on either side of white line.	Lay on one side, wheels facing approaching traffic, handlebars lane of oncoming traffic.

- *After the first lap on-road 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 pick-up will drive around and collect the on-road 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 pick-up 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. The boxes will be in the Prep Room.

- 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 (Cadillac or Black Explorer).
- 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 VTTI. The Pick-up driver will be responsible for picking up large bikes, kid's bikes, and tire treads. Explorers 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 turn-around (Explorers).
- Uncover the signs at the bottom of the road (Explorers).
- Collect the parking cones from the first turn-around (Explorers).
- Return the vehicles to the VTTI.
- Check the gas level of each vehicle. If it is below ¼ of a tank write a note at end of prep sheet.
- Return Explorers 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 the VTTI.
- ❑ Make sure all the doors are locked and the garage door is closed.
- ❑ Return the keys to the lock box.
- ❑ 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.

Vehicle/Headlamp Combinations Acronym List:

BLK HID1	BLK HID 2	Black Explorer High Intensity Discharge 1 & 2
BLK HLB 1	BLK HLB 2	Black Explorer Halogen Low Beam 1 & 2
BLK LO UV-A 1	BLK LO UV-A 2	Black Explorer Low output UV-A 1 & 2
WH HID 1	WH HID 2	White Explorer High Intensity Discharge 1 & 2
WH HLB 1	WH HLB 2	White Explorer Halogen Low Beam 1 & 2
WH MID/HI UV-A 1 thru WH MID/HI UV-A 5		White Explorer Mid/High output UV-A 1 thru 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 headlights prior to the team meeting, and especially prior to the road preparations. Minimum alignment time is 1 hour when no headlamps need to be switched between vehicles, but you should plan on 1 ¼ - 1 ½ hours as a general rule. Alignment times will be greater on days when headlamps must be moved.
- Lighting in the Sim Bay. Be ready to turn off half of the lights at 4 PM to begin alignment. The lights may not be turned down prior to 4 PM, and other Sim Bay users (namely members of the Advanced Vehicle Dynamics Lab) must be notified 15 minutes prior to lights out. The lights must be turned back on once the alignment procedure has been completed.
- Turn on the ventilation fans prior to beginning the alignment process.
- Since we are leaving half of the lights, it is important to remember to use the ZERO function on the photometer prior to aligning each light. This is particularly important when recording the photometer values on the Headlamp Alignment form.

1. Setting up the Non-UV-A headlamps

Applies to the following Vehicle/Headlamp combinations:

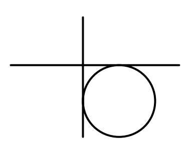
WH HID (1&2), BLK HID (1&2)
WH HLB (1&2), BLK HLB (1&2)
P/U HOH(HHB) (1&2)

- 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 "hot spot" 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 headlights are not switched; gross will be required if the headlights are switched.

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

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

Hot Spot Location: The circle represents the target hot spot location with respect to the target crosshairs. The center of the circle is the center of the hot spot.



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 hot spot. 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.

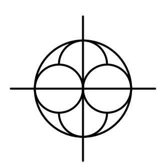
2. Setting up the UV-A headlamps

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 form 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 "hot spot" 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.

Hot Spot Location: The large outer circle represents the overall target area. The center of the large circle is the target hot spot 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 hot spot. If the hot spot 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 Explorer]	
1 (Left)	*2 (Right)*
visual alignment based on other light	41.6 w/cm^2

WH HLB; BLK HLB [either Explorer]	
1 (Left)	*2 (Right)*
44.7 w/cm^2	50.1 w/cm^2

BLK LO UV-A [Black Explorer]	
1 (Left)	*2 (Right)*
100 μw/cm^2	92.0 μw/cm^2

WH MID/HI UV-A [White Explorer]		
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

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 Explorer]	
1 (Left)	*2 (Right)*
visual alignment based on other light Actual:	41.6 w/cm^2 Actual:

WH HLB; BLK HLB [either Explorer]	
1 (Left)	*2 (Right)*
44.7 w/cm^2 Actual:	50.1 w/cm^2 Actual:

BLK LO UV-A [Black Explorer]	
1 (Left)	*2 (Right)*
100 μw/cm^2 Actual:	92.0 μw/cm^2 Actual:

WH MID/HI UV-A [White Explorer]		
Top Row lights		
1 (Top Left)	*2 (Top Center)*	*3 (Top Right)*
590 μw/cm^2 Actual:	472 μw/cm^2 Actual:	484 μw/cm^2 Actual:
Bottom Row lights		
4 (Bottom Left)	*5 (Bottom Right)*	
486 μw/cm^2 Actual:	565 μw/cm^2 Actual:	

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 on-road experimenters**

2. Take care of all the experimental materials
    - **Get radios for on-road and in-vehicle**
    - **Check that all the materials needed are in the blue boxes and that flashlights all work**
    - **Get vests for all the on-road crew**

3. Assist On-Road 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
    Valets should have a radio on channel 2 and a radio on channel 3
7. Place the stepstools on the side of the road
8. Wait for drivers to arrive at the first turnaround
9. <u>First night:</u> **drivers will do a practice lap.**
<u>Second Night:</u> **drivers will stop so Valets can confirm that the proper headlights are on.** *Make sure to wear your safety glasses.*
10. 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.

11. 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.

12. 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

13. 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.

14. Before driver goes down the road, ensure the headlights are on and working. USE SAFETY GLASSES.

- Cadillac: Regular headlamps only.
- Black Explorer: If UV is required, make sure they are working. Otherwise, make sure the two standard ones are on (HLB or HID).
- White Explorer: 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.
- Pick-up: 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).

15. Take a 15 minute break between sessions (if running a double)
- **Pick up On-Road 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)**

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

17. SHUT DOWN PROCEDURES:
- ❑ **Assist On-Road 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

Cadillac

- 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 headlights all the way (two clicks). Make sure they are on before you leave the vehicle.
- Show the participant how to adjust the interior lights. If necessary, help them to adjust it by asking them to tell you when it is comfortable.

Black Explorer

- 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 Explorer

- 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.

Pick-up

- 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.

Part I: Questionnaire

Please answer the following questionnaire by making a circle around the number that best describes **how likely** you think you are to be involved in the following driving scenarios.

Example:

Trying a new route that you think will be a shortcut without the benefit of a map.

Extremely Likely	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Not at all Likely*

Type of Roadway:

		Extremely Likely 1	2	3	4	5	6	7 Not at all Likely
1	Driving during daytime at a roadway with high volume traffic.	1	2	3	4	5	6	7
2	Driving during nighttime at a roadway with high volume traffic.	1	2	3	4	5	6	7
3	Driving during daytime at a roadway with low volume traffic.	1	2	3	4	5	6	7
4	Driving during nighttime at a roadway with low volume traffic.	1	2	3	4	5	6	7

Passengers:

5	Driving during daytime alone (no passengers).	1	2	3	4	5	6	7
6	Driving during nighttime alone (no passengers).	1	2	3	4	5	6	7
7	Driving during daytime with another adult.	1	2	3	4	5	6	7
8	Driving during nighttime with another adult.	1	2	3	4	5	6	7
9	Driving during daytime with children.	1	2	3	4	5	6	7
10	Driving during nighttime with children.	1	2	3	4	5	6	7

	Extremely Likely	1	2	3	4	5	6	7	Not at all Likely
Weather:									
11	Driving during daytime with clear weather.	1	2	3	4	5	6	7	
12	Driving during nighttime with clear weather.	1	2	3	4	5	6	7	
13	Driving during daytime with rain.	1	2	3	4	5	6	7	
14	Driving during nighttime with rain.	1	2	3	4	5	6	7	

Type of Place (Assumption: It is a safe place):

15	Driving during daytime in a known roadway.	1	2	3	4	5	6	7	
16	Driving during nighttime in a known roadway.	1	2	3	4	5	6	7	
17	Driving during daytime in an unknown roadway.	1	2	3	4	5	6	7	
18	Driving during nighttime in an unknown roadway.	1	2	3	4	5	6	7	

Part II: Unstructured Interview - Open Ended Questions

<u>Instructions for Interviewer:</u>

- Make sure the equipment to record the audio is working.
- Read the following instructions to the participant. Then guide them through the different topics
- Elicit the participant to expand in the topics below.

The purpose of this session is to expand on the topics on the questionnaire and cover some new topics. Could you please let us know how ***you perceive the risk*** *that the following situations might pose while driving at* ***night****?*

- ❑ Traffic volume or congestion
- ❑ Type of Passenger (alone, adult, kids)
- ❑ Adverse Weather
- ❑ Going to a Known vs. Unknown place
- ❑ Driving at night increases the risk of an accidents
- ❑ Vision
- ❑ Speed Limit
- ❑ Is there anything else that you think might be a potential risk of driving at night to the point that you might prefer not to drive?
- ❑ What do you think can eliminate or reduce nighttime driving risks?

Daytime – Potential Risk Perceived

Daytime-Neg-Passenger-Adult
- Sometimes my husband gives me too many directions

Daytime-Neg-Passenger-Alone
No Cases contained the code

Daytime-Neg-Passenger-Children
- When having children you have to kind of watch them more, so you pay less attention to the road and more about what's going on with them, especially if they are "cutting up" or whatever, or talking to you a lot and you've got to answer questions.

Daytime-Neg-Place-Known
No Cases contained the code

Daytime-Neg-Place-Unknown
- It puts a little bit more stress on your driving because not only do you have to pay attention to the road, you have to pay attention to where you're going and stuff like that.
- I try not to go into unknown roadways because I don't really know where I'm going I don't want to get lost.
- I'd be a little less hesitant to go out if I didn't know where I was going, but I would still go

Daytime-Neg-Roadway-High Volume Traffic
- I really don't care for driving in traffic because it used to not bother me but I live in Christiansburg now and I don't like the big city.
- I find traffic risky all the time.
- It is harder to see.

Daytime-Neg-Roadway-Low Volume Traffic
- In real curvy roads it's more dangerous in the daytime that it is at night.

Daytime-Neg-Speed
- I'd say it's more of a risk if the speed is high because you have less time to react to things.
- you don't see things until they're right in front of you.
- I would speed more during the daytime because I feel safer
- There are probably more police out but I feel more comfortable because it is easier to see

Daytime-Neg-Vision
- Definitely [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*]

Daytime-Neg-Weather-Clear
- Generally you feel a little more comfortable driving during the day.

Daytime-Neg-Weather-Adverse

- The rain does block your vision a little bit.
- Of course, that makes your driving a little bit more difficult, it is raining, so your visibility is not quite as good, but since I've done a lot of driving it doesn't bother me that much.
- It bothers traffic.
- People drive slow and erratic in the rain.
- It is fairly hard to see.

Daytime – No Potential Risk Perceived

Daytime-Pos-Passenger-Adult

- If you go out somewhere for lunch or something like that I usually end up driving. That's because I think I'm a better driver than everyone else.
- Because of work that is what I do all day.

Daytime-Pos-Passenger-Alone

- I drive alone all the time during the day.
- I just drove ten hours; five hours up to D.C, and back in one day, myself alone. I don't hesitate doing that at all.
- I am generally more comfortable driving by myself for sure.
- I drive around, and do errands by myself.

Daytime-Pos-Passenger-Children

- I have two children, so it is extremely likely that I'm going to be driving during the daytime with kids and that doesn't bother me.
- With my granddaughter I am very comfortable.
- During the day they're awake and likely to do more, but if they are strapped in good, and I feel that they are strapped in and comfortable it is okay.
- I drive a lot with a lot of grandkids in the daytime, is fine.
- With divided attention between children, in the daytime if you can see really clearly, you could pull off, slow down, and take care of the kids. Or, you could say, "shut up," and if they didn't you'd have more options in the daytime.
- I'd feel safer driving during the day with them, just because I can see more what is going on.
- I will drive with kids anytime during the day.

Daytime-Pos-Place-Known

- Daytime on an unknown roadway, I do all right.
- You know the road, you're familiar with it, you know where you're going, you can pay more attention to what on the road, rather than where you're going and stuff like that.
- I am extremely likely to drive during the daytime on a known roadway.
- I feel more comfortable driving in the country around here than I do in the big city.
- I like to go to a known place during the daytime because you can see different places to use as a reference.
- I feel more comfortable if I know where I'm going, and it's easier to see things during the day than it is at night.

- It is very likely that I will drive during daytime on a known roadway.

Daytime-Pos-Place-Unknown
- I would prefer to take the unknown roadway more during the daytime than I would at nighttime.
- I am more apt to do it during the day.
- If it is unknown to me I have to pay more attention to where I'm going, even though I can see very well because it is daytime.
- I can see everything, where the road ends and see how far it is going.
- Now an unknown roadway during the day, I'd be more apt to do that than I would at night.
- In the daytime, chances are you can find somebody to ask directions of, chances are you can see places that you might directions of.
- I would rather do it in the daytime.
- You know you could read the road signs better.
- I guess I would be more likely to go somewhere that I didn't know the directions to during the day.
- At least I can see signs and things like that easier.
- More businesses would be open and things like that and I would be able to ask for directions if that was the case.
- I would just feel more comfortable in the daytime with more people out.
- I would probably be more comfortable during the daytime definitely.

Daytime-Pos-Roadway-High Volume Traffic
- During daytime driving you have more of a chance to see where you are going, and see if you may be congested within a quarter of a mile, but then past that you can see that it is clear, or you can see behind you and if you see that there are some people playing around a little bit, you can slow down or speed up to get out of it.
- I don't prefer it, but I have no problem driving in high volume traffic.
- It really doesn't bother me.
- I am in a job now and I drive around all the time with this conditions.
- I would be much likely to drive in high volume traffic during the day.

Daytime-Pos-Roadway-Low Volume Traffic
- I am more relaxed.
- Driving during the daytime at a roadway with low volume traffic, I am extremely likely to be doing that.
- The reason I chose that way is because it's a faster way to get home, you don't have the stoplights to go through. Plus the low volume.
- Driving during the daytime in a roadway with low volume traffic that's no problem.
- Most of my travel is in low-volume traffic. I live out in the country. Unless I go to a big city of something like that, I am in low-volume traffic
- If I want to go to the store, I'll try to go in the morning when there are fewer people.
- I do prefer driving with low-volume traffic.
- I feel safer in low-volume.

Daytime-Pos-Speed
No Cases contained the code

Daytime-Pos-Vision
- During the day, if the sun is bright then it constricts down and I can see better than nighttime.
- I think in the daytime you have a better chance of recognizing or your vision or whatever, or you conscious would see it.
- Vision is certainly a lot better in the daytime.
- You can see things at a further distance.
- You can see things happening further down the road, and kind of anticipate them coming.
- You have more clear vision.
- You can see further in the daytime.
- I'd rather drive during the day than at night just because the visibility.
- I think that it is easier to see what's around you during the day.
- I can see better, and I can see objects to keep me interested.
- Daytime is less strenuous on your eyes definitely.
- I don't wear my glasses during the daytime.

Daytime-Pos-Weather-Clear
- It is an ideal situation for driving, clear daytime weather.
- I like to get out and drive around through the mountains or anywhere like the parkway or anywhere like that in the clear weather.
- I drive a lot during the day and of course prefer it to be clear weather.

Daytime-Pos-Weather-Adverse
- If I had to make a choice, I would rather do it in the daytime.
- You can see further in the daytime.
- Driving in the rain during the day is probably easier, so I would do that.
- The rain doesn't bother so much.

Nighttime – Potential Risk Perceived

Nighttime-Neg-Passenger-Adult
- Having with me somebody that I didn't really know that well, I'm very anxious about my driving habits then.
- Well, if you're used to driving alone, and you have a passenger, if that passenger is interactive a lot with you, you know, that may interfere with how you normally drive because you're more paying attention to what their conversation is, than what you destination is, or what surroundings you have to deal with.
- An adult is just going to try to get your attention verbally, and sometimes visually.
- As far as risk, I think anybody is a little bit more cautious when you're turning into a lane, you're always cautious because of yourself, but I think with someone else, especially if they're talking or something like that, you have the tendency to be a little bit more cautious.

- When you're driving with another adult, I would probably be more concerned about the fact whether I'm driving good enough. Or whether this person thinks I'm driving crazy.
- I guess when I'm always driving in the car with another adult and it's raining, I always think, am I driving too slow or am I driving too fast?
- Probably with another adult, maybe they could distract you or whatever.
- You're so overly concerned with how you are driving.
- If you are with somebody you are going to be talking and sort of distracted.
- If someone is talking to you then you have to kind of pay attention to what they are talking about so that you can answer them back.
- It's not too much risk at night.
- If someone is a nervous passenger and they think that you are too close this way or that way or too close is going to hit you and they scream or they, then that is a risk and it makes you jerk the wheel sometimes and it frightens you.
- It makes me more nervous at night.
- They are going to be talking or asking you something and drawing your attention.
- There is more risk when you have someone else that you're responsible for, you must be careful.
- If it's an adult I tend to talk to them a lot and then that could be distracting.
- Maybe slightly more risky than if I was by myself.
- People tend to react, and to call things out, or get nervous and scream, and make me nervous when I shouldn't be.
- At night, I drive differently when I have passengers.
- You have to be completely conscientious of the passenger.
- You have someone else's life in your hands.
- I would be talking to them and things like that and would not be paying as much attention to the road.
- I think if it's someone that makes the driver stressed out, something like that it might affect it, higher risk.
- I would think that driving with a passenger could be a little riskier maybe. Particularly if you're with a friend or something maybe talking, not paying close attention to the road.

Nighttime-Neg-Passenger-Alone

- If I'm alone I'm more likely to gut it out and try to get where I'm going, and there's probably more of a chance of me falling asleep.
- I might be a little bit more hesitant just because it's nighttime.
- Slightly more stressful without a passenger, especially if you're driving at nighttime you may tend to get tired, relaxed, no one to talk to, even though you have a radio or something like that.
- You take more risks when you're by yourself.
- And I'm by myself? I would think it would be a little more risky.
- At night, that's a little different, its not that there is a chance of accident, it's just that the concern is more stressful, or sort of dreary alone at night with no one to check our uncertainties of the road and so forth.
- Whereas with yourself, you have to watch the road, and can't think about as many things as two people can.

- Maybe a little bit more risky because of the concentration factor.
- I don't really like driving far by myself at all.
- When you are by yourself, there are no distractions so you're fine.
- Driving nighttime alone is a little less likely for me.
- I hardly go alone.
- I don't do errands at night that I do alone.
- I accelerate faster.
- I corner harder.
- I brake harder.
- I would drive more aggressively.
- If it's a long trip on the interstate you know, you can get tired maybe nodding off.

Nighttime-Neg-Passenger-Children

- I prefer to not drive with them at night.
- And safety I just feel better with them not driving at night in case I guess I tend to think that there's more accidents at night and I don't know if statistically that's right but so I prefer to not have them in the car.
- I think if I have children in the car I might worry more.
- It's like children, if you have children with you, children can distract you, and they can also do things that make you take your eye off the road.
- So, having children in the car is a totally different scenario than just having an adult, because they are so apt to get into anything.
- I believe that a high risk would be if you have someone with you, and that someone was a child, you're attention is almost on them as much as it is on where you're going.
- I wouldn't be as comfortable, just because of the safety of the child.
- I know, especially if I have children with me, I'll think twice before I pull out, even though I know my car can get in front of another car, I'll probably wait.
- Anytime you have children in the car you have to not take risk. You have to slow down and be careful.
- They could distract you and that could cause a problem.
- I think that obviously if I had a child in the car I might be more concerned that, it may make me more cautious.
- Much more difficult to pay attention to the road, especially at nighttime when you can't see as well, and plus also you're in a car and it's dark, if you have children you want to know what they're doing, so it makes it a little bit more difficult than daytime.
- The higher risk would be if you were driving with children, especially at nighttime.
- You're trying to pay attention to the road and then you also have children you're trying to pay attention.
- The more children of course the more stressful it's going to be.
- It takes a lot of your attention away from outside the car.
- Very high risk.
- It's a risk at night.
- With children I think you have to be careful with, and be more watchful.
- Driving with kids would be different.

- If you have children it is always in the back of your mind.
- I'm careful anyway but more careful with children.
- At night, if its young children, I wouldn't be able to take as good care of the road while I was concerned with what the kids were doing at night. And, I wouldn't be able to see as well, so it's not as much leeway to make mistakes.
- In the nighttime you wouldn't have so many options.
- It is definitely riskier to have kids, because even assuming they are in their correct seats and seatbelts and all that, and if they're good kids, things come up that they are concerned with, and they don't recognize what you're up against in driving, and you have to divide your attention.
- They are going to be talking or asking you something and drawing your attention.
- Especially if you have kids in the car - you are going to be thinking "oh gee! I am going to have to watch this and that."
- I try to be a little safer if I have children in there. I try to be a little more alert and be careful because I feel responsible.
- With children, I raised six children so I know what its like to have a bunch of kids fighting in the car, and its very distracting, and of course at night its going to be a lot worse, because you need a lot more attention to watch the road.
- I think it's riskier with children.
- If the kids are being bad I think it would produce more of a risk, yes I think so, because it would just be distracting.
- With kids I'd actually probably be more cautious at night.
- If I'm driving with kids I think I'd be extremely distracted as opposed to an adult.
- Kids are unexpected; you can't predict them.
- Kids need things all the time.
- If I was driving with kids I would probably be a lot more distracted and less focused on driving.
- I think its more distracting if you have kids in the car.
- I definitely drive more carefully just because I am responsible for them.
- I have to be responsible for especially other kids. I have to be responsible for my actions.
- I would personally concentrate more on the road, but if you're trying to worry about the child, keeping them in their seat, or behaved I guess could be a little riskier, you wouldn't watch the road as close.

Nighttime-Neg-Place-Known

- If you have a road to where you know you can go faster then I think the risk increases because there's that part in you that wants to go faster.
- The known roadways could be risky too if you're alone and you're daydreaming.
- I don't drive that much really at night unless it is an emergency.
- You just kind of almost do it without thinking because you've done it so many times before.
- Especially when you get near a house and you have gone that way 100 times, you just do it and you are kind of complacent about it, which isn't necessarily good.
- If there is a curve marked 15 mph curve but you know you can take it at 45 mph, you just take it at 45 mph.

- If you're going to a known place you're not paying so much attention just like most people get in accidents near their houses.

Nighttime-Neg-Place-Unknown

- You can't see the overall picture.
- It is like a goldfish bowl vision; its hard to see far out.
- I find it more difficult at night to find unknown places.
- A lot of my "noise" comes up with safety issues and stuff too. Well I guess with unknown roadway too would be visibility, if I'm not familiar with the road and if I can't see and depending on the speed I'm going and the headlights, how far ahead I can see.
- If it's not a major highway, back roads, it could be risky.
- I would consider a risk traveling into an area that you're not that familiar with, out of your own area.
- If the conditions involve bridges, or back where I'm from we have toll roads, and draw bridges, and things like that, but there are a lot of risks involved in traffic patterns, as far as safety.
- You may be entering an intersection that is known to be a dangerous intersection and you don't know until you are there, and you may be the victim of something there.
- A problem might be your time element, as far as your destination on how long its going to take you to get there.
- Road conditions, and traffic volume; if you're heading into an area that you've never been to, and you have no idea of the population, then you're going to be getting into a whole different group of circumstances that you didn't have before.
- It doesn't bother me to hit an unknown area, but I am less likely to do it at night.
- I don't know where I'll end up going at night.
- You don't know what to expect.
- On an unknown roadway at night, it is hard to see.
- You don't know what you are doing.
- Your visibility is greatly reduced.
- You are more looking for a street or you are looking for road signs and things like that, more so than you are actually watching the road ahead of you.
- You're twice as unlikely to know where you are going, because you're not familiar with the road.
- It's dark, so you have to pay more attention to where you're going.
- You got to slow down because it's dark.
- You're looking for signs or familiar things on the side of the road to familiarize yourself with where you're going or where you're at.
- It just makes it that much more difficult.
- If it's a known place, of course you're going to be more familiar with it, you can spend more time looking at the road, instead of looking at road signs, or slowing down and looking for unknown objects that you're not familiar with.
- If I could avoid it I would
- At night, you can't always see, especially if it is not lit.
- There is a moderate risk because you don't know where you are going and you don't know the road.

- You must plan ahead if your going to an unknown place.
- I just would feel more comfortable if I had someone with me on an unknown roadway. I don't know, maybe women are supposed to be afraid of the night maybe.
- I just, I think that women are sort of easy targets at night for a lot of men.
- I think you have to be very cautious about where you're going to be and I think its up to the women to be very careful about where she's going to be.
- And I'm by myself? I would think it would be a little more risky.
- At nighttime, I wouldn't have wanted to drive that road not knowing it at all.
- If you're going on a highway, and you go past your exit not knowing, you can go a hundred miles and you don't know if whether you're a foot or a horseback.
- I feel much more concerned about going on an unknown roadway at night.
- You can get lost and you can't find your way out of being lost; you don't know if there's someplace you could ask, there may not be somewhere to ask and you can get really lost.
- Driving at night in an unknown situation, I think there is more risk, I guess I'm probably more cautious; at least I try to be.
- Making the decisions as to what turn to take, and sometimes you might make a quicker turn than another time if you are not sure where you are, or you might be driving slower, which is in itself a risk.
- Unless it is an emergency, I don't get out in places that I don't know or don't need to be.
- I am not going to drive to any unknown places unless I have to.
- Yes, because you're always wondering where you need to turn next, and if you're on the right road, and if you're going in the right direction, and all that sort of thing when you're on an unknown road. And you don't know what to expect, so you have to be more careful I would say.
- During nighttime you have to be very careful, you would probably have to drive half of the speed you would in the daytime to be able to find the house number or road number.
- You have to compensate with speed.
- It's definitely harder to see stuff at night I mean like road signs and landmarks and stuff, it wouldn't like prevent me from doing it I might just be a little slower.
- If I need to read signs then, yes, it's a lot harder. You got to slow down and like watch out for traffic while you're trying to do it at the same time.
- I would say if it was somewhere I didn't know, like if I was maybe focusing my attention on looking at signs, and then maybe it'd be an increase.
- I try not to go into unknown roadways because I don't really know where I'm going I don't want to get lost.
- I would say unknown is a lot more risky.
- If you have never driven on it before, then you don't know what's on the road; you don't know what's around the road.
- You have to expect everything because you don't know what to expect. It's just unfamiliar.
- At night I would be a little more scared of it.
- I'd be a little more cautious, and have to go slower, and might miss a turn.
- I wouldn’t know what is coming up ahead of me.
- If I don't know where I'm going, I definitely slow down.

- It depends if there's more lighting on the road or not, because I can't really see that far in front of me, and if I don't know what turn I'm making, or where the road is going, I think it's a lot more riskier
- I am not really good with directions anyway, so I would end up getting lost.
- On an unknown road you definitely drive a bit slower and more cautious.
- It is riskier when you're trying to figure out where you're going as well as trying to concentrate on driving.
- I would think that would be a little more risky, going to an unknown place.

Nighttime-Neg-Roadway-High Volume Traffic

- I have been in places where there are a lot of cars, and the headlights bugged the hell out of me.
- It makes me tired.
- Definitely it is riskier high volume at night, just due to the fact that some people don't see as well.
- The fact that you have older drivers on the road, you have younger, sportier drivers on the road.
- The more congested you are the less space you have to drive.
- During nighttime it's a little bit harder to see.
- It is more risky at night during high volume traffic.
- You've got to be concerned at night because you have people drinking.
- More cars, more vehicles, more chance for accidents.
- If one messes up, everybody does.
- I worry about the other person. I try to drive defensively being a professional driver.
- I'd probably be extra cautious, probably be more tense.
- Stopping distance if you had to drive in heavy traffic where there's a lot of traffic and you're trying to keep your distance people running in front of you and you had to stop you could have a real problem there.
- I can't see as well as I can during the daytime.
- At nighttime in high volume of course you have a lot more risk, because you have a lot more traffic around you.
- Not only you got to pay attention more to as much as the cars in front of you, but cars behind you, beside you, and everything.
- A lot of people out there that can't see real good during the night.
- Headlights are probably not adjusted right.
- People are getting glare.
- Reaction time is probably slower because of the being dark.
- Probably some people drinking.
- I would try to avoid doing that.
- If I would have to, then I would do it, and I do drive in high volume traffic at night, but I don't like to do that and I don't do it very often.
- I think the risk is greater with high volume.
- All the lights that you have to deal with.
- If I'm driving in a city at night, you are just more careful.

- The minute I get into high volume traffic I am careful!
- At high volume you are closer together, you have to be more alert.
- You have to slow down.
- You have to watch what you're doing.
- People can't see you and judge difference in how far they are from you, or I couldn't judge as well how far I am from other traffic.
- There's little space between cars and you could, without seeing really clearly, you can get into an accident.
- If you have high-density traffic, you can't really tell one headlight from another
- I would prefer not to drive at night in high volume traffic.
- There's always a danger in a situation like that, because of other people, not just myself, but with other people.
- I think the risk is greater with high volume.
- Just because more traffic, there are more different people involved, and different people making different decisions.
- You have a lot of people on the road and you have to be a lot more careful and more focused
- You wouldn't be as able to relax.
- You would have to be more alert.
- If you are in a lot of traffic at nighttime, or something like that, you are going to take it a little slower and be a little more careful.
- I don't see as well at night as I used to.
- You're supposed to be more careful when you get older because you can't see as well as you used to.
- The lights bother me more.
- It is more critical at night.
- Usually if it's heavy volume it's a straight road. And you just got lights coming at you all the time.
- The difference with the night is your reactions aren't as quick, and distances and stuff aren't the same; appear to be the same, so you have to concentrate even more on the other things.
- At night you need more concentration because everything is not as visible, particularly at angles, away from your headlights, things like that that you have to use more of your concentration, and watch out for other cars, in your blind spots a lot of the time, you can't pick them up as well.
- It's pretty risky.
- It's a little bit more of a risk when it's high volume traffic, because you can't always see the cars as well in front of you, I mean the taillights help, but it's always a little bit more of a risk.
- I probably would be a little less comfortable if it was at nighttime just because it's harder to see and it's harder for a lot of other people to see. And I don't trust a lot of other drivers.
- I think it's very risky if there is a lot of volume at nighttime.
- It's harder to see.
- You can't really see other cars and things around you as well as during the daytime.
- I find traffic risky.
- When you are driving in traffic at night it is very irritating on your eyes, because you are looking at bright lights all the time.

- I would say it is more risky.
- In high volume especially on an industrial highway like 460, there are lots of intersections and things and people are always moving around.
- You really have to pay attention to what the guy next to you is doing and in front.
- Some people try to beat the light.
- Some slam on their brakes, so it is definitely more risky.
- You are just more likely to get in an accident where there are more cars around.
- Having a lot of cars on the road means more chance of getting in an accident.
- If there's high volume it could cause more risk, because it's just more people, a higher probability of someone making a mistake.
- I would say it's a little riskier driving in congestion particularly on the highway, maybe not so bad as in a city or where the traffic is moving very slow, but it's, I think it's riskier.
- The proximity of the other cars I think makes it riskier.

Nighttime-Neg-Roadway-Low Volume Traffic
- If its low volume I see it going up, the risk of driving at night going up.
- Lack of visibility.
- The less cars there are, the less things are lit up.
- I think visibility is a little bit tougher when there are not as many cars around.
- I'd probably think there is more risk with lower traffic, people can go faster, and the judgment might not be accurate.
- I'd probably be extra cautious, probably more tense.
- I don't pay attention as much because there is not as much going on around you, in front of you, or in back of you.
- Now nighttime, you might pay a little more attention, because you don't see things as clearly.
- Low volume is probably going to a country road, and you're going to have to watch out for the objects, your visibility is limited, so things come up on you quicker.
- It is less common for me to drive under these conditions.
- I feel fairy comfortable, but not like I used to be.
- Low volume wouldn't be as risky as high volume at night, but still risky.

Nighttime-Neg-Speed
- If the speed limit is high, and I'm going slower, I get nervous because everyone around me is trying to go their speed, and I fell like I'm in the way, you know the old granny on the road.
- I get behind these little old grannies that are going 35 in a 65, and it drives me nuts, and it's like I just want to get around them.
- I'm not too comfortable going too fast because I don't want to fly off the side of the road.
- Speed, it's kind of nice to know that there is a change in the speed pattern, like on the interstate here, the speed limit drops, if there is a construction area it is nice to know that there is one there before you know you're going to be dropping, especially your time element of how you're going to get there, how long? If you know that there is a road widening, or construction going on, you know that you're going to be dropping down to the construction zone speed limit.
- Well, as far as assuring that the people in front of you are adapting to the speed limit, and the people behind you are, because you're moving at the steady flow of traffic, and if they're not

adhering to the same speed, especially with tractor-trailer traffic with 40,000 pounds behind them.

- Or, at night when people are driving under sleepy conditions, or over-worked conditions, if they are not coherent or alert to what is going on, then your driving is affected by their driving.
- Other risks would be if you are in an area that is heavily populated by deer, or any type of animal like that, and other people aren't aware of it, then you pretty much have to watch their driving along with your driving.
- If a speed limit is posted, and if it's a high speed limit, if it's a country road and its still 55-mph, if you've not been on that road then you really don't know what your getting ready to get into.
- You may be going too slow and the traffic behind you is going faster, if you're not familiar with the road then you are going to be in their way, you're going to be detrimental to them.
- You may be taking a turn at 55 mph, or going over the crest of a hill at 55 mph
- If you're in an area where there is a chance of an accident because of bumper-to-bumper traffic, or congested intersections, then speed has a lot to do with whether someone survives an accident.
- Some people are comfortable driving 55 in a 65, minding their speed limit, some people like to drive 75 in a 65.
- If you have a 45 mph speed limit zone, and its straight road, peoples going to hit, they're going to top-off.
- If you have a road to where you know you can go faster then I think the risk increases, because there's that part in you that wants to go faster.
- If you have a lot of in-coming traffic the risk factor increases.
- The speed limit is 65 mph people are going 70-75 mph, they're not going 65 mph.
- When I'm always driving in the car with another adult, and it's raining, I always think, am I driving too slow or am I driving too fast?
- If you go faster it's going to be riskier.
- I think it's, everybody is driving fast and if there were an accident or a problem would be much more severe than if you were just going 25mph.
- The faster you go the more risk there is of not being able to stop as fast or respond as quickly.
- I think that it increases the risk would increase at night versus the daytime in higher speed limits.
- Depending on your speed, or if you're taking turns, or going down hill or whatever, you can easily go into a slide if you have to make a sudden stop, or if something darts out into the road in front of you
- If it is not well lit and it is very windy somebody would have to be crazy driving 55 mph.
- If there weren't any streetlights and it was rather windy or something, then I would feel a lot more stress on me, because of the stress involved, and not being able to see, and the road being so windy that anything could be around the corner, and it's harder to react to that stuff because you're not going to be able to see as far as you could so you would have to drive a lot slower.
- The faster you are going the higher the risk, because your reaction time is slower.

- Slow your speeds down, you have less time to react to things because of the surface adhesion of the road, visibility…
- Of course, at higher speeds if you do have an accident, it's going to be worse probably, than going 25 opposed to 70.
- You just have to go slower.
- Usually the 25 or 35 are residential and people and pulling in and out and darting across when you least expect.
- On the interstate, I do think 70 mph is too fast.
- Well the faster you go, the more risky it is… I'm sure.
- Speed kills!
- Now on 81 it's very dangerous, but you have to go fast because if you don't the trucks will run you right off the road. So you have to keep up with them or go a little faster. But then you're speeding.
- I think it's a great deal more risky at night, at a high speed, because if you put the brakes on and it is going to take you a lot longer to stop, or whatever the situation is, you can't correct it as fast because of your speed.
- There's probably more risk on the roads that allow a higher speed.
- People don't adhere to the speed limit.
- I think if everybody would obey the speed limits there would be a lot less accidents.
- Well it's probably more risk at 25 mph than at 50 because people are driving in and out and pulling out in front of you.
- You must adjust your speed accordingly to weather. If the speed limit is 65 mph with rain you should drop it back to a comfortable speed where you can handle your vehicle.
- During nighttime you have to be very careful, you would probably have to drive half of the speed you would in the daytime to be able to find the house number or road number.
- You have to compensate with speed.
- Reaction distance and stopping distance.
- The 55 mph is greater risk than a 25 mph.
- Just the clarity of the lights and stuff, and some, if there's bright lights coming at you, they bother you more at night when you get older, and its an uncomfortable feeling.
- If it's an unlighted road, and it's curvy or whatever, I'll slow down.
- Just because of the visibility factor. I always slow down; I slow down at night because of that.
- I think that people drive differently at night than during the day, so if you are driving quickly at night it would affect you a little bit more.
- I think it is a little more dangerous to be on a slower road if it is windy.
- To be on a road with a high speed and high volume of traffic, I think that is more dangerous because there are other factors involved with the other drivers, so that would make that a little more dangerous.
- More risk in a high speed limit.
- I'd say the faster you're going like at night you can't see objects far in the distance, so I'd say that would be an increased risk.
- If I don't know where I'm going, I definitely slow down.
- I know that some people think that driving on the highway is more risk just because they are going faster.

- The faster you're going. Maybe not that there would be a higher volume of accidents, but the accidents would certainly be more severe.
- In terms of volume of accidents, there is probably more driving around town where the speed limit is only like 25 mph, because there's a lot more obstacles.
- It would be more risky at night with the higher speed limits, I would say, just because you probably can't see objects on the road as well and turns.

Nighttime-Neg-Vision

- I can't stand to have headlights in.
- The other thing at nighttime that I noticed bothered me, and I figured it out, was the dashboard lights.
- I know it does [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- At nighttime my left eye pupil dilates and I can't see as well.
- My vision gets blurry.
- The headlights in the rearview mirror irritate me.
- I sometimes have wondered if I'm starting to have trouble driving at night.
- Peripheral vision is limited a little bit.
- Definitely [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- The clearer you can see will determine how quickly you're able to respond and that is not always the case at night.
- I think I was more comfortable as far as not having contacts, now I have contacts, and sometimes your eyes dry out late at night.
- I do have trouble seeing at night a little bit out of my headlights, because I have a very old car it's not real clear for me if I have always had trouble seeing at night. I don't know if you call it night blindness, or whatever you call it, but I don't see as easily as I do during the day.
- I don't see as well at night, it is the big concern for me.
- Decreased a little bit because of vision [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- I think the risk is greater.
- Yes, because your visibility is greatly reduced.
- Perhaps a little bit. As I get older.
- A place that has a little street sign, sometimes if my lights are not directly upon it, I have trouble seeing it.
- Seems to be a little bit more in the older I get. I think that I'm, my vision isn't as good as it was 20 years ago, and I feel like I notice it more.
- I just don't feel like I see as well at night, as I did.
- Maybe my distance isn't as good as it was a few years ago.
- And I have reading glasses that I can wear and I have stigmatism, that could be creating some problems that I didn't have four years ago or five years ago.
- During the nighttime your vision is not as clear, so you really have to pay more attention to what's going on around you.
- Your vision is a lot less at night.
- If I don't have any reason to drive at night, I wouldn't.

- At this point, getting up in my age, I don't see quite as well as I used to, especially at nighttime.
- If I can avoid driving at nighttime, if I can put it off, say "you can go tonight, or you can wait until the morning and drive during the daytime," it doesn't matter which way you go, I would probably say "well, I'll wait and drive during the daytime, because I know that I can see much better, I'll know where I'll be going, if I have any problems at least I won't have to worry about not being able to see signs, and stuff like that." I would just prefer to drive during daylight hours than I would at night because of the risks involved.
- I don't get too panicky or anything like that. But I did for a while there now, I couldn't drive at night because I didn't have glasses.
- The visibility at night is a problem for me.
- Low volume is probably going to a country road, and you're going to have to watch out for the objects, your visibility is limited so things come up on you quicker.
- The visibility isn't as good for me, the truck lights, the SUV lights. They are all a deterrent to me driving comfortably.
- A great risk because you can't see; the visibility is a problem.
- I don't think I can see as well at night as I can during the day.
- Well, maybe it isn't my eyes - maybe it is the fact that it is dark and we have the visibility problem again.
- The glare from other lights hitting me.
- If I am driving alone on an unlit roadway at night even though you turn your brights on, you still can't see as far ahead.
- I drive with my brights on a lot when no one else is on the road at night and I can.
- I don't get out that much at night because I can't see that much at night.
- It's not just the oncoming lights even the streetlights and everything.
- Usually when you get home in the evening you stay there, but not always.
- You can't see as far, and you can't detect.
- No, no, now I don't mind driving at night at all. My vision does not deter me from driving at night, but it's just because of the night itself. Your peripheral vision is not as good and you can't see as far ahead, regardless how good your eyesight is.
- At night when you get to be my age your eyes are fading a little bit, and some things at night bother more than they used to.
- Bright overhead lights can do it to you, too, and if somebody's got their signs lit incorrectly so where the light is reflecting back onto the roadway is bad too.
- If I can avoid driving at night, I do.
- Just because of the visibility factor. I always slow down; I slow down at night because of that.
- If it's an unlighted road, and it's curvy or whatever, I'll slow down.
- The visibility in a lot of places is bad, it depends on the lighting, roadway, headlights, and the car.
- I think that it is riskier to drive at night, especially in places where it is not well lit.
- It's definitely harder to see stuff at night I mean like road signs and landmarks and stuff, it wouldn't like prevent me from doing it I might just be a little slower.

- It depends if there's more lighting on the road or not, because I can't really see that far in front of me, and if I don't know what turn I'm making, or where the road is going, I think it's a lot more riskier.
- I wear my glasses at night.
- I just got these glasses a month ago specifically for night driving
- If I was going on a long trip with someone like going home I would drive during the daytime and let them drive at night.
- It was more difficult for me to read signs at night.
- It is darker and would be harder to see.
- My vision is probably a little worse at night then driving during the day.
- Night makes visibility a lot lower, just makes it harder to drive, riskier.
- Visibility is lower, so I'd assume it would increase the risk.

Nighttime-Neg-Weather-Clear
No Cases contained the code

Nighttime-Neg-Weather-Adverse
- Visibility at night in bad weather is atrocious, I can't stand it.
- Rain reflects back, especially if it's coming down real fast.
- Snow is worse, I know, I've been there. Yeah, because it reflects back into the headlights.
- The road is all one color and you can't see any lane markings.
- I know that the reason I had my accident was because there was a dog running out and I did not see it until the last minute. And maybe had the headlights been better I could have stopped that from happening.
- Nighttime driving would be that you're are not aware of how much rain is on the road, how heavily it has already rained, what the condition of the road was; whether there was oil on the road, and then when the water mixes with oil, that's a pretty unsafe condition.
- If it's raining and you know that it's in a freezing zone, a freezing temperature, then it's going to totally change, it's no longer rain, now you're in the condition where you're going to be sliding because of ice, and then if it's not cold enough to freeze, then you may look at how much it has rained; you may start hydroplaning.
- Rainy conditions is a little bit hard.
- My grandmother was in the hospital, that's how I remember, but I was determined to get there. All these people were pulled off to the side of the road, but I just kept driving in about 10 mph, and it was really, really bad weather, but if I had my choices, no, I would not have.
- I guess when I'm always driving in the car with another adult and it's raining, I always think, am I driving too slow or am I driving too fast?
- It's very risky.
- You can't see, is the main concern.
- The road conditions are totally different than they are when there's clear weather. You certainly have to include what's happening with the other cars.
- You couldn't see the cars tail lights two feet in front of you. Scary.
- I try to allow more distance.
- I slow down and allow myself more following distance in adverse conditions.
- I am never totally relaxed.

- I think there's a greater risk than there would be in the daytime.
- Visibility is a problem.
- The slick roads.
- Breaking distance.
- There are situations where I have driven in the rain where I have pulled off the side of the road because I couldn't see at all.
- A lot more risky because you can't see as well.
- The road conditions are a lot more riskier.
- Depending on your speed, or if you're taking turns, or going down hill or whatever, you can easily go into a slide if you have to make a sudden stop, or if something darts out into the road in front of you
- The rain blocks your vision, and a lot of it has to do with how hard the rain is coming down.
- I've had rain come down so hard that you couldn't see hardly anything in front of you.
- I've seen cars come almost to a standstill because the rain was that hard.
- Now if it was ice it would be different. I'm talking about ice that's on the roads, that's different. You don't go out on ice. You just don't do it.
- Driving in the rain doesn't bother me; it just means I'm going to have to go slower, going to have to be more careful.
- I'd say that raises the risk of accidents because of visibility and reaction time.
- The rain and the fog are going to be more with visibility and just how careful you're being.
- Well the snow is going to depend on what kind of tires you got probably. Your visibility is going to be good. Your tires are going to be the main thing.
- The rain, your tires are going to matter if you have to stop suddenly.
- Slow your speeds down, because everything, you have less time to react to things because of the surface adhesion of the road and visibility.
- Fog at night is probably the worst condition to drive in.
- Rain at night is of course worse than daytime.
- I would rather not, but it never deters me from going somewhere if I need to go.
- A great risk because you can't see, visibility is a problem.
- Rain isn't as bad for me as much as fog because I can't see very far ahead.
- Ice is always bad. I just won't go fast in the ice, slow way down and keep one road on the side that has some roughness on it.
- Now, in fog that's a different thing. I've been in fog where you have no vision. I was afraid to pull off of the road, but I couldn't tell where I was.
- In bad weather, I think it is just always much more risky; bad weather at night, because you have weather factors that you can't see as readily. Like, you could have black ice, or you can have certain slippery conditions that you wouldn't really see as well, or falling rocks.
- Well, fog you can't see where you're going, you can be right up on top of something and not see it, that's very dangerous.
- Ice, you can't always control it, if you're on ice you're out of control.
- I think it is that there is much more possibility or accidents or mishaps during the rain.
- I think that it is the condition of the automobiles, the other drivers, that is where I think the risk lies. I know what I do, and what I normally do, but I can't speak for the other drivers.
- I don't try to get out in the rain unless I have to.

- Naturally it is going to be probably more difficult to drive at night in the rain.
- More risky because the road would be slippery.
- I pay more attention to the road than maybe normal dry weather.
- It's always more critical for you, you have to use all your senses as best you can when that happens.
- Something maybe happening and you're more ready to put on the breaks or whatever you have to, or steer away from something when it's like that.
- Because at night you don't have the visibility anyway, and then the lights shining on the water and everything it just, it makes it more difficult at night.
- I think one of the hardest and worst types of driving there is in a snowstorm, well you can't see anything. And the snow gets all over you headlights and blocks your light and usually it gets on the low part first and if you put them on low beam, have you ever tried to drive in a snow storm with high beams? You can't see anything because its up in the snow and it all comes back at you. And so, that's the worst type driving there is in the snowstorm.
- You must adjust your speed accordingly to weather. If the speed limit is 65 mph with rain you should drop it back to a comfortable speed where you can handle your vehicle.
- But the risk at night is much greater than in the daytime.
- Your headlights, even in clear weather, your headlights will show further than it will in the rain, and most of the time in the rain you have to drive in your low beam, so you have to adjust accordingly.
- It's definitely more risky at night to drive in rain.
- It's much less visibility.
- I'd just be a little more cautious.
- I think it would to a degree. Especially like in the rain I think it would definitely be more likely that you'd get in an accident at night.
- I'd say increase it, especially rain.
- I try not to drive if it's anything but clear weather.
- I hate driving with windshield wipers because I don't feel they work well enough.
- If it's raining and its nighttime I almost never drive.
- If it's nighttime I can't really tell how slick they are, how wet they are and I don't know how much to account for that, so I don't know.
- It's not as safe to me.
- I would say fog and snow are the two worst ones.
- Fog, I hate fog because I just can't see anything. I got to maybe drive five miles an hour or really slow to make sure that I see stuff because I'll catch myself like I'll loose the line on the side of the road.
- Snow it's just slippery. You don't know what's underneath the snow. It could be ice, it might not be ice, you don't know.
- Rain you can presumably see most of it.
- At nighttime in the rain; it’s probably harder to see the road.
- You need to be cautious at night with rain.
- Snow scares me.
- I think that ice is the worst.
- I kind of got used to the snow, and it doesn't really bother me to drive in it, but I do slow down a lot and take my time.

- It's still hard to see out of your windshield.
- You can't really see the ice at night, so that's scarier.
- I won't go out just because it is cruddy weather.
- It would be my least favorite weather to drive in.
- You deal with the wipers.
- It gets tiresome.
- Reflection of lights off the rain.
- It is just more difficult to see.
- You strain to see.
- It is risky
- Visibility is so much less.
- Stopping distances.
- Distraction is a problem.
- I drive more carefully in the rain.
- Traction is a problem.
- It is harder to see at night.
- It is harder to see.
- It is more dangerous when it is raining
- A lot slippery on the road.
- More glare.
- You have less visibility I think, especially if the rain is coming down really hard you know you have a hard time even seeing headlights in the road.
- The driving conditions are worse at night, because the road is a little bit slicker.
- The risk is higher, for sure,
- Makes visibility a lot lower, just makes it harder to drive, riskier.
- Visibility is a problem.
- Other drivers are a problem.
- You may be a fine driver in the weather, but someone else may get more shaken up.

Nighttime – No Potential Risk Perceived

Nighttime-Pos-Passenger-Adult

- When I have a passenger with me at nighttime, they will help keep me awake if I'm getting sleepy.
- It's probably better to have a passenger so you can say, "keep me awake, or take over driving."
- I feel safer.
- Always more cautious when I have someone with me.
- At nighttime if I'm out I'm usually with somebody else and not driving.
- Sure, they're kids. They don't want to ride with their mother. But they'll let me go with them.
- It is less risky.
- I will probably drive a little safer.

- I feel just as comfortable at night, maybe more so than I do during the day, and if you have another adult you might talk more, but that doesn't make any difference.
- Another adult wouldn't bother me at all.
- At nighttime usually if I go out at night, I'm going to play bridge or go to my book club, something like that. And I usually pick up some other ladies and give them a ride. So I would have someone with me at night.
- I just would feel more comfortable if I had someone with me on an unknown roadway. I don't know, maybe women are supposed to be afraid of the night maybe.
- I just do feel safer at night with someone else with me.
- I would feel safer.
- If there is some decision to be made, of any kind, while driving, if you have someone to talk it over with, "was that the exit coming up? Or let me see...I wasn't sure of that sign at night," that sort of thing.
- I think it's less risky to drive at night with an adult passenger. I mean, assuming the passenger is a reasonable person.
- You have two people to perceive what's going on.
- I have no problem with anybody riding with me.
- Talking, it doesn't bother me.
- If it's just a friend driving with me or something, that's the same as me driving by myself.
- You can tell an adult to be quite, and they'll pretty much understand that you need to concentrate on your driving.
- I think that maybe during the night you've got someone else to help you look for things, so I guess that would make it easier.
- I probably feel better driving with someone at nighttime.
- I don't like driving alone at nighttime.
- In case something happens I'd have someone else there, that kind of thing.
- I would say at nighttime I would rather drive with an adult.
- I go out at night, I am going to do something with other people.
- Having a passenger does not provide a distraction for me or bother me.
- I am conscientious of other people.
- If you're driving a long ways then you would probably feel a little less comfortable by yourself just because you get fatigued and tired.
- If somebody is there with you that can keep you entertained.

Nighttime-Pos-Passenger-Alone

- Driving alone you just have to deal with whatever factors you involve.
- But, by yourself, other than your radio, or anything else you got going on in the car, your almost more apt to be determined to get where you are going and just pay attention to what's on the road.
- I think when you're alone you're not as concerned.
- I think when you are by yourself, you may talk to yourself but that is a good way.
- I usually get out at night by myself.
- I would rather be alone.
- Nobody to worry about but me.
- The concentration at night requires a lot more of your attention.

- I'd rather be by myself.
- I like driving by myself.
- If you're just driving around town, I would probably feel more comfortable just driving by myself.

Nighttime-Pos-Passenger-Children

- For me, there is no risk now.
- Well, it could be I just don't have a problem. I just have a four-year old granddaughter that I strap in the seat and we talk to each other while we drive.
- Probably, just another breathing body would be good.
- I will drive with kids anytime.

Nighttime-Pos-Place-Known

- If I know where I'm going, it's easier, much easier.
- I know where the turns are in the road.
- I know what need to be looking for.
- If I know the road, then the speed limit doesn't make a difference to me.
- Whereas if you are traveling in an area that you are familiar with, or you have been to before, then you are aware of the time element, as far as when the traffic is heaviest, and when it is not.
- I know where I'm at, I know what to expect, I know what is around me, so even though it is dark I'm more familiar with what's on the road, and what to expect because I am familiar with the area.
- If it is a known area you know what to expect.
- All of your attention is mainly what's out in front of you, you don't have to worry about road signs or anything because you already know where you're going.
- It is just easier to drive on a road that you know.
- I'm more comfortable going to a known place, because I know the streets, and I know the corners, and the intersections and so forth.
- Very low risk.
- If I'm familiar with the place I don't see it as an increase in risk.
- I know where I'm going I feel a lot better at night.
- I can just jump in my car and head right there without getting directions.
- I am much more likely be going to a place that I know.

Nighttime-Pos-Place-Unknown

- If I don't know the road, then I tend to go slower.
- I don't think it is any riskier going to an unknown place.
- I'm going on an unknown road I want good directions or a good map. I don't like getting out somewhere and not knowing where I'm going.
- Nighttime, I would also go on a known roadway but not as much.
- Very low risk.
- Try to follow directions.
- You are looking for signs, so you usually drive slower and more carefully.
- On a road you don't know you would drive the required speed limit.

- If it was night it wouldn't stop.
- Sometime if you're going to an unknown place you're paying closer attention, because you're looking out for the drive, looking what the roads you're on, where you're, your surroundings.
- Maybe a little safer going to an unknown place.

Nighttime-Pos-Roadway-High Volume Traffic
- The more cars there are the more things are lit up.
- At night, in high volume, again everything is well lit if it is high volume, it's usually in an urban area and everything is lit. Cars in front of you, and I feel more comfortable at night, probably driving in a high volume area than a low volume area.
- I do quite often drive in high volume traffic at night so it wouldn't bother me.
- At night I like to be where there're a lot of other cars.
- It doesn't bother me.
- It depends on traffic, if you use traffic ahead of you, you can tell maybe more what is in front, than if you're alone.
- I guess when there is a high volume its easier to see people's brake lights and things while driving at night.
- In some ways you know you're able to see headlights.
- If they're up beside you in a blind spot you might not see them as easily if it was daytime.

Nighttime-Pos-Roadway-Low Volume Traffic
- That would be the type of condition I would prefer with low volume would be in the evening.
- If the traffic is moderate or light, I don't see a problem with the speed limit.
- Low volume traffic you tend to be more relaxed.
- Still you're more relaxed because of the fact that you don't have quite the traffic.
- You may have more distance in between cars in front of you.
- It is a big difference to me because the low volume gives you a break sometimes in between cars and there just aren't as many lights coming at you.
- I feel its no problem if there's low volume, there more leeway, there's more, you know, slippage is not as critical.
- I would much rather drive at night in low volume traffic than high volume traffic.
- With less traffic the cars are further apart, the headlights, the taillights are much more visible.
- It doesn't bother me.
- It is safer driving with low volume traffic at night.
- In low volume really you don't have to worry about the cars because, even if it's curvy because you can see the lights before it gets there and you know there's a car there.
- So in a way it's safer at night.
- We go up in the mountains to our hunt club and at night you can just go right along and you don't have to worry about anything because you can see the car coming.
- If its not heavy volume traffic at night then I don't care what speed I'm going.
- I drive at nighttime a lot but it just that the roads aren't as high volume traffic.
- I would rather drive in low traffic volume if possible.
- The road is more open.

- It is less dangerous.

Nighttime-Pos-Speed
- If I know the road, then the speed limit doesn't make a difference to me.
- If I don't know the road, then I tend to go slower.
- I'd probably feel safer on a faster one.
- I still drive at what I consider a decent but safe speed.
- If you have a windy road, then you're going to respect that.
- If the traffic is moderate or light, I don't see a problem with the speed limit.
- If it is light on the road and I am the only one out there I am not worried about it.
- If it is a straight road and it is fairly well lit that you think you have good judgment as far as seeing at a good distance, it wouldn't bother me to drive 55 mph even at nighttime.
- You going to be able to see what it is before you hit it, if you're going slower.
- There are speed limits for a reason, and you shouldn't exceed it no matter what it is, if its clear weather, of course 70 mph is going to be a four-lane interstate probably, 25 mph is going to be a smaller, residential or country road.
- I don't see a risk in the 55 to 65 mph or even a 70 mph because it is usually on a highway with three or four lane and everyone else is going that speed.
- In town, you know, so many 25 mph roads and you just get used to that and you don't want a ticket so you behave by what the sign says.
- I just adjust to them. I usually try to drive the speed limit whatever it is so. And there is no risk.
- But on the 70 mph you have very gradual curves and you can see for a long ways and everybody's traveling along at the same speed more or less.
- At night if I'm going slower I think there is less risk.
- If its not heavy volume traffic at night then I don't care what speed I'm going.
- I think speed limits are pretty well matched to the roads so I don't think speed limits pose a bigger risk for me.
- Speed limit doesn't affect the risk at all.
- It is less likely to be a risk.
- In areas where the speed limit is 65 mph, it's 65 mph because you know there's not supposed to be anything in your way.

Nighttime-Pos-Vision
- I see very well, I perceive very well, usually.
- Sometimes at nighttime you can almost see more because your able to see lights, and you can actually be guided by the lights.
- I would maybe be a little more cautious, although I'm not a very cautious person.
- I'm not going to stay home because it's nighttime.
- If it is light on the road and I am the only one out there I am not worried about it.
- Now that I've got glasses I can see the signs better.
- I got glasses and now I can see good now.
- No my vision is fine and all. And I can drive fine at night. That's not a problem.

- At night, in high volume, again everything is well lit if it is high volume, it's usually in an urban area and everything is lit. Cars in front of you, and I feel more comfortable at night, probably driving in a high volume area than a low volume area.
- My particular vision, I don't have any night-vision problems, and I prefer to drive at night if I'm going on a long trip, or something.
- Probably because of visibility problems.
- I see just as well at night, I'm not afraid.
- No [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- I think I see very well at night.
- I have pretty good vision.
- So far I have, my ophthalmologist says that my night vision is good.
- I have good vision.
- I have good night vision. I can actually see just as good without my glasses as I do with glasses at night.
- No, it just makes me more careful [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- I don't really have trouble seeing at night.
- No [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- I don't have 20/20, but I mean it's good enough to drive at night, I mean the only thing is sometimes maybe like seeing a road sign from far away.
- I don't think it really affects it, I mean I don't wear glasses or anything and for the most part I see pretty well at night.
- No [*Answer to the question "Do you think that your vision affects the likelihood of you driving?*].
- At night it is easier to tell when cars are coming because of headlights.
- I have really good vision.
- Mine does not, I don't think.

Nighttime-Pos-Weather-Clear

- It is clear, but is still dark, you can't see as well, you might have to pay a little more attention so you can see things on the road.
- But if it's...There is certainly no reason not to drive at night with clear weather.
- If you're on a dark country road that you can see on-coming traffic if there are headlights, you're on a twisty, dark, rural road, that's in a way safer at night.
- I feel almost like if the weather is not bad, then I feel safer driving at night than during the day.
- It is just easier to see in clear weather.
- I would much rather drive in clear weather.
- It is fun to drive in clear weather.

Nighttime-Pos-Weather-Adverse

- I'm usually not the type of person that would pull over; if it is raining really hard I'll just drive at a constant, slow speed.
- I pay more attention.
- Snow I can handle.
- If I have somewhere that I have to go, I certainly wouldn't stay home because it was raining. I would get in the car and go.
- I grew up in Minnesota, so I'm used to driving in the snow.
- I feel comfortable driving at night in most any weather conditions.
- I'll drive if I have to, but I try not to.
- I can tell how wet and how slick the roads are, so it's not a problem.
- I will do anytime.

Nighttime – Other Topics

No driving at night under these conditions

- Snow particularly, those white reflecting things, I can't stand them.
- Blizzards.
- Weather at night.
- Drunk people.
- Usually I don't drive on new years and Halloween.
- If I only had a car that only had one headlight I'd prefer to not drive or really bad headlights.
- If your vision gets to the point where light bothers you
- Heavy fog
- Extreme rain
- It's just that if I'm going with my boyfriend, he's not going to ride with me I'm going to ride with him. I have an old vehicle. And if I'm going somewhere with my kids I would go with them. It has nothing to do with my comfort zone. I'll drive at night I have no problem with that. It has to do with my scenario in my life, who I would go with.
- Especially with rain, if it were pouring blinding rain I would probably reconsider going out.
- Bad weather
- Hurricanes
- Blizzard
- Poor road conditions
- Weather
- Traffic
- Condition of the highway
- If it was snowing so hard
- I don't go on the ice
- Snowing
- Hailing
- Storming
- My lights not working properly

- If it is really raining very hard and I was going to be driving to some place that I know had poor lighting, roads, maybe some back roads that maybe had no lighting with it raining very hard.
- Now if it was ice it would be different. I'm talking about ice that's on the roads, that's different.
- In a flood
- Real high winds
- Real heavy, heavy rain
- Real heavy snow
- Ice
- Other than physical, your eyes having night vision problems, I can't think of any other reason I wouldn't drive at night.
- Blizzard
- I just really don't like to drive at night.
- Snow
- Ice
- I would just rather not travel in fog
- Ice
- I think of that every now and then, you know at night, someone dropping a rock off of an overhead.
- Unless say if the roads are icy I don't, I try not to get out on them.
- If it was pouring down rain and I didn't really have to go.
- Fog
- Ice
- Snow
- Icy conditions
- I hope I don't have a flat at night in the dark and I hope a deer don't come off the bank in the nighttime on me.
- Unless you would really have to be out there, I think you would be more sensible to wait until daylight and then go.
- Thunderstorm
- Heavy snow
- Ice
- The only time I have ever had to refuse to drive was when I was sick.
- Snowstorm
- If it was a cloudburst I'd wait until it was over because usually they don't last but just so long and I'd just wait until it was over
- Fog
- Rain
- Thunderstorms, heavier rain than others, you...I've had to pull over and stop, and it's greater risk. That's a danger within itself, someone running into you if you pull over and stop, it's a very dangerous thing.
- Heavy rain
- Heavy snow

- An ice storm
- A lot of lighting
- Raining very, very hard
- Snowing a lot
- If there was snow of the ground already
- Hail
- Animals in the road
- Snowing really, really hard
- Really icy at night
- At night people tend to be drunk, and that would be an increased risk
- In country roads or places where like unlit roads
- If your high beams aren't very good
- Hailing
- A lot of wind and rain all at once
- If the roads are really icy
- I'd probably say hail. Because hail would damage and I wouldn't want to put that at risk.
- If I'm drinking
- If there is ice, if its been raining and its freezing ice, that scares me a lot because its really slick and there's black ice
- If I'm really tired, and I can't keep me eyes open, I'd rather stay where I am
- If there is a lot of deer around, because I have a house up-state in New York and there is constantly people hitting deer all of the time
- I were really tired I would not drive at night
- Maybe the weekends, because of drunk drivers
- If it's raining really really hard
- Snow
- Ice
- The type of car might have something to do with it. If you're driving an unknown car or something new to you, or maybe an old junk car I might prefer not to drive something like that
- Bad weather
- Heavy rain
- Snow

Eliminating or reducing nighttime driving risks
- Dashboard design.
- The confusion of the construction when there's changes, and how do you say that, when they don't take up the old lines at nighttime, and they give you these signs, and everything is so narrow, and the little concrete barriers, and you've got two lanes of traffic that is stuck in there, its really spooky.
- Removing distractions off of that thing, like extra barrels and cones, because there are a lot of extra cones out there and you really don't know which one points you in the right direction
- Overhead illumination.
- Wearing the right clothing at night.

- Lighter clothing definitely, and reflectors.
- Slowing down when the weather gets bad.
- Figure out how to use your headlights the best way.
- Roads need to be marked better along the sides.
- Quarter-mile reflector.
- The color of the road.
- Dark roads are harder to see at night, they like suck up all the light, and lighter roads reflect it a little bit.
- Divider lines.
- Do something about when you're going up a hill, because a lot of times when you crest a hill it's dark at the bottom. You know and I rise up on the seat to see over because the headlights are going up in the air, so if they could fix that.
- It would be nice if they could do something where if there was an animal getting ready to cross the road even a little squirrel, because I don't like hitting squirrels. Could make it like red on there, or the headlights would I don't know do what.
- Curfews.
- Taking drunks off the road.
- No cell phones.
- A big airbag on the outside of the car.
- Lighting on your vehicle, if you could have lighting that would increase your depth, and broaden your range, as far as your peripheral, and still not affect the people coming at you then you're definitely at an advantage because you've more in front of you, as far as the whole picture, whereas if you're limited to just so many feet in front of you, then you're not going to be as comfortable.
- More visibility, through say, heavy rain.
- Better fluorescent lines on the roads.
- Reflectors they have in the middle of the roads.
- I'm not a big one on lights on roads, because of reflections on the roads that they create.
- Better headlights.
- Windshield wipers are real important.
- Better lights, driving lights.
- Anti-glare.
- I think all intersections should be lit.
- Dress people in light colored clothing.
- Black clothing is very difficult to see.
- Reflective paint and better markings on the highway.
- Warning device for construction zones.
- I think there ought to be a law passed that if somebody is walking on a highway in dark clothing that they should be ticketed because it is just as bad as drinking.
- Better visibility.
- It's kind of hard to have all the roads in the country lit up but certainly if there was more, in a built up area lighting helps, you know where there's a lot of traffic.
- Road reflectors help.
- Signs that are illuminated well helps.

- Anything that you can, that helps you see where you're going, where you're getting off, where you know, directions or you know road signs that are telling you where you are and where you're going, being illuminated as well would help.
- Better lighting system.
- If you make it brighter you got to worry about on coming and how are they going to notice it.
- Design a type of light that wouldn't be blinding, but that would make you see a lot better, see further, clearer, some type of night vision or something that wouldn't affect on-coming traffic.
- Better lighting system on the road, overhead, because overhead lighting wouldn't affect drivers in any direction.
- Better headlights.
- Glare.
- Something that would not let you start your car if you've been drinking.
- If it could detect that you can't see good at night it wouldn't let you drive.
- Probably the biggest risk is just fatigue, or just the monotony of, you just lose your focus on what you're doing.
- Better visibility.
- Better headlights.
- Better markings, road markings.
- Have separate roadways for trucks.
- Better lighting on the roadways.
- Be sure your lights on your car are in good order.
- Low volume traffic, which is impossible anymore.
- Better overhead lights.
- I think that anyone outside at night should have on reflective stuff.
- The markings on the pavement I think help, as long as the lines are in the center of the road, and the outside edges are marked well, I think that helps to cut down risk.
- Where I live there is not any lighting at night, overhead lighting, and I think lighting always helps.
- Make sure that the markings on the road would be visible.
- Reflectors in the road and guardrails - all that should be kept and up to date to make it safer.
- Fill up the potholes.
- Better lighting systems.
- Better marking.
- I know in several cases I've wanted to go to a certain place and the road signs wouldn't be right to direct you where you want to go.
- I've seen places where signs were turned or vandalized and that's risky.
- Different speed limit at night.
- Lights.
- Lighting the streets, you know, with streetlights on the roadways helps.
- More reflectors in the road. Particularly, in situations where you have rain, because most lines will washout in rain, but the reflectors, generally, you can still see those, but the painted lines will be almost gone in the rain, particularly at night.

- Better lighting on smaller roads.
- An indication in a car that another car is coming, or behind you.
- Better windshield wipers.
- Better lights.
- If you knew more about the road ahead of time, if you could find out information about roads that you haven't been on.
- Came up with headlights that you could just see things better or farther ahead.
- Well I think lighting, seeing like farther off into the distance and also seeing off to the sides a lot too. Because like animals, deer like if you can see them coming from, if you have more time to see them coming then I would say that that would help out a lot.
- The glare, oncoming glare can be kind of annoying.
- Probably better ways to see things. If you could see things more easily and make things clearer when you're driving in that bad weather.
- Reducing speed limits.
- Making more requirements as far as how well the driver has to be at driving just to be on the road at night. Because a lot of people aren't good drivers at night.
- Good lighting at night, so maybe some more lighting or reflectors on the side of the road.
- Maybe road signs that tell you where the roads are before you come to the road, actually. Its like, "Huntsman Blvd.: next right," so you see its coming up before you actually hit it.
- Better lit streets.
- Better headlights.
- Better marked roads.
- Better lighting on the roadways.
- Better headlights to so you can see better at night.
- Windshield wipers.
- Headlights.
- LED taillights, you know where they light up faster, I know it only gives like a split second, you know a millisecond faster, but maybe that helps.
- Better visibility systems on cars.
- Markings on the roads.
- The number of people on the roads, because there's always a higher risk when there's more people involved.
- Create lights that were bright, but didn't hurt the other cars' eyes so bad.
- I've noticed on a lot of the newer cars that the lights are really bright and I'm sure it's great for the driver but then for the other people it hurts their eyes.
- If you could make the roads able to, if there was ice or snow able to melt the ice or snow which I'm sure would cost a lot of money.
- A lot of the salt trucks and stuff can't run as quick enough to keep it from freezing.
- Better windshield wipers.

Pro-Driving at night increases risk of accident

- Oh, probably, because I don't see as well at night, yeah, for me it is an increased risk.
- I guess I connect it with people drinking, driving drunk.
- I guess probably just visibility.

- As far as visibility, I do.
- Just the fact that your depth of field is different, you don't really see the whole picture, and that depends on if you've got your bright lights on, if you're able to run bright lights, if you're not able to run bright lights then you're pretty limited on what you've got right in front of you.
- Some people just don't travel at night, and then there are a lot of people that can't adapt to the difference in the light and dark, and then a lot of people can't adapt to the fact that there are other headlights coming at them.
- If a road is bad; it has potholes, or there's no shoulder, things like that, unless you see a sign, if it's not marked with a sign, you don't know about it.
- Yes.
- Due to the fact of the distance that you can see.
- At nighttime, sometimes other people aren't as cautious.
- Peripheral vision is limited a little bit.
- I just find that at nighttime I have more drivers to pull out in front, or not give signals than I do during the day.
- I would say so.
- I don't see as well at night is the big concern.
- At nighttime you have an over abundance of people who are going to put you at risk because they don't care.
- Yes, because your visibility is greatly reduced.
- I'd say so, I haven't been in an accident at night but I would say, yes.
- Visibility, especially if it was raining.
- Sure. Because you cannot see as far as you could during the daytime.
- Your reaction time is a lot less to react to anything.
- I'd say it does.
- The visibility is a problem.
- You should be a little more careful.
- When I go driving at night I don't think of it that way, but I'm sure it is a higher risk.
- At night, fog at night specially.
- Probably because of visibility.
- That's different if it's at night because there is just more chance of accidents of all kinds.
- I've never had an accident at night, but I think it probably does increase the risk. I've driven a lot at night and I've never had an accident, but since I prefer to drive in the daytime that at night, I must perceive that there is a risk.
- I think that anytime anybody drives at night would be a little more vulnerable to an accident than they would in daytime.
- In the daytime, you could relax a little more than you could at night.
- It probably increases the risk, but I've never had an accident at night.
- Night driving has got to be more difficult.
- You can't see as far, and you can't detect as fast.
- If I want to go, I'm going doesn’t matter there is an increased risk at night. And so, that doesn't affect whether I'll go or not. I haven't gotten to that age yet.
- But the risk at night is much greater than in the daytime.

- Absolutely.
- Because of your vision. You can't see as far.
- Your headlights will not allow you to see as far and you have to adjust accordingly.
- It depends on traffic, if you use traffic ahead of you, you can tell maybe more what is in front, than if you're alone.
- Maybe a little bit not much.
- I think it would to a degree. Especially like in the rain I think it would definitely be more likely that you'd get in an accident at night.
- I would say if it was somewhere I didn't know, like if I was maybe focusing my attention on looking at signs, and then maybe it'd be an increase.
- I would probably be a little more tired at night.
- Less visibility.
- I would say there's a higher risk.
- Visibility is lower. I'd assume it would increase the risk.
- Yes, I think so.
- Because of the darkness.
- People are more tired.
- People have been drinking alcohol.

Con-Driving at night increases risk of accident

- Not really.
- If you have good lights, and you are not over-driving you lights, you should be able to stop your car if you have to, if there is some trouble ahead of you.
- I don't think that.
- I feel like I'm a safe nighttime driver.
- I don't really think so.
- No, I don't think so. It's basically about the same.
- I haven't had a wreck or an accident. It just doesn't bother me. I'm just careful.
- I guess it's harder to see other things around, but as far as coming into contact with other vehicles people usually have their lights on, so you can see people from far away, as long as the road is not too windy.
- If I'm familiar with the place I don't see it as an increase.
- I would say no, because I would think there's more of a risk driving during the daytime when there's more congestion and traffic.
- Nighttime, even though it's harder to see and stuff there's such a dramatic difference in the amount of people on the road that it's a lot safer if you ask me.
- People have headlights and I can see their car, unless they're drinking, I have pretty good vision, and it doesn't really bother me to drive at night.
- Not for me.
- I have experienced most of close calls during the day.
- I think that people are more aware of the cars around them because of the lights and they stand out.
- It is easier to tell the cars in your blind spot because you will see the lights reflecting off the road.

Comment on the Vision Enhancement System

- So that way if it was a different color you would know it was something that like an animal that could move right in front of you. As opposed to a stationary object. [Comment related to IR-TIS]
- When you first turn them on its just an extremely bright, not a yellowish type, but a real bright whitish type light. If I knew that was in oncoming traffic, to me that would be more, it lighted the road up better for me. [Comment related to configurations with HIDs]
- If I were in a vehicle that I knew I could see better with, I would also be concerned with, I'd also be concerned with, if it's bright enough for me, is it too bright for them. Same thing if their lights are too bright, they may be seeing great, but their totally blinding me, so it has to be friendly with the person for on-coming traffic, too, or its going to be dangerous for you too, because their going to run into you, or their going to react in a way that may affect your driving.
- *Interviewer: Are you talking about the thermal imaging system?* Participant: Imaging, yeah, it was interesting, and it definitely contrast, set a contrast, but it is hard to follow that, and follow where you're going, and it's hard to just singly follow that. [Comment related to IR-TIS]
- You felt like you had two things to look at. It's only a small image in front of you, but yet you've got the entire picture on the windshield that you're trying to look at too, so you're afraid that if you just look at that thermo-imaging 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, or sometimes both, you feel like something may appear in the picture that you don't really see, and you got two totally different contrast, if you looked at one some things are more obvious and noticeable than if you didn't have that. [Comment related to IR-TIS]
- *Interviewer: Will you be more willing to drive at night if you have that system would you use it?* Participant: Yeah, I'd be more willing to try to adapt to it, to get used to it if I had that system on my car, if it were feasible, cost factor, but I definitely enhances the total picture as far as increase in visibility. *Interviewer: What about what you mentioned?* Participant: Well, the fact that it would have to be a larger screen, but then the larger it is, of course, it cuts down on everything else that you're seeing, too. But, the average person, I think, the elderly, they would have a hard time with that because it would be such a new system that they really wouldn't know what to look at. *Interviewer: So, do you think that it was distracting to you?* Participant: A little bit distracting, because I wasn't used to it, and then the size of it: 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, but it made me want to look away to see what else is outside of the picture, it felt like a closed caption type thing, with like a mini screen, but the large screen was actually what was going on through the windshield. I felt like the concept of it made sense, as far as contrast. *Interviewer: How will you evaluate it terms of driving at nighttime with rain?* Participant: As far as saying a 1-7 scale, I would say with rain, as long as its not distracting you from what you're used to looking at, which would be out of your windshield, I would say that with rain you're able to pick up, like I was able to pick up darker objects better, and then of course, lighter objects got that much lighter, but it definitely helped and you could see the rain itself. You can see how much rain you are getting, and I would be more apt, and probably more likely to use that system if it were a little bit more of

a larger picture, like I said, because it does put a contrast more; you don't really have any contrast without that.

- The UV out there seemed to help some.
- This Cadillac with this heads up display with night vision works good outside the rain. In the rain, it is terrible. When you a see a person, it is like a ghost. I had to stop and the guy walked out there about 20 feet in front of me and I could barely see him in the rain. Outside the rain, it does good. I believe it needs some kind of contrasting detail to what's white turns up black there and what's black turns up white on this night vision. When rain is coming down it is like snow on an old television set and you can't distinguish anybody out there. I could see them with my eyes but not on the heads up display. I think it needs a contrasting knob or something that when you get in rain or snow, you will have to contrast up or down.
- In dry weather and I was outside the rain, I was impressed with it. [Comment related to IR-TIS]
- I think the UV lights is really going to be a good thing because of the way it picks up.
- If you have good lights, and you clean them off before you go, and I do that. If I'm in Staunton, and I'm coming back at ten o'clock at night, I go right to the service station, get all my gas, clean off my headlights, wipe off my taillights, an then I feel pretty comfortable, just as comfortable as I do in the daytime.
- Well I think what we were doing with the lights, see I didn't realize how good those lights were until after the first night we'd finished driving and then I got in a 1996 Cutler supreme, a used car that we had. And I turned the lights on and it was starting to get foggy just like it was down there. And I said "My God"; I said I didn't know how good those lights were. You know because our lights were halogen you know they were supposed to be pretty good in 1996. But they weren't near as good as the lights that we were driving. And I wouldn't have known that.
- Well I thought the lights that had a blue hue to them cut through everything more than the ones with the yellow lights. [Comment related to configurations with HIDs]
- Maybe it was my imagination and I'm sure the tests will probably bear something out and I don't know what that'll be, but it seem like to me the ones that had that kind of blue look to them were better than the ones that had a yellow light. [Comment related to configurations with HIDs]
- Both of the Explorers, they had great lights.
- The truck I thought the beam was way too high.
- The Cadillac wasn't good at all, I didn't like that night vision thing. [Comment related to IR-TIS]
- I couldn't see through it when it was raining. I couldn't see, I didn't like that at all, I enjoyed it a lot better the time I drove it and it didn't have it on, but in the rain I could not see through that thing, maybe its something I could get used to. [Comment related to IR-TIS]
- I've noticed with some of the headlights that we were testing, some of them were very good in the rain, but there was a couple of them that they were bright enough, and the right intensity that they reflected back in, and momentarily blinded you from seeing anything.
- One of the trucks I drove, I could see the objects the best, I think it was UV; it made the white guy look purple, that was a really good headlight, it was my favorite one; I could see further than anything else.
- Most of the headlight systems we did help better in the rain than my vehicles.

- They don't seem to reflect off the rain as much.
- Whereas when you drive through the rain or fog with my high beams on, all you see is just the beams in the rain.
- The lights that I liked the best I didn't know that they had UV on at all until I saw the white pedestrian from far away. I could tell those lights were on and those were the ones that I said were the best.
- The Cadillac you know with the night vision, it doesn't really do anything during the rain it just looks all fuzzy.
- The ones with the, you know where they light up something that's white. That, I thought that was a really good system. [Comment related to configurations with UV-A]
- *Interviewer: Something else that you can think of that can be redesigned?* Participant: Well the night vision thing on the Cadillac is, it was, it's good for certain things, but not for, I guess it's good for seeing vehicles I noticed because they're warmer and it tends to pick up on heat better. *Interviewer: So what about the other objects or things or people?* Participant: Well for me being that I was a first time user with it, in some instances it kind of posed as a distraction. *Interviewer: In which way?* Participant: Just because you don't, you know it's 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 it as like a, if you see something flash through there, then you look down at it, you shouldn't use it as like a out of the corner of your eye kind of thing. But it was a little confusing to get used to; I mean I definitely think it's cool. But it was, and it's kind of down low and its, I kind of want to scrunch down to try to look through it, but it was a little awkward at first, but I guess if you're using it all the time you get used to it.

CURRICULUM VITAE

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EDUCATION:

01/00 – 05/2002	Virginia Polytechnic Institute and State University, Blacksburg, VA **Ph.D., HUMAN FACTORS ENGINEERING** **Degree:** *May 2002* **GPA: 4.00**
08/97 – 12/99	Virginia Polytechnic Institute and State University, Blacksburg, VA **MS, HUMAN FACTORS ENGINEERING** **Degree:** *December 1999* **GPA: 4.00**
08/91 – 12/96	University of Puerto Rico - Mayaguez campus, Mayaguez, PR **BS, INDUSTRIAL ENGINEERING** **Degree:** *December 1996* **GPA: 3.81**

PROFESSIONAL EXPERIENCE:

03/00 – Present	Virginia Tech Transportation Institute, Blacksburg, VA **SENIOR RESEARCH ASSOCIATE** Develop and conduct research related to safety and human factors in operator-vehicle systems such as information transfer, displays and controls design, operator training, operator fatigue assessment and countermeasures, and the effects of new technologies, including nigh vision, on operator performance and safety.
05/99 – 08/99	Scientific Research Lab - Ford Motor Company, Dearborn, MI **SUMMER INTERN – VEHICLE SAFETY RESEARCH** Justify, design, execute, and analyze a research experiment related to vehicle safety using navigation systems. The experiment was performed in Ford's driving simulator and included 31 participants. The goals of the experiment were to find a surrogate measure of visual demand while driving, develop a relationship

between eyes-off-the-road time and total task time, and provide a basis for evaluation/refinement of SAE-2364.

07/96 – 7/97 Techno Plastics Industries, Añasco, PR
SAFETY AND HEALTH ENGINEER
Evaluate company compliance with OSHA regulations. Develop comprehensive plans to document compliance with these regulations. Evaluate Personal Protection Equipment for a variety of work environments. Develop monitoring procedures for several chemicals. Serve as a liaison between employees and management in matters related to Industrial Safety and Health.

08/95 - 12/95 Techno Plastics Industries, Añasco, PR
UNDERGRADUATE ENGINEERING RESEARCH
Researched the ergonomic difficulties presented by a repetitive manual operation to various workers. Suggested economically feasible improvements to the operation. Considerably reduced cycle times for the operation. Greatly reduced operator's complains concerning the operation.

SPONSORED PROJECTS:

02/98 – Present Federal Highway Administration, Washington, D.C.
TEAM LEADER – DRIVER/PEDESTRIAN RESEARCH
Contract No. DTFH61-98-C-00049: Enhanced Night Visibility

05/01 – Present General Motors, Warren, MI
PRINCIPAL INVESTIGATOR
Contract No. 439042: Night Vision

POSITIONS HELD IN COLLEGE:

05/98-03/00 Virginia Tech Transportation Institute, Blacksburg, VA
GRADUATE RESEARCH ASSISTANT
Conduct applied research on human factors issues in transportation, specifically dealing with the human information processing aspects of different types of in-vehicle information systems. Present research results to varied audiences, including the general public, sponsors, and academia.

08/97 – 05/98	Virginia Polytechnic Institute and State University, Blacksburg, VA **GRADUATE TEACHING ASSISTANT** Responsible for all grades assigned to the work turned in by nearly 120 sophomore and senior undergraduate students, including homework and exams. Tutored students requesting help on class problems or general course material.
12/94 - 06/95	U. of Puerto Rico - Mayaguez campus: Solar Car Project, Mayaguez, PR **RESEARCH ASSISTANT - COMPOSITE MATERIALS** Undertook, with a team of other students, the design and construction of a body shell for a solar car. Accomplished goals, which included: low weight, modularity and high strength. Gained experience with the several composite materials used in the body shell, including fiberglass, carbon fiber and Kevlar. Analyzed all aspects of manufacturing, including economics, and suggested appropriate material usage considering all goals and restrictions. The team exceeded overall expectations, improving its position by more than 50 percent, compared to past races.

MEMBERSHIPS:

08/98 – Present	Phi Kappa Phi, *Virginia Tech Chapter,* Blacksburg, VA
12/97 – Present	American Industrial Hygienists Association
08/97 – Present	Human Factors and Ergonomics Society, Blacksburg, VA
05/95 – Present	Alpha Pi Mu, *Puerto Rico Alpha Chapter*, Mayaguez, PR **Vice-president:** *08/95 – 12/96*
08/95 - Present	Tau Beta Pi, *Puerto Rico Alpha Chapter*, Mayaguez, PR
05/95 – Present	Institute of Industrial Engineers, Blacksburg, VA
05/96 – Present	Golden Key National Honor Society, *PR Chapter,* Mayaguez, PR

HONORS:

08/99 – 05/01	IIE - E.J. Sierleja Memorial Transportation Fellowship
08/97 - 05/98	Graduate Dean's Assistantship Recipient
05/96, 05/97, and 05/99	Hispanic Scholarship Fund Scholar
08/97 - 05/98	Outstanding Graduate Teaching Assistant Award - Alpha Pi Mu

PROFESSIONAL SERVICE:

08/00 – 10/01	Human Factors and Ergonomics Society – Surface Transportation Technical Group **TECHNICAL PROGRAM CO-CHAIR**

PUBLICATIONS:

Farber, E., Blanco, M., Foley, J.P., Curry, R., Greenberg, J.A., and Serafin, C.P. (2000). Surrogate measures of visual demand while driving. In Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting, Vol. 3, 274-277. Santa Monica, CA: Human Factors and Ergonomics Society.

Blanco, M., Hankey, J.M., Binder, S., and Dingus, T.A. (2001). Detection and recognition of non-motorists and objects using new technologies to enhance night vision. In Proceedings of the Intelligent Transportation Society of America 11th Annual Meeting and Exposition. Washington, DC: Intelligent Transportation Society of America.

Blanco, M., Dingus, T.A., and Hankey, J.M. (2001). Effects of in-vehicle information system (IVIS) tasks on the information processing demands of a commercial vehicle operations (CVO) Driver. In Proceedings of the Intelligent Transportation Society of America 11th Annual Meeting and Exposition. Washington, DC: Intelligent Transportation Society of America.

Blanco, M., Hankey, J.M., and Dingus, T.A. (2001). Evaluating new technologies to enhance night vision by looking at detection and recognition distances of non-motorists and objects. In Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting. Santa Monica, CA: Human Factors and Ergonomics Society.

Curry, R., Greenberg, J., and Blanco, M. (2002). An alternate method to evaluate driver distraction. Submitted for publication in Proceedings of the Intelligent Transportation Society of America 12th Annual Meeting and Exposition.

TECHNICAL REPORTS:

Blanco, M. (1999). Effects of in-vehicle information systems (IVIS) tasks on the information processing demands of a commercial vehicle operations (CVO) driver. Unpublished master's thesis, Virginia Polytechnic Institute and State University, Department of Industrial and Systems Engineering, Blacksburg, VA.
URL: http://scholar.lib.vt.edu/theses/available/etd-122299-195616/

Farber, E., Blanco, M., Curry, R., Greenberg, J.A., Foley, J.P. and Serafin, C.P. (1999). Surrogate measures of driving performance (Technical Report SRL-99). Dearborn, MI: Ford Motor Company-Scientific Research Laboratory.

Farber, E., Curry, R., Greenberg, J., Foley, J., Serafin, C.P., and Blanco, M. (2000). Surrogate measures of visual demand while driving: part I (Technical Report SRR-2000-0191). Dearborn, MI: Ford Research Laboratory.