Comparing LED Lighting Systems in the Detection and Color Recognition of Roadway Objects

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ABSTRACT

This study compared two LED luminaires and their abilities to provide detection distance and color recognition distance of potential roadway hazard. Detection distance is regarded as a metric of visibility. Color recognition distance is a metric for comparing the impact of the (Correlated Color Temperature) CCT of each luminaire and their color contrast impact. Mesopic vision, the mode of vision most commonly used for night driving, was considered in this study. Off-axis objects were presented to participants to assess the peripheral abilities of the luminaires. The impacts of luminance and color contrast were addressed in this study. The experiment was performed on the Virginia Smart Road where standard objects of different colors and pedestrians wearing different colors were detected by drivers of a moving vehicle in a controlled environment. The key difference between the two luminaires was their color temperatures (3500K versus 6000K). The results indicated that neither light source provided a significant benefit over the other although significant interactions were found among object color, age, and lighting level. The results indicate that the luminaires provide similar luminance contrast but their color contrasts depend heavily on the color temperature, the object, and the observer. This study followed the protocol developed by the Mesopic Optimisation of Visual Efficiency (MOVE) consortium developed by the CIE for modeling mesopic visual behavior.

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INTRODUCTION

The National Safety Council's (2007) statistics indicate there are 5.4 deaths per million vehicle miles driven at night compared to 1.6 in the daytime. This may be due to the reduction in visual acuity at night. In 2007, the Federal Highway Administration reported that 50% or more of fatal crashes over the previous twenty-five years occurred at night despite the smaller number of vehicles on the roadway (Mayeur, 2008). Nighttime driving poses many unique hazards that are not present during the day, such as reduced visibility and contrast sensitivity (Pretto & Chatziastros, 2007). The reduction of these necessary components of nighttime vision impairs a driver's ability to detect and identify roadway objects and potentially hazardous situations (Wood, Tyrrell, & Carberry, 2005). Nighttime driving uses both the rods and cones of human vision, referred to as *mesopic* vision (Alferdink, 2006). During nighttime driving, the eye must use mesopic vision to take in all available light and still control for glare and discrimination of objects. There is very little literature on mesopic visual modeling. The goal of this study is to validate the Mesopic Optimisation of Visual Efficiency (MOVE) consortium, which has attempted to standardize mesopic visual modeling.

Currently, most roadway lighting uses a high-pressure sodium (HPS) light source. Designers choose HPS because it is efficient in output per watt of input power, but it provides a yellow-colored light that has very poor color-rendering properties. The color-rendering properties of HPS lamps can be improved by increasing the sodium vapor pressure, but this would require a greater expense and a loss of efficiency in terms of lumens per Watt (CIE, 2009). While an HPS light source is more efficient photopically than white light sources that have better color-rendering properties, the ambient light conditions present during nighttime driving situations prevent the human eye from operating in a photopic condition. Photopic vision is mainly responsible for color and is dominated by the use of cones in the retina. Conversely, scotopic vision is used for low light levels and is dominated by the use of rods located in the fovea. Mesopic vision is region between photopic and scotopic (at around 0.001 cd m^{-2} and 10 cd m^{-2}) (CIE, 2010).

While the literature has frequently considered white light to provide a benefit to mesopic lighting levels the impact of color contrast provided by a high color-rendering source has not been considered. This project considers the impact of color contrast in the driving environment.

Rationale

This investigation compared the performance of a driver in two activities related to vision: a detection task and a color recognition task. These tasks were performed under two LED lighting systems with differing color temperatures.

The two LED lamps have correlated color temperatures (CCT) of 3500 K and 6000 K. A studio lamp has a CCT of approximately 3500 K while 6000 K is closer to the CCT of typical daylight or an electronic flash (MacEvoy, 2010). It is expected that the 6000-K LED luminaire will have more ambience and better color-rendering properties than its 3500-K counterpart, particularly in the blue portion of the spectrum.

The purpose of this research is to compare the overall efficiency of object detection during nighttime driving using the two light sources. This research will then be utilized for future designs and technologies.

Research Objectives

1. To determine the visual performance in the detection of an object while driving under each of the two light sources.
2. To determine visibility among different color objects while driving under each of the two light sources.

Research Questions

Research Question 1

To what extent will target detection distance differ between the LED 6000K and the LED 3500K?

Hypothesis 1

H1: There is a difference between the LED 6000 K and the LED 35000 K light for drivers in regard to average detection distance of targets

Research Question 2

To what extent will pedestrian detection distance differ between the LED 6000K and the LED 3500K?

Hypothesis 2

H1: There is a difference in detection distance between the LED 6000 K light source and the LED 3500 K light source for pedestrians.

Research Question 3

To what extent will target color recognition distance differ between the LED 6000K and the LED 3500K?

Hypothesis 3

H1: There is a difference in color recognition distance between the LED 6000 K light source and the LED 3500 K light source for targets.

Research Question 4

To what extent will pedestrian clothing color recognition distance differ between the LED 6000K and the LED 3500K?

Hypothesis 4

H1: There is a difference in color recognition distance between the LED 6000 K light source and the LED 3500 K light source for targets.

BACKGROUND

Vision

Dim or reduced lighting has major impacts on visual acuity and detection capabilities. Thus, driving at night reduces the ability to detect contrast and poses visual obstacles such as night-time glare. According to Stephenson (2006), even someone with 20/20 vision is not necessarily immune to poor contrast sensitivity, which makes distinguishing foregrounds and backgrounds more difficult because similar colors tend to blend.

Nighttime Driving

New technology has allowed for nighttime driving to be studied via eye-trackers. Eye-trackers typically involve cameras that follow the pupils of the human eye and, based on an algorithm, can predict where the individual is gazing. Not surprisingly, eye-tracker studies infer that the longer the gaze, the more time the looker needs in order to obtain the information necessary to make sense of their environment or situation. These longer gazes likely signify the looker's inability to see and identify their targets confidently. Well-lit areas, which promote high visibility, require shorter gazes because information within the roadway is easy to detect. Conversely, dimly lit stretches of road require longer gaze points and thus entail slower reaction times (Crundall, Chapman, Phelps, and Underwood, 2003).

Current roadway lighting is designed for the foveal view, or the driver's center view (American National Standard Practice and Roadway Lighting, 2001). However, peripheral information is also required for safe driving (Owsley and McGwin, 1999). Although off-axis pedestrians and targets may not be directly relevant to the immediate safety of the driver, it is almost impossible to quantify this claim. As Bullough and Rea (2004) explain, off-axis targets may not always be an immediate concern to the driver, but it is better to detect potential hazards even a little bit sooner rather than a short time later when there is less time to avoid potential danger.

There are two major light-sensitive photoreceptors in the human eye known as rods and cones. Photopic sensitivity utilizes cones while scotopic sensitivity utilizes mainly rods. At night the eye uses mesopic vision, in which both the cones and the rods are active in the retina to produce the visual response. Mesopic vision shifts the color sensitivity of the eye in two ways. The influence of the rods shifts color sensitivity toward blue. Additionally, reduced cone usage and increased usage of the monochromatic rods reduces color sensitivity, shifting sensitivity toward color blindness. These factors must be considered when reviewing the performance of a driver under a broadband light source.

Mesopic Vision

Photopic vision is responsible for the perception of color because the cones respond to light of wavelengths between 360 nm and 760 nm (blue to red). Photometry relies on the photopic luminous efficiency function (*Vλ)* to represent output from a light source. Cones are mainly found in the fovea of the eye, which is responsible for visual acuity. Scotopic vision is necessary for pitch-black or very low light levels, in which the rod receptors are sensitive to wavelengths of 400 nm to 610 nm (violet to orange) (Josefowicz and Ha, 2008). Rods are concentrated mainly in the periphery, which is responsible for achromatic vision and detection. Most lit roadways and parking lots fall within the mesopic range (Josefowicz and Ha, 2008). Table 1 summarizes the differences in rod and cone vision.

Table 1: Comparing Rods to Cones (Kandel et. al., 2000)

Rods	Cones
Used for scotopic vision	Used for photopic vision
Light sensitive; sensitive to scattered light	Not light sensitive; sensitive only to direct light
Loss causes night blindness	Loss causes legal blindness
Low visual acuity	High visual acuity; better spatial resolution
Not present in fovea	Concentrated in fovea
Slow response to light, stimuli added over time	Fast response to light, can perceive more rapid changes in stimuli
Have more pigment than cones, can detect lower light levels	Have less pigment than rods, require more light to detect images
20 times more rods than cones in retina	20 times fewer cones than rods in retina
Confer achromatic vision	Confer color vision

There are currently not as many reliable models available for defining mesopic visual levels as there are for photopic and scotopic visual levels. There have been several attempts to contrive a visual model for mesopic vision, but ultimately it becomes too difficult to establish consistency, according to Alferdink (2006). Yunjian He was an early pioneer in the attempt to establish a unified system of photometry. He sought to form a connection between the photopic efficiency function and the scotopic efficiency function, whose interstice defines the mesopic function region.

Eloholma et al. (2005) provided an overview of mesopic models that had been characterized by their performance in nighttime driving. There were 15 models listed, 10 of which utilized heterochromatic brightness matching (HCBM) as their method. The visual angles for all fifteen of the models varied between 2 and 10 degrees. The models that did not use HCBM used reaction time (RT), binocular simultaneity (BSM), search time (ST), or achromatic detection threshold (ADT).

Rea and Bullough (2007) urge the international communities to create a unified system of photometry. In a widely publicized 2007 memorandum, they acknowledge that an effort has been made by the MOVE consortium as well as by the Illuminating Engineering Society of North America (IESNA). When comparing several models for mesopic vision, Rea and Bullough (2004) mention that the underlying difference between each model is whether or not they follow Abney's law of additivity. The example given by the law is that if there are four stimuli and **A** matches **B**, **C** matches **D,** and (**A**+**C**) matches (**B**+**D**), then (**A**+**D**) matches (**B**+**C**) (Wyszecki and Stiles, 1982). Rea and Bullough (2004) stress that this law, the cornerstone of photometry, must be upheld for a unified system of photometry to warrant merit. The methods that do not use Abney's law of additivity tend to use psychophysical tests, such as brightness matching, which ignore Abney's law.

In 2010, the CIE published a final model that is the combination of the MOVE and the Unified System of Photometry derived from the work of He et al. (CIE, 2010)

It is important to note that the mesopic effect occurs primarily in the periphery of the eye. The fovea contains no rods, so the shift to a mesopic light level is not evident in the fovea. The data obtained from the off-axis identification of targets throughout the study will be used to assess the contributions of the LED light sources to mesopic vision. It can be determined whether either lamp type enhances peripheral visibility of off-axis objects which represent potential roadway hazards (pedestrians, wildlife, other vehicles, etc.).

Color Contrast

The other effect of the nighttime light levels is the change in color sensitivity. The color appearance of an object also influences the ability of a person to see it. The mesopic effect is strictly a change in the visual performance due to a change in the eye's sensitivity and is related to luminance contrast. Color contrast refers to the chromatic difference of an object from its background. This effect is primarily effective in the fovea of the eye, where most of the color determination of the visual system is evident.

Very little research has been performed in the effect of color contrast on object visibility. Eastman (1968) discusses an experiment in which color targets were considered in relationship to their visibility. The impact of the color contrast was evident only at low luminance contrast levels and showed an impact of only 5% at higher luminance contrast levels. It is important to note that no human participants made any assessments in this investigation; rather, a visibility metric was used to perform the assessment. It is also important to note that the lighting levels were 100 lux and above. These results may have little or no impact at low lighting levels and in a dynamic environment as that experienced in a nighttime driving situation.

The Eastman paper did show an interesting effect that might need to be considered in the analysis of the color contrast results: small-target tritanopia. There are fewer blue cones in the fovea of the retina than red or green, so for very small objects the fovea has a limited blue sensitivity.

Freiding et al. (2007) explain that the ability to detect a target at night without necessarily being able to identify its color is referred to as *achromatic threshold detection*. Detecting a target or potential hazard is the first step toward taking an appropriate driving action to avoid it. Results by Freiding et al. indicate that detection threshold for color in the periphery increased as the luminance in the mesopic region decreased. Also, the blue targets had a smaller contrast threshold than the red and green targets for all background luminances used in the study (0.01, 0.1, and 1 cd/m^2). This means the blue targets were more easily identifiable. These results are expected in respect to the spectral sensitivity to shorter wavelengths present as the background luminance is reduced. Szalmas (2006) adds that the shorter reaction time to blue could be caused by the spectral sensitivity of rods. Another explanation proposed by Szalmas for the higher mesopic luminance only, compared to that of red or green, might be the greater visual "conspicuity" of blue light. When the equivalent brightness formula is applied to achieve equal luminance for each of the three colors (green, red, and blue), the difference in reaction times between blue and either green or red become smaller.

The effect of light sources on the color targets to be used in this study has been evaluated. The impacts of the light sources on the visibility of the targets were used as a covariate and can be found in the discussion section.

Age Effects

Age is an important factor in nighttime driving and mesopic vision. Older drivers (55+) make up nearly one-fourth of all fatal crash victims and nearly one-fourth of all drivers involved in a fatal crash (National Highway Traffic Safety Administration, 2007). Horswill et al. (2008) found a correlation between age and hazard perception response time, as older drivers responded more slowly to traffic conflicts. The contrast sensitivity variable had the most significant impact on hazard perceptions because several of the participants had bad cataracts. Horswill et al. also found that the useful field of view was crucial for hazard perception, as any reduction of vision within the useful field of view makes traffic conflicts more difficult to detect. A separate study (Owens, Wood, and Owens, 2007) used foam roadway objects to represent hazards. The study showed that elderly participants were surprised by the foam objects regardless of the lighting level while the two younger age groups identified the objects and avoided them. They hypothesize that the age-related decrease in target detection is likely due to the diminished visual systems in older drivers, including contrast sensitivity.

As the eye ages, changes occur in the optical density (OD) of the crystalline lens. When this occurs, the lens alters the wavelengths of light entering it. With age, the lens becomes more yellow, which effects the perception of hue and contrast (Bierne, 2008). This could cause an older driver preference for the yellow hue of a ~3500K color temperature as opposed to the blue hue of ~6000K.

The ability of older drivers to respond to the presence of roadside pedestrians at night is considerably weaker than that of younger drivers. In Wood's (2005) study, older drivers detected and recognized only 59% of pedestrians whereas younger drivers recognized 94% of pedestrians. Older drivers also recognized pedestrians much later than did the younger drivers.

Owens and Tyrell (1999) found that steering accuracy for older drivers in low-luminance settings was poorer than that of younger drivers. However, Owens et al. (2007) found that older drivers tended to drive more cautiously in a low-luminance setting than did the younger drivers.

Comparing Light Sources

Color temperature describes the color of a radiating source at a particular temperature. The temperature does not relate to the heat radiating from the source but instead is the absolute temperature of a blackbody radiator having a color equal to that of the light source. Correlated color temperature (CCT) is the absolute temperature of a blackbody whose color most nearly resembles that of the light source, in the case of this study, the two LED's. Color temperature is often used to define the color performance of a light source. This may not always be effective because the same color temperature can be reached by a variety of spectral output characteristics (IESNA Lighting Handbook, 2000).

The light source has shown to have a significant impact on visual performance. In a laboratory trial, Rea (1996) compared HPS light sources and metal halide (MH) sources, each at two luminance levels (0.1 and 1.0 cd/m^2). Participants completed a discrimination task with these two light sources. HPS and MH lamps lit opposite portions of an isolated roadway. Participants were asked which end of the street appeared brighter and which end they would feel safer walking along at night. The participants perceived the MH lamps to be much brighter and safer for walking along at night. The study suggests that white light, in this case produced by the MH lamps, appear brighter than the light from the HPS lamps of the same luminance (Rea, 2009).

Three studies (Fotios and Cheal, 2007; Boyce and Bruno, 1999; and Chen, 1998) suggest that color recognition is greater for white light sources than for HPS or yellow, light sources. The lamp type (white or HPS) and the amount of luminance affected color recognition. Two of the three studies suggest that the color rendering for a white light source with a luminance of 0.1 cd/m^2 is almost equal to or better than the color rendering for an HPS source with a luminance of 1.0 cd/m^2, a ten-times greater luminance (CIE, 1999).

A nighttime driving study by Rea et al. (1997) found that reaction times to off-axis targets were shorter under a MH lamp than under an HPS lamp. Ratings of overall visibility and peripheral reaction times were also greater under the MH illumination.

A study by Akashi et al. (2007) used off-axis targets and found that MH light sources were responsible for shorter reaction times versus HPS lamps of the same photopic light levels. This study also demonstrated that task performance improves with unified luminance. In addition, under unified luminance, objects on and off axis could be detected much more quickly without increasing energy requirements. Akashi et al. also point out that an increased peripheral view may not be appreciated by drivers and may not change their driving behaviors.

Light sources that improve mesopic visual ranges, like those that produce white light, may also have negative consequences, such as increased glare in fog and snow conditions (Bullough and Rea, 2001). Also, because white light increases luminance on the immediate roadway as well as in the periphery, falling snow could be a possible distraction to the driver.

The IESNA Lighting Handbook (2000) states that the color rendering properties of lamps, for example between a low-pressure sodium lamp and a yellow fluorescent lamp, will be much different compared to daylight. Under sodium lamps, objects will lose their daylight appearance and appear as one hue. Under the yellow fluorescent lamp, more hues can be recognized, but the colors will still differ considerably from those seen in daylight alone.

It is important to note that the studies described here typically have a limited assessment of the impact of color on performance.

EXPERIMENTAL METHODOLY

Experimental Design

A 2x2x2x2 mixed factors experiment was used to investigate the relationship of color contrast to object detection and recognition in the roadway environment. The factors are shown in Table 2.

Table 2. Experimental design.

Variable	**Levels**
Age (between-subjects)	younger, older
Lighting (within-subjects)	LED (3500 and 6000 K)
object/color (within-subjects)	targets (red, green, blue, gray), pedestrians (blue clothed, black clothed)
lighting level (within-subjects)	12 lux, 6 lux vertical

Independent Variables

As shown in the experimental design, this study included many variables. Independent variables included age, light level, object, object color, and lighting type. There were two age groups, younger (25-34 years) and older (55 years and up). The vertical illuminance on the object of interest was the basis for determining the two light levels chosen: 12 lux and 6 lux. Objects, as will be discussed later, were pedestrians and square, wooden targets. Lighting type comprises the two lighting systems tested in the study: the 3500 K LED and the 6000 K LED (Figure 1).

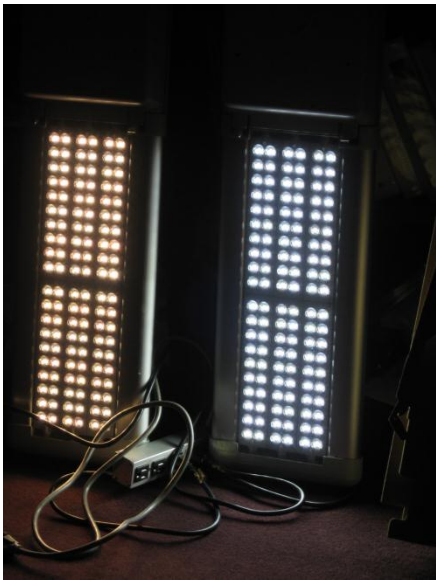

Figure 1: 3500 K (left) and 6000 K (right)

The color temperatures (3500 and 6000) are highlighted in Figure 2 on the color spectrum diagram. The Planckian curve is shown here with the correlated color temperatures (CCT) marked. The 6000K is in the white-blue region of the spectrum, 3500K is in the white-yellow region of the spectrum, and a typical HPS lamp would appear in the deeper-yellow region at approximately 2500K.

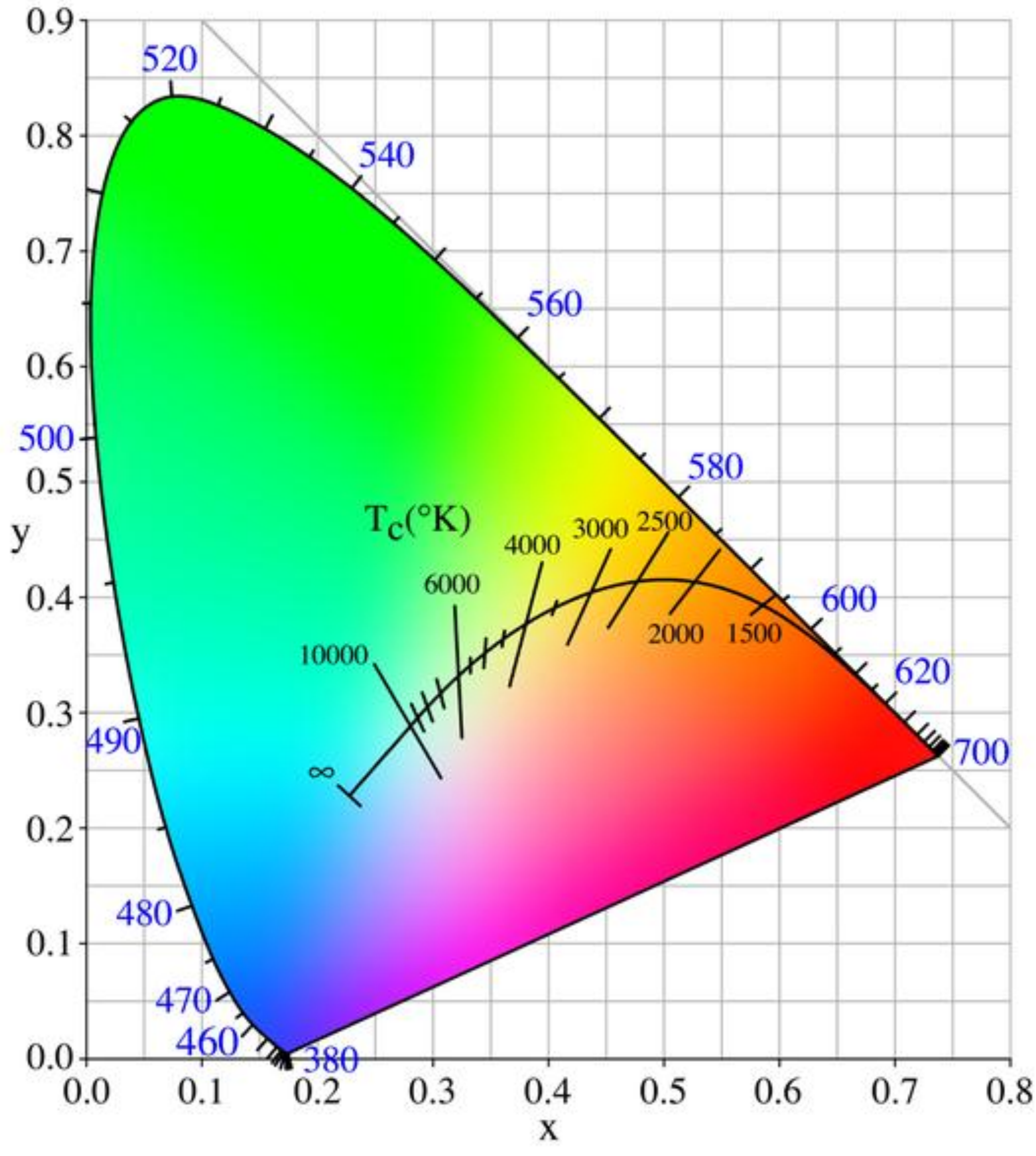

Figure 2: XY Chromatic Diagram (CIE, 2010)

It is important to note that during this study, a 4200 K Fluorescent light source was also tested among the same participants however results from that light source are outside of the scope of this LED comparison.

Dependent Variables

This experiment used two dependent variables: the initial detection of the object placed along the roadway and the point where the object's color is recognized.

This study operationally defines detection distance as the distance between the onset of verbal detection and physically passing the object in the vehicle. Detection distance is an important factor in determining an object's visibility. Logically, if a participant can see an object, then it is visible. The distances at which a participant can see objects correspond to the objects' visibility at those distances.

This study defines detection distance and recognition distance the same way, with recognition distance being related to color. After the participant detects the object, they then recognize its color and state it aloud. The recognition distance is the distance between the point of recognition and the physical passing of the object.

Experimental Equipment and Setup

This experiment required a variety of equipment and vehicles, including the visual targets, the test track, and the measurement systems.

Smart Road Testing Facility

The research was conducted at the Virginia Tech Transportation Institute's Smart Road. The Smart Road is a 2.2-mile test track with guard rails and pavement markings. Dispatchers control entry to the facility. The Smart Road has one intersection with a signal, which was not used for this study. The Smart Road also has three bridges. No tasks or events related to the study occurred on or near the bridges.

Figure 3 illustrates the Smart Road test track. The blue numbers indicate the stations along the road where targets and pedestrians were placed. There were four stations (1, 2, 5, & 6) placed under the luminaires and three stations (3, 4, & 7) placed in the dark. Data obtained from the dark sections of the road were not analyzed for the LED comparison. The events on unlit areas of the road served to maintain driver attention throughout the course of the study.

The orange section of the road is the lighting test bed containing the LED and fluorescent lights. Twelve luminaires spanned the three-quarter of a mile lighting test bed. The Smart Road has five turnarounds, one on each end and three in the middle. This study used four of the five by omitting Turnaround 1.

Both experimental vehicles began in Turn 2. The first vehicle drove to the bottom turnaround and back to Turn 2 for one lap. The second vehicle remained in Turn 2 until the first vehicle was out of sight. Once out of sight, the second vehicle traveled to Turn 3 where it then traveled back up the road toward the top turnaround. One lap for the second vehicle was completed once that vehicle passed Turn 2. By doing this, both vehicles experienced the same conditions on the lighted portion of the road without passing each other or being visible to the other.

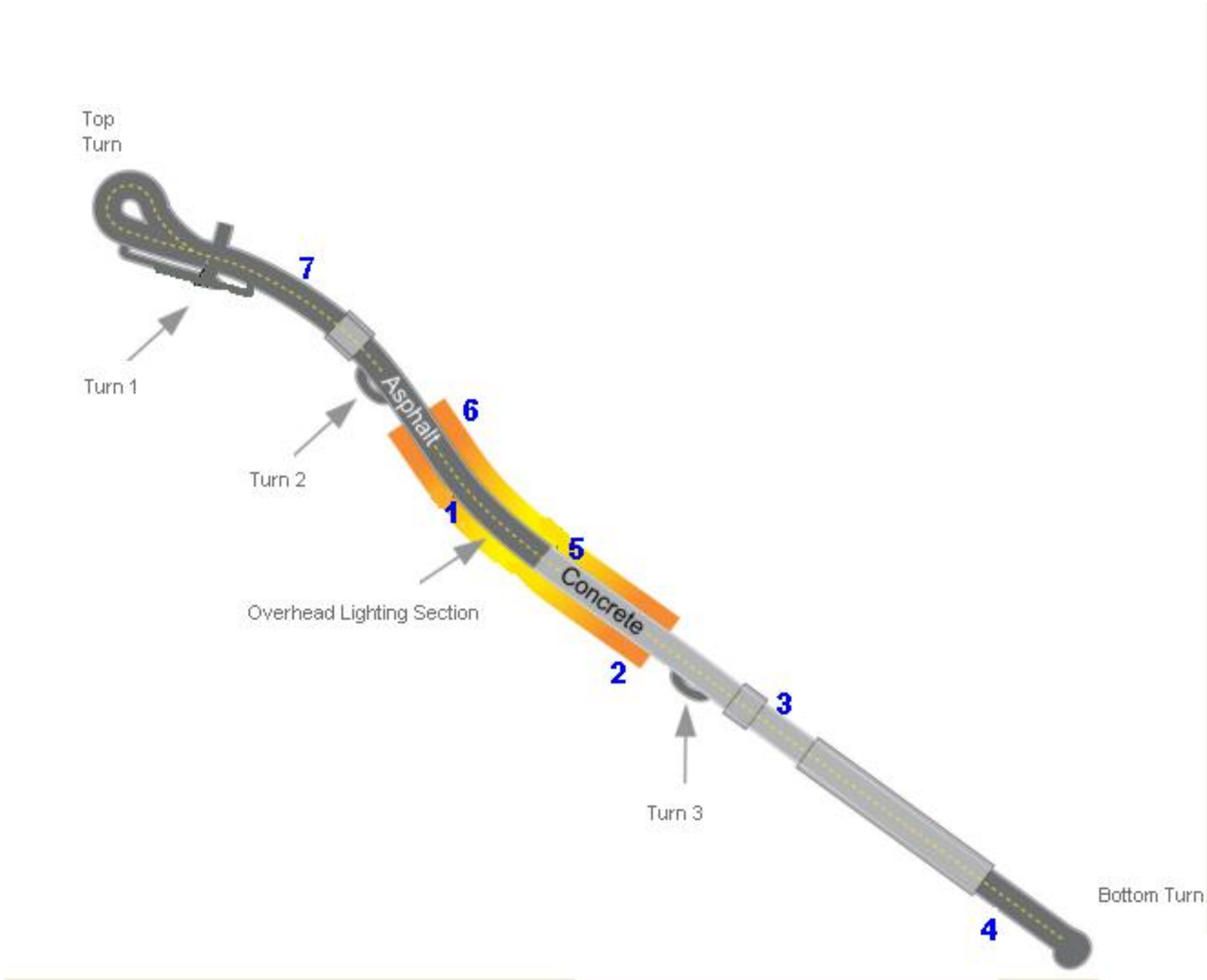

Figure 3: Smart Road Test Track

The lighting system on the Smart Road used for this testing was spectrally measured using an Ocean Optics S2000 spectroradiometer. Figure 4 presents the results.

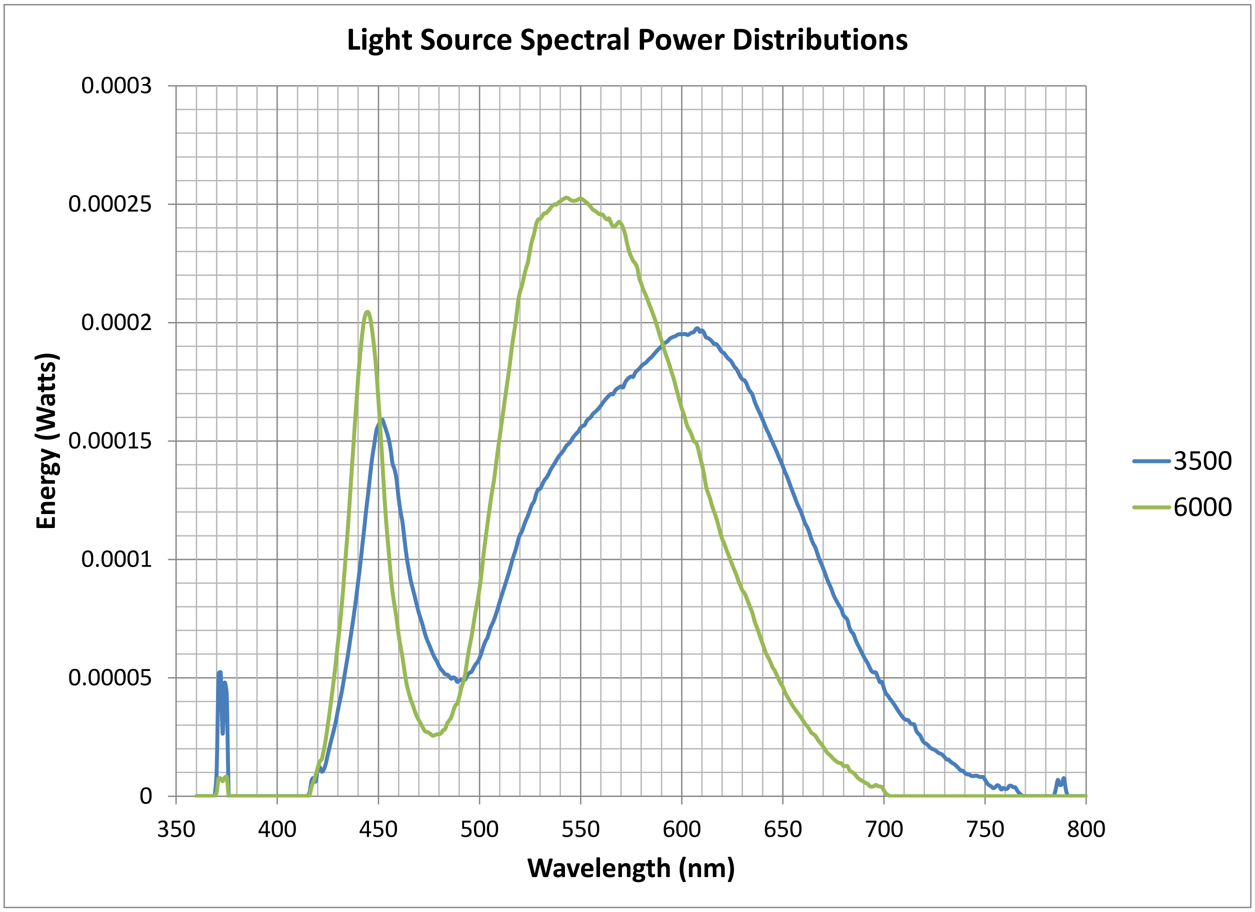

Figure 4: Spectral Power Distributions of the Test Lighting Systems

Pedestrians and Targets

The roadside objects for participant detection were pedestrians and painted wooden targets. Vehicles striking pedestrians at night is an obvious concern. Pedestrians in the study wore all-denim scrubs, because denim is a commonly worn type and color of clothing, or all-black scrubs to represent a worst-case scenario for a pedestrian at night. The pedestrians stood on the right side (outside) of the shoulder line on the roadway and remained static as the experimenting vehicles passed.

The wooden targets measured 18 cm by 18 cm. Many roadway obstacles fall within this size range. As Figure 5 shows, each target was uniform in color and had a flat face, which facilitated gathering luminance data from the targets. Determining the contrast of an obscurely shaped object, like a pedestrian who is not always consistent, is much more difficult than with a flat, smooth surface like the wooden targets. The four colors for the targets—gray, blue, green, and red—were chosen based on their contrast to the roadway and the color sensitivity present with the two different light sources. Gray is a neutral color while green, blue, and red are additive primaries.

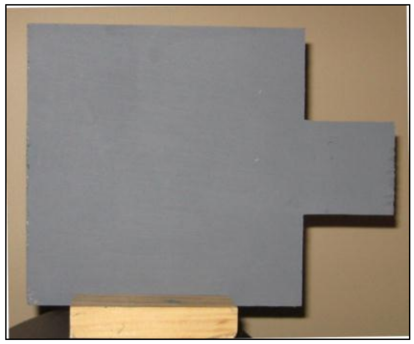

Figure 5: Targets

The wooden targets were designed to break on impact if a participant mistakenly ran them over. They were placed two feet outside the right-hand white edge line on the roadway, upright, facing oncoming vehicles. The targets were presented at locations of equal illuminance for both light sources (6 and 12 lux). The participants were asked to drive toward the targets and identify 1) the presence of a target and 2) the color of the target. Once the participant identified the target the in-vehicle experimenter pressed a button to record within the data stream when the identification was made. A button press was also recorded when the color of the target was identified by the participant. A third button press was recorded when the participant vehicle passed the object. These button presses were used to generate algorithms that measured the distance of detection from the actual target. In-vehicle experimenters kept notes to decipher the button presses if they did not follow the order of identification and recognition. Each video file for every participant was also reviewed during data analysis to more precisely determine the moment of identification, recognition, and passing of the object.

Figure 6 depicts a red off-axis target though only gray targets were used on off-axis. These targets were placed just beyond the right guardrail to represent objects that were potential hazards instead of immediate ones. These objects were placed to appear in the peripheral vision of the driver to assess how the two LED lighting systems and the fluorescent system affected ambient detection. The targets were mounted on tripods so that drivers could see them over the guardrail and still recognize their shape. The silver legs of the tripod were covered in a black plastic bag so that they would cast no reflection that might give away the target's presence and location.

Figure 6: Off-Axis Target

It is important to note that these targets adhere to Adrian's (1989) small target visibility (STV) model. The off-axis targets were larger than 18 cm square to maintain object size based on the increased distance and altered visual angle from the standard on-road targets. The off-axis targets were 30 cm square. The model suggests that the ability to detect a standard small target (~18 cm square) propped vertically on the road is a quality measure for assessing the visibility made available by a particular roadway lighting system. The visibility level (VL) is computed as the ratio of the contrast between the target and its background and the detection threshold. The greater the VL, the more visible the target (Mayeur, 2008).

The target reflectance was measured spectrally using the same Ocean Optics S2000 spectroradiometer. The spectral reflectance of each target is shown in Figure 7. Note that the yellow target was not used in this investigation made prior to this current study.

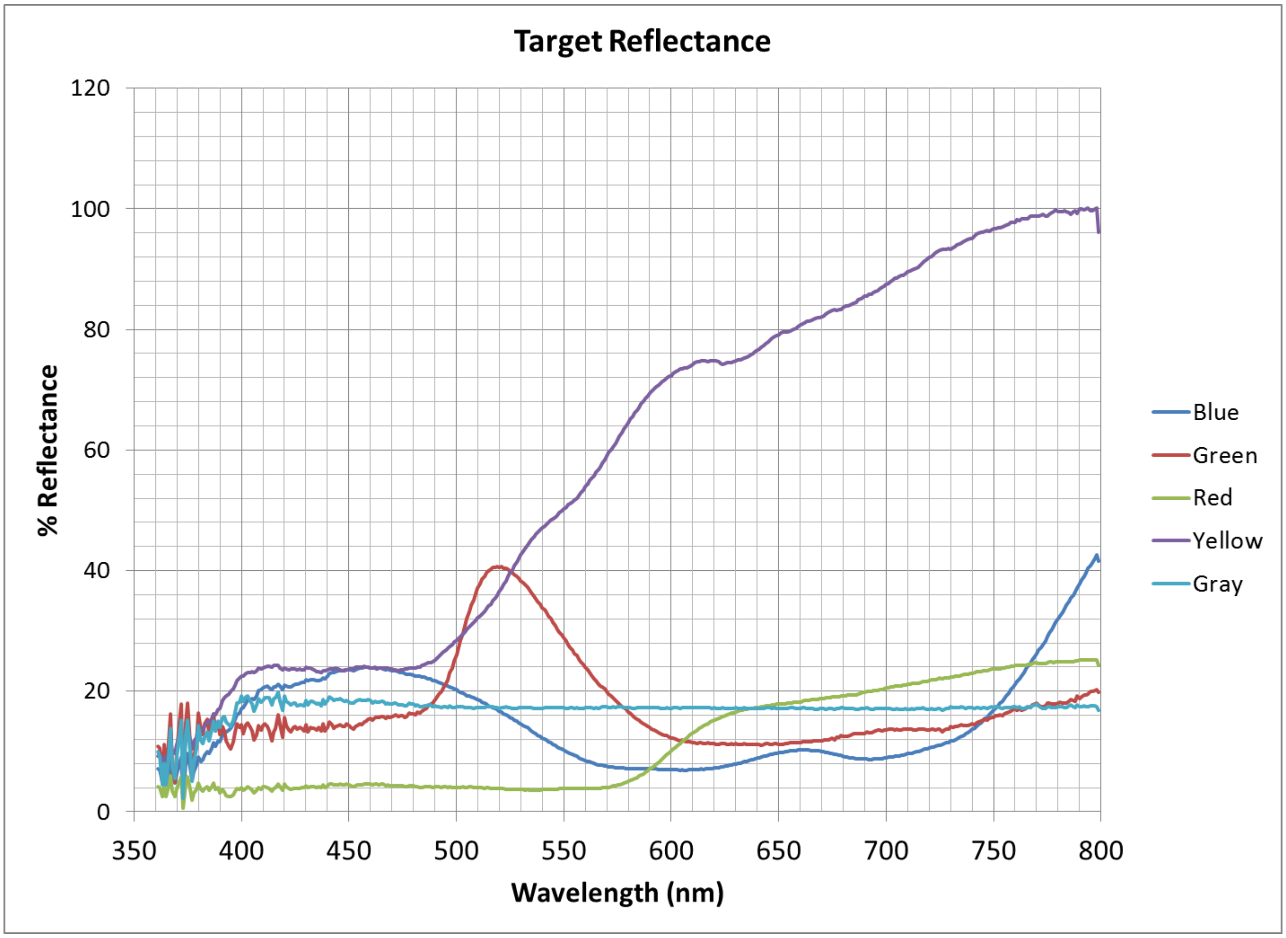

Figure 7: Target Spectral Reflectance

Figure 8 shows the location of each of these targets in the CIE color diagram. This figure shows the targets as a reference reflectance and the target colors as they would appear under each of the light sources. Here, the target color is indicated by the marker color, and the color temperature of the light source is indicated by the marker shape. It is noteworthy that the color appearance of the red target is relatively unchanged by the light source with the exception of the 6000-K LED. The gray target remains relatively close to the Planckian locus and would remain generally spectrally neutral. The blue target is pulled to the spectrum locus under the 6000-K LED light source but retains a blue appearance under the other light sources.

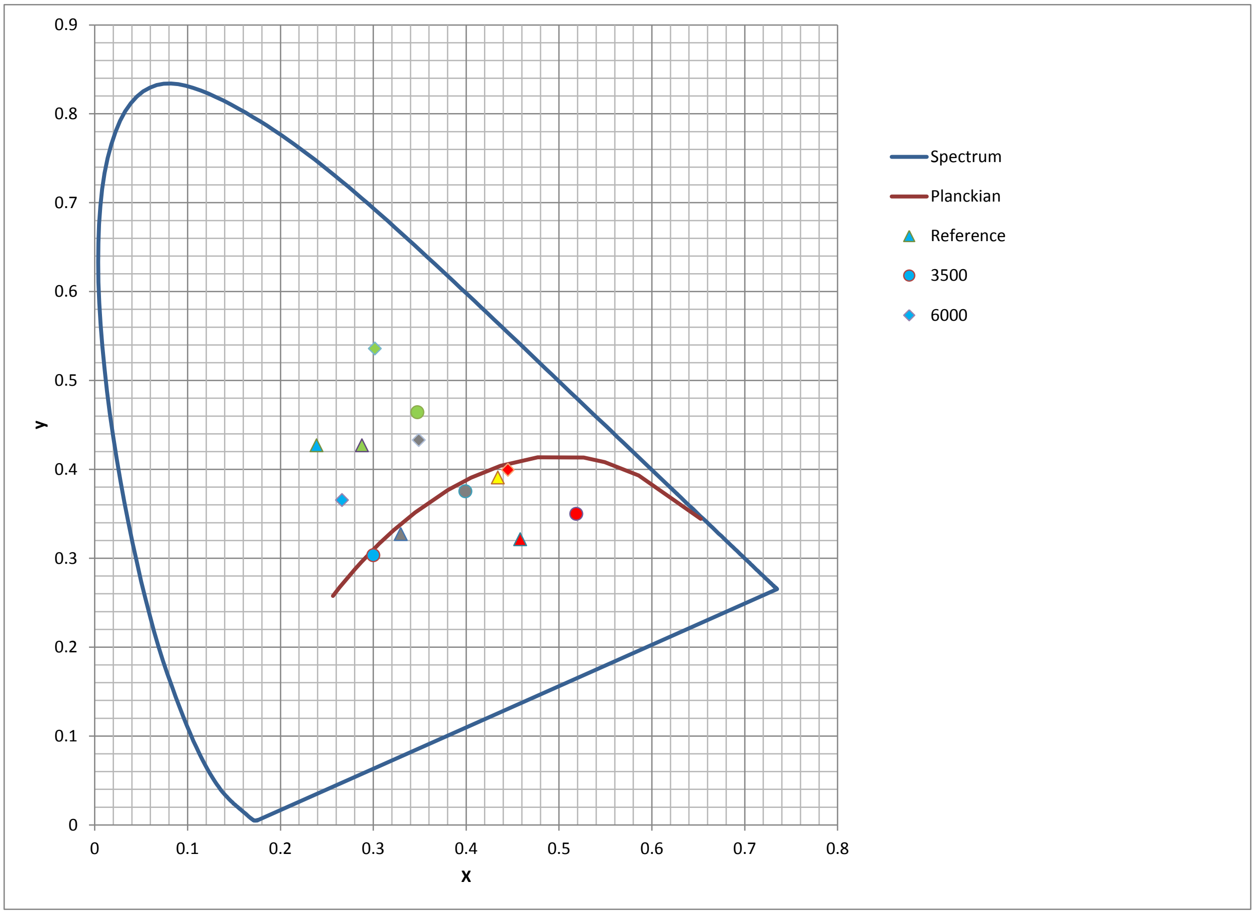

Figure 8: CIE Diagram with Target Colors Highlighted

Vehicles

Figure 9 shows one of the vehicles used for the study: two SUVs (a 1999 Ford Explorer and a 2000 Ford Explorer) instrumented for data collection. The data collection equipment includes digital audio and video recorders, luminance and eye-tracking cameras, small monitors, and keyboards.

Figure 9: Ford Explorer

The headlamps of both vehicles had been characterized for their spectral and luminance contribution to objects along the roadway. The headlamps for both were aligned prior to the study to control the angle of light coming from the vehicles. Each vehicle was equipped with a color camera and a luminance camera mounted to the windshield to record luminance data throughout the length of the study (Figure 10). For every target and pedestrian detection, the luminance and color data are captured from the time the in-vehicle experimenter presses the button. The cameras had undergone a successful calibration with a relatively high level of accuracy based on comparisons to other known luminance values. The calibration study for the luminance camera was conducted at the Virginia Tech Transportation Institute (VTTI) in 2009 and has been published by The National Surface Transportation Safety Center for Excellence (Meyer, Gibbons, and Edwards, 2009).

Figure 10: Luminance and Color Cameras

Participants

The forty participants were selected from the VTTI subject database on the basis of age. Of the forty participants ran in the study, thirty-five participants were kept for data analysis due to equipment malfunctions, inability to properly follow protocol, or in one case, excessive fog. Seventeen participants between the ages of 25 and 34 years made up the younger participant group and eighteen participants 55 years and older made up the older participant group. Because contrast sensitivity diminishes with age (Owens, Wood, and Owens, 2007), it was important to compare the two age groups' ability to detect objects under each lighting condition. The populations chosen for this research study reflect different driver characteristics, including visual and physiological characteristics. For example, older drivers benefit from their driving experience. However, visual and physiological changes may occur with age, which may result in different amounts of discomfort and disability glare. Younger drivers more often have normal vision. However, they may react to glare sources in a different manner.

Screening criteria for participant selection included:

1) Must hold a valid driver's license.
2) Must not have more than two moving violations in the past three years.
3) Must have normal (or corrected to normal) vision.
4) Must be able to drive an automatic transmission vehicle without assistive devices.
5) Must not have caused an injurious accident in the past three years.
6) Females must not be pregnant.
7) Must not have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Must not have had epileptic seizures within 12 months. Must not have current respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, or chronic migraine or tension headaches.
8) Must not currently be taking any substances that may interfere with driving ability, cause drowsiness, or impair motor abilities.
9) Must be eligible for employment in the United States.
10) Must drive at night at least two times per week.
11) Must not have had eye surgery.

Participants were compensated $20 for every hour they participated in the study, including time spent filling out questionnaires and being greeted. Participants were also awarded a $30 bonus for completing all three nights of the study. The telephone screening script for this study can be located in Appendix A – Telephone Screening. Informed consent forms can be found in Appendix B-1: Eye Tracking Informed Consent and Appendix B-2: Informed Consent (Non Eye-Tracking Participants). Note that an eye tracker was used for half of the participants. This data was recorded but not used as part of this investigation.

The two age groups were chosen on the basis of driving experience and age characteristics that can affect vision. The younger participants (25-34) typically had similar driving experience, drove frequently at night, and did not usually have a notable yellowing of their lenses. The older participants (55 and up) had much more driving experience, may still have driven a substantial amount at night, and had a greater likelihood of lens discoloration. Figure 11 (Coren and Gurgis, 1972) shows how the yellowing of the lens starts at birth and becomes more rapid around ages 45-50 years. Based on this chart, the older age group was anticipated to have more difficulty detecting contrast than the younger age group due to changing optical density with age.

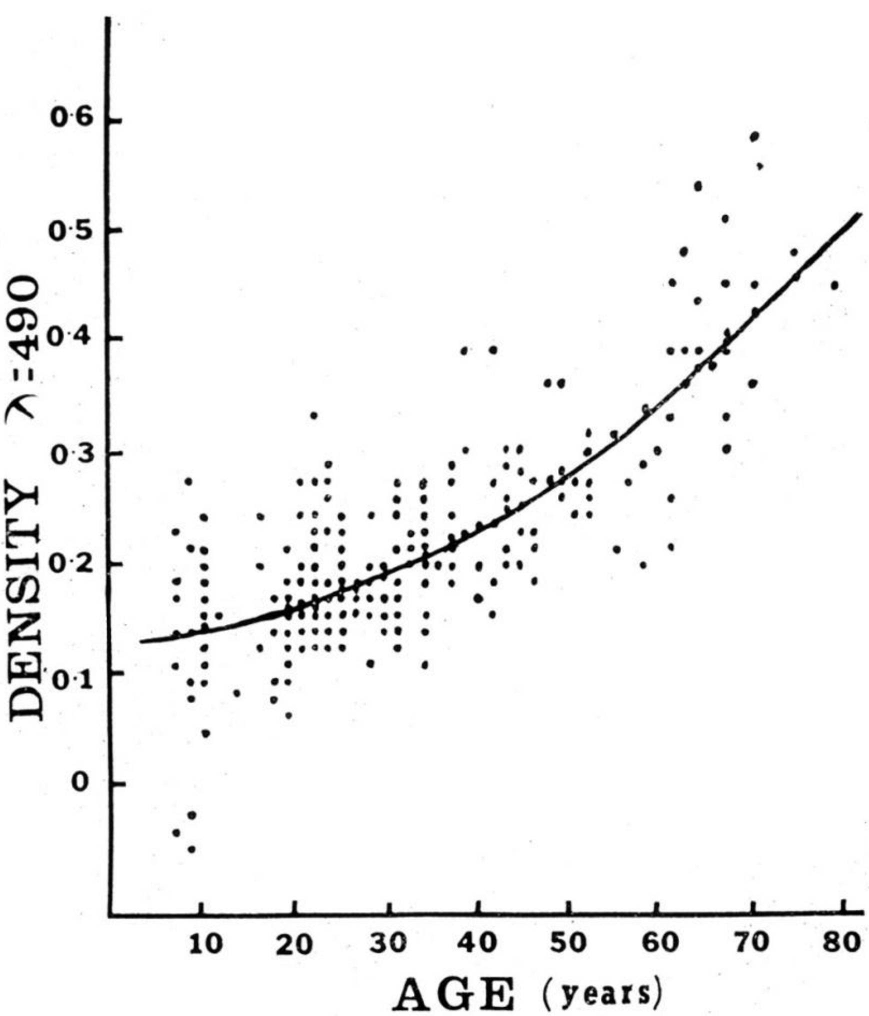

Figure 11: Yellowing of the Human Lens with Age (Coren and Girgus, 1972)

Experimental Methods

Participant Orientation

Once the participants arrived at VTTI, they were taken into a conference room to be briefed and screened. The in-vehicle experimenter recorded the time the participant arrived on the participant's receipt and asked to see the participant's driver's license to verify its validity.

The participant was then asked to carefully read and sign the appropriate informed consent form (Appendix B-1 and Appendix B-2). The eye-tracking participant had a separate informed consent form. Once the participant had read and signed the informed consent form, the participant was asked to complete a W-9 tax form (Appendix C: W-9 Tax Form) as well as a brief medical questionnaire (Appendix D: Pre-Drive Health Screening). Once these were completed, the participant was ready to begin the vision tests.

Pre-Drive Vision Tests

Snellen

The first vision test given to participants after the completion of their paperwork was the Snellen. Using both eyes, participants were required to read the smallest line of print they could on the Snellen chart. This vision test is the only test that could disqualify a participant from the study. All participants were required to score a 20/40 or better with both eyes at once. The Snellen eye chart exam is the most commonly used form of testing for obtaining a driver's license in the United States (Osgood, 1982).

Color Vision

The color vision test was given using an Ishihara Color Vision Exam. The participants were asked to identify the numbers on each of seven slides. The researchers were interested to see how participants with poor color vision would fare during the driving study; perhaps one light would make a clear difference in their abilities to identify the colors of the targets and pedestrians. No one failed the color vision test.

Brightness Acuity Test

Although glare was not a construct built into the study, participants were tested using a Brightness Acuity Tester (BAT) to determine their sensitivity to glare. The BAT is a handheld device that a participant places over one eye while covering the other. A light inside the eyepiece adjusts the amount of glare directed toward the lens of the eye. While doing this, participants were asked to read lines from the Snellen eye chart, and their scores were recorded for each eye. Participants could not be disqualified based on this exam, but the data from the exams were recorded to examine possible correlations between the two light sources.

Participants were not screened on the basis of transition or photochromic lenses because these lenses have almost no effect on night driving. Photochromic lenses require ultraviolet radiation to initiate a dark transition and very little UV permeates through automobile windshields (Lewis, personal communication, May 19, 2011).

Figure 12: Brightness Acuity Tester (BAT)

Contrast Sensitivity

This test was particularly important to the study itself because contrast sensitivity plays a major role in the differentiation between objects and their backgrounds. The test itself is a chart with various contrast ratios between grated lines.

Figure 13: Contrast Sensitivity Chart

The lines are more pronounced for the top rows and more detailed for the bottom. Participants were asked to look across each row and identify the orientation of the lines in each circle until the lines disappeared. The lines slant left or right or are completely vertical. The participants completed the test for each eye while covering the other.

Vehicle Familiarization and Practice Run

The participant was shown to the experimental vehicle by the in-vehicle experimenter. The experimenter demonstrated to the driver how to correctly adjust the seat, steering wheel, and mirrors. The side mirrors in the study were covered with a felt cloth to prevent the driver from being distracted by potential headlamp glare from the other participant vehicle. The rearview mirror remained uncovered, and the participant could adjust it. The experimenter also gave instructions on how to operate the headlamps and other dashboard operations. It was important to make all these adjustments so that the driver was in a normal, comfortable position prior to the movement of the vehicle.

Once the eye-tracker was calibrated for the eye-tracking participant (Appendix N: Eye Tracker Protocol), the in-vehicle experimenters instructed both participants to enter the Smart Road. (It is important to note that the eye-tracking data was not utilized in the analyses for this thesis.) Upon entering the Smart Road, the participants were told to drive to a turnaround point near the middle of the Smart Road known as "Turnaround 2". Once both vehicles arrived there and the on-road experimenters verified that the road was clear, the participants began a practice lap on the section of the road where they would soon perform four test laps. The purpose of this practice lap was to familiarize the participants with the upcoming experimental tasks, remind them of the speed limit (40 mph), and make them more comfortable with the vehicle. Once the practice lap and four test laps were completed, both vehicles returned to turnaround 2 for a brief questionnaire. Scripts for beginning the practice laps and roadway tasks can be found in Appendix J: In-Vehicle Experimenter Scripts.

Two participants partook in the study simultaneously but were at opposite ends of the road (top and bottom). Both participant vehicles used Turn 2 as a starting point. The first vehicle departed from Turn 2 and traveled to the bottom turn and returned to Turn 2 for a single lap. The second vehicle departed Turn 2 shortly after the first vehicle and in the same direction except turned at Turn 3 and travelled to the Top Turn and back down. Once the second vehicle passed Turn 2 on their way toward Turn 3 they had completed a lap. For every lap, both participants saw the same targets and pedestrians placed in the lit portion of the road, as this part of the road was shared. The unlit portions of the road were different in terms of number of targets and pedestrians however the colors of these objects were counterbalanced. The participants were also counterbalanced for what end of the course they drove (top or bottom) and the order they drove them in. The participant vehicles never approached each other throughout the experimental session.

When participants returned to VTTI on subsequent nights for the other light sources, the same protocol was followed for entering the road and completing the practice lap and four test laps. On the second night, once participants returned to the building, they were administered the "Night Two" questionnaire, which asked them to compare the lighting of the current night to the lighting from their previous visit. These questionnaires can be found in appendices E, F, and G. The third visit was similar. Participants were administered a questionnaire that asked them to compare the lights from all three visits. Each questionnaire also asked the participant to rate their own abilities to accurately remember the previous visits. Those with limited confidence had their questionnaires omitted from data analysis.

It is important to note that although participants received questionnaires concerning the fluorescent lamp, the data for this lamp were not considered in data analysis for this thesis which compares only the two LED lighting systems.

Data Collection

The participants drove four test laps that consisted of one lighting condition each night (6000 K LED, 3500 K LED, or fluorescent). The subsequent nights included a different lighting scenario under the same protocol so that each participant received each type of lighting type paired with each scenario. Light presentation order was counterbalanced. Participants were asked to verbally identify targets, target color, pedestrians, and pedestrian clothing color as they drove with the in-vehicle experimenter pressing the button that triggered the data recorder. Upon completion of the four test laps, both vehicles met in turnaround 2, and the participants were administered a Post-Scenario Questionnaire (Appendix E: Post-Scenario Questionnaire). The same protocol was followed for the second and third nights for every participant. Protocols for the in-vehicle experimenter during Smart Road tasks can be found in Appendix I: Research Protocol.

Experimental Procedure

As participants drove up and down the Smart Road, they passed a certain number of the seven stations located alongside the road depending on which end of the course they drove. Confederate experimenters were at each station to either place a target or pose as a pedestrian. The confederates had order sheets that instructed what object and color they were to present for each lap. The orders were counterbalanced across all three light sources so that on subsequent nights, participants were less likely to expect a particular object or color at certain spots of the course. Experimenters also attempted to alternate each participant's end-of-the-road course (top or bottom) on each night.

Using a computer in the passenger's seat of the vehicle, the in-vehicle experimenter pressed a button as the participant verbalized an identification to flag the instance in the data to be reviewed later. After verbal color recognition, the participant would again press the button to flag the instance. As the vehicle passed the object, specifically when the object was parallel to the passenger, the experimenter pressed the space bar to advance the program to the next object.

Speed and the time between button presses determined the detection distance between verbal recognition and the object.

Questionnaires

Once the laps and the post-task questionnaires were completed, both vehicles returned to VTTI. The participants were allowed to use the restroom. On the second and third nights, they were then administered different questionnaires (Appendix F: Post-Drive Questionnaire (Night Two) and

Appendix G: Post-Drive Questionnaire (Third Night)), which were more comprehensive questionnaires of the entire study. Once these were completed, the participant's end-time was logged, and the participant was paid based on their time engaged in the study. The protocol for payment and shutting down the study for the night is located in Appendix K: Payment and Shutdown. Participants who completed all three nights received a $30 bonus, which had been explained to them in their recruitment.

DATA ANALYSIS

The data analysis was performed in series of steps: video reduction to determine the detection and color recognition distances, a luminance analysis, and the statistical analysis.

Video Reduction

VTTI uses in-house software, Data Analysis Reduction Tool (DART), to reduce videos taken from experimental vehicles. This tool is specific to the data collected in the vehicle and records several variables, including speed, object distance, time, and when an experimenter flagged a participant's identification of an object and its color.

Reducing a video with this software tool requires aligning the frame number of the video to the data and observing the video for when the experimenter pressed a button to flag an event. These instances are made obvious in the data. The reducer watches this segment of video to more precisely determine the point of identification and the point that the object was passed by the vehicle. The difference between the point of detection and the point where the vehicle passed the object was used as the detection distance. Similarly, the point of proper color recognition and passing point were used to calculate the recognition distance.

Target Luminance Analysis

The contrast and luminance of the targets and pedestrians were assessed using a program created in MATLAB® for luminance as part of a National Surface Transportation Safety Center of Excellence (NSTSCE) endeavor. This reduction used the still images taken by the luminance cameras mounted on the windshield of the vehicle and tracing the target image at the frame number associated with the detection or recognition. Once the image was traced, the reductionist verified the image's validity and the program calculated the luminance of the target object, and thus the contrast of the image as well using the surrounding elements outside of the trace.

The program was created to utilize a number of different contrast metrics, including CIE95, Michelson, IESNA, RSS, PSS, and Doyle. This project did not use these metrics, but additional information about them can be found in Meyer, Gibbons, and Edwards (in press). This study, as well as most other studies that use the program, use the Weber contrast metric, which is the comparison of a target of uniform luminance to its background of uniform luminance. This metric incorporates negative contrast, which many other metrics do not. The ones that do not use negative contrast instead convert the negative values into absolute values. The Weber metric was selected because true negative contrast is important in this study.

The equation below is used to calculate Weber contrast.

Equation 1: Weber Contrast

$$Weber\ contrast = \frac{\Delta L}{L_{bkg}}$$

Where:

ΔL = Luminance of a target – Luminance of the background

L_{bkg} = Luminance of the background

After each cutout is assigned a luminance value for the target image and its surrounding elements, it is automatically uploaded to a database that places the contrast and luminance information on the same line as the object's identification and color recognition distances (Gibbons et al., in review).

Statistical Analysis

After DART was used to reduce the data from its raw state, a statistical program analyzed the findings. SAS Enterprise Guide 4.2® was used to design an analysis of variance (ANOVA) to determine the various effects of the treatment conditions. The ANOVAs were used based on lognormal transformations to adjust the data to normal (Appendix Y). The ANOVA highlighted the interactions that were found to be statistically significant regarding the varying combinations of object color, lighting level, lighting type, age, contrast, and detection and recognition distance. Separate ANOVAs were used for targets, pedestrians, off-axis targets, and off-axis pedestrians because each shared different traits, such as color, size, and viewing angle. Separate ANOVAs were also used to differentiate the significance of the object detection distance and the significance of the color recognition distance. Two ANCOVA's were used to assess the covariate relationship between target and pedestrian detection distance and luminance contrast using the Weber contrast metric.

The Student-Newman-Keuls (SNK) test was also useful for determining the levels of significance between each interaction. The SNK is a *post hoc* test used for finding patterns and relationships between subgroups.

RESULTS

The results are presented in terms of the significant interactions from the ANCOVA and ANOVA analyses. These results were investigated for both the detection of the wooden targets and pedestrians. The Weber contrast metric was used as a covariate in the ANCOVA with detection distance. Weber contrast was not used as a covariate with color recognition distance as it is strictly a luminance contrast metric.

The Main Effects

The results for the main effects tested in Research Question 1 are shown in Figure 14. The results for the two light types and the detection of targets were insignificant (*df=1, F Value=2.17 p=0.1572)*, however the 3500 K LED did have a greater average detection distance of nearly ten feet more than the 6000 K LED.

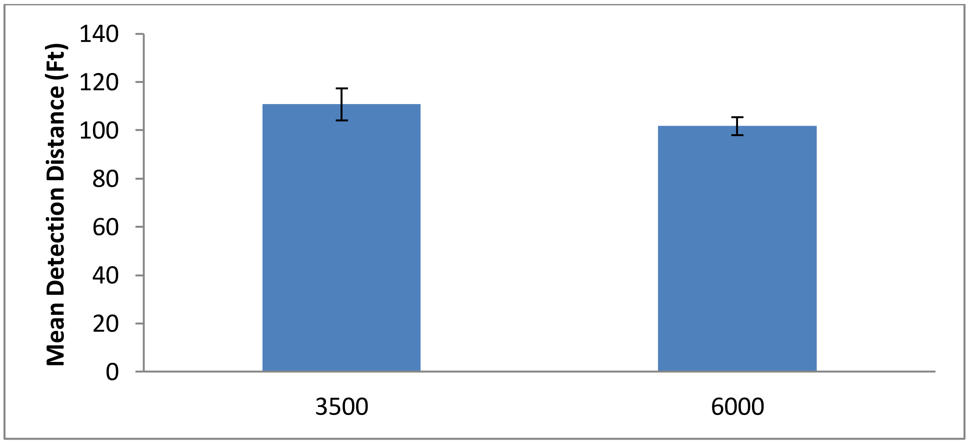

Figure 14: Average Target Detection Distance by Light Type

The results for the main effects tested in Research Question 2 are shown in Figure 15. The results for the two light types and the detection of pedestrians were deemed insignificant by the ANOVA. The post-hoc SNK test revealed a significant difference between the two isolated variables suggesting that factors such as speed variance, ambient lighting, driver attention, or gaze directions might have had an impact on the ANOVA results. The 6000 K LED did have a greater average detection distance than the 3500 K LED by approximately sixty feet.

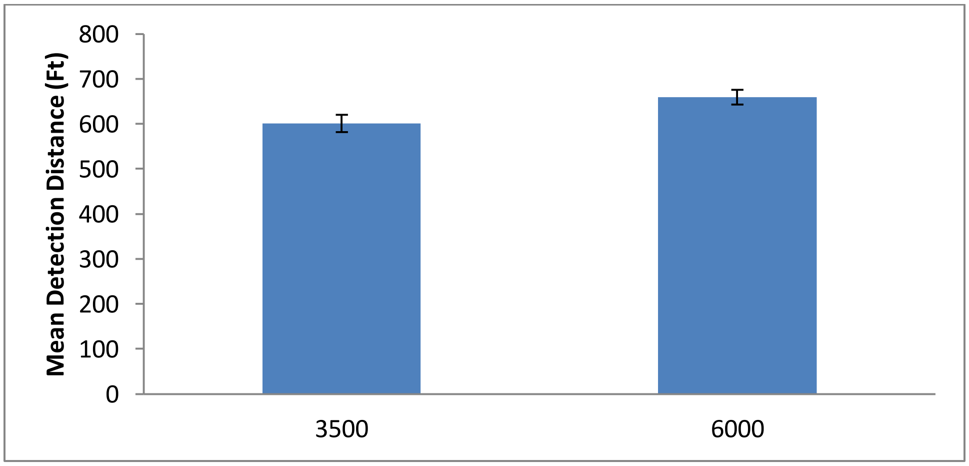

Figure 15: Average Pedestrian Detection Distance by Light Type

Figure 16 illustrates the results for the main effect for Research Question 3 of lighting and target color recognition distance. The difference between the two light types were insignificant (*df=1,* *F Value =0.48, p=0.4988)* however the 3500 K LED had an average of merely three feet greater than the 6000 K LED.

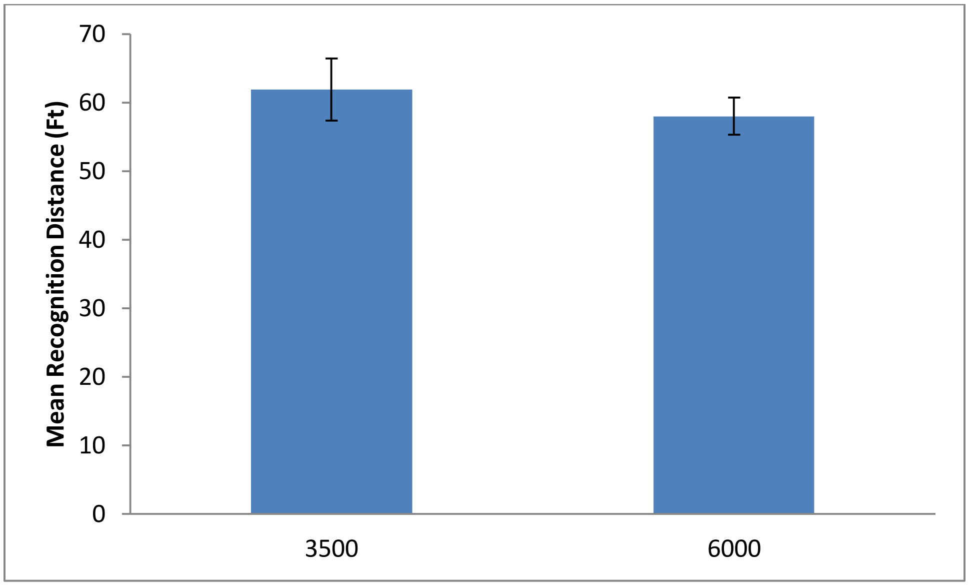

Figure 16: Target Color Recognition Distance by Light Type

Figure 17 illustrates the results for the main effect of Research Question 4 of lighting and pedestrian clothing color recognition distance. The ANOVA did not find the difference to be statistically significant (*df=1, F Value 2.53, p=0.1299).* The 6000 K LED outperformed the 3500 K LED in pedestrian clothing color discrimination by an average of approximately 125 feet.

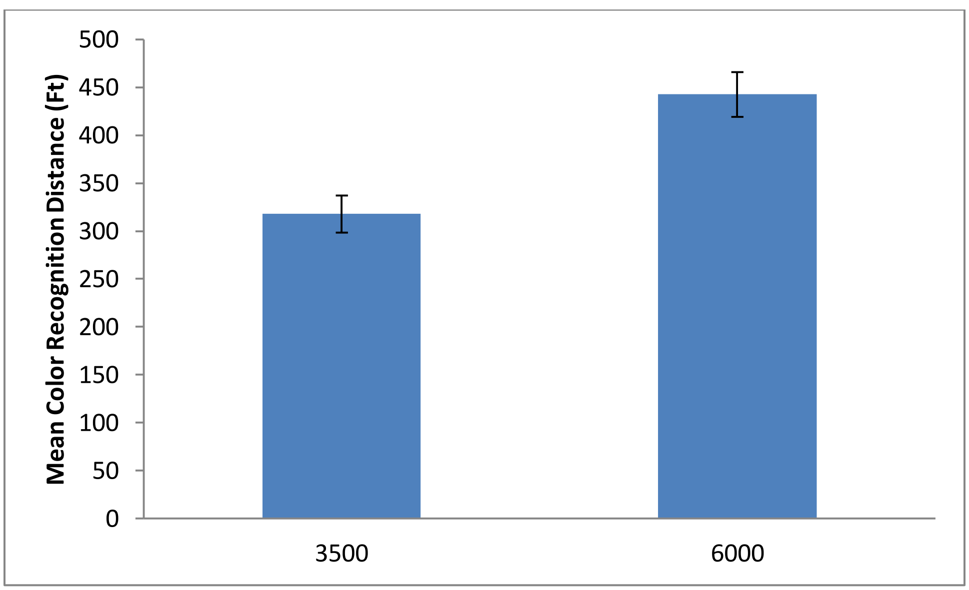

Figure 17: Pedestrian Clothing Color Recognition Distance by Light Type

ANCOVA with Weber Contrast

The results for the ANCOVA yielded only two significant p values. The object colors were significant when detection distance and Weber contrast were included in the ANCOVA as covariates.

A significance level of 95% (alpha=0.05) was used for each analysis of variance and covariance. Tables 3, 4, and 5 detail the findings for each analysis.

Table 3 shows the list of interactions highlighted by the ANCOVA analysis for the detection distance of targets and pedestrians. The results for object detections are presented below. In these figures, the participant age categories are denoted by O and Y for older and younger, respectively.

Table 3: ANCOVA Results for Detection

ANCOVA for Detection

SIGNIFICANT INTERACTIONS

BETWEEN	Target Detection	Pedestrian Detection	Off-Axis Target Detection	Off-Axis Pedestrian Detection
Age				
WITHIN				
Lighting Level				
Lighting Level by Age				
Object Color	p = 0.0078	p = 0.0499		
Object Color by Age				
Lighting Level by Object Color				
Lighting Level by Object Color by Age				
Lighting type				
Lighting type by Age				
Lighting Level by Lighting type				
Lighting Level by Lighting type by Age				
Object Color by Lighting type				
Object Color by Lighting type by Age				
Lighting Level by Object Color by Lighting type				

Lighting Level by Object Color by Lighting type by Age				

Figure 18 shows the results for the significant interaction found for target color in the ANCOVA *(df=3, F Value4.26, p-value=0.0078)*. The upper chart shows the average detection distance by target color while the lower chart shows the average Weber contrast by target color. Here we see that the contrast of blue is much lower than that of gray and green, however blue was detected soonest. This is expected as blue has a shorter wavelength coupled with the spectral sensitivity of rod vision (Szalmas, 2006).

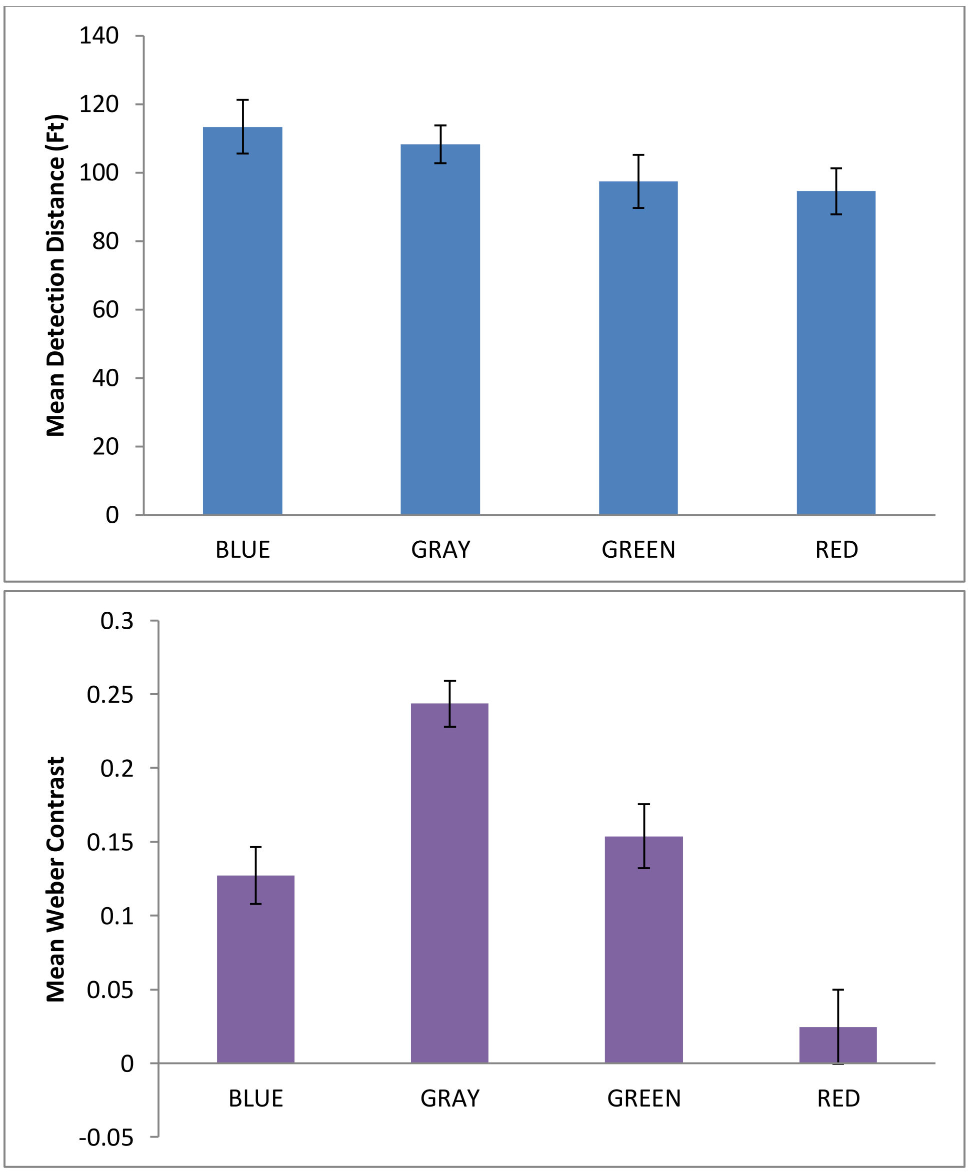

Figure 18: Target Color Recognition Distance by Target Color & Weber Contrast by Target Color

Figure 19, similar to Figure 18, shows the significant interaction found for pedestrian clothing color in the ANCOVA *(df=1, F Value=4.15, p-value=0.0499)*. Participants were able to detect denim clad pedestrians much sooner than those clothed in black with much less contrast. The color black typically has more negative contrast than any color it is paired against because black is typically darker than its background. This result indicates that color contrast impacts the perception of denim clothing to be detected as well as black with significantly less luminance contrast.

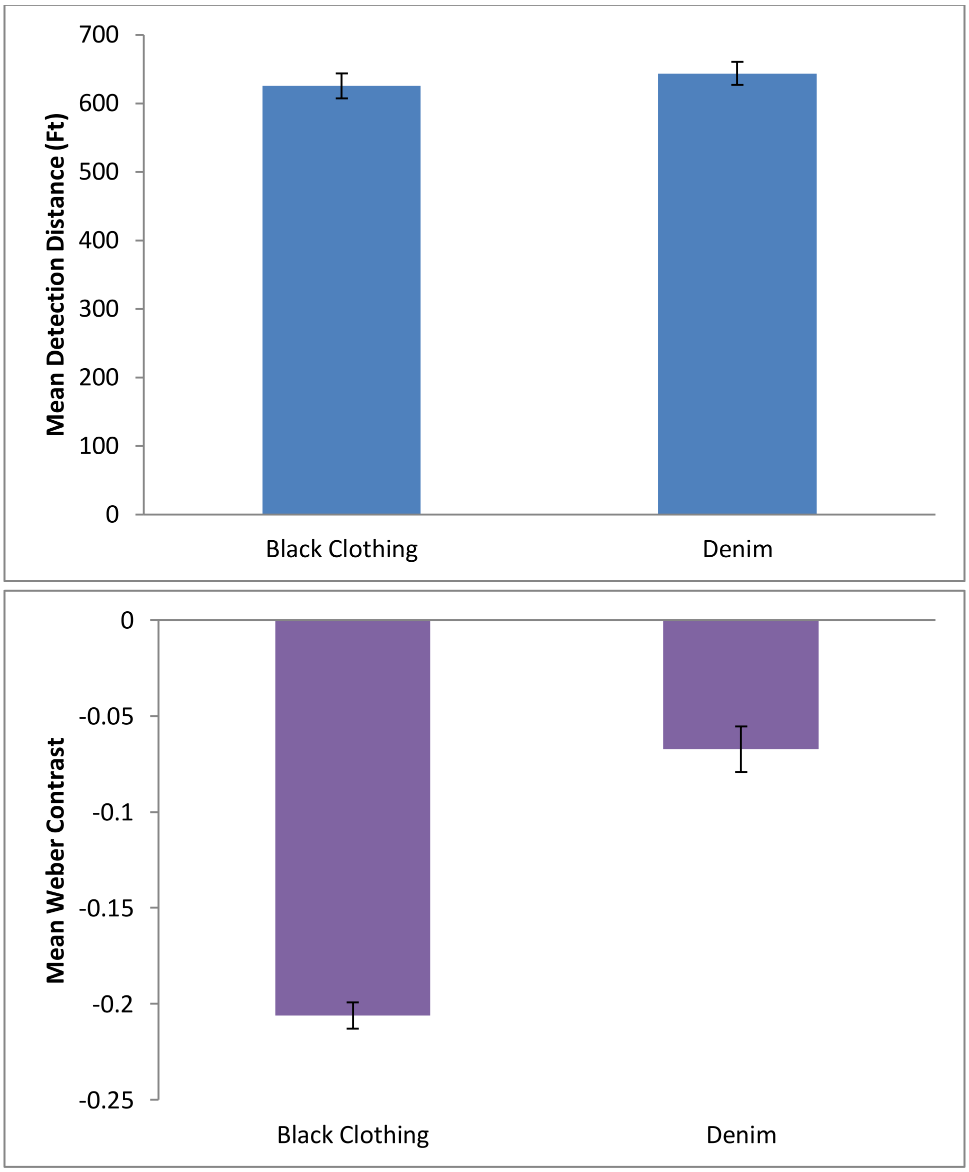

Figure 19: Pedestrian Clothing Color Detection Distance by Clothing Color & Weber Contrast by Clothing Color

Detection Distance ANOVA

Table 4 charts the significant results found in the ANOVA for detection distance. For target detection, the ANOVA found significance in the interaction of light level and object color. A Student Newman-Keuls test found object color to have significance. Pedestrian detection had a significant interaction of light level and age. Off-axis target detection had significance for age found in both the ANOVA and SNK tests.

Table 4: ANOVA Results for Detection

BETWEEN	Target Detection	Pedestrian Detection	Off-Axis Target Detection	Off-Axis Pedestrian Detection
Age			P=0.0487 SNK	
WITHIN				
Lighting Level				
Lighting Level by Age		P=0.0462		
Object Color				
Object Color by Age				
Lighting Level by Object Color	P=0.0184			
Lighting Level by Object Color by Age				
Lighting type				
Lighting type by Age				
Lighting Level by Lighting type				
Lighting Level by Lighting type by Age				
Object Color by Lighting type				
Object Color by Lighting type by Age				
Lighting Level by Object Color by Lighting type				
Lighting Level by Object Color by Lighting type by Age				

Target Detection

Figure 20 represents the significant interaction found in the ANOVA for lighting level and target color *(df=2, F Value=5.03, p=0.0184)*. Blue and red targets were detected further away under six lux versus twelve however gray targets were significantly opposite. Due to a limitation in the study's design, green targets were not used under 6 lux of illumination.

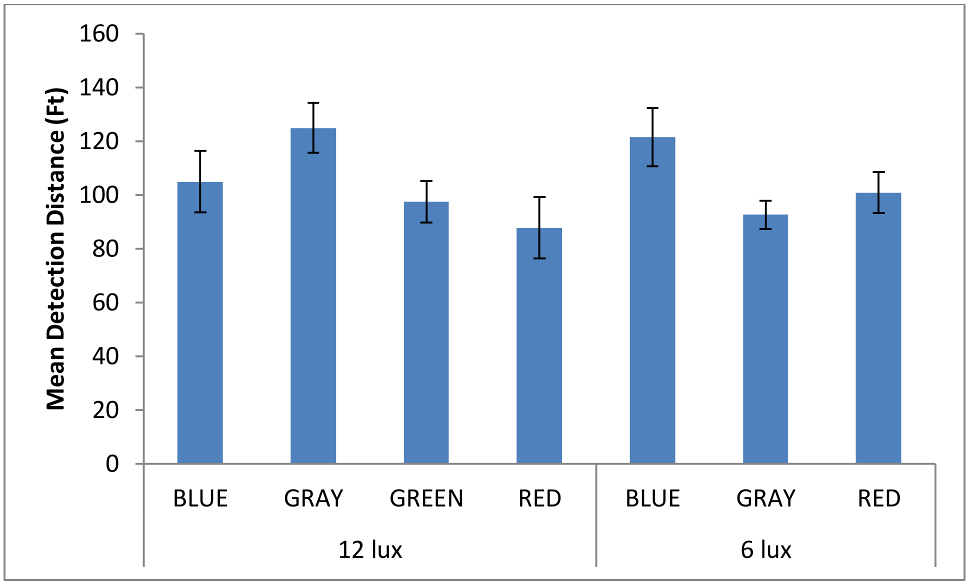

Figure 20: Target Detection Distance by Light Level and Color

Pedestrian Detection

Figure 21 illustrates the significant difference found for the interaction between light level and age *(df=1, F Value =4.30, p-value=0.0462)*. The results indicate that the different illumination levels affected the age groups differently. Targets and pedestrians placed under 6 lux were detected sooner than those placed under 12 lux for the older participants. Younger participants underwent an opposite effect. These differences suggest there are age related differences in regard to luminance contrast detection thresholds (Adrian, 1989).

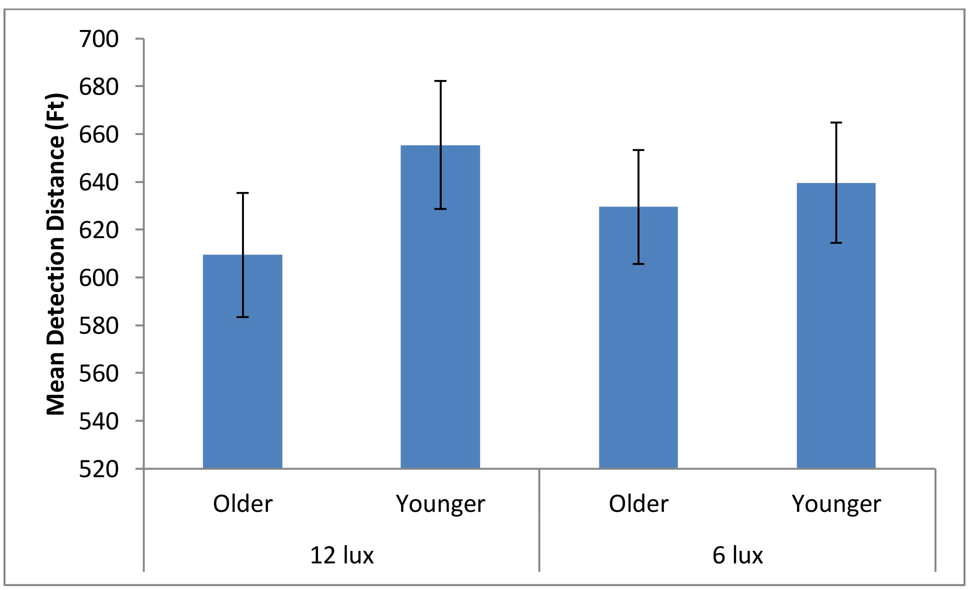

Figure 21: Pedestrian Detection Distance by Light Level and Age Group

Figure 22 and Figure 23 show the contrast results for the pedestrians. Here the influence of the headlamps is not seen. Of primary interest is that the contrast for the black-clothed pedestrians is more negative than that of the denim-clothed pedestrians.

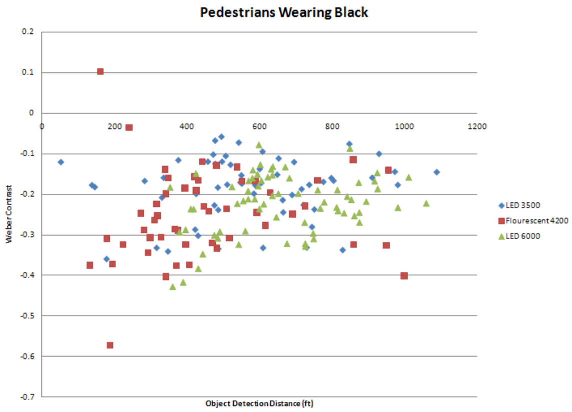

Figure 22: Pedestrian Detection: Weber Contrast for Pedestrians Wearing Black

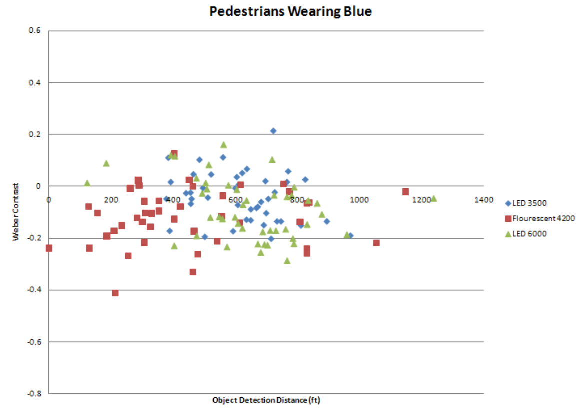

Figure 23: Pedestrian Detection: Weber Contrast for Pedestrians Wearing Blue (Denim)

Off-Axis Target Detection

Although off-axis detection was not included in the scope of the research questions, the results from the off-axis detection are important in the contribution to mesopic lighting. MOVE was derived by a consortium of researchers to develop standards for quantifying mesopic vision and and to model mesopic visual behavior. Such models exist for photopic and scotopic vision. The standard procedure of MOVE is a three step process which involves the recognition and identification of an object while in a moving vehicle at night. This study utilizes such procedure. Mesopic vision is not concentrated in the fovea but instead influences the peripheral vision thus the data from off-axis target detection is an important contribution to mesopic literature on behalf of the LED light sources.

While not significant, the results indicate that for target detection the 6000 K LED provided a greater average detection distance of approximately forty feet compared to the 3500 K (6000 K = 262.87ft, 3500 K = 224.41ft).

There was a significant difference between age groups regardless of lighting (*df=1, F Value=4.31, p=0.0487)*. On average, younger participants identified the presence of off-axis targets approximately 120ft sooner.

Figure 24 shows the results for off-axis target detection and age by light source. To achieve similar results to the 6000 K LED in terms of detection distance, the 3500 K LED required much greater contrast as can be seen in the Weber Contrast graph.

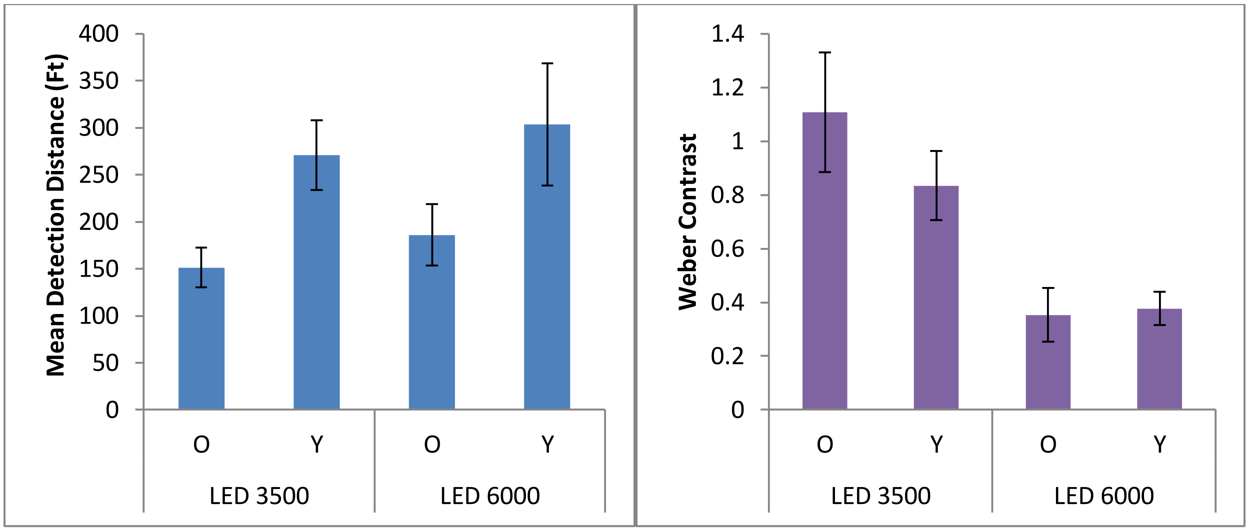

Figure 24: Average Off-Axis Target Detection Distance and Weber Contrast by Light Type and Age Group

Color Recognition ANOVA

Table 5 charts the significant interactions and main effects found in the ANOVA for color recognition distance. There were four interactions found to be significant for target color recognition. Object color was a significant main effect.

Pedestrian clothing color recognition had five significant findings. All five were found significant by the ANOVA and three were found significant by SNK groupings. Age, lighting level, and light type were significant main effects found by both the ANOVA and the SNK. Lighting level and light type by age was a significant interaction as was clothing color by light type by age.

Table 5: ANOVA Results for Color Recognition

BETWEEN	Target Color Recognition	Pedestrian Clothing Color Recognition
Age		p=0.0035 SNK
WITHIN		
Lighting Level		p=0.0049

		SNK
Lighting Level by Age		
Object Color	P=0.0315	
Object Color by Age		
Lighting Level by Object Color	P=0.0106	
Lighting Level by Object Color by Age		
Lighting type		
Lighting type by Age	P=0.0192	
Lighting Level by Lighting type	P=0.0120	
Lighting Level by Lighting type by Age		
Object Color by Lighting type		
Object Color by Lighting type by Age	P=0.0305	P=0.350
Lighting Level by Object Color by Lighting type		P=0.0472
Lighting Level by Object Color by Lighting type by Age		

Target Color Recognition

A significant interaction between light level and light type can be found in Figure 25 (*df=1, F Value=14.81, p=0.0120).* The figure shows the nearly opposite interaction for the light types and light levels. The 3500 K LED yielded a similar detection distance at the higher lighting level as the 6000 K LED did for the low.

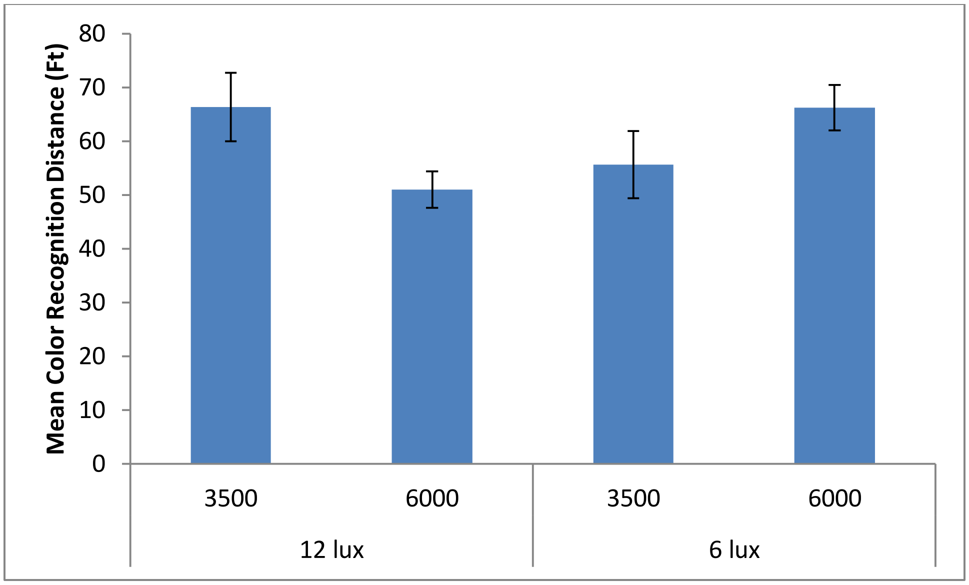

Figure 25: Average Target Color Recognition Distance by Light Level and Light Type

Another significant interaction in target color recognition is shown in Figure 26 *(df=2, F Value 7.41, p-value=0.0106)*. As was found significant in the detection of targets, the target colors of blue and red are more easily recognized under 6 lux than under 12. Gray targets underwent an opposite reaction by being detected later under 6 lux. These results suggest color contrast has a greater impact on the target's visibility at varying light levels.

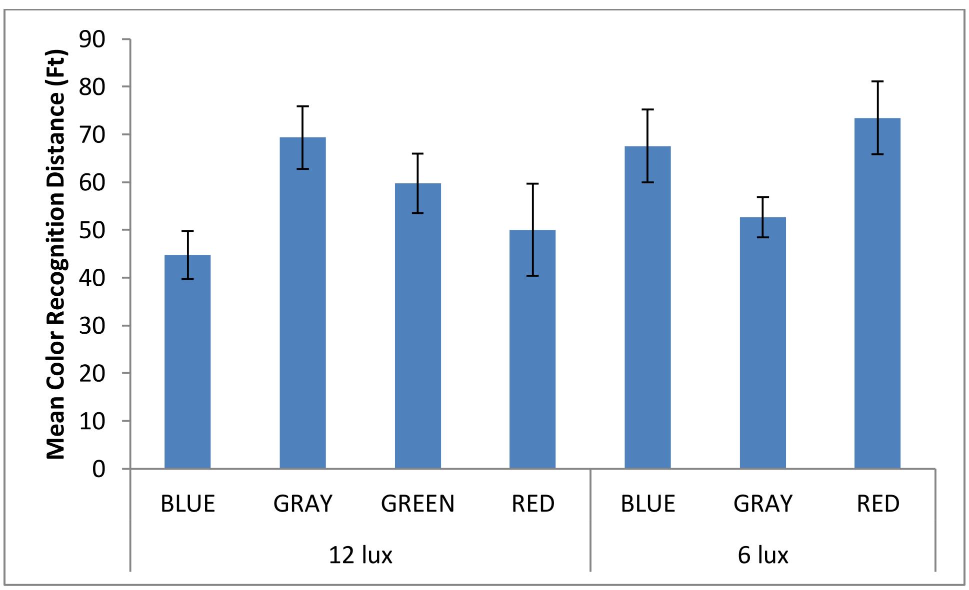

Figure 26: Target Color Recognition by Color and Light Level

Figure 27 illustrates the significant interaction found between target colors, light types, and age groups (*df=2, F Value =9.45, p=0.0305)*. One possible explanation for this significant results was due to the limitations placed on the green target to only be included under 6 lux scenarios and not 12 lux. The results do point out an interesting result for the red target. Red targets were the only target color viewed sooner for older age groups compared to younger for both light types.

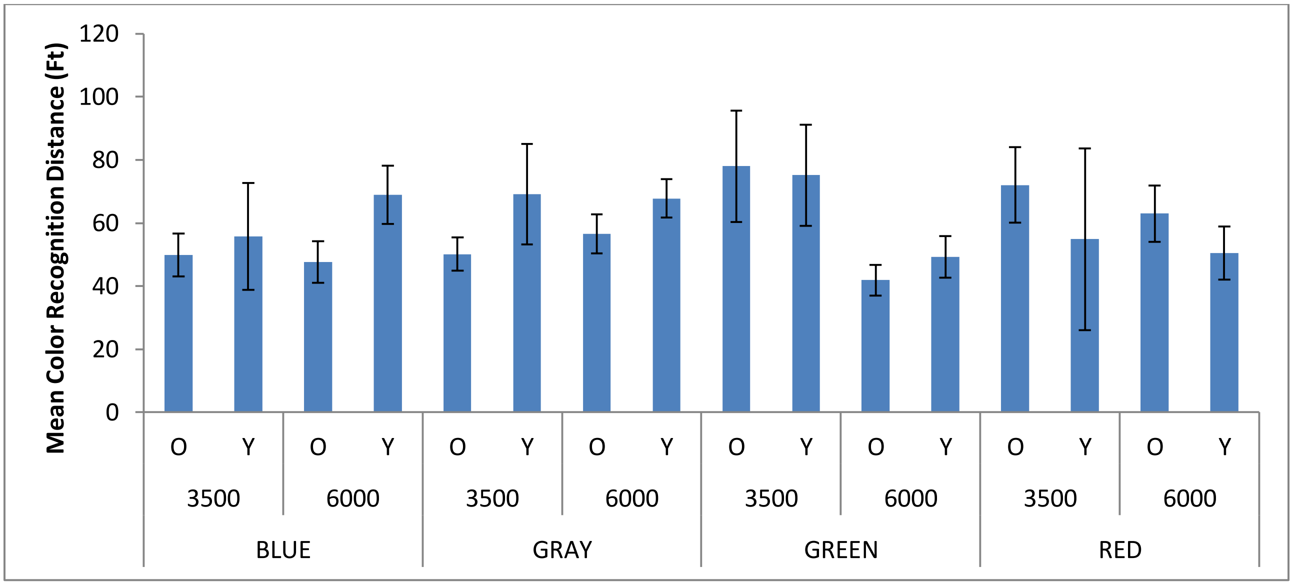

Figure 27: Target Color Recognition by Color, Light, and Age Group

Pedestrian Clothing Color Recognition

There were four significant findings for pedestrian clothing color recognition. There were significances for age, light level, color by light type by age, and light type by level by age.

Figure 28 represents the results for the significant interaction for age (*df=1, F Value=11.91, p=0.0016*). The ANOVA and the SNK test found a significant difference between age groups for detecting the color of pedestrian clothing. The results indicate that the younger participants could detect the color of pedestrian clothing from approximately 173ft further away.

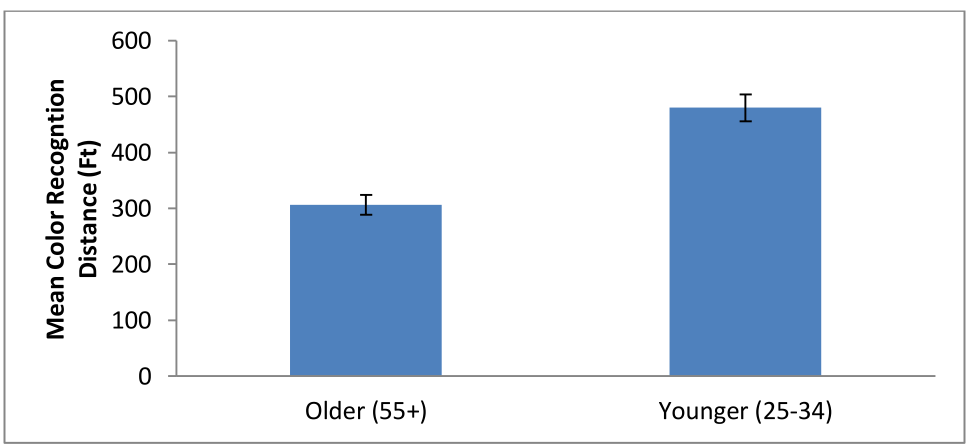

Figure 28: Average Pedestrian Clothing Color Recognition Distance by Age Group

The results shown in Figure 29 indicate a significant interaction between the levels of lighting used when recognizing the color of pedestrian clothing (*df=1, F Value =9.35, p=0.0048).* Both the SNK and ANOVA found there to be a significant difference between pedestrians placed under 12 lux and pedestrians placed under 6. Pedestrians placed under 12 lux had their clothing color recognized approximately 74ft sooner than those placed under 6.

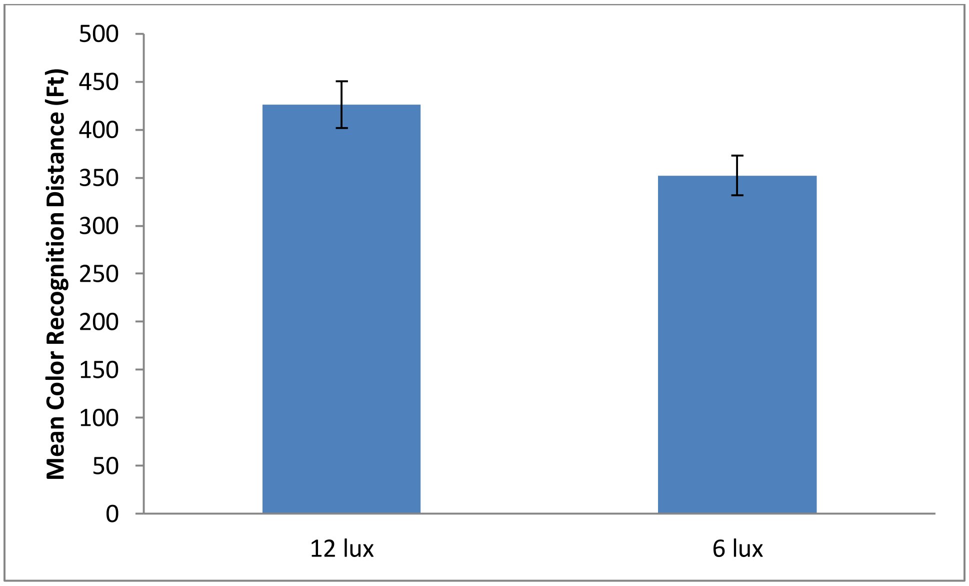

Figure 29: Average Pedestrian Clothing Color Recognition Distance by Light Level

Shown in Figure 30 are the results for the interaction between light type, pedestrian clothing color, age (*df=1, F Value=7.35, p=0.0350).* The best results for color recognition distance came from the younger age group when driving under the 6000 K light type. Results indicate that the 6000 K benefitted younger drivers in the detection of both clothing color. The results for older drivers under both light types were similar for both clothing colors.

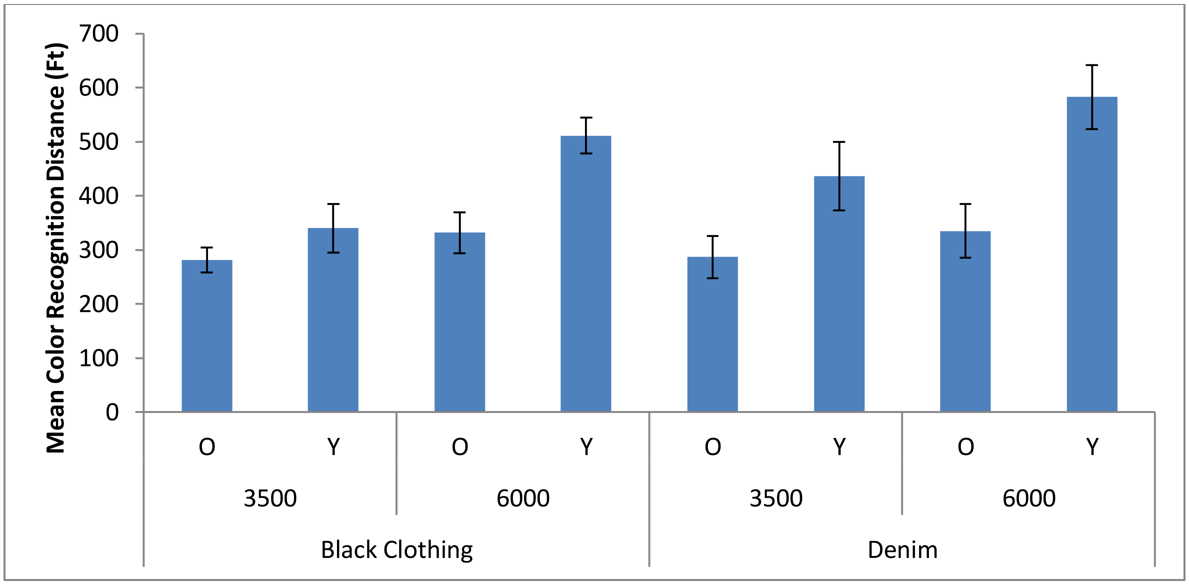

Figure 30: Pedestrian Clothing Color Recognition Distance by Clothing Color, Light Type, and Age

Questionnaire Results

Questionnaire data were coded and entered into a spreadsheet for further analysis. There were different modes of answering questions within the questionnaires (Appendix E, F, & G) therefore different analysis types were used.

One type of answering mode was a Likert-type scale, as found in all three questionnaires. The answers for the nightly questionnaire (Appendix E) were analyzed using a non-parametric ANOVA. Likert-type questions such as those found in Appendix F and G were also analyzed using a non-parametric ANOVA however questionnaires that participants rated themselves low for remembering previous nights were removed from analysis. Questionnaires of participants who rated their abilities to remember previous nights below neutral were omitted. Participants who rated themselves as neutral (or 4) to very well (7) were kept for analysis. This method prevented participants who were not confident in their ability to recall previous light types from being included in the data pool.

Using the Wilcoxon Signed Ranks procedure for ranked data, just one Likert-type question had asignificant difference for light types. Participants felt clothing color more affected their ability to detect pedestrians under 3500K ($df=1$, $Z=1.74$, $p=0.037$). The question read, “Did clothing color affect your ability to detect pedestrians?”. Participants received the questionnaire immediately following four laps under one of each light source each night. The anchors were (1) Strongly Disagree, (4) Neutral, and (7) Strongly Agree. Participants more strongly felt that the color of the pedestrian clothing affected their ability to detect pedestrians under the 3500K light type suggesting that under the 6000K light type, participants felt that pedestrians could be detected regardless of clothing color Figure 31. This result may indicate that participants preferred the 6000K for color and detection of pedestrian clothing. (Figure 31).

When separated by age, it was found that a significance was found for this question for older participants but not younger *(df=1, Z=1.77, p=0.0384).*

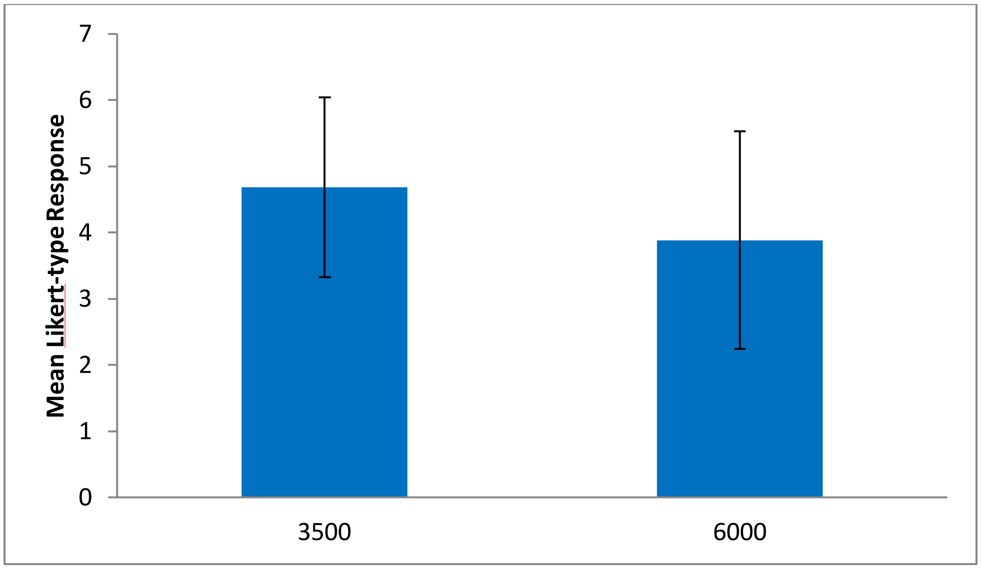

Figure 31: Clothing Color and Detection Ability of Pedestrians

When asked if the lighting increased the glare they experienced, younger participants significantly chose the 6000K as more glaring than the 3500K *(df=1, Z=1.83, p=0.0336).*

Figure 32: Glare and Light Type for Younger Participants

Another type of answering mode required the participant to check one answer from a list. The answer pool was consistent from question to question and required the participant to compare their experiences with the light types (Appendix F: Post-Drive Questionnaire (Night Two)

Appendix G: Post-Drive Questionnaire (Third Night)). The light types were referred to by their night orders so that participants were not required to know any details about the lights that were being tested. These answers were coded based on the light order the participants received and their ability to recall previous nights. Participants who rated themselves as four or above when asked to rate their ability to compare the lights were kept for data analysis, the rest were omitted. These answers were analyzed using frequency counts for when the two light types were preferred over the other or when the answer was neutral.

Figure 33 illustrates the results for the question "Of the two types of overhead lighting, which allowed you to see pedestrians sooner?" Twelve participants chose the 6000 K and eleven chose the 3500 K indicating no significant difference between the two. Table 6 contains the Chi-Square results for this question.

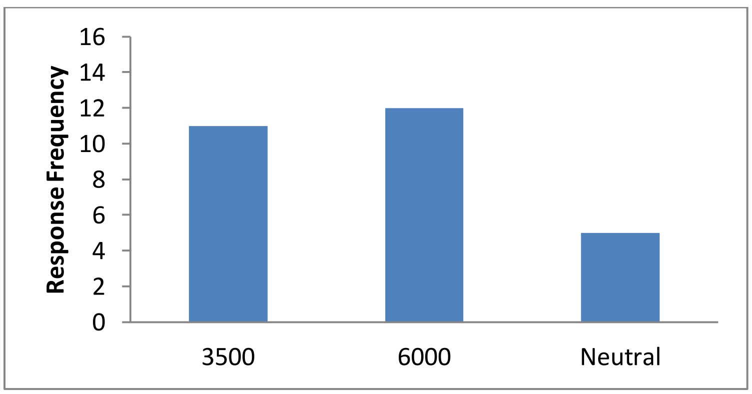

Figure 33: Of the two types of overhead lighting, which allowed you to see pedestrians sooner?

Table 6: Chi-Square Results for Figure 33

Chi-Square Test for Equal Proportions	
Chi-Square	3.3793
DF	2
Asymptotic Pr > ChiSq	0.1846
Exact Pr >= ChiSq	0.2132

Figure 34 is the results for the question "Of the two types of overhead lighting, which allowed you to see targets sooner?" Results indicate that fourteen participants preferred the 3500 K compared to seven for the 6000 K. The Chi-Square statistic in Table 7 found these results to be insignificant. The on-road data for target detection tasks, while also non-significant, did result in the 3500K having a greater detection distance for targets.

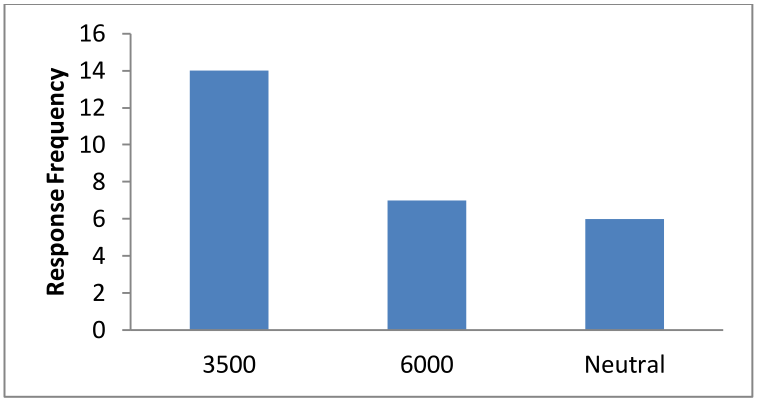

Figure 34: Of the two types of overhead lighting, which allowed you to see targets sooner?

Table 7: Chi-Square Test for Figure 34

Chi-Square Test for Equal Proportions	
Chi-Square	2.9655
DF	2
Asymptotic Pr > ChiSq	0.2270
Exact Pr >= ChiSq	0.2569

Figure 35 represents the answer to the question of which light was more glaring. Fourteen participants selected the 6000 K as being more glaring than the 3500 K which only four participants chose. The Chi-Square test was nearly significant (p=0.065). While this study did not utilize the metrics of glare, future studies should investigate glare and its impact using these two light sources.

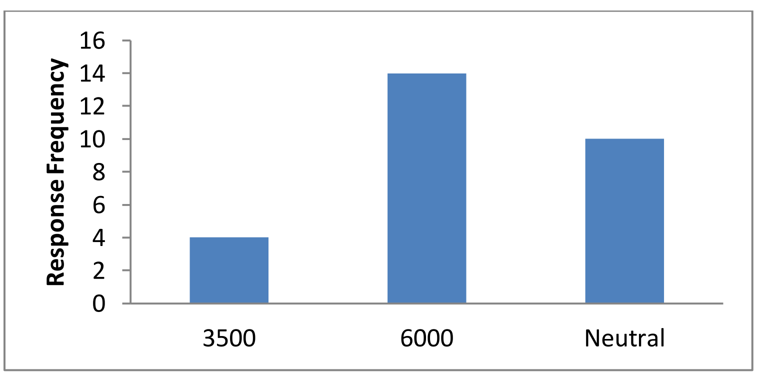

Figure 35: Of the two types of overhead lighting, which was more glaring?

Table 8: Chi-Square test for Figure 35

Chi-Square Test for Equal Proportions	
Chi-Square	5.4483

Chi-Square Test for Equal Proportions	
DF	2
Asymptotic Pr > ChiSq	0.0656
Exact Pr >= ChiSq	0.0626

Open ended questions and comments sections were coded using content analysis. Content analysis is a method of research by which inferences are made based on textual data (Weber, 1990). For each comment, the overall theme was assessed. Comments were first reduced for usability. If the researcher could not determine which light source the comment referred to or if the comment had no direct relevance to the study, it was removed from analysis. Questionnaires that participants did not rate their ability to recall previous nights as a four or above were also stricken from analysis. The content analysis results can be found in Figure 36.

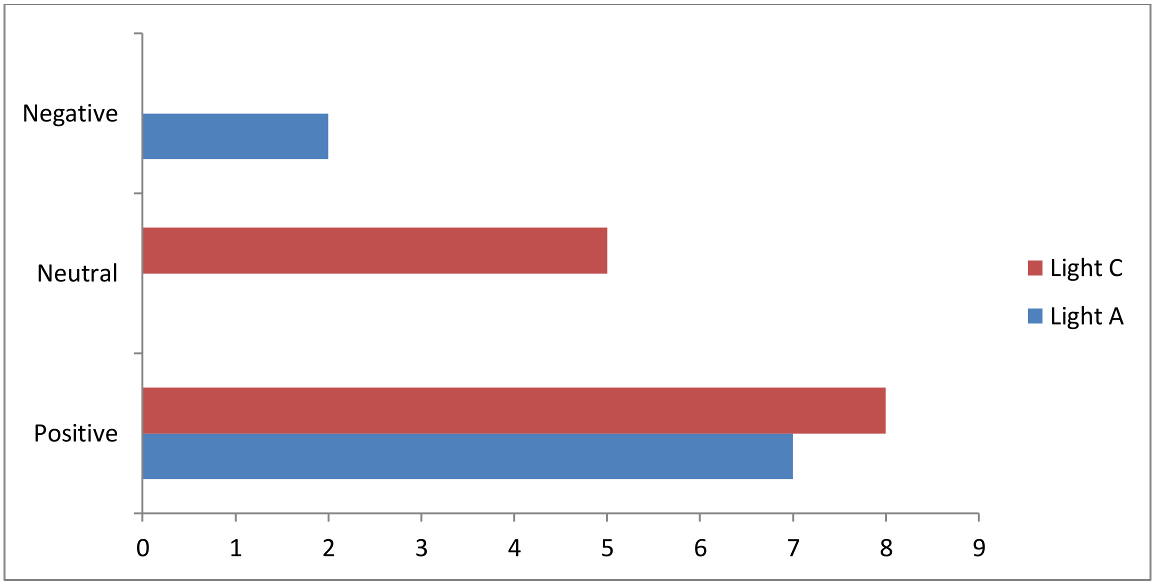

Figure 36: Content Analysis

After each comment was read, a set of criteria was developed. A list was made to accommodate the subject of each comment. Each criterion was divided into three categories: positive, negative, and neutral. A tally for each comment was placed into the chart based on its criteria and category. A chi-square test found no significances between light sources for positive and negative themes. An example of each answer type is presented in Table 9.

Table 9: Content Analysis Examples

Theme	Example Answer
Positive	The color was easier to identify

Neutral	Could see targets as well tonight as other nights
Negative	I was less aware of the colors under this light

CONCLUSIONS

Hypothesis Testing

The research questions and their resulting hypotheses are listed below.

Research Question 1: To what extent will target detection distance differ between the LED 6000K and the LED 3500K?

For this research question the null hypothesis has been accepted. Where the 3500K light source was found to provide a better overall detection distance for targets, this result was not statistically significant via the ANOVA.

Research Question 2: To what extent will pedestrian detection distance differ between the LED 6000K and the LED 3500K?

For this research question the null hypothesis has been accepted. The 6000K light source was found to provide a better overall detection distance of pedestrians; however, this result was not statistically significant via the ANOVA.

Research Question 3: To what extent will target color recognition distance differ between the LED 6000K and the LED 3500K?

For this research question the null hypothesis has been accepted. The 3500K light source was found to provide a better overall color recognition distance of targets; however, this result was not statistically significant via the ANOVA.

Research Question 4: To what extent will pedestrian clothing color recognition distance differ between the LED 6000K and the LED 3500K?

For this research question the null hypothesis has been accepted. The 6000K light source was found to provide a better overall clothing color recognition distance of pedestrians; however, this result was not statistically significant via the ANOVA.

Conclusions and Discussion

There were no significant differences found between the two light sources in terms of detection distance or color recognition distance for either small targets or pedestrians. There were very small differences between the lights for target detection or color recognition suggesting that perhaps their small size constrained visibility for both lights. The differences in detection and clothing color recognition of pedestrians were much greater and favored the 6000K. However, younger participants indicated via questionnaire answers that the 6000K produced more glare.

Even though the F-Value of the ANOVAs show no significance between the luminaires, a post-hoc SNK test did group the lights differently for pedestrian detection and pedestrian clothing recognition. This suggests that extraneous factors such as ambient lighting, minute speed variances, and driver attention and gaze may have impacted potential significance.

Questionnaire results indicated no overall preference of one light source over the other. Participants did indicate that pedestrian clothing color influenced their ability to be detected under 3500K lighting suggesting the 6000K was preferred for pedestrian detection and clothing color recognition no matter the color. These results were reflected in the road test data as well.

Using data from similar previous studies conducted on the Virginia Smart Road using HPS (High-Pressure Sodium) lighting systems suggest both LED luminaires have better color rendering qualities. In the previous study (Gibbons, in press), the HPS were spaced 40m apart versus 80m for the LEDs in this study. Targets and pedestrians were presented in similar locations of the Smart Road, in similar conditions, and using the same colors. Table 10 represents these results.

Table 10: HPS and LED Comparison

Event	HPS (40m)	3500K LED (80m)	6000K LED (80m)
Target Detection	263ft	110ft	101ft
Pedestrian Detection	604ft	601ft	659ft
Target Color Recog.	96ft	61ft	58ft
Ped. Clothing Color Recog.	275ft	317ft	442ft

The closer orientation of the HPS luminaires (40 meters) compared to the LEDs (80 meters) is likely responsible for the increased detection distance of the small targets. However, the difference between HPS and the LEDs for target detection decreases for target color recognition (Table 11). For pedestrian detection, the 6000K LED outperforms the HPS even with wider orientation. For pedestrian clothing color recognition, the HPS is outperformed by both LEDs. Table 11 presents an average of the LEDs distances from Table 9 in the right column and the percent difference of the HPS light source in the left column.

Table 11: Percentage of HPS distances to LED distances

Event	HPS (%)	LEDs (Averaged)
Target Detection	250.47%	105ft
Pedestrian Detection	95%	630ft
Target Color Recog.	162.71%	59ft
Ped. Clothing Color Recog.	72.56%	379ft

As Table 11 shows, the HPS outperforms the LEDs by approximately 250% in target detection but for target color recognition, the percent drops by 88 suggesting the LEDs perform better for color rendering. Even with the closer orientation, the HPS are 95% or similar to the LEDs in pedestrian detection but drop 23 percent for pedestrian clothing color recognition. Future research should compare HPS and LED luminaires directly with similar spacing to gain more insight on their performance differences.

Secondary Conclusions

Many secondary conclusions can be made based on interactions between variables within the study. The visibility of certain target colors, the nature of contrast, the effect of light levels, off-axis visibility, and the impact of age were all observed in the results.

The blue target was detected sooner, overall, than any of the other target colors while red was detected latest. This result supports past studies that have achieved the same conclusions. The wavelength of blue is shorter and thus more sensitive to the eye. Target colors, such as red which appear brighter and are commonly perceived to be more easily seen in the dark than blue, are impacted by color contrast and the nature of their wavelengths. Alferdink (2005) used mesopic lighting levels with a driving simulator to gauge driver response to different target colors by reaction time (RT). Alferdink found that drivers could detect the presence of blue targets from further away than red. Blue outperformed red in all eccentricities (in degrees) as well as at different luminance levels. The difference in RT between blue and red ranged from between two seconds to less than half a second. Blue also outperformed yellow and white. Alferdink concluded that the performance of red is worse than the other colors (blue, yellow, and white) at low luminances. Alferdink's findings in this experiment are consistent with his similar laboratory experiments. The RT relationship between blue and red in this study reflect the findings of Alferdink.

To determine the amount of contribution color contrast had, a relationship between the color coordinate difference and threshold luminance contrast was investigated. Color coordinate difference refers to the coordinates of the XY chromaticity diagram in Figure 2. A gray target's threshold contrast, or luminance contrast (the amount of luminance contrast necessary before the target is visible) was measured and used as a multiple for the other target colors. The multiple 1 is the gray target that the other targets refer to under each light source (Figure 37). The graph shows that as the threshold luminance of the gray target is multiplied the percentage of color coordinate difference also increases. The relationship suggests that color contrast has a positive impact on detection. The differences in target color coincide with the detection threshold of the target being separated from its background or pavement in this case.

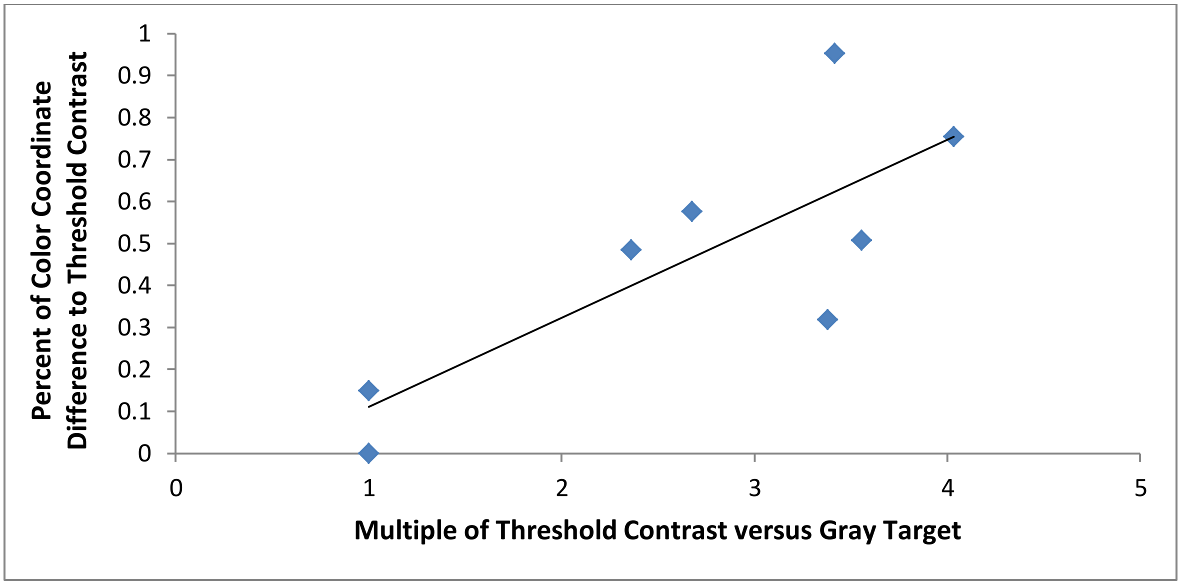

Figure 37: Color Coordinate Difference versus Gray Target Threshold Multiples

The 12 lux light setting allowed participants to recognize the color of pedestrian clothing from further away than the 6 lux setting for both light types and both age groups. This suggests that the brighter the light, the easier clothing color is to recognize. However, for the small targets the results found that participants were able to recognize colors sooner under 12 lux for the 3500 K LED and 6 lux for the 6000 K LED. This suggests that color contrast is involved. The 12 lux position for the 6000 K LED may be powerful enough to "wash-out" the colors from being detected sooner while the 3500 K LED at 6 lux may not be powerful enough to make the colors visible. The results may also suggest that the 3500 K LED requires 12 lux to achieve the same color rendering abilities as the 6000 K LED does at 6 lux.

Younger participants could identify the presence of off-axis targets significantly sooner than older participants. This finding supports Fotios and Cheal's 2009 study where they found that younger drivers (18-45) could detect off axis objects of similar size, shape, luminance, and contrast significantly sooner than older drivers (60+).

Due to the aging effects on vision and the "yellowing" of the eye's crystalline lens that comes with age, younger drivers outperformed older drivers consistently. However, in some instances, particularly situations involving the detection or color recognition of red targets, older participants performed better no matter the light type being used. This result supports Suzuki's (et al., 2004) study that compared color visibility based on RT by comparing elderly participants to younger, adult participants with eye-glass filters that simulated the yellowing of the crystalline lens and to young adults without the eye-glass filters. Suzuki found that for elderly drivers red has the better RT (~590ms) compared to gray (~750ms), green (~680ms) and blue (~760ms). The difference in the detection of blue and red targets for older participants was not significantly different, thus, no definitive claims can be made; however, the relationship found in this study is support by Suzuki.

The filters used by Suzuki indicated that the yellowing of the crystalline lens impacted the color blue more than gray, red, or green. This finding could be a possible explanation for the large difference between young and old drivers and their detection and color recognition distances of blue targets.

However, Suzuki's finding indicated that the elderly, on average, do not react to red sooner than young adults unlike the findings of this study but the response times for red are closer among the two age groups than the other colors suggesting that red is least impacted by the aging human lens.

Questionnaire Discussion

It is important that the questionnaire data and the data obtained from the on-road portion support each other. Before there can be broad adjustments made to the lighting community, the public preference must also match the data. A good design can provide safety but requires public approval before it can be accepted and installed. The questionnaire data and on-road data for this study appear to correlate. Neither found a significant difference or preference overall for either light source however the participants and the roadway data suggest that the 6000K has better properties regarding color detection.

The questionnaire results showed that there was no overall preference for one light over the other. However, participants felt that the difference in clothing color affected the visibility of pedestrians under the 3500K, suggesting that the pedestrians were visible under the 6000K no matter the color. This result supports the road test data that found pedestrians were detected sooner and their clothing was recognized sooner under the 6000K.

Younger participants indicated that the 6000K produced more glare than the 3500K. While older participants also answered that the 6000K provided more glare, these results were not significantly different.

While the content analysis yielded no significantly different results, the 6000K received one more positive comment and two less negative comments than the 3500K.

Limitations of the Study

The results of this study are limited to the light sources and the targets tested in this investigation. Further effort must be considered to provide a more broadly applicable correction factor.

One of the primary assumptions of this investigation is that object detection is linearly related to contrast. Investigation into the metric that can be related to the object detection would also be required to develop the correction factor.

The study required participants to participate in the study at least three times over the course of a week to two weeks. Over time the participants' memories of their previous scenarios begin to fade. When comparing the light sources in their questionnaires, the inconsistent time gaps between subjects participating in their three nights of the study serve as a weakness to the study's design, especially for questionnaire data.

This investigation did not consider the impact of glare.

Due to the study's focus and design, there were no color recognition tasks for off-axis objects. To full explore the mesopic capabilities of these LED lighting system, this must be explored.

A majority of the participants used in this study reside in the Blacksburg, Christiansburg, and Radford areas of Virginia. The driving and road scanning behaviors of drivers from these rural areas may differ from those in more urban settings.

Future Research

Further research is required to fully establish the impact of the color contrast. The nature of the light source, a wider variety of targets, and the impact of the headlamps all have to be considered in the development of the results. Narrower luminaire spacing may also boost the overall illuminance on the roadway and eliminate dark spots.

While the results lean toward the 6000K LED, especially in terms of color rendering, it is at the cost of glare which younger participants believed to be a factor with this luminaire. Future research should measure the impact of glare for both luminaires as well as compare their glare to conventional lighting systems currently used.

The LED luminaires should be compared directly to a conventional lighting system such as Metal Halide or HPS to construct more generalizable claims about their proficiency for safety.

This study found that the 6000 K LED was able to provide comparable off-axis target detection with less contrast. This information may be a good starting point for lighting manufacturers as further research could delve into finding the perfect thresholds for identifying off-axis objects in regard to light power, CCT, and contrast. Also, future studies could tailor questionnaires to obtaining more information about off-axis detection as well as potential over-lighting or light pollution caused by the luminaires.

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Appendix A – Telephone Screening

Eligible: Yes No

Name____Male/Female
Phone Numbers ____
Best Time to Call ____
Screener____

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding eligibility for this study. Once this questionnaire is completed, remove this cover sheet and file separately from the screening questions.

Introductory Statement:
After prospective participant calls or you call them, use the following script to guide you through the screening interview.

Hello. My name is _____ and I am a researcher at the Virginia Tech Transportation Institute in Blacksburg, VA. I am recruiting participants for a new driving study that looks at nighttime driving and will be conducted here at the Smart Road. I obtained your contact information from the VTTI internal participant database.

Non Eye-Tracker Participants
The purpose of the study is to evaluate lighting conditions and nighttime driving. If you choose to participate, you will drive a test vehicle on the Smart Road. While you drive the vehicle, an in-vehicle experimenter will be with you at all times to answer questions and give instructions. The vehicle is equipped with cameras that allow us to collect data, however, they are very small and placed out of the way.

This study has several parts to it. First, we will perform some simple vision tests. Providing these are passed, we will introduce you to the vehicle you will be driving. Once this is complete, you will drive an instrumented vehicle around a close course test track. The study takes approximately 2 hours to complete. Participants are paid $20/hr. Does this sound like something you would be interested in doing?

Eye-Tracker Participants
The purpose of the study is to evaluate lighting conditions and nighttime driving. If you choose to participate, you will drive a test vehicle on the Smart Road while wearing an eye tracker, in order to monitor your eye movements. The eye tracker will have 2 small LED lights, and 3 small cameras (2 aiming at your eyes, 1 aiming forward) all attached to a set of goggles. The goggles will be held securely onto your head using a padded headband. The eye tracker will not interfere with your driving as you will still be able to clearly see the road and you may still wear

your prescription eyewear if you need to. You will be driving the vehicle, however an experimenter will be with you at all times while you are driving. The vehicle is equipped with cameras that allow us to collect data. The cameras, however, are very small and are placed out of the way.

This study has several parts to it. First, we will perform simple vision tests. Providing these are passed, we will move on to the second part which involves calibration of the eye-tracker and fitting the eye-tracker goggles. For this, you will wear the goggles while watching a laser point move on a wall. Once this is completed, you will drive an instrumented vehicle around a closed-course test track. The study takes approximately 2 hours at the Transportation Institute to complete. Participants are paid $20/hr. Does this sound like something you would be interested in doing?

If they indicated that they are <u>not</u> interested:

Thank you for your time.

If they indicated that they are interested:

That's great. Is it alright if I ask you some screening questions?

Questions

1. *Do you have a valid driver's license?* (Criterion for participation: the response must be *Yes*)
   □ Yes □ No

2. *What is your age?* ________ (Criterion for participation: must be 25-34, or 55 and older at time of experiment)

3. *Have you had any moving violations in the past 3 years? If so, please explain each case.*
   □ **Yes** (Criterion for participation: the driver must not have more than two moving violations in the past 3 years)
   Description: ____
   □ **No**

4. *Do you have normal hearing and vision?* (Criterion for participation: subject must have normal hearing and vision)
   □ Yes □ No

5. *Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number or Virginia Tech ID number (for VT employees) to receive*

payment for participation in our studies. You do NOT need to provide it now, but are you willing to provide us with your social security number?

□ Yes □ No

6. *Are you able to drive an automatic transmission vehicle without assistive devices or special equipment?* (Criterion for participation: the driver must be able to drive an automatic transmission vehicle without assistive devices)

   □ Yes □ No

7. *(Females only) Are you currently pregnant?* (Criterion for participation: the response must be *no*)

   □ **Yes** □ **No**

   If "yes" politely inform the participant that due the nature of this particular study we are not able to allow pregnant women to participate. Answer any questions and thank them for their time

8. *Have you been involved in any accidents within the past 3 years? If so, please explain.* (Criterion for participation: the driver must not have caused an accident in the past 3 years.)

   □ **Yes** ____

   □ **No**

9. *Do you have a history of any of the following? If yes, please explain.*

   Heart Condition □ 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________________________________

(Criterion for participation: subject cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, current respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, and balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.)

10. Are you currently taking any medications on a regular basis? If yes, please list them.

□ Yes ____

□ No

(Criterion for participation: subject cannot currently be taking any substances that may interfere with driving ability, cause drowsiness or impair motor abilities.)

11. Are you eligible for employment in the United States? (Driver must be eligible for employment in the US)

□ Yes □ No

12. *How often do you drive at night*?

□ Less than 2 times per week

□ 2 to 4 times per week

□ More than 4 times per week

(Criterion for participation: Participants must drive at night at least 2 times per week)

Note to Researcher:

If a response to any of the first 12 questions does not meet its criterion, read the following:

Unfortunately you are not eligible for this particular study. Thank you for your time. Would you like to be called for future studies?

Criteria For Participation

1. Must hold a valid driver's license.
2. Must not have more than two moving violations in the past three years.
3. Must have normal (or corrected with contacts to normal) hearing and vision.
4. Must be able to drive an automatic transmission vehicle without assistive devices.
5. Must not have caused an injurious accident in the past three years.
6. Females cannot be pregnant.
7. Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, current respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.
8. Cannot currently be taking any substances that may interfere with driving ability, cause drowsiness or impair motor abilities.
9. Must be eligible for employment in the U.S.
10. Must be willing to provide SSN or Virginia Tech ID number when they come in.
11. Participants must be one of two age groups: 55+ years old or 25-34 years old to fulfill age group requirements.
12. Must drive at night at least 2 times per week.

Once the researcher determines that the participant is eligible for the study:

You are eligible for the study.

I would like to set up a time when you can come to VTTI and participate in this study. Would it be possible for you to come in on ____________ (day of week) *at____:____ hrs* (time)*?*

If the response is yes, go ahead and schedule the participant.

If the response is no, ask the following to the participant:

What day and time would be convenient for you?

If requested day and time is available then schedule the participant. If requested day and time is <u>not</u> available then suggest closer day and time slots and see if that will work for the participant.

Once the researcher has scheduled the participant, repeat the schedule day and time back to the participant.

Great! I have you scheduled for __________ *(day) at* ___:____ hrs.

I will be calling you a day before to remind you of your schedule. If you need to cancel or reschedule, please call me at 540-XXX-XXXX.

Here are the directions to the Institute. I can also email them to you if you wish.

From I-81:
1. Take exit 118B onto US-460 W towards Christiansburg.
2. Continue on US-460 W for approximately 10 miles.
3. Take exit 5AB toward US-460-BR W/US-460-BR E. The sign for this exit will read "Smart Road Center/Control Center.
4. Stay to your right on the exit ramp until you come to a stop sign at Industrial Park Drive.
5. Turn right onto Industrial Park Dr.
6. Take an immediate right onto Transportation Research Dr.
7. Turn left onto Transportation Research Plaza.
8. Drive up to the building

We ask that all subjects refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study.

Please bring reading glasses if you typically use them for filling out forms.

Do you have any questions that I can answer for you? (Answer the questions if any).

Great then I'll see you on ______________ (day) *at* ____:____ hrs *for the study. Thanks.*

Have a good day.

Appendix B-1: Eye Tracking Informed Consent

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Development of Methodologies to Evaluate the Nighttime Safety Implications of the Roadway Visual Scene

Investigators: Dr. Ronald Gibbons, Chris Edwards, Brian Williams, and Jason Meyer

I. The Purpose of this Research/Project

The focus of this study is roadway lighting and night driving. We will be testing two roadway light sources and how they affect a driver's vision while driving at night. To test this, we will calculate detection distances and questionnaire data from the participants. We will also be equipping some participants with an eye-tracker to compare results with other con-current, eye-tracking studies. Once this data has been collected, we can determine the lighting type that is more reliable for vision and detection. Approximately 24 people will take part in the study.

II. Procedures

During the course of this experiment you will be asked to perform the following tasks:

1) Read this Informed Consent Form and sign it if you agree to participate.
2) Show your valid driver's license.
3) Complete vision tests.
4) Calibrate the eye tracker.
5) Drive an instrumented vehicle on the Smart Road, and observe different scenarios while wearing the eye tracker. Video and audio data of the vehicle interior will be collected during the drive.
6) Complete questionnaires throughout the study.

For the Smart Road portion of the study, you will be exposed to pedestrians and other objects on and off of the roadway which you might normally encounter on public roads. Objects could be staying still or moving. Objects encountered on the road may include the following:

- Small wooden targets
- Pedestrians

It is important for you to understand that we are not evaluating you or your performance in any way. You are helping us to evaluate different lighting conditions and their effects on target detectability. The opinions you have will only help us do a better job of identifying factors that may improve a driver's vision during night driving. The information and feedback that you provide is very important to this project. Today's total experiment time will be approximately 2 hours.

III. Risks

There are risks or discomforts to which you may be exposed in volunteering for this research. They include the following:

For the eye testing prior to the experiment, you may feel discomfort from having a small LED light briefly shined into your eyes.

For the Smart Road portion of the study, the risks to you are similar to that of driving an unfamiliar vehicle in clear weather conditions at night on a road with minimal traffic and various objects and pedestrians at up to 40 miles per hour.

Additionally, you may experience physical and mental discomfort because of the eye-tracking apparatus (goggles, cameras, and LED lights). You may experience discomfort similar to that of wearing tight swimming goggles.

Some studies at VTTI involve an unanticipated event. You may or may not encounter such an event during this study. Please be aware that events such as equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly. Although unlikely, such an event could also cause the airbag to activate, which would increase the risk of an eye injury due to the eye-tracking goggles.

Finally, due to the length of the study, you may experience fatigue.

The following precautions will be taken to ensure minimal risk to you:

1) An experimenter will monitor your driving and will ask you to stop if he or she feels the risks are too great to continue.
2) You are encouraged to take breaks if you desire, and may withdraw from the study at any time.
3) The experimenter will be present while you are driving. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe and legal manner.
4) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit.
5) The Smart Road will be closed to traffic not involved in the study.
6) If an accident does occur, the experimenter will arrange medical transportation to a nearby hospital emergency room. You may elect to undergo examination by medical personnel in the emergency room.

7) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case. The eye-tracking goggles are mounted on the frames of safety goggles, which are intended to reduce the chance of injury in case of an airbag deployment.
8) Testing will be cancelled in the event of poor weather resulting in wet or icy pavement, or poor visibility.
9) The eye-tracking goggles will be held in place using a padded headband, and may be adjusted by the experimenter at any time.
10) The small eye-tracking cameras on the goggles will be aimed so as to not occlude any part of your field of view.
11) All components of the eye-tracking system (cameras and small infrared LED lights) are designed to operate well within the safe limits of exposure for humans.
12) On-road experimenters are in contact with in-vehicle experimenters to notify them when objects are in place.
13) All objects are chosen and placed such that impact with them will not harm the driver.
14) On-road experimenters will maintain a safe distance of at least 80 feet from all moving vehicles on the roadway, and will clear the roadway if that distance is breached, or if instructed by in-vehicle experimenters.

In the event of an accident or injury in an automobile owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of driver safety.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, 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. 1). At no time will the researchers release data identifiable to an individual to anyone other than VTTI staff working on the project without your written consent. All written and digital data associated with this project will be destroyed after seven years.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation

You will be paid $20.00 per hour for participating. You will be paid at the end of this study in cash. If you choose to withdraw before completing all scheduled experimental tasks, you will be compensated for the portion of time of the study for which you participated. If these payments are in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS.

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 that you completed. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw while you are driving on the test route, please inform the experimenter of this decision and he/she will provide you with transportation back to the building.

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. This form is valid for the period listed at the bottom of the page.

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.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat and lap belt.
4. To abstain from any substances that will impair your ability to drive.
5. To obey traffic regulations and maintain safe operation of the vehicle at all times.
6. To adhere to the posted speed limits on public roads, and to a 40 mph (maximum) speed limit on the Smart Road for this experiment.

X. Participant'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.

Participant's Name (Print) Signature Date

Experimenter's Name (Print) Signature Date

Should I have any questions about this research I may contact:

Ron Gibbons 231-1500

Travis Terry 231-1500

If I should have any questions about the protection of human research participants regarding this study, I may contact :

Dr. David Moore,

Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects

Telephone: (540) 231-4991;

Email: moored@vt.edu;

Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

Appendix B-2: Informed Consent (Non Eye-Tracking Participants)

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Development of Methodologies to Evaluate the Nighttime Safety Implications of the Roadway Visual Scene

Investigators: Dr. Ronald Gibbons, Chris Edwards, Brian Williams, and Jason Meyer

I. The Purpose of this Research/Project
The focus of this study is roadway lighting and night driving. We will be testing two roadway light sources and how they affect a driver's vision while driving at night. To test this, we will collect ratings and eye tracking data from the participant during the study. Once this data has been collected, we can determine the lighting type that is more reliable for vision and detection. Approximately 24 people will take part in the study.

II. Procedures
During the course of this experiment you will be asked to perform the following tasks:

1) Read this Informed Consent Form and sign it if you agree to participate.
2) Show your valid driver's license.
3) Complete vision tests.
4) Drive an instrumented vehicle on the Smart Road, and observe different video and audio data of the vehicle interior will be collected during the drive.
5) Complete questionnaires throughout the study.

For the Smart Road portion of the study, you will be exposed to pedestrians and other objects on and off of the roadway which you might normally encounter on public roads. Objects could be staying still or moving. Objects encountered on the road may include the following:

- Small wooden targets
- Pedestrians

It is important for you to understand that we are not evaluating you or your performance in any way. You are helping us to evaluate different lighting conditions and their effects on target detectability. The opinions you have will only help us do a better job of identifying factors that may improve a driver's vision during night driving. The information and feedback that you provide is very important to this project. Today's total experiment time will be approximately 2 hours.

III. Risks

There are risks or discomforts to which you may be exposed in volunteering for this research. They include the following:

For the Smart Road portion of the study, the risks to you are similar to that of driving an unfamiliar vehicle in clear weather conditions at night on a road with minimal traffic and various objects and pedestrians at up to 40 miles per hour.

Some studies at VTTI involve an unanticipated event. You may or may not encounter such an event during this study. Please be aware that events such as equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly.

Finally, due to the length of the study, you may experience fatigue.

The following precautions will be taken to ensure minimal risk to you:

1) An experimenter will monitor your driving and will ask you to stop if he or she feels the risks are too great to continue.
2) You are encouraged to take breaks if you desire, and may withdraw from the study at any time.
3) The experimenter will be present while you are driving. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe and legal manner.
4) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit.
5) The Smart Road will be closed to traffic not involved in the study.
6) If an accident does occur, the experimenter will arrange medical transportation to a nearby hospital emergency room. You may elect to undergo examination by medical personnel in the emergency room.
7) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case. Testing will be cancelled in the event of poor weather resulting in wet or icy pavement, or poor visibility.
8) On-road experimenters are in contact with in-vehicle experimenters to notify them when objects are in place.
9) All objects are chosen and placed such that impact with them will not harm the driver.

10) On-road experimenters will maintain a safe distance of at least 80 feet from all moving vehicles on the roadway, and will clear the roadway if that distance is breached, or if instructed by in-vehicle experimenters.

In the event of an accident or injury in an automobile owned or leased by Virginia Tech, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in an automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the automobile owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of driver safety.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, 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. 1). At no time will the researchers release data identifiable to an individual to anyone other than VTTI staff working on the project without your written consent. All written and digital data associated with this project will be destroyed after seven years.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation

You will be paid $20.00 per hour for participating. You will be paid at the end of this study in cash. If you choose to withdraw before completing all scheduled experimental tasks, you will be compensated for the portion of time of the study for which you participated. If these payments are in excess of $600 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS.

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 that you completed. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw while you are driving on the test route, please inform the experimenter of this decision and he/she will provide you with transportation back to the building.

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. This form is valid for the period listed at the bottom of the page.

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.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat and lap belt.
4. To abstain from any substances that will impair your ability to drive.

5. To obey traffic regulations and maintain safe operation of the vehicle at all times.
6. To adhere to the posted speed limits on public roads, and to a 40 mph (maximum) speed limit on the Smart Road for this experiment.

X. Participant'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.

Participant's Name (Print)   Signature   Date

Experimenter's Name (Print)   Signature   Date

Should I have any questions about this research I may contact:

Ron Gibbons	231-1500
Travis Terry	231-1500

If I should have any questions about the protection of human research participants regarding this study, I may contact :

Dr. David Moore,

Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects

Telephone: (540) 231-4991;

Email: moored@vt.edu;

Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

Appendix C: W-9 Tax Form

Substitute

Form W-9

Certification of Taxpayer Identification Number for Individuals

Please check one:

______ I am a U S citizen, or

______ I have been granted permanent residency (green card holder), or

______ I am a Resident Alien for tax purposes and have contacted Janet Kunz at 540-231-3754 or jakunz@vt.edu to discuss the additional documentation that is required by federal law.

1. Name

First: ____________________ Middle: __________________ Last: ________________________

2. U.S. taxpayer identification number (required)

____

3. Address (number, street, and apt. or suite no.)

____

4. City, State and ZIP code

____

Certification:
Under the penalties of perjury, I declare that to the best of my knowledge and belief, the above statements are true, correct, and complete and that:

1. The number shown on this form is my correct taxpayer identification number, **and**

2. I am not subject to backup withholding because: (a) I am exempt from backup withholding, or (b) I have not been notified by the Internal Revenue Service (IRS) that I am subject to backup withholding as a result of a failure to report all interest or dividends, or (c) the IRS has notified me that I am no longer subject to backup withholding, **and**

3. I am a U.S. person (including a U. S. resident alien).

Certification Instructions. You must cross out item 2 above if you have been notified by the IRS that you are currently subject to backup withholding because you have failed to report all interest and dividends on your tax return.

Signed:____ Date: ______________

Revised 1\05

Appendix D: Pre-Drive Health Screening

Participant #________________

1. Current age: ________ years old
2. Gender: Male Female
3. Are you in good general health? Yes No

   If "No", list any health-related conditions you are experiencing or have experienced in the recent past.

   ____

   ____

   ____

4. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

5. Do you have a history of any of the following?

   Visual Impairment Yes No

   (If yes, please describe.)

   ____

   ____

   ____

Seizures or other lapses of consciousness — Yes No

(If yes, please describe.)

____

____

Any disorders similar to the above or that would impair your driving ability — Yes No

(If yes, please describe.)

____

____

____

6. List any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours that may interfere with your ability to drive (e.g., medications that may cause drowsiness, medications that may make you dizzy).

____

____

7. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

____

8. Have you had any eye injury or surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery)

- □ Yes: Type of surgery/injury____
- □ No

9. How often do you drive at night?

- □ Less than 2 times per week
- □ 2 to 4 times per week
- □ More than 4 times per week

10. How comfortable are you driving at night?

- □ Very comfortable
- □ Somewhat comfortable
- □ Neutral
- □ Somewhat uncomfortable
- □ Very uncomfortable

For experimenter use only:

Visual test (Snellen):________

Contrast:

Right: A__ B__ C__ D__ E__

Left: A__B__C__D__E__

Color vision: ____________

____

____

____

BAT:

Right: Lo___ Mid___ High___

Left: Lo___ Mid___ High___

Appendix E: Post-Scenario Questionnaire

Participant # _____ Post Scenario Questionnaire Lighting Type____

1. Clothing color affected my ability to see the pedestrians.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

2. I feel I could see the pedestrians on the road from a safe distance.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

3. I feel I could see the targets on the road from a safe distance..

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

4. The roadway lighting increased the glare I experienced.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

5. I feel that the overhead lighting **did not** help in seeing objects sooner.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

6. The headlight glare reduced the distance at which I could see other objects under the overhead lighting.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

7. Comments:____
____
____

Appendix F: Post-Drive Questionnaire (Night Two)

Participant # ____ Second Night Questionnaire

1. How well would you rate your ability to compare and contrast the overhead lighting for tonight and your previous night driving experience at the Smart Road?

   1 2 3 4 5 6 7

   Not Very Well Very

2. Clothing color affected my ability to see pedestrians more so on the previous night versus tonight's light.

   1 2 3 4 5 6 7

   Strongly Strongly

   Disagree Agree

3. Overall, I noticed a clear difference between the previous night's roadway lighting and the roadway lighting used tonight.

   1 2 3 4 5 6 7

   Strongly Strongly

   Disagree Agree

4. Under which lighting condition could you see pedestrians more easily?
   (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference

   Participant Comments:

   ____

   ____

   ____

5. Under which lighting condition could you see targets more easily?
   (Check one answer)

- ☐ Previous night
- ☐ Tonight
- ☐ There was no difference

Participant Comments:

____

____

____

6. Of the two types of overhead lighting used, which allowed you to detect pedestrians sooner? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

7. Of the two types of overhead lighting used, which allowed you to detect targets sooner? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

8. Of the two types of overhead lighting used, which was more glaring? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

____

____

____

9. I thought that I would be able to detect pedestrians in the road _______ than I did for either night. (Check one answer)
   - ☐ Sooner
   - ☐ Later
   - ☐ At about the same time

   Participant comments:

   ____

   ____

   ____

10. I thought that I would be able to detect targets in the road _______ than I did for either night. (Check one answer)
    - ☐ Sooner
    - ☐ Later
    - ☐ At about the same time

    Participant comments:

    ____

    ____

    ____

11. I much prefer the previous night's roadway light over the tonight's roadway light.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

12. If you were to design overhead roadway lighting, how would you improve upon existing designs?

    ____

Appendix G: Post-Drive Questionnaire (Third Night)

Participant #_____ Third Night Questionnaire

1. How well would you rate your ability to compare and contrast the overhead lighting for tonight and your previous night driving experience at the Smart Road?

   1 2 3 4 5 6 7

   Not Very Well Very

2. Clothing color affected my ability to see pedestrians more so on the previous night versus tonight's light.

   1 2 3 4 5 6 7

   Strongly Strongly

   Disagree Agree

3. Overall, I noticed a clear difference between theprevious night's roadway lighting and the roadway lighting used tonight.

   1 2 3 4 5 6 7

   Strongly Strongly

   Disagree Agree

4. Under which lighting condition could you see pedestrians more easily?
   (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference

   Participant Comments:

   ____

   ____

   ____

   ____

5. Under which lighting condition could you see targets more easily?
 (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference

   Participant Comments:

   ____

   ____

   ____

   ____

6. Of the two types of overhead lighting used, which allowed you to detect pedestrians sooner? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

   ____

7. Of the two types of overhead lighting used, which allowed you to detect targets sooner? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

____

8. Of the two types of overhead lighting used, which was more glaring? (Check one answer)
   - ☐ Previous night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

   ____

9. I thought that I would be able to detect pedestrians in the road ________ than I did for either night. (Check one answer)
   - ☐ Sooner
   - ☐ Later
   - ☐ At about the same time

   Participant comments:

   ____

   ____

   ____

   ____

10. I thought that I would be able to detect targets in the road ________ than I did for either night. (Check one answer)
    - ☐ Sooner
    - ☐ Later
    - ☐ At about the same time

    Participant comments:

    ____

    ____

    ____

____

11. I much prefer the previous night's roadway light over the tonight's roadway light.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

12. How well would you rate your ability to compare and contrast the overhead lighting for tonight and your first night driving experience at the Smart Road? (Omitting the second night)

1	2	3	4	5	6	7
Not Very Well						Very

13. Clothing color affected my ability to see pedestrians more so on the first night versus tonight's light.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

14. Overall, I noticed a clear difference between the first night's roadway lighting and the roadway lighting used tonight.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

15. Under which lighting condition could you see pedestrians more easily? (Check one answer)
    - ☐ First night
    - ☐ Tonight
    - ☐ There was no difference

    Participant Comments:

    ____

    ____

    ____

    ____

16. Under which lighting condition could you see targets more easily?
(Check one answer)
- ☐ First night
- ☐ Tonight
- ☐ There was no difference

Participant Comments:

____

____

17. Of the two types of overhead lighting used, which allowed you to detect pedestrians sooner? (Check one answer)
- ☐ First night
- ☐ Tonight
- ☐ There was no difference between the two types of lighting

Participant comments:

____

____

____

____

18. Of the two types of overhead lighting used, which allowed you to detect targets sooner? (Check one answer)
- ☐ First night
- ☐ Tonight
- ☐ There was no difference between the two types of lighting

Participant comments:

____

____

____

____

19. Of the two types of overhead lighting used, which was more glaring? (Check one answer)
   - ☐ First night
   - ☐ Tonight
   - ☐ There was no difference between the two types of lighting

   Participant comments:

   ____

   ____

   ____

   ____

20. I thought that I would be able to detect pedestrians in the road _______ than I did for either night (First and Tonight). (Check one answer)
   - ☐ Sooner
   - ☐ Later
   - ☐ At about the same time

   Participant comments:

   ____

   ____

   ____

   ____

21. I thought that I would be able to detect targets in the road _______ than I did for either night. (First and Tonight) (Check one answer)
   - ☐ Sooner
   - ☐ Later
   - ☐ At about the same time

   Participant comments:

   ____

   ____

   ____

---

22. I much prefer the first night's roadway light over the tonight's roadway light.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

23. Overall, which lighting did you prefer? (Circle One)
    The first night
    The second night
    Tonight
    None

Appendix H: In-Vehicle Protocol: Setup & Greeting

Object COLOR

Nightly Research Preparation

- **Meet with on-road crew and discuss**
    - Current readiness (i.e., equipment, and scheduled staff)
    - Current assignments (i.e., responsibilities of in-vehicle and on-road experimenters)
    - Previous difficulties encountered
    - Future readiness (equipment condition, on-road personnel availability, etc.)
- **Experimenter 1**
    - Check current weather and forecasts. Cancel session for any conditions that might reduce visibility (rain, fog, etc.)
    - Prepare participant numbers and address participant forms accordingly
    - Check email for any possible changes with Smart Road scheduling or potential absences of on-road help
    - Check that no participants have called to cancel their scheduled session
    - Collect participant packets, order-sheets, and 2 radios with headsets for the in-vehicle experimenters, 2 flashlights, and laser pointer
- **Check participant order sheet to determine:**
    - Correct lighting configuration, which should be communicated to the lead on-road experimenter who will radio dispatch to turn the lights on at the appropriate time.
    - The correct vehicle order, so in-vehicle experimenters know which participant will start at the bottom, and which participants will start at the top of the road
- **Prepare conference room for participants**
    - From Funky Town/Lighting Lab, bring:
        - BAT
        - Color vision test
        - Eye occluder
        - Alcohol and cotton balls
    - Close all shades
    - Turn on all overhead lights
    - Turn off halogen lamps
    - Position work light for contrast sensitivity chart. Place chairs or tables around the light to prevent anyone from being burned.
- **Vehicle setup**
    - Get the vehicle keys for Blanca 1 and 2 from lockbox in Funky Town
        - Make sure vehicles are clear of trash and clutter
        - Make sure vehicles have at least a half tank of gas
        - Clean the windshields
    - Park vehicles by front door

        - Reverse both explorers
        - Leave the vehicles running
    - Start DAS
        - No Protocol for this yet?

Greeting and Eye Exams

- **Record the participant's arrival time on the payment form**
- **Informed Consent Form**
    - The first participant to arrive will be the eye-tracking participant
        - Give the participant the appropriate informed consent
    - Encourage the participant to read the entire form
    - Offer to answer any questions they may have
    - Ask to see the participant's driver's license as they read the form
        - Check for expiration date and validity
- **W9 Tax Form**
    - If asked, the taxpayer ID number is the same as their SSN
    - If asked what the form is for, you may reply:
        - *This says that while we are paying you, we are not hiring you full time. There won't be any health benefits or paid vacation, etc. We cannot fire you because we are not really hiring you. You can quit at anytime without being held liable for services by the University. You are a one-time contractor. If you already work for Tech, this is completely separate from your job, and your performance will not have any effect on your employment with Virginia Tech.*
- **Health Screening Questionnaire**
    - Ask the participant to fill out the form, and answer any questions they may have
- **Snellen Eye Chart**
    - Ask the participant to stand with their toes behind the 20ft line
    - Ask them to read the lowest line that they can read all the way through.
        - If they get every letter correct, ask them if they would like to try the next line down. Continue until they make a mistake and mark their acuity score as the most recent line they got entirely correct
        - If they make a mistake, ask them to read the next line up. Continue until they get a line entirely correct, and record that as their acuity score
        - A minimum score of 20/40 for both eyes together is required to participate.
- **Contrast Sensitivity Chart**
    - Ask the participant to stand with their toes behind the 10ft line
    - Point out the sample patches at the bottom of the cart with the three possible responses (left, right, or up)
    - Ask the participant to cover their right eye with the occlude
    - Instruct the participant to begin with row A and identify which way the lines tilt, starting at column 1 and going across until they can't see any more lines

- Record the last column they got correct for row A on the vision test form
  - Repeat these steps for all rows and then again with the same participant covering their left eye
- **Brightness Acuity Test (BAT)**
  - Ask the participant to return to the 20ft marking for the Snellen eye chart
  - Give the participant the BAT and instruct them to look through it with one eye, while covering the other eye
  - Repeat the Snellen protocol for each eye for all levels of the BAT (off, low, medium, and high)
  - Record the results
  - To prevent the participant from memorizing lines of the chart, sometimes ask them to read lines backwards or to read extra lines
- **Color Vision Test**
  - Ask the participant to sit back down where they completed the paperwork
  - Place the color vision test book on the table facing the participant and ask them to hold the red tip of the bar to their nose
  - One at a time, flip the pages of the test and ask the participant to identify what number they see
  - Record each answer on the vision test form
- **Pre-Drive Questionnaire**
  - Ask the participant to answer all questions on the questionnaire

Participant Orientation

- **Script to participants**

  Tonight you will drive a sport utility vehicle on the Smart Road. Our primary interest is the effect of different light sources on visibility. As you drive up and down the road, objects will appear that we would like for you to identify. Objects that may appear include pedestrians and wooden targets [show participant the target]. *The objects may appear either on the shoulder of the roadway, or beyond the guardrail* [show participant the picture of the offaxis target]. *We would like for you to identify when you can first see these objects by verbally identifying them. For example, you would say "Pedestrian" or "Target" depending on what object is presented. Then we'd like you to identify the color of the object. Pedestrians will be wearing either black or blue clothing, and targets may be blue, gray, green or red. Try to be very clear when you identify the objects and their colors, and please try to avoid sounds of uncertainty such as "uh" or "um" as we want to determine your exact point of detection as best we can.*

  For safety, the targets are designed to break on impact so there is no danger if you accidentally hit one during the study. Also, the pedestrians *have been instructed to move to the shoulder if we start getting too close to them.*

I will be in the vehicle with you at all times to record data and instruct you where to drive. I can also answer any questions you have during the study.

During the experiment there will be one other vehicle on the road. The other vehicle will be the other participant vehicle. That vehicle will be driving on the opposite end of the road, and we should not pass it during the study.

The speed limit for tonight's study will be 40 mph, and we'll drive with low-beams on at all times.

Do you have any questions?

- **Offer participants opportunity for restroom and/or drink of water from water fountain before leaving the building**
- **Escort the participant to their vehicle**
    - Remember to bring radio, binder, flashlight, and laser pointer [If eye-tracking participant]

Appendix I: Research Protocol
OBJECT COLOR

Escort Participants to the Experimental Vehicles

- Before the participant enters the vehicle, instruct them on how to adjust the steering wheel, seat, and mirrors to fit their comfort
- The participant who will wear the eye-tracker during the study will be directed to park in the Bay 3 area to calibrate the equipment while the other participant arrives and is greeted
- Once the eye-tracker has been calibrated and the other participant (not wearing the eye-tracker) has been greeted and situated inside the vehicle, the cars may enter the road.

Entering the Road

- The experimenter in Vehicle 1 should radio dispatch that **both** vehicles are entering the Smart Road
  - "Dispatch, do you copy Dispatch?"
  - "We have Blanca 1 and 2 entering through the main gate for White Light, please"
- Once through the gate, instruct the participants to drive through the upper turnaround and stop at Turnaround 2

Practice Lap

- When both vehicles get to Turnaround 2, the Vehicle 1 experimenter should confirm that the road is ready by radioing the lead on-road experimenter
- Instruct the participant to begin a practice lap:
  - *We're going to start tonight's session by driving a practice lap. The purpose of the practice lap is to familiarize you with the vehicle and the route you will be driving. We may begin when you are ready, and remember that the speed limit is **35mph.***
- Vehicle 2 will begin their practice lap first. Once beyond the sign bridge, the lead on-road experimenter will radio to Vehicle 1 that they are clear to begin their practice lap

Data Collection

- **Object Detection**
  - As participants drive laps up and down their portion of the road (upper or lower), several objects will be presented (e.g. pedestrians, small targets, tire treads, deer decoys)
  - When the participant can identify the object, they will say aloud what the object is (e.g., "pedestrian" or "tire"). Press the button to mark the detection distance.
  - If a pedestrian is being presented, ask them to clear once the participant has detected them
    - Radio: "Clear Station [#]"

    - Press the button a second time when the vehicle passes the object to mark its location in the data
        - The button should be pressed when the object, participant, and the experimenter are lined up.
    - If an erroneous button press occurs, make a note of it on the in-vehicle note sheet
    - Once each participant has completed the first 3 laps on the Smart Road, ask them to return to Turnaround 2
        - Radio the lead on-road and tell them you are ready for the next lighting configuration
        - Administer the Post-Task questionnaire. Use the lights in the overhead visors for participants to see
    - When the lead on-road indicates that the road and lights are ready, have the participants drive the final 3 laps on the opposite end of the road. No practice lap is necessary.
    - Once these laps are finished, return to Turnaround 2
        - Administer another Post-Task questionnaire for the 3 laps just completed.

Leaving the Road

- Once each participant has completed all laps and questionnaires, instruct them to leave the road by driving to the main gate
- Both vehicles should exit the road together, with the experimenter in the lead vehicle radioing dispatch
    - “Dispatch, do you copy Dispatch?”
    - “We have Blanca 1 and 2 ready to exit through the main gate please.”

Appendix J: In-Vehicle Experimenter Scripts

OBJECT COLOR

In Building

Tonight you will drive a sport utility vehicle on the Smart Road. Our primary interest is the effect of different light sources on visibility. As you drive up and down the road, objects will appear that we would like for you to identify. Objects that may appear include pedestrians and wooden targets [show participant the target]. *The objects may appear either on the shoulder of the roadway, or beyond the guardrail* [show participant the picture of the offaxis target]. *We would like for you to identify when you can first see these objects by verbally identifying them. For example, you would say "Pedestrian" or "Target" depending on what object is presented. Then we'd like you to identify the color of the object. Pedestrians will be wearing either black or blue clothing, and targets may be blue, gray, green or red. Try to be very clear when you identify the objects and their colors, and please try to avoid sounds of uncertainty such as "uh" or "um" as we want to determine your exact point of detection as best we can.*

For safety, the targets are designed to break on impact so there is no danger if you accidentally hit one during the study. Also, the pedestrians have been instructed to move to the shoulder if we start getting too close to them.

I will be in the vehicle with you at all times to record data and instruct you where to drive. I can also answer any questions you have during the study.

During the experiment there will be one other vehicle on the road. The other vehicle will be the other participant vehicle. That vehicle will be driving on the opposite end of the road, and we should not pass it during the study.

The speed limit for tonight's study will be 40 mph, and we'll drive with low-beams on at all times.

Do you have any questions?

Practice Lap

We're going to start tonight's session by driving a practice lap. The purpose of the practice lap is to familiarize you with the vehicle and the route you will be driving. We may begin when you are ready, and remember that the speed limit is ***40 mph****. (While driving, you can urge them to keep it between 35 and 40).*

Begin Laps (after practice lap)

For the next part of the study, we're going to drive 4 laps around the Smart Road, and you'll identify objects that you see in the roadway. Just as a reminder, the objects you may see are pedestrians and targets, and you can just verbally identify these when you see them as well as their color. We will begin driving on the [(1) upper, (2) lower] *portion of the road, while the* *other participant vehicle drives on the* [upper or lower] *portion. When we're through, we'll stop to do a short questionnaire. Again, the speed limit is **40 mph.** Do you have any questions?*

Appendix K: Payment and Shutdown

OBJECT COLOR

Escort Participants back to Building 1

- Bring in any questionnaires, order sheets, or note sheets
- Offer the participants an opportunity to use the restroom and/or get a drink of water
- Administer the post-drive questionnaire and ask them to complete it while you retrieve their payment
- One experimenter should stay with the participants while the other gets the payment

Payment

- Each participant should receive $20 per hour
    - Round up to the nearest half-hour
        - An authorized account holder must sign each check
- Record the participant's time-out, total time and payment amount on the receipt form
- Participants will be paid via a mailed check
- Participants are awarded a bonus of $30 for completing all three nights of the study
- Have each participant fill out the payment log

Shutdown

- Packets
    - Put all questionnaires, forms, and note sheets in the appropriate participant packet, and place the packets on the "to be entered" spot on the shelf in Funky Town
- Return radios, headsets, flashlights and binders to Funky Town
- Download Data; remove hard-drives from vehicles and upload them to the server

Meet with On-Road Experimenters

- Discuss any problems that arose during the study
- Get volunteers to fuel the participant and other on-road vehicles

Appendix L: Confederate On-Road Preparation Protocol
OBJECT COLOR

Dress Appropriately

- Wear short sleeves so that your shirt will not be visible beneath the scrubs
- Wear pants or shorts that allow the scrubs to fit over top
- Wear non-reflective shoes (as dark as possible)
- You may wear a jacket when not standing as a pedestrian

Meet with Research Crew

- Discuss:
    - Current readiness (i.e. equipment and scheduled staff)
    - Current assignments (i.e., responsibilities of in-vehicle and on-road experimenters)
    - Previous difficulties encountered
    - Future readiness (equipment condition, on-road personnel availability, etc.)
- Collect the order sheet for your assigned station

Equipment Preparation

- Each confederate will be given an order sheet which details the equipment you will need to take with you to your station
- Equipment will likely include

Pair of colored scrubs from Bay 4

Flash light

Keys to a transport vehicle

Road Cones

Targets and stands

Radios

Setting up the Road

- Once on the Smart Road, make sure there are no obstacles or debris on the road near your station
- Clear the road, including yourself, and await the practice lap

Appendix M: Confederate On-Road Research Protocol

OBJECT COLOR

Object Detection Tasks

- The in-vehicle experimenters will radio to announce each time the vehicle is heading up or down the road
    - "Vehicle 1, down 1"
    - "Vehicle 1, up 1"
- Each on-road experimenter should have their station setup for the current run
    - Radio the lead on-road if there is a problem preventing you from getting your station ready
    - The lead on-road will acknowledge the in-vehicles' messages by repeating
        - "Copy, Vehicle 1, down 1"
    - If there is a problem, the lead on-road should ask the in-vehicle experimenters to wait. Once the problem has been solved, ask the in-vehicle experimenters to continue their lap
- <u>Object Presentation</u>
    - When on the road as a **<u>pedestrian</u>**, stand 1 foot inside the white edge line in the participant's lane. Stand facing the vehicle with your arms by your side and your feet together.
    - When presenting a **<u>target</u>,** it should be placed 2 feet inside the white edge line
    - A **<u>catch</u>** trial means that no object or pedestrian should be presented

Leaving the Smart Road

- After both participants have finished they will return to Turnaround 2
- At this point, the on-road experimenters should begin picking up any items used at their stations, and placing them in the glare vehicles
    - Targets and target stands
    - Order Sheets, cones, etc.
- The lead on-road should ask Dispatch to turn off the overhead lighting
        - "Dispatch, do you copy Dispatch?"
        - "The lights can be turned off now, we're finished"
    - Once the participant vehicles have exited the road, the on-road experimenters should meet by the gate and all exit together. The lead car should radio Dispatch to request the gate be opened as well as remind Dispatch that the study is finished.

Shutting Down

- Return to VTTI
- Check fuel levels in all vehicles

    - If the vehicle needs fuel, keep the keys and bring them to the post study meeting
    - Vehicles should be fueled if they are at least 50% or less
- Return:
    - Scrubs to Bay 4
    - Cones, Targets, Target stands to Bay 4
    - Radios to Funky Town
        - Place them in the chargers and make sure they are off
    - Order sheets to Funky Town
    - Keys to lockbox in Funky Town
- Meet with the in-vehicle experimenters
    - Discuss any issues that arose during the study
    - The in-vehicle experimenters will ask for volunteers to fuel any vehicles that need it.

Appendix N: Eye Tracker Protocol

Eye Tracker Protocol

INITIATING EYE TRACKER AND VIEW POINT PROGRAM

- Checklist of hardware items for in-vehicle
  - Keyboard
  - USB Mouse
  - Shuttle Box
  - Shuttle Box power cord
  - Monitor
  - Monitor – Shutter Box cable
  - Monitor AC adapter
  - Eye-tracker
  - Eye-tracker AC adapter
  - Laser Pointer
- Turn on Shuttle-Box and monitor after all necessary hardware is properly plugged in (No password required for Log-in)
- Double click the "View Point" application short-cut icon on the desktop to begin the software
- Click the white "Arrington Research" box to continue once the program is loaded

ADJUSTING CAMERAS and LEDS TO EYES

- Go to *Binocular* > *Binocular Mode* to bring up cameras for eyes A & B.
- Also, within the *Binocular* menu, select *Show average of eye positions* so that only one tracking dot will appear, instead of two
- Go to *Stimuli* > *View Source* and select *Head Mounted Scene Camera*
- First make sure the head mounted scene camera clearly represents what the subject is looking at. Adjust if needed.
  - Ask subject to look straight ahead and focus on an object directly in their line of view. If the object is in the center of the scene camera, the head mounted camera is positioned correctly
- Adjust the cameras so that they are focused straight into the eye from a horizontal direction and provide enough light via the LED that when the subject looks in all four directions, the pupil remains encircled on the ViewPoint screen.
  - Adjust until the pupil remains focused and does not flutter
  - Make sure the LEDs do not show up in the camera view
- *(When adjusting the cameras and lights while a subject is wearing the instrumentation, be conscientious of their eyes and avoid causing discomfort)*

CALIBRATING THE EYE-TRACKER

- Position the vehicle approximately 10 feet away from the Bay 3 door
- To calibrate, ready the Laser Pointer and maximize the head mounted scene display window
    - To avoid the participant focusing on the refraction of the laser on the windshield, roll down the passenger side window to point the laser
- Instruct the participant that when you position the red laser point and say "Now" or "Here" for them to look at that point outside of the windshield and say "Okay" when they are gazing at it.
- For each circle on the screen (Within the GazeSpace window) that is blue, aim the laser pointer out the windshield until you see it within that circle on the computer screen, say "Now"
- Once the participant confirms, immediately press the F8 key to record that position and do the same thing for the rest of the blue circles until you notice the tracking dot becoming extremely accurate.
- Once you feel the tracking is accurate, minimize the head mounted scene display window and view the calibration points in the EyeSpace windows for eyes A & B.
- If calibrated correctly, the calibration points should form a relatively neat rectangle. If the points are not rectangular or there are some rogue points, continue with the calibration until you are satisfied
    - If after several trials, the EyeSpace window still does not represent a rectangular calibration area, refer back to adjusting the cameras on the eyes and making sure the pupil remains focused in extreme gaze directions (up, down, left, and right)
    - If after several trials and several attempts at adjusting the camera, there are still points outside of the rectangle, omit those points by selecting *Omit* in the respective EyeSpace window for eye A or B after selecting the appropriate point(s).

COLLECTING VIDEO & DATA

- Before collecting data be sure to click the *Display* tab on the center control box and deselect *Tracker, Display Grid, and Calibration Box*
- To collect data, go to File > Data > New Data File **OR** press Control + N
- To stop data collection, File > Data > Close Data File` **OR** press Control + U

APPENDIX O: ANCOVA Results for Target Detection

Weber Contrast as covariate.

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	2053.572547	2053.572547	0.43	0.5183

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux	1	293.5873200	293.5873200	0.20	0.6608
lux*agecat	1	92.8581056	92.8581056	0.06	0.8049

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color	3	14498.01814	4832.67271	4.26	0.0078
color*agecat	3	7153.30811	2384.43604	2.10	0.1070

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	5262.116090	5262.116090	2.23	0.1515
lighting*agecat	1	213.316633	213.316633	0.09	0.7668

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color	2	13708.61881	6854.30940	3.18	0.0658
lux*color*agecat	2	1321.79986	660.89993	0.31	0.7399

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*lighting	1	1538.043174	1538.043174	0.79	0.3952
lux*lighting*agecat	1	3516.320026	3516.320026	1.80	0.2089

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color*lighting	3	6641.422026	2213.807342	1.06	0.3934
color*lightin*agecat	2	2485.969037	1242.984518	0.59	0.5636

APPENDIX P: ANCOVA Results for Pedestrian Detection

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	15182.11660	15182.11660	0.26	0.6129

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux	1	37718.83677	37718.83677	1.85	0.1835
lux*agecat	1	77477.57406	77477.57406	3.80	0.0602

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color	1	92534.16295	92534.16295	4.15	0.0499
color*agecat	1	1234.72433	1234.72433	0.06	0.8154

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	9545.44912	9545.44912	0.19	0.6683
lighting*agecat	1	11871.76438	11871.76438	0.24	0.6330

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color	1	25218.43275	25218.43275	0.99	0.3317
lux*color*agecat	1	1092.81813	1092.81813	0.04	0.8381

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*lighting	1	134.6602608	134.6602608	0.02	0.8776
lux*lighting*agecat	1	957.6120433	957.6120433	0.18	0.6825

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color*lighting	1	7850.02426	7850.02426	0.42	0.5347
color*lightin*agecat	1	15070.74087	15070.74087	0.80	0.3944

Tests of Hypotheses Using the Type III MS for sub*lux*col*lig(age) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color*lighting	1	2169.064583	2169.064583	0.26	0.6430
lux*colo*light*ageca	0	0.000000	.	.	.

APPENDIX Q: ANOVA Results for Target Detection

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
agecat	1	0.00731061	0.00731061	0.02	0.8931

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lux	1	0.01671038	0.01671038	0.11	0.7438
lux*agecat	1	0.01190755	0.01190755	0.08	0.7826

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
color	3	0.12160976	0.04053659	0.35	0.7857
color*agecat	3	0.91604430	0.30534810	2.67	0.0531

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lighting	1	0.00017041	0.00017041	2.17	0.1572
lighting*agecat	1	0.01405680	0.01405680	0.06	0.8093

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lux*color	2	2.00666761	1.00333380	5.03	0.0184
lux*color*agecat	2	0.08804989	0.04402494	0.22	0.8041

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lux*lighting	1	0.08413884	0.08413884	0.47	0.5104
lux*lighting*agecat	1	0.06028256	0.06028256	0.33	0.5762

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
color*lighting	3	0.31014982	0.10338327	0.39	0.7594
color*lightin*agecat	2	0.09394786	0.04697393	0.18	0.8379

Tests of Hypotheses Using the Type III MS for sub*lux*col*lig(age) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lux*color*lighting	2	1.29692148	0.64846074	1.29	0.5290
lux*colo*light*ageca	0	0.00000000	.	.	.

APPENDIX R: ANOVA Results for Pedestrian Detection

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	0.03651055	0.03651055	0.21	0.6536

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux	1	0.00923754	0.00923754	0.14	0.7087
lux*agecat	1	0.27964526	0.27964526	4.30	0.0462

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color	1	0.32806254	0.32806254	3.54	0.0689
color*agecat	1	0.00009770	0.00009770	0.00	0.9743

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	0.44241273	0.44241273	2.59	0.1243
lighting*agecat	1	0.06774212	0.06774212	0.40	0.5367

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color	1	0.07075744	0.07075744	1.00	0.3289
lux*color*agecat	1	0.00239772	0.00239772	0.03	0.8558

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*lighting	1	0.12433453	0.12433453	2.86	0.1214
lux*lighting*agecat	1	0.02524256	0.02524256	0.58	0.4633

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color*lighting	1	0.00719611	0.00719611	0.09	0.7719
color*lightin*agecat	1	0.06129132	0.06129132	0.76	0.4058

Tests of Hypotheses Using the Type III MS for sub*lux*col*lig(age) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color*lighting	1	0.03156649	0.03156649	7.47	0.0718
lux*colo*light*ageca	0	0.00000000	.	.	.

APPENDIX S: ANOVA Results for Off-Axis Ped Detection

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
agecat	1	41040.58408	41040.58408	1.91	0.1776

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lighting	1	9797.87870	9797.87870	0.65	0.4305
lighting*agecat	1	21803.46248	21803.46248	1.46	0.2451

APPENDIX T: ANOVA Results for Off-Axis Target Detection

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
agecat	1	36.51000056	36.51000056	0.00	0.9631

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lighting	2	100266.2047	50133.1024	2.00	0.1577
lighting*agecat	2	5324.7225	2662.3612	0.11	0.8998

APPENDIX U: ANOVA Results for Target Color Recognition

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	0.03762893	0.03762893	0.06	0.8138

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux	1	0.05295362	0.05295362	0.17	0.6874
lux*agecat	1	0.00954216	0.00954216	0.03	0.8642

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color	3	2.00675386	0.66891795	3.12	0.0315
color*agecat	3	2.86554073	0.95518024	4.46	0.0064

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	0.00438385	0.00438385	0.48	0.4988
lighting*agecat	1	1.80181866	1.80181866	6.61	0.0192

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color	2	3.45849838	1.72924919	7.41	0.0106
lux*color*agecat	1	0.64439982	0.64439982	2.76	0.1276

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*lighting	1	1.28309054	1.28309054	14.81	0.0120
lux*lighting*agecat	1	0.02067410	0.02067410	0.24	0.6459

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color*lighting	3	0.55545821	0.18515274	1.99	0.2584
color*lightin*agecat	2	1.76157846	0.88078923	9.45	0.0305

Tests of Hypotheses Using the Type III MS for sub*lux*col*lig(age) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color*lighting	1	0.00652357	0.00652357	2.62	0.1358.
lux*colo*light*ageca	0	0.00000000	.	.	.

APPENDIX V: ANOVA Results for Pedestrian Clothing Color Recognition

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	11.75884952	11.75884952	11.91	0.0016

Tests of Hypotheses Using the Type III MS for subnum*lux(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux	1	2.45151412	2.45151412	9.35	0.0048
lux*agecat	1	0.41765248	0.41765248	1.59	0.2169

Tests of Hypotheses Using the Type III MS for subnum*color(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color	1	0.00474400	0.00474400	0.01	0.9063
color*agecat	1	0.69675888	0.69675888	2.07	0.1609

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	2.07952933	2.07952933	2.53	0.1299
lighting*agecat	1	1.05647865	1.05647865	1.29	0.2723

Tests of Hypotheses Using the Type III MS for subn*lux*colo(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color	1	0.05743124	0.05743124	0.18	0.6806
lux*color*agecat	1	0.33358156	0.33358156	1.02	0.3270

Tests of Hypotheses Using the Type III MS for subn*lux*ligh(ageca) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*lighting	1	0.03136321	0.03136321	0.12	0.7405
lux*lighting*agecat	1	0.73492929	0.73492929	2.73	0.1326

Tests of Hypotheses Using the Type III MS for subn*colo*ligh(agec) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
color*lighting	1	0.26389582	0.26389582	3.61	0.1061
color*lightin*agecat	1	0.53739844	0.53739844	7.35	0.0350

Tests of Hypotheses Using the Type III MS for sub*lux*col*lig(age) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lux*color*lighting	1	1.95786013	1.95786013	10.62	0.0472
lux*colo*light*ageca	0	0.00000000	.	.	.

APPENIDX W: ANOVA Results for Off-Axis Target Color Recognition

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
agecat	1	53717.91088	53717.91088	9.59	0.0053

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
lighting	1	333.487189	333.487189	0.04	0.8483
lighting*agecat	1	6680.302050	6680.302050	0.78	0.4012

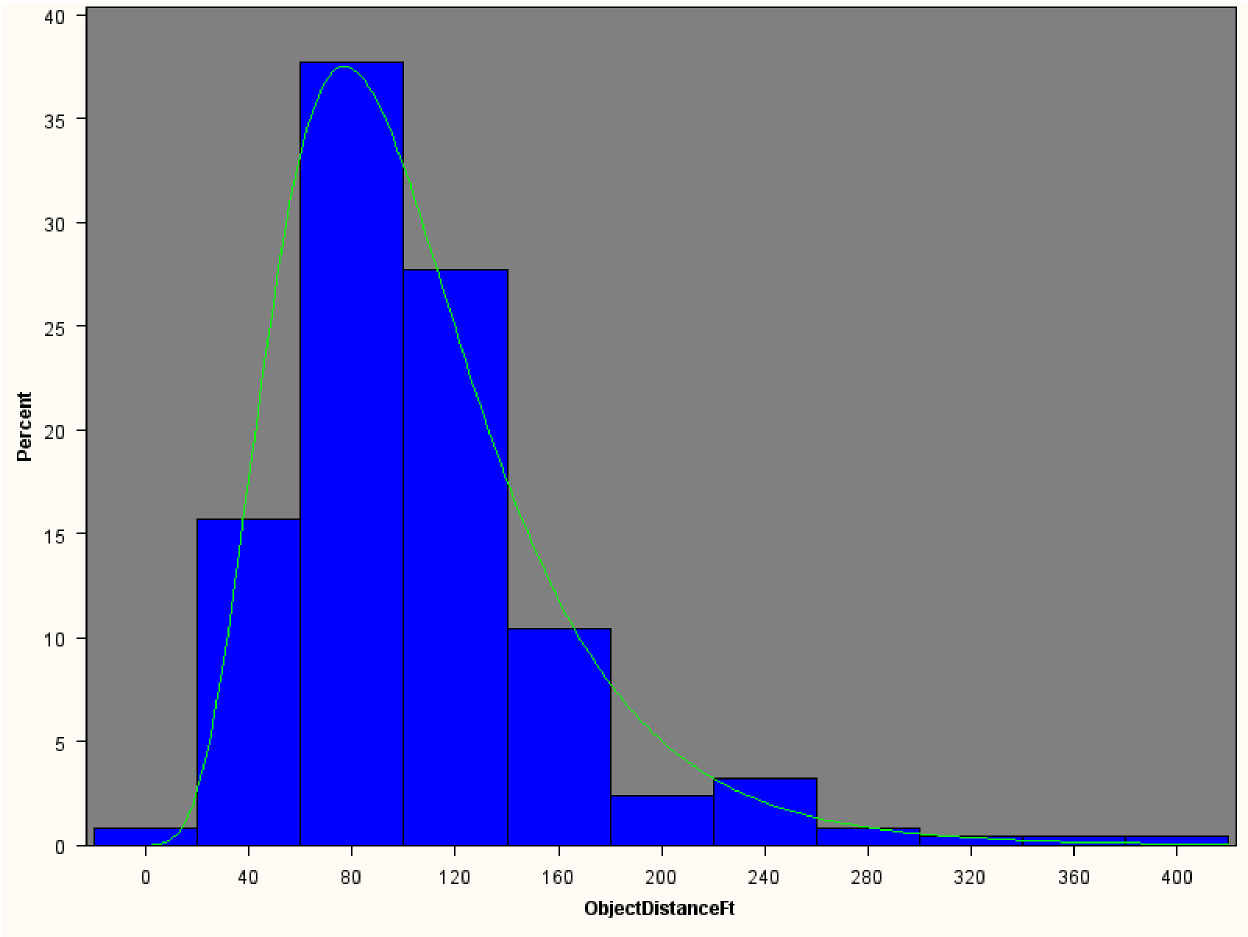
APPENDIX X: ANOVA Results for Off-Axis Pedestrian Clothing Color Recognition

Tests of Hypotheses Using the Type III MS for subnum(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
agecat	1	84588.25963	84588.25963	5.65	0.0243

Tests of Hypotheses Using the Type III MS for subnu*lighti(agecat) as an Error Term					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
lighting	1	21693.52242	21693.52242	0.96	0.3425
lighting*agecat	1	12930.44607	12930.44607	0.57	0.4609

Appendix Y: Tests for Normality

Target Detection



Basic Statistical Measures			
Location		**Variability**	
Mean	105.7052	**Std Deviation**	55.77857
Median	94.3898	**Variance**	3111
Mode	81.2008	**Range**	391.33858
		Interquartile Range	56.33202

Goodness-of-Fit Tests for Lognormal Distribution				
Test	**Statistic**		**p Value**	
Kolmogorov-Smirnov	**D**	0.04481608	**Pr > D**	0.169
Cramer-von Mises	**W-Sq**	0.05246349	**Pr > W-Sq**	>0.250
Anderson-Darling	**A-Sq**	0.40370193	**Pr > A-Sq**	0.227

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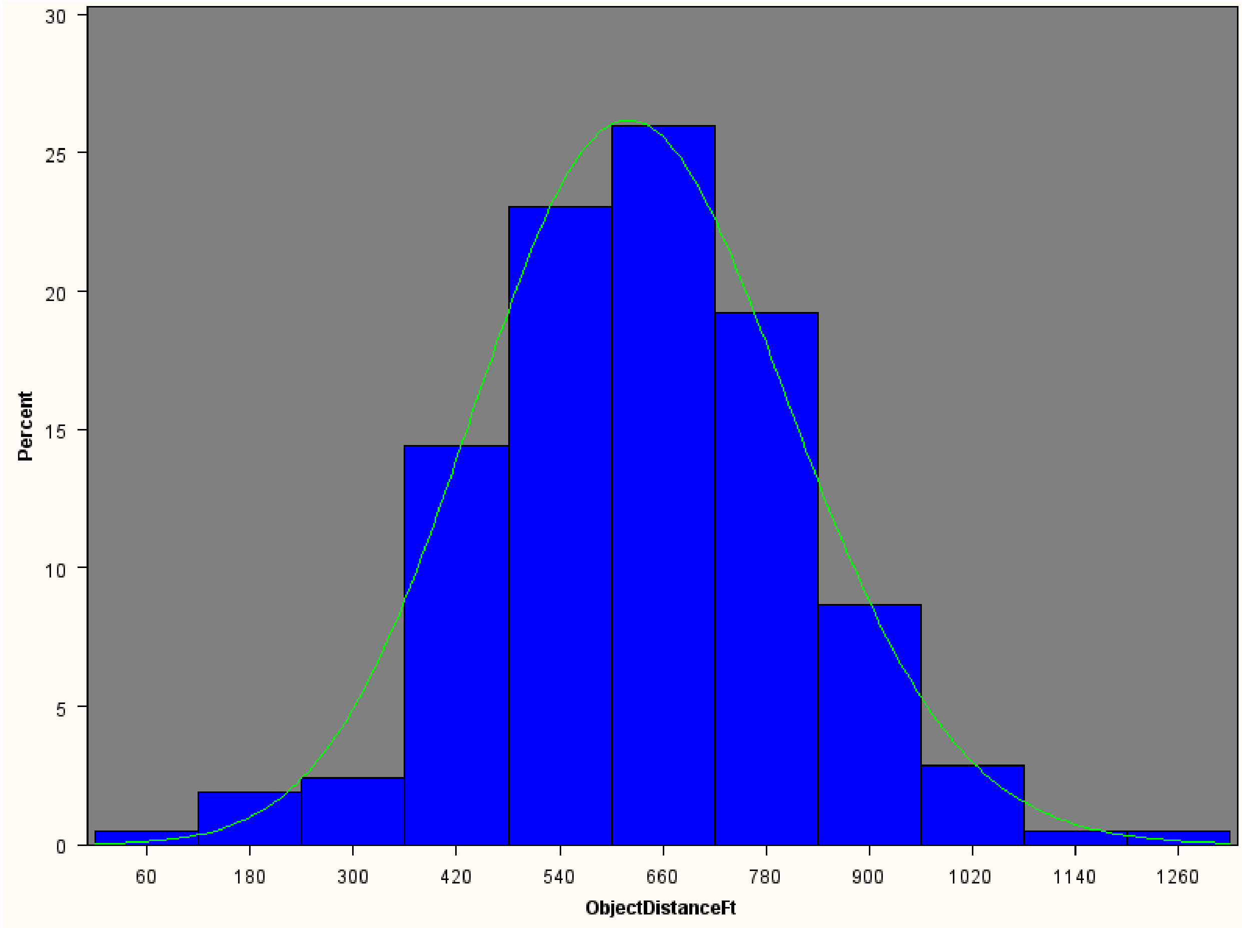
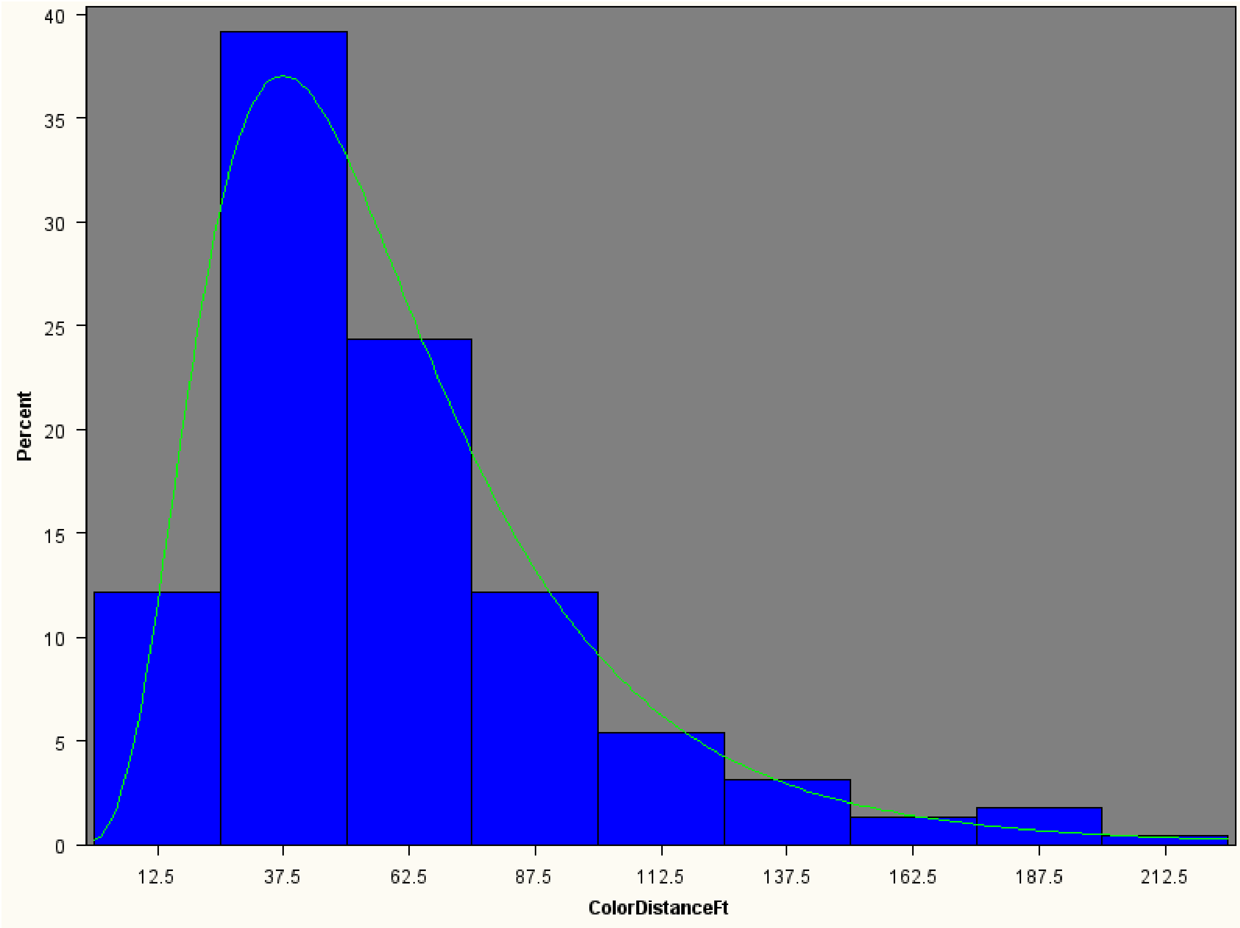
Pedestrian Detection



Basic Statistical Measures			
Location		Variability	
Mean	632.9672	Std Deviation	182.60926
Median	623.6549	Variance	33346
Mode	485.7940	Range	1185
		Interquartile Range	243.07743

Goodness-of-Fit Tests for Lognormal Distribution				
Test	Statistic		p Value	
Kolmogorov-Smirnov	D	0.03442244	Pr > D	>0.500
Cramer-von Mises	W-Sq	0.02976419	Pr > W-Sq	>0.500
Anderson-Darling	A-Sq	0.29738498	Pr > A-Sq	>0.250

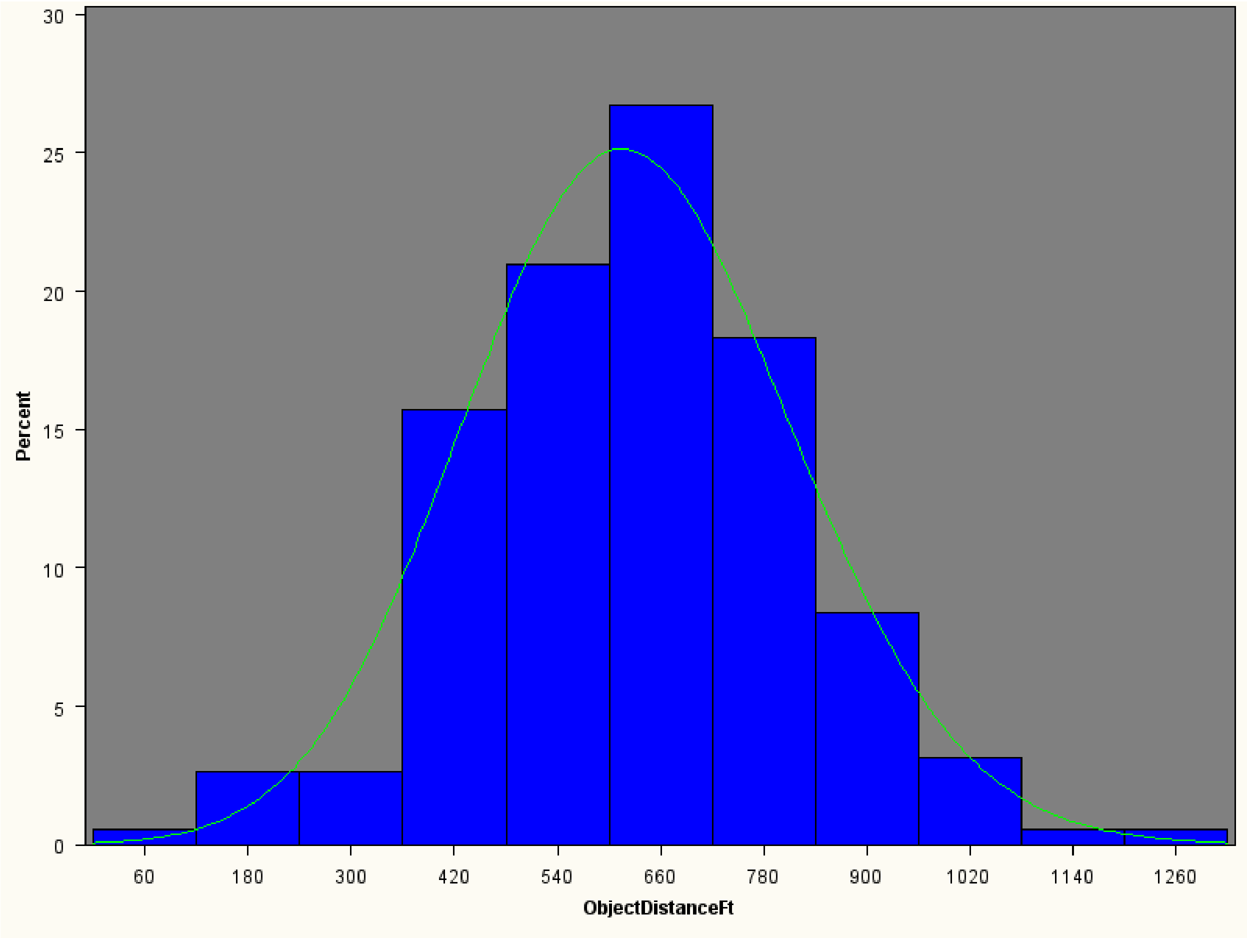
Target Color Recognition



Basic Statistical Measures			
Location		**Variability**	
Mean	59.69060	**Std Deviation**	37.24270
Median	49.50787	**Variance**	1387
Mode	25.19685	**Range**	212.07349
		Interquartile Range	40.78084

Goodness-of-Fit Tests for Lognormal Distribution				
Test	**Statistic**		**p Value**	
Kolmogorov-Smirnov	**D**	0.03521059	**Pr > D**	>0.500
Cramer-von Mises	**W-Sq**	0.05247412	**Pr > W-Sq**	>0.250
Anderson-Darling	**A-Sq**	0.36964525	**Pr > A-Sq**	>0.250

Pedestrian Clothing Color Recognition



Basic Statistical Measures					
Location		**Variability**			
Mean	627.6558	**Std Deviation**	189.92379		
Median	623.6549	**Variance**	36071		
Mode	485.7940	**Range**	1185		
		Interquartile Range	251.21391		
Goodness-of-Fit Tests for Lognormal Distribution					
Test		**Statistic**		**p Value**	
Kolmogorov-Smirnov		**D**	0.04092752	**Pr > D**	>0.250
Cramer-von Mises		**W-Sq**	0.04259117	**Pr > W-Sq**	>0.250
Anderson-Darling		**A-Sq**	0.36626813	**Pr > A-Sq**	>0.250