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# An Evaluation of the Effects of Motorcycle LED Brake Lamp Flash Frequency Sequences on Conspicuity During Texting in a Static Vehicle

Jeffrey A. Krupa

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AN EVALUATION OF THE EFFECTS OF MOTORCYCLE LED BRAKE LAMP  
FLASH FREQUENCY SEQUENCES ON CONSPICUITY DURING TEXTING IN A  
STATIC VEHICLE

A Dissertation

Submitted to the School of Graduate Studies and Research

in Partial Fulfillment of the

Requirements for the Degree

Doctor of Philosophy

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December 2017

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Title: An Evaluation of the Effects of Motorcycle LED Brake Lamp Flash Frequency Sequences on Conspicuity During Texting in a Static Vehicle

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The objective of this study was to use mobile eye tracking methodology to examine the effect on a motorcycle appliqué's conspicuity to determine if oculomotor capture was achieved by three LED brake lamp treatments: (1) 83.30 millisecond flash frequency sequence, (2) 117.50 millisecond flash frequency sequence, and (3) the continuous state. This study is based upon the findings of Wierwille, Llaneras, and Neurauter (2009). Using subjective impression rankings, Wierwille et al. (2009) determined the optimal attention-grabbing flash frequency for LED automotive tail lamp assemblies is 83.30 milliseconds, and 117.50 milliseconds is a near-optimal flash frequency, compared to the continuous state. Research further suggests oculomotor capture of visual attention can be achieved by the abrupt introduction of a new, relevant, sensory-based visual stimulus.

Motorcycle conspicuity research indicates the low conspicuity of a motorcycle is a major cause of multivehicle accidents involving motorcycles. A literature review suggests no testing has been done to determine whether flashing a motorcycle's brake lamp significantly increases the conspicuity of a motorcycle.

During data collection, participants were positioned in a static vehicle and engaged in the secondary task of texting. Texting while driving is a major causal factor

for rear-end collisions among distracted drivers (Carney, McGehee, Harland, Weiss & Raby, 2015; Fitch et al., 2013).

An analysis of visual behavior responses across the three treatments to determine the effect of the treatments on the conspicuity of the motorcycle appliqué could not be conducted because only one treatment, the 83.30 millisecond flash frequency sequence, generated an oculomotor capture response. The 83.30 millisecond flash frequency achieved oculomotor capture with three of 16 participants exposed to this treatment.

Analysis of the subjective impression rankings of the LED brake lamp's ability to capture the participant's visual attention at a 100-foot intravehicular distance found a statistically significant difference between the means of the 83.3 millisecond flash frequency sequence and the continuous condition. However, analysis of the subjective impression rankings at a 30-foot intravehicular distance found no statistically significant difference across the three LED brake lamp treatments.

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To my family, words alone cannot express my gratitude for the support I received from all of you. From Michael bringing hot coffee out to the pilot study during that cold October rain, to Jess being my assistant, thank you. Rob said it best, “it’s what families do.”

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## CHAPTER ONE

### INTRODUCTION

Low conspicuity of a motorcycle is a major factor in accidents involving motorcycles being rear-ended by a trailing automobile, and a primary cause of multivehicle accidents involving a motorcycles (Association des Constructeurs Europeens de Motocycles (ACEM), 2009; Craen, Doumen, Bos, & van Norden, 2011; Gershon & Shinar, 2013; Gkritza, Zhang & Hans, 2010; Huang & Preston, 2004; Hurt, Ouellet, & Thom, 1981; International Motorcycle Manufacturer's Association (IMMA), 2010; Mahshid, Law, Hussain, Alfian & Ng, 2013; Motorcycle Safety Foundation (MSF), 2014; Shaheed, Gkritza, & Marshall, 2012; Shaheed, Zhang, Gkritza & Hans, 2011; Shinar, 2007; Suraji & Tjahjono, 2012; Wells et al, 2004).

Using a design based on the research of Wierwille, Llaneras, and Neurauter (2009), this study gathered data from an outdoor uninformed static test and incorporate texting as a secondary task. According to numerous studies (Callaway, Rushing, & Stallman, 2014; 2013; Rumschlag, Palumbo, Martin, Head, George, & Commissaris, 2013), texting while driving has been shown to be a significant form of driver distraction. In fact, according to the National Highway Traffic Safety Association (NHTSA, 2013), the use of cell phones is now the leading cause of driver distraction resulting in fatal motor vehicle accidents.

In this research study, a mobile eye tracking system was used to examine the effect of three levels of a motorcycle's LED brake lamp on attributes of visual conspicuity, henceforward referred to as *conspicuity*. The use of the eye tracking system advanced the data collection methodology used by Wierwille et al. (2009). Wierwille et

al. used an outdoor uninformed static test design to examine the participants' visual detection performance times to determine the influence of automotive LED tail lamp assembly treatments on attributes of conspicuity. The Wierwille study used an automobile appliqué, and measured visual detection performance times by using two video recordings synchronized between the LED automotive tail light assembly treatments and the participant's face.

According to Wierwille et al. (2009), the optimal oculomotor capture flash frequency across an array of automotive LED tail lamp assemblies ranged from 4.25 to 6.5 hertz. Using subjective impression rankings, the researchers further found the single optimal oculomotor capture flash frequency sequence to be comprised of six 83.30 millisecond flashes using a 50% duty cycle. Findings also suggested six 117.50 millisecond flashes using a 50% duty cycle are a near-optimal oculomotor capture flash sequence.

In this study, the methods and findings of Wierwille et al. (2009) for automotive LED tail lamp assemblies were applied to an LED motorcycle brake lamp on a motorcycle appliqué in an outdoor environment. Three treatments used were: (1) six 83.30 millisecond flashes using a 50% duty cycle, henceforward referred to as the 83.30 millisecond flash frequency sequence; (2) six 117.50 millisecond flashes using a 50% duty cycle, henceforward referred to as the 117.50 millisecond flash frequency sequence; and (3) the continuous state. As in Wierwille et al., the continuous state of the LED lamp was used as the base condition.

Pre-attention or pre-knowledge of the existence and spatial location of the motorcycle appliqué was not provided to the participants, nor were they informed of the

objective of the study. Lacking such information, the sensory aspects of the LED brake lamp treatments could freely compete for the participants' visual attention against other objects in their field of view.

To advance Wierwille et al. (2009) data collection method, mobile eye tracking methodology was used to directly measure the two major components of visual behavior, i.e., saccades and visual fixations, to examine the effects of the LED brake lamp treatments on attributes of conspicuity of the appliqué. The Wierwille study analyzed visual detection performance times, as well as participants' subjective impressions of the brake lamp's attention-getting capability. In addition to these two variables, this study attempted to also analyze the rank of the first visual fixation landing in the area of interest, and the total visual fixation duration time during the data collection period.

Interpretation of the visual behavior data generated by the mobile eye tracking system was based upon psycho-physiological studies of human vision and conspicuity. Statistical tests were used to analyze the data from the mobile eye tracking system for the three LED brake lamp treatments to determine if the treatments caused a statistically significant effect as an attribute of conspicuity of the motorcycle appliqué.

A statistically significant increase in the motorcycle appliqué's conspicuity would provide actionable findings regarding the feasibility of flashing a motorcycle's LED brake lamp to prevent rear-end collisions. The flashing brake lamp could be used as a counter-measure, in situations where the operator of a trailing automobile is engaged in a secondary task.

## **Statement of the Problem**

Early motorcycle conspicuity studies infer motorcycle-related sensory elements can be used as measures of the conspicuity of a motorcycle. Such studies relied on the use of statistical data on sensory elements of multivehicle accidents involving motorcycles to infer a sensory element made the motorcycle more, or less, conspicuous. Inferring conspicuity as an attribute of a motorcycle conflicts with evidence from psycho-physiology studies of visual behavior concluded that conspicuity is not a measurable component of vision, nor is it a physical attribute of an object. Psycho-physiology studies on visual information processing have provided evidence the conspicuity of an object is comprised of sensory and cognitive elements forming a mental relationship between the observer and the object. Furthermore, the conspicuity of the object is influenced by the object's relationship to its environment (Wertheim, 2010). Methodologies based upon sensory elements as a measure of conspicuity resulted in inconsistent findings in early motorcycle conspicuity studies.

To resolve the problem of measuring the effect of a treatment on the conspicuity of a motorcycle, this study used a mobile eye tracking system to directly measure participants' qualitative and quantitative reactions to the conspicuity of a motorcycle appliqué. To resolve the problem of inconsistent interpretation of visual behavior data, evidence from psycho-physiology studies was used to support the interpretations and conclusions of this study.



## **Research Questions**

The researcher examined the following research questions:

1. Is there a significant difference in the order of visual fixations based upon the type of LED brake lamp treatment?
2. Is there a significant difference in visual detection performance times based upon the type of LED brake lamp treatment?
3. Is there a significant difference in the total visual fixation duration times in the area of interest based upon the type of LED brake lamp treatment?
4. Is there a significant difference in the rankings of participants' subjective impressions based upon the types of LED brake lamp treatments?

## **Research Hypotheses**

The researcher hypothesizes the following:

1. Of the three test conditions examined in this study, the 83.30 millisecond flash frequency sequence will have the lowest rank for the first visual fixation landing in the area of interest.
2. Of the three test conditions examined in this study, the 83.30 millisecond flash frequency sequence will receive the highest overall subjective impression ranking.
3. Of the three test conditions examined in this study, the 83.30 millisecond flash frequency sequence will have the lowest visual detection performance time.
4. Of the three test conditions, the 83.30 millisecond flash frequency sequence will have the lowest total visual fixation duration time in the area of interest.

## **Significance of the Problem**

Of the 57,000 multivehicle crashes involving a motorcycle for the year 2012, 9,000 (15.5%) involved the motorcycle being rear-ended by a trailing automobile. Of those 9,000 accidents, 5,004 (55.6%) resulted in the motorcycle operator sustaining injuries. Of those 5,004 injury cases, 213 (2.4%) resulted in motorcycle operator fatalities. Motor-vehicle fatal accidents involving rear-ending a motorcycle have increased from 163 in 2012 to 213 in 2014 (NHTSA, 2014). The National Highway Traffic Safety Administration (NHTSA) indicates, per 100,000 registered motorcycles, motorcyclist fatalities from being rear-ended have risen from 1.62 in 1995 to 1.94 in 2011. This may suggest the ineffectiveness of static, low conspicuity countermeasures that incorporate the sensory elements of a motorcycle (Turetschek, Fussl, Oberlader, & Schaner, 2011).

In the United States, motorcycles constitute the class of highway vehicles with the highest crash cost per mile among all U.S. Federal Highway Administration vehicle classifications. Motorcycle crash costs per mile ranged from \$3,100 to \$3,457, in 2014 dollars (Lawrence, Max, & Miller, 2002). Further, the total lost quality of life resulting from injuries sustained in motorcycle accidents cost \$19 billion annually, valued in 2014 dollars (Lawrence et al.). The estimated annual total economic cost associated with motorcycle accidents, adjusted to 2014 dollars, was \$14.6 to \$16 billion (Naumann, Delinger, Zaloshnja, Lawrence & Miller, 2005; U.S. Government Accountability Office, 2012).

The average cost of a motorcyclist fatality is \$1.2 million, with the average cost of non-fatal motorcyclist injuries ranging from \$2,500 to \$1.4 million (U.S. Government

Accountability Office, 2012). This means the 213 motorcyclists who died in 2012 from being rear-ended by a trailing vehicle cost \$256 million. On average, each state will pay \$140,400,767 annually for motorcycle accident related injuries (Preusser, Williams, Nichols, Tison, & Chaudhary, 2008).

A flashing motorcycle brake lamp as a low conspicuity countermeasure may be an alternative to public motorcycle safety campaigns. The NHTSA (2010a) acknowledges public campaigns to heighten the awareness of motorcyclists on the highway have been ineffective. The futility of these campaigns has prompted the NHTSA to suggest shifting the use of public funds to programs designed to increase the motorcycle's conspicuity by modifying its sensory design features.

To address the low conspicuity of a motorcycle, the federal government has suggested corrective actions such as recommending the use of brightly colored clothing and helmets by motorcyclists (NHTSA, 2006). These countermeasures are not consistent with evidence provided by conspicuity studies of multivehicle accidents involving motorcycles. Evidence suggests the inherent weakness of such a strategy is that effectiveness is dependent upon the color and complexity of the environmental background in which the motorcycle is operating (Rößger et al., 2011).

The performance of secondary tasks while operating a motor vehicle is a common occurrence and is thus incorporated into the current research design. Unlike the research of Wierwille et al. (2009) which incorporated programming of a factory installed GPS as a secondary task, this study will incorporate texting as its secondary task. According to Pickrell and Ye (2013), manipulation of hand-held devices while driving has increased from 0.2% of drivers in 2005 to 1.3% in 2011. According to Cooper, Yager, and

Chrysler (2011), 20% of all automobile drivers admit to texting while operating an automobile. Because texting combines visual, manual, and cognitive sources of distraction, Callaway, Rushing and Stallman (2014) concluded texting had the greatest negative impact on the ability to drive a vehicle as compared to other forms of distraction.

According to the NHTSA (2013), the use of cell phones while driving is now the leading cause of distraction in fatal crashes, accounting for 12% of all fatal crashes. Of all fatal crashes caused by distracted driving, 32% are rear-end collisions (NHTSA, 2013). According to Strayer, Drews, and Crouch (2006), the use of a cell phone while driving results in the same level of impairment as driving while intoxicated.

The use of cell phones while operating an automobile has a negative impact on the reaction time of the operator, affecting the operator's ability to visually scan the road ahead, and interfering with the operator's ability to attend to relevant information is directly related to the task of driving the automobile (Alm & Nilsson, 1995; Caird, Johnston, Willness, Asbridge, & Steel, 2014). According to Alm and Nilsson, when reacting to road hazards, operators failed to increase intravehicular distance to compensate for the decrease in reaction time.

Drews, Yazdani, Godfrey, Cooper and Strayer (2009) found 86% of collisions occurred while the automobile's operator was texting. This equaled a six-fold increase in collisions when compared to non-distracted driving. Drews et al. found evidence demonstrating texting while driving creates a greater risk of a crash than speaking on a cell phone.

In a naturalistic study, Carney, McGehee, Harland, Weiss and Raby (2015) found distracted driving was the causal factor for 76% of rear-end collisions. Of those rear-end collisions, 88% involved lead vehicles that were stopping or stopped ahead of the test vehicle. Carney et al. found in 50% of the rear-end collisions, there was no defensive reaction on the part of the automobile operator who was engaged in cell phone use while driving. Furthermore, they found rear-end collisions were more likely to cause the test vehicle to lose control compared to angled collisions. The manual manipulation of a phone, such as occurs when texting, results in the operator removing visual attention from the road ahead for an average of 4.1 seconds of the six seconds prior to the crash (Carney et al.).

In an earlier naturalistic study by Fitch et al. (2013), automobile operators who were engaged in texting took their eyes off the road ahead for the longest period, averaging 23 seconds. Texting was found to have a significant effect on safety-critical events and resulted in a 200% increase in the risk of being involved in a crash or near crash. The risk associated with texting while driving has become so significant that in 2010, Ray LaHood, U.S. Transportation Secretary, introduced sample legislation to aid states in legally banning the act of texting while driving. Secretary LaHood stated, “texting while driving, like talking on cell phones while driving, is an extremely dangerous and life-threatening practice.” Federal legislation was also introduced to ban texting for all commercial drivers (NHTSA, 2010b). As of May 2016, 46 states have legally banned texting while driving (Governors Highway Safety Association, 2016).

## Definitions

Accuracy: In eye tracking systems, the average difference between the positions of true gaze and the gaze position recorded by the mobile eye tracking system (Holmqvist, Nystrom, Andersson, Dewhurst, Jarodzka, & Weijer, 2011; Bojko, 2013).

Area of Interest: An area, defined by the researcher, surrounding the object of visual interest and typically slightly larger than the actual object of visual interest. When a visual fixation is inside the area of interest, visual attention has been given to the object.

Covert attention: Attention directed to stimuli that are not at the center of gaze (Martinez-Conde, Macknik, Troncoso, & Hubel, 2009).

Gaze: The direction the eyes are looking (Bojko, 2013).

Inhibition of Return: The phenomenon by which a stimulus presented at a recently attended location evokes a weaker reaction than a stimulus appearing at a location not yet attended (Martinez-Conde et al., 2009).

Latency: The average end-to-end delay starting at the time the tracked eye moves and ending when the computer has actually recorded the tracked eye's movement (Holmqvist et al., 2011).

Motorcycle: A two- or three-wheeled motorized vehicle. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than a steering wheel. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles and three-wheel motorcycles (U.S. Department of Transportation Federal Highway Administration, 2011).

Perception: Images created in the visual brain because of the interpretation of visual input data, in conjunction with cognitive elements related to the observer's knowledge, experiences, and reward system (Green, 2013b; Porathe & Strand, 2011).

Precision (Spatial): Reliably repeat the measure (Holmqvist et al., 2011; Bojko, 2013).

Rear Impacted: Impacted at 5 o'clock through 7 o'clock, when one vehicle's front strikes another vehicle traveling in the same direction as the striking vehicle (NHTSA-FARA, n.d.; Kusano & Gabler, 2011).

Saccade: Rapid eye movements from one visual fixation to the next with durations from 30-80 milliseconds, amplitudes of 4-20°, and velocity of 30-500°/second, that re-locate the point of visual fixation.

Scan path: The route of oculomotor events through space within a certain time span assuming the path has a beginning and end and therefore a length (Holmqvist et al., 2011).

Visual Attention: Mechanism to reduce available visual input information to match the processing capacity of the visual brain. Visual attention is comprised of (a) engagement of an object of visual interest, (b) spatial location, (c) locking, e.g. fixating, and (d) suppression of irrelevant information, or distractors (Steinman, Steinman, & Ciuffreda, 2002).

Visual Conspicuity: A characteristic of a visible object determines the likelihood the object will be noticed against its background by virtue of its sensory aspects, its (retinal) position not being known beforehand (Engel, 1976).

Visual Detection Performance Time: The total time duration from the presentation of the stimulus to the landing of the first visual fixation in the area of interest. It is also a quantitative measure of an attribute of conspicuity (Bojko, 2013).

Visual Fixation: Temporary stop in eye movement with a duration from 100-500 milliseconds (Bojko, 2013). For this study, a visual fixation will be defined by the researcher as a pause in eye movement of at least 100 milliseconds, with less than one-degree average pupillary movement over three consecutive movements. These are acceptable research study parameters and are commonly used in studies that use mobile eye tracking methodology (Bojko, 2013).

### **Assumptions**

The researcher assumed the following in this study:

1. The participant, by landing their visual fixations in the area of interest, has given the motorcycle appliqué their visual attention.
2. The participants' visual fixations in the area of interest processes visual information on localization and identification of the object of visual interest.
3. The LED brake lamp treatments on the motorcycle appliqué will provide enough visual stimuli for the participants to re-direct their visual attention from texting on their cell phones and onto the motorcycle appliqué.
4. Research participants will correctly complete the subjective impression ranking scale.
5. When the participants direct their visual attention from their cell phones onto the motorcycle appliqué, it will be done involuntarily due to the LED brake lamp treatment.
6. The design of the study is adequate to prevent environmental factors from affecting the visual behavior of the participants.



## **Delimitations**

The delimitations of this study were as follows:

1. The study was delimited to comparing flash frequency sequences of 83.30, 117.50 milliseconds, and a continuous state of the LED brake lamp to determine the effect of the LED brake lamp on the conspicuity of the motorcycle appliqué.

2. The study was delimited to examining the participants' visual detection performance time, total visual fixation duration time, and the participants' rank of the first visual fixation landing in the area of interest and the LED brake lamp's effect on the conspicuity of the motorcycle appliqué.

3. The participants of this study were delimited to those who hold only an automobile endorsed driver's license and who are at least 18 years of age at the time of the study.

4. The study was delimited to examining the secondary task of texting as the distraction activity.

## **Limitations**

The limitations of this study were as follows:

1. Participants are voluntarily participating in the study.

2. The participants are aware they are participating in a research study may influence their visual behavior via the Hawthorne effect.

3. Participants were selected from volunteers which is a non-probabilistic sampling technique.

4. Participants were primarily from employees of the Sheetz Corporation.

## CHAPTER TWO

### LITERATURE REVIEW

#### **Introduction**

The objective of this study is to use mobile eye tracking methodology to analyze the effect of three LED motorcycle brake lamp treatments on attributes of conspicuity of a motorcycle appliqué. The analysis determined if the LED brake lamp treatments caused a significant difference in the conspicuity of the motorcycle appliqué. The design of this study is based upon a review of the literature on the subjects of (a) vision, (b) psycho-physiology of visual behavior, (c) risk of texting while driving, and (d) motorcycle conspicuity.

The vision studies are reviewed to develop an understanding of how vision functions. They include the following subjects: visual mechanics, visual components, visual attention, gaze, and visual perception. These are critical to understanding visual behavior.

The psycho-physiology studies of visual behavior provide the basis for understanding conspicuity. Computational modeling studies in this field shows how the visual brain constructs a saliency map to establish the levels of conspicuity of objects of visual interest. Furthermore, psycho-physiology studies provide support for the interpretation of the visual behavior data that is collected in this research. Evidence from psycho-physiology studies is used to substantiate the interpretation of data from: (a) the rank of the first visual fixation landing in the area of interest; (b) visual detection performance times; and (c) total fixation duration time spent in the area of interest.

Past motor vehicle conspicuity studies used statistical data related to the sensory characteristics of motorcycles as measures of the motorcycle's conspicuity. However, studies based on inferences relating to sensory characteristics have resulted in contradictory conclusions across studies.

Past problems associated with the study of sensory characteristics of motorcycles have been resolved using mobile eye tracking systems to conduct visual behavior studies. The literature indicates mobile eye tracking systems are the most advanced methodology available for conducting visual behavior studies, in the components of visual behavior measured by these systems are direct measures of the attributes of conspicuity. As such, mobile eye tracking methodology has replaced methods relying on the use of statistical data.

Finally, the literature shows a significant risk of causing a rear-end collision when automobile operators engage in texting while driving. Because of the growing number of automobile drivers who text while driving, this study selected texting as its secondary task.

### **Vision**

In less than a millisecond, vision can focus on an object, encode the visual information, interpret the input, create the image within the visual brain, and store the information in iconic memory (Coltheart, 1983). For perception to occur, the visual brain must make inferences as to the input received from the external world and create a meaningful image for the observer. Without the integration of input and the creation of an image, the visual brain would create vision consisting of only clutter (Wandell, 1995b).

The experience of vision begins at the interface of the eye's cornea and the lens that focuses the light entering from the external world onto the eye's retina (Wandell, 1995a). At the retina, the light frequencies react with retinal neurons, and a neural encoding of the information extracted from the various light frequencies begins to take place. Through several channels of processing, the visual brain interprets the encoded data as an image; *vision* is created within the human brain as a representation of the external world (Wandell, 1995a).

Vision actively seeks out information from the images vision creates (Land & Furneaux, 1997). Helmholtz (1962) explains we see what our visual brain believes is the most likely outcome from the sensory input received by the eyes. According to the literature, the sensory input into the eyes results in five unique qualities of visual behavior: (a) visual attention; (b) gaze; (c) perception; (d) visual fixations; and (e) saccades.

### **Visual Attention**

The literature provides evidence visual attention is comprised of extremely complex systems, processes, and neural networks designed to reduce the enormity of the available visual data in the external world to match the processing capacity of the visual brain (Steinman et al., 2002). According to Yantis and Pashler (1998), visual attention is the brain's strategy for reducing visual information to only the relevant parts of the objects of visual interest, solely for visual recognition.

Visual attention is comprised of: (a) engagement of an object of visual interest; (b) spatial location; (c) visual fixations; and (d) suppression of irrelevant information (Steinman et al., 2002). Humans do not have the capacity to be fully conscious of visual

attention because visual attention functions simultaneously in bottom-up and top-down modes when processing visual information (Bojko, 2013). Bottom-up visual information is processed involuntarily and is controlled by eye reflexes to visual stimuli. Top-down visual information processing is cognitively-based and is goal oriented (Corbetta & Shulman, 2002; Pashler, Johnston, & Ruthruff, 2001; Vecera, Cosman, Vatterott & Roper, 2014; Yantis & Pashler, 1998). Visual attention precedes visual gaze, with visual gaze referring to where the eyes are physically looking (Bojko, 2013). According to Dore-Mazars and Collins (2005), visual attention provides explicit guidance to the landing location of visual fixations.

The explicit guidance that visual attention provides for gaze is the result of perception having the capacity to acquire pre-programmed information from the visual brain prior to the execution of saccades (Dore-Mazars & Collins, 2005; Hayhoe, McKinney, Chajka & Pelz, 2011). Hooge, Vlaskamp, and Over (2007) suggest a model where the visual brain pre-programs saccades as a matter of visual information processing efficiency. Findings of Hooge et al. (2007) were based on Viviani (1990), who concluded there are three stages to a visual fixation: (a) saccade programming, (b) foveal image analysis, and (c) selection of the next object. Similar to Hooge et al., Greene and Rayner (2001) suggested a *process-monitoring* model where a visual fixation duration is pre-programmed by the visual brain based on the real-time analysis of the current visual fixation. Earlier, Hooge and Erkelens (1998) found evidence visual fixations were pre-programmed based on prior foveal analysis conducted by the visual brain, and the visual fixation pre-programmed sequence could not be voluntarily altered by participants.

Comparing visual behavior models to the participants' visual fixation locations, Foulsham and Underwood (2008) concluded information obtained from previous visual fixations on an object can influence the participants' scan path. Triesch, Ballard, Hayhoe, and Sullivan (2003), utilizing a virtual reality set-up to determine the influences on visual behavior of performing a task, provided support for the process-monitoring model. According to Triesch et al. (2003), visual behavior is highly task-specific and visual fixations are guided by the need to extract visual information, when needed, to achieve the task at hand.

The literature provides evidence that for a participant's gaze to be directed towards the motorcycle appliqué, the stimulus must be strong enough to capture the participant's visual attention from the secondary task. Once the participant's visual attention is captured, the participant involuntarily directs their gaze from the secondary task towards the motorcycle appliqué. The participant's gaze directed towards the motorcycle appliqué results in the participant's visual fixations landing on the motorcycle appliqué. This process allows perception of the appliqué to occur. The literature demonstrates that the visual brain uses overt visual attention to perceive objects of visual interest. However, studies have also detected the existence of covert visual attention.

**Covert and overt visual attention.** Covert visual attention is used to describe attention to objects that are not at the foveal point of focus, e.g., the person's visual attention is directed at an object they are not looking at. Just and Carpenter (1980) formulated the strong eye-mind hypothesis, opposing covert visual attention in favor of overt visual attention.

Overt visual attention describes attention to objects at the foveal point of focus. The strong eye-mind hypothesis suggests that there is no appreciable lag time between what the eyes fixate on and the visual information processing associated with the visually fixated object. According to Just and Carpenter (1980), covert visual attention conflicts with the strong eye-mind theory because the mind cannot attend to something other than what the eyes are looking at. Studies on *inattention blindness*, i.e., when a person does not perceive what they are looking at, provide evidence conscious perception requires visual attention (Green, 2013a; Hoffman & Subramaniam, 1995; Hollingworth & Henderson, 2002; Mack, 2003; Mack & Rock, 1998).

Overt visual attention is supported by Bojko (2013) and Rensink, O'Regan, and Clark (1997). According to their research, conscious perception requires focused visual attention and likewise, giving visual attention to an object that is not within the foveal point of focus is unnatural and difficult. Findlay and Gilchrist (1998) found that participants would not elicit covert visual attention if given the opportunity to move their eyes. This led them to conclude that eye movements are the visual brain's most effective method of gathering visual information in a natural scene search.

Based on the literature, the researcher concludes: (a) visual attention has been paid where gaze is directed; (b) perception of an object of interest requires visual fixations to land on the object of interest, and (c) covert visual attention is inconsistent with visual information processing and is not used in normal vision.

### **Gaze and Perception**

According to findings in the literature, only a visual fixation can result in conscious perception. Therefore, conscious perception of the motorcycle appliqué

requires capturing the participant's visual attention, thereby directing the participant's gaze on to the motorcycle appliqué. Evidence of visual attention preceding conscious perception is supported by Motter (1998) who concluded paying visual attention only occurs where the eyes are gazing.

The control guidance for gaze is acquired from visual attention (Itti & Koch, 2001; Steinman & Werner, 2003). Gaze permits the creation of detailed vision by permitting light, the most effective stimulus for vision, to be processed by the fovea into bioelectrical signals that are interpreted by the visual brain. It is the visual brain's interpretation of the bioelectrical signals, in conjunction with the observer's cognitive elements of their visual behavior, that creates the images within the visual brain referred to as perception, e.g. vision (Green, 2013b; Porathe & Strand, 2011).

For visual attention to occur across a scene, attention must be shifted from one object of visual interest to the next object of visual interest. Controlling gaze through a scene in real time is necessary to preserve the on-going demands of perceptual tasks, cognitive tasks, and behavioral tasks (Henderson, 2003). According to Henderson (2003), and supported by Henderson and Ferreira (2004), the control of gaze in a natural scene is critical because eye movements provide for: (a) real-time acquisition of relevant visual information as it is needed; (b) insight into the function of memory and the cognitive elements of visual behavior; and (c) a tool to construct a real-time behavioral index for sensory and cognitive visual processing.

Wertheim, Hooge, Krikke, and Johnson (2006), in a study to determine the influence of lateral masking, concluded visual search behaviors thought of as being cognitively driven, are influenced rather by lateral masking based on the count, density,



and asymmetry of the targets and distractors in the peripheral field of vision. According to evidence in this study, peripheral vision can influence visual attention shifts.

### **Visual Fixations**

Using mobile eye tracking methodology, visual fixations can be understood as qualitative attributes of conspicuity. Visual fixations create a stable platform for the eyes to extract radiation from the external world by allowing for an uninterrupted input of radiation to strike the eye's fovea. The fovea accounts for the best object discrimination in terms of definition and color, and provides the highest degree of visual information processing capabilities (Itti & Koch, 2001; Lans, Pieters, & Wedel, 2008; Pelz & Canosa, 2001). According to Just and Carpenter's (1980) strong eye-mind hypothesis, visual information is processed only during visual fixations. Without visual fixations, the images presented to the retina would be erased before processing is completed as the eye moves to the next object of visual interest (Micic & Ehrlichman, 2011).

Visual fixations address the brain's limitations in processing visual information by reducing such information to the states of localization and identification (Niebur & Koch, 1998). Lans, Pieters, and Wedel (2008) suggest localization and identification are the fundamental states of conspicuity. The radiation input from visual fixations onto the retinal area is divided into two pathways for visual information processing. First, the visual brain processes information regarding the object's spatial location. Then, the more complex visual information regarding the identification of the object is completed (Desimone & Ungerleider, 1989; Findlay & Walker, 1999)

The orderly progression of visual fixations through the objects of visual interest is guided by a hierarchy based on a descending level of conspicuity. The level of

conspicuity is established by the saliency map of each object of visual interest. The hierarchy provides a mechanism for the orderly shifts in gaze from one visual fixation point to the next, during which visual attention provides guidance for the progression through the hierarchy. In complex scenes, repeated visual fixations may be necessary to obtain the required information to complete the identification of the object (Henderson, Weeks, & Hollingsworth, 1999).

The capacity of an object to capture a participant's visual attention, thereby directing the participant's gaze onto the object, is determined by two primary control mechanisms: stimulus-based control and knowledge-based control (Henderson, 2003). Henderson, Brockmole, Castelhana, and Mack (2007) used the visual inspection of two-dimensional photographs to conclude the sensory characteristics of an object, such as contrast and edge definition, provide a strong influence in determining the locations of visual fixations.

However, the visual brain's determination of visual fixation locations is dominated by the cognitive, knowledge-based elements of visual behavior (Henderson, Brockmole, Castelhana, & Mack, 2007; Turano, Geruschat & Baker, 2003). Without these cognitive, knowledge-based elements, all humans would have the same visual behavior (Bojko, 2013). Henderson et al. (2007), used the saliency map theory and cognitive control of visual behavior to explain how visual fixations are based on information processing. According to Henderson et al. (2007), cognitive, knowledge-based elements provide for the control of visual fixation locations based on the real-time information-gathering needs of the task being performed. Sensory-based elements are a strong influence on visual behavior, but cognitive, knowledge-based elements are the

determining factor for visual fixation locations (Henderson et al. 2007). Furthermore, visual fixation locations are influenced by iconic memory (Henderson, 2003).

Henderson (2003) suggests the more knowledgeable an observer is about their environment, the less reliant the person becomes on stimulus-based control for visual fixation locations. Based on expectations developed from past experiences, cognitive, knowledge-based elements of visual behavior can be strong enough to guide the observer's visual fixations to points where objects of visual interest should be located, regardless of whether these objects are present or not (Henderson, 2003; Tsotsos et al., 1995; Yantis & Jonides, 1984). Like Henderson (2003), Henderson and Ferreira (2004) found evidence suggesting the location of visual fixations is driven primarily by cognitive, knowledge-based elements.

According to Henderson and Ferreira (2004), iconic memory is a source of cognitive-based knowledge influencing visual fixation location. Using eye tracking methodology with visual memory testing, Williams, Henderson, and Zacks (2005) concluded the details of visual information of real-world objects are incidentally stored in iconic memory. They further postulated the existence of a direct relationship between iconic memory duration and visual fixation duration. Similar findings were made by Castelhana and Henderson (2005).

In a study on natural scene perception using eye tracking methodology, Hollingworth (2004) found iconic memory has the capacity to accrue visual information. Aivar, Hayhoe, Chizk, and Mruczek (2005) arrived at the same conclusion by demonstrating how iconic memory stores detailed spatial information and carries it across visual fixations by saccades

Iconic memory influences visual detection performance time and total fixation duration time on an object of visual interest. That influence is exerted when the visual brain fills in the voids in visual information input created by saccades as the eyes progress through three to five visual fixations per second. During saccades, there is a disruption of input to the retina and no visual information is processed by the observer (Henderson & Castelhana, 2005). Despite the fragmented input to the visual brain, the visual experience of the external world appears seamless to the observer. According to Henderson and Castelhana, the creation of seamless vision from disrupted input is possible because of iconic memory.

Short-term iconic memory is responsible for real-time acquisition of knowledge from the present visual experience and is characterized by visual re-fixations to objects of visual interest. Short-term iconic memory also retains image information across a perception episode lasting several fixations (Henderson & Castelhana, 2005). Hollingworth and Henderson (2002) provided evidence visual information from objects of visual interest which had been previously visually fixated, accumulates in short-term iconic memory. They concluded visual information retained in short-term iconic memory acts to facilitate the processing of scene information by the visual brain.

Supporting the findings of Hollingworth and Henderson (2002), using desktop computers and desk-mounted eye tracking methodology, Pertzov, Avidan, and Zohary (2009) found short-term iconic memory is directly related to the number of visual fixations made upon an object of visual interest. Once visual attention directs gaze elsewhere, the detailed information on the prior object rapidly fades. However, when visual fixations return to the object of visual interest to acquire additional information,

the detailed information is retained in short-term iconic memory for a longer duration. The findings of Pertzov et al. suggest a direct relationship between a longer total visual fixation duration time on the object of visual interest and the complexity of the object.

Long-term iconic memory is acquired through repeat exposures to the same scene (Henderson & Hollingworth, 1999). According to Loftus and Mackworth (1978), there is a link between long-term iconic memory and the method by which an observer processes visual information. Participants in this study displayed faster visual detection performance times and longer visual fixation duration times for objects would not normally appear in the given scene, providing evidence of a relationship between longer duration times and the complexity of processing scene information (Bojko, 2013 and Nasanen, Ojanpaa, and Kojo, 2001).

According to Henderson and Ferreira (2004), task-related knowledge is a source of cognitive-based knowledge influencing visual fixation locations. Task-related knowledge engages a strategic cognitive visual behavior plan to progress through the task at hand (Henderson et al., 2007, citing Yarbus, 1967). The cognitive-based knowledge element of visual behavior has the capacity to override bottom-up visual information-processing of the brain (Findlay & Walker, 1999; Land & Hayhoe, 2001; Stirk & Underwood, 2007).

In a test of the saliency map theory using eye tracking methodology to examine images of natural scenes, Underwood, Foulsham, Van Loon, Humphreys, and Bloyce (2006) determined the conspicuity of an object during a search task can be overridden by cognitive processes based on the relevance of the task. The findings of Underwood et al. were later corroborated by Nyström and Holmqvist (2008) using eye tracking

methodology. According to Nyström and Holmqvist, the modified visual fixation behaviors exhibited by participants indicated their cognitive information processing of images overrode bottom-up information processing. Betz, Kietzmann, Wilming, and König (2010) achieved similar findings.

**Oculomotor capture.** Based on the saliency map theory, Irwin, Colcombe, Kramer and Hahn (2000) and Theeuwes, Kramer, Hahn, and Irwin (1998) suggest at the top of the conspicuity hierarchy controlling visual fixation locations, is *oculomotor capture*. Oculomotor capture is the capturing of visual attention via a reflexive mechanism of visual behavior brought about by the abrupt introduction of a new, relevant, sensory-based visual stimulus.

According to Theeuwes et al. (1998), the visual brain has the capacity to parallel program the control of saccades. The cognitive component of the parallel programming of the saccades is goal-oriented, driven by the object of visual interest related to the task at hand. The second component of the parallel programming of saccades is a reflex mechanism driven by the relevant sensory characteristics of a new object, e.g. oculomotor capture.

In oculomotor capture, the newly introduced visual stimulus has the capacity to circumvent top-down visual information processing and, by a default-like action, directs visual attention to the newly introduced relevant object. The involuntary reflex to direct the gaze to the new relevant object can be strong enough to overtake cognitive searches of objects in scenes (Brockmole & Henderson, 2005a, 2005b).

According to the literature, the mechanisms driving oculomotor capture are unclear. However, evidence shows a highly conspicuous object newly introduced into the

field of view can have the capacity to overtake the cognitive elements of visual behavior, thereby directing the gaze onto the new relevant object of visual interest via an involuntary reflex mechanism of visual behavior.

Like Wierwille et al. (2009), this study examined the capability of an LED brake lamp treatment to invoke the visual behavior of oculomotor capture. To achieve oculomotor capture, the stimuli must have the capacity to interrupt the top-down information processes associated with the pre-attention being paid to the task at hand, and by an involuntary reflex, must direct the participant's visual gaze onto the newly introduced relevant object of interest (Bojko, 2013; Doshi & Trivedi, 2012; Lenne, Rößger, Mitsopoulos-Rubens, Underwood, & Espie, 2013; Risko, Anderson, Lanthier, & Kingstone, 2011; Shinoda, Hayhoe, Shrivastava, 2001).

**Saccades.** Saccades are pre-determined, jerky, step-like eye movements varying in trajectory and used to relocate visual fixations. In normal visual behavior, three to five saccades are made every second (Holmqvist et al., 2011; Liversedge & Findlay, 2000). Saccade movements are influenced by involuntary sensory stimulus-based guidance through bottom-up information processing. However, they are dominated by the influences exerted by the cognitive, knowledge-based element of visual behavior.

Studies indicate the visual brain pre-programs saccades. The visual brain can pre-program direction and amplitude into the saccade, and can do so in any order, independently, one of the other. Pre-programming of saccades reduces saccade latencies and each pre-programming function requires the same time on the part of the visual brain (Abrams, 1992).

Saccades are a critical aspect of this study's design and are recorded by the mobile eye tracking system. The higher the degree of conspicuity generated by the stimuli, the greater the amplitude of the saccade is generated (Over, Hooge, Vlaskamp, & Erkelens, 2007).

**Inhibition of return.** The instant return of a visual fixation to a prior location is prohibited by the inhibition of return, which is a transient bias mechanism within the visual brain (Godijn & Theeuwes, 2004; Itti & Koch, 2000; Sun, Fisher, Wang, & Gomes, 2008). The inhibition of return acts to protect the efficiencies required to process visual information at an estimated rate of  $10^7$  to  $10^8$  bits per second at the optic nerve (Itti & Koch, 2001; Tipper, Weaver, Jerreat, & Burak, 1994).

The inhibition of return facilitates the orderly progression of visual fixations through the conspicuity hierarchy for objects of visual interest in the field of view. Without the inhibition of return, visual fixations would be bound only to the objects with the highest level of conspicuity. However, for complex objects, the visual brain permits re-fixations to complete information processing on locations where the visual fixation left prematurely (Sun et al., 2008). When the saliency map is regenerated after each visual fixation, the inhibition of return is retained by the visual brain to ensure the visual fixations do not oscillate between objects that have already been localized and identified (Henderson, 2003).

Godijn and Theeuwes (2004) studied the relationship between the inhibition of return and the saccades deviating from areas in the field of view are inhibited by the inhibition of return. Godijn and Theeuwes (2004) found an association between the inhibition of return and deviations made by saccades, concluding the inhibition of return



and saccades are influenced by the same saliency manipulations. Godijn and Theeuwes (2004) further concluded the inhibition influencing the inhibition of return and saccades is contained within a spatial mapping system in which saccade programming occurs.

Once the participants in this study localize and identify the motorcycle appliqué, studies suggest the visual brain will pre-program saccades to deviate away from the appliqué. Deviation is a characteristic of the inhibition of return but can be overwritten if additional information is needed by the brain to complete visual information processing. The inhibition of return can also be over-written by the cognitive, knowledge-based elements of visual behavior.

### **Visual Information Processing**

The brain simultaneously processes visual information using bottom-up and top-down information processes (Nyström & Holmqvist, 2008). The former is associated with the sensory characteristics of an object such as shape and color, but also includes more complex features of the object such as edge, contrast, and motion. The latter is associated with the observer's knowledge, experiences, expectations, and endogenous reward system (Porathe & Strand, 2011; Zapata, Pulg, & Super, 2011). Recarte and Nunes (2003) suggest in perceiving the external world, endogenous distractors are as relevant as exogenous distractors because exogenous influences can direct the individual's visual attention away from the task at hand.

Bottom-up and top-down visual information processes compete for cues are responsible for the control of visual behavior. In the initial few seconds of a new scene, bottom-up visual information processing dominates the visual brain's processing of the creation of perception (Reinagel & Zador, 1999). Underwood and Radach (1998) suggest

the guidance provided to visual attention from bottom-up visual information processing is limited to supplying the brain with just enough sensory information to process the scene, and as much cognitive, knowledge-based information as demanded by the task at hand. Similarly, four decades earlier, Helmholtz (1962) arrived at the same conclusion, stating: “we are not in the habit of observing our sensations accurately, except as they are useful in enabling us to recognize external objects.”

For this study, the literature suggests differences in the measures of the attributes of conspicuity caused by the LED brake lamp treatments results in differences in the participants’ top-down visual information processing (Bojko, 2013; Rößger et al., 2011). The literature supports that the participant’s bottom-up processing first localizes the motorcycle appliqué as the object of visual interest. Then, the more complex and time-consuming top-down processing dominates as it identifies the object of visual interest.

### **Saliency Map Theory**

Saliency map theory is used in computational modeling of visual behavior and scene statistics and is now widely accepted and used by researchers (Foulsham & Underwood, 2008; Henderson et al., 2007). Saliency map theory is the leading theory explaining how the visual brain establishes the conspicuity of objects.

Furthermore, it explains the mechanism by which the visual brain executes the orderly progression of visual attention through the objects of interest based on a hierarchy of conspicuity (Henderson et al., 2007). Studies based on the saliency map theory provide evidence that attributes of conspicuity can be measured qualitatively and quantitatively by the examination of the participant’s scan path created by eye tracking methodology.

Computational modeling of saliency maps is based on known properties of vision. Saliency map theory postulates the visual brain constructs a mental, multi-layered, two-dimensional topographical map providing an unbalanced scalar qualification for the level of conspicuity of each object of visual interest. Each layer of a saliency map represents a sensory characteristic of conspicuity such as motion, color, intensity, contrast or orientation (Itti, Koch, & Niebur, 1998; Itti & Koch, 2001; Lans et al., 2008).

Evidence of multiple layering of the saliency map is supported by findings by Lans et al. (2008) who suggest a saliency map's two-dimensional topographical layers are comprised of a layer each for (a) the color red; (b) the color blue; (c) the color gold; (d) contrast at the edges; and (e) luminance. Of these layers, contrast appears to be the dominant feature for determining the level of conspicuity of an object of visual interest (Craen et al., 2011; Hole, Tyrrell, & Langham, 1996; Green, 2013a; Hurt et al., 1981; Itti & Koch, 2001; McCarley, Steelman, & Horrey, 2014; Recarte & Nunes, 2003; Rogé et al., 2011; Shaheed et al., 2012; Underwood, Humphrey, & Loon, 2011).

Based on saliency map theory, Peters and Itti (2007) proposed a computational model integrating bottom-up and top-down visual information processing to predict where visual attention gets spatially located by the brain. The bottom-up component of the model handled predictions of visual fixation locations from 12 multi-scaled sensory features. The top-down component of the model is responsible for constructing a low-level representation of the image. Peters and Itti (2007) tested the model with videogames using eye tracking methodology and concluded the computational model successfully predicts the locations of visual fixations on a qualitative scale.

Saliency maps are spatially constructed to contain only objects of visual interest within the current field of view (Cerf, Cleary, Peters, Einhauser, & Kock, 2007). This restriction provides an involuntary information filtering mechanism to safeguard against mental overload created by attempting to process visual information in which there are an estimated 100 million instantiations (Mozer & Sitton, 1996; Yantis and Pashler, 1998; Webster & Ungerleider, 1998). The visual brain's involuntary information filtering mechanism is facilitated by the selection of only relevant objects to receive visual attention within the field of view (Sullivan, Johnson, Rothkopt, Ballard, & Hayhoe, 2012).

In addition to explaining the mechanism used by the visual brain to establish levels of conspicuity, the saliency map theory also explains how the visual brain achieves the orderly progression used by visual attention to progress through the objects in the field of view. The theory suggests the progression of visual attention is based upon a hierarchy of conspicuity established for each object of visual interest in the field of view.

Research shows visual fixations are guided through the scene in a winner-take-all competition for visual attention based on the progressively weaker level of conspicuity from one object to the next (Itti et al., 1998; Lans et al., 2008; Rößger et al., 2011; Wertheim, 2010; Zapata et al.). The implication of saliency map theory is a change in the rank of the first visual fixation landing on the object of visual interest is directly related to a change in the level of conspicuity of the object.

### **Factors Influencing Visual Behavior**

The literature suggests certain factors influence visual behavior. These are: (a) pre-knowledge or pre-attention of the existence or spatial location of the motorcycle

appliqué; (b) pre-knowledge of the objective of the study; and (c) motorcycle driving experience.

**Pre-attention or pre-knowledge.** Past motorcycle conspicuity studies often provided participants with pre-attention or pre-knowledge regarding the existence and spatial location of the motorcycle. This violates Engel's (1976) definition for conspicuity. Providing pre-attention or pre-knowledge causes visual attention to be driven by cognitive, knowledge-based information processing. This results in the participants intentionally directing their gaze to find the object of visual interest. Furthermore, pre-attention or pre-knowledge increases the likelihood the object of visual interest will be perceived by the participants (Craen et al 2011; Engel 1976).

Similarly, Cole and Hughes (1984) evaluated the relationship between visual searches and conspicuity. Their research indicated a systematic relationship between the two factors, with results showing participants to be three times more likely to find an object of visual interest they were directed to search for, compared to participants who were not given pre-attention or pre-knowledge of the object. Similarly, Corbetta and Shulman (2002), Engel (1976) and Rößger et al. (2011) conclude when participants are directed to look for an object, the likelihood of finding the object increases.

The influence of pre-attention and pre-knowledge of the existence and spatial location of an object can be influential enough to cause participants to overlook a highly salient object (Rößger et al., 2011). Underwood et al. (2006) concluded conspicuity is not a good predictor of visual attention when participants are given a directive to search for a specific object.

In a study on *change blindness*, i.e., why people don't see what they are looking at, Rensink et al. (1997) conclude the ability to locate an object accelerates when verbal cues are given, even though there is no change in the sensory level offered by the object. Rößger et al. (2011) reported a near perfect visual detection rate of motorcycles when the participants were instructed to look for a motorcycle in a visually demanding environment.

This study did not provide the participants with pre-attention or pre-knowledge of the presence or spatial location of the motorcycle appliqué, nor did it inform them of the objective of the study. By withholding this information, the examination of the participants' visual behavior was measured solely on the basis of attributes of conspicuity influenced by the sensory characteristics of the three LED brake lamp treatments. By restricting pre-attention or pre-knowledge, compliance with Engel's (1976) definition of conspicuity is maintained by this study.

**Motorcycle operating experience.** People with motorcycle operating experience have a higher awareness of motorcycles on the highway than participants who have only operated automobiles, according to Jenness et al. (2011). Therefore, Jenness excluded drivers whose operator's licenses were endorsed for both an automobile and a motorcycle. The literature provides evidence an operator with a driver's license endorsed for both an automobile and motorcycle, (henceforward referred to as a dual licensed operator), exhibits more hazard perception awareness for motorcycles than an operator with a driver's license endorsed only for automobiles, henceforward referred to as a single licensed operator.

In an assessment of gap distances, Rößger et al. (2011) found dual licensed operators to be more apt to have a higher number of visual scans of the highway and to recognize a motorcycle at a greater distance, compared to single licensed operators. Using a driving simulator and eye tracking methodology, Roge, Douissembekov and Vienne (2012) concluded dual licensed operators could detect a motorcycle at greater distances as compared to single licensed operators. Using a driving simulator, Ohlhauser, Milloy, and Cair (2011) found dual licensed operators to be less likely to be responsible for multivehicle accidents involving motorcycles compared to single licensed operators. Similar findings were made by Magazzu, Cornelli, and Marinoni (2006) and Hurt, Ouellet, and Thom (1981) who conducted a statistical analysis of motorcycle accident data from ACEM (2009).

Using videos to evaluate reaction times to various dangerous traffic scenarios to test hazard perception performance, Rosenbloom, Perlman, and Pereg (2011) concluded dual licensed operators out-performed single licensed operators. Using mobile eye tracking methodology, Muttart et al. (2010) compared the visual behaviors of drivers operating automobiles and motorcycles and found dual licensed operators exhibited a higher level of defensive driving strategy when operating a motorcycle as compared to an automobile. The defensive driving strategies of dual licensed operators include significantly larger visual search areas and more frequent safe glances. Similar findings were reported by Crundall, Bibby, Clarke, Ward and Bartle (2008).

Using a motorcycle simulator to evaluate the hazard perception and visual fixation patterns of dual licensed operators, Hosking, Liu, and Bayly (2010) found dual licensed operators exhibit a tighter visual fixation pattern about a road hazard. Similar

findings were observed by Chapman and Underwood (1998) and Underwood, Humphrey, and Van Loon (2011). These findings provide further evidence dual licensed operators have different visual behaviors compared to single licensed operators.

Horswill and Helman (2003) compared risk-taking behaviors of motorcycle operators and automobile operators using laboratory-based methodologies, roadside observations, and a video-based driving simulator. They concluded participants who operated a motorcycle had more refined visual behavior, including a higher degree of hazard perception, than those operating an automobile.

Similarly, using mobile eye tracking methodology, Muttart et al. (2011) evaluated the glance behavior of dual licensed operators and single licensed operators in a test of crash avoidance behaviors. Specifically, with respect to visual attention maintenance and hazard anticipation, they conclude dual licensed operators spent less time observing the road ahead and made fewer last glances at threatening traffic before turning.

Crundall, Crundall, Clarke, and Shahar (2012) used the presentation of video clips of traffic scenarios to evaluate the visual performance of single licensed operators compared to dual licensed operators. Crundall et al. concluded both novice and experienced single licensed operators were outperformed on visual measures by dual licensed operators.

A study by Ragot-Court, Munduteguy, and Fournier (2012) of French single and dual licensed operators concluded dual licensed operators outperformed single licensed operators on visual behavior parameters. They suggest the dual licensed operator's capacity to outperform single licensed operators is the result of the former's ability to



develop dual schemas alerting them to motorcycle-specific risks while operating an automobile.

In summary, the literature suggests dual licensed operators exhibit significantly different visual behaviors compared to single licensed operators. Furthermore, dual licensed operators have been shown to demonstrate greater awareness of the presence of motorcycles, compared to single licensed operators. The literature also provides evidence of dual licensed operators developing knowledge and experience-based strategic visual behaviors thus reducing the likelihood of contributing to a multivehicle accident involving a motorcycle.

### **Motorcycle Conspicuity**

The low conspicuity of a motorcycle has been shown to be a major causal factor in multivehicle accidents involving motorcycles. Studies on the subject can be grouped into various categories, including: (a) motorcycle conspicuity; (b) motor vehicle rear-end collisions; (c) previous motorcycle brake lamp studies; and (d) the influence of LED lamps on conspicuity. The literature further indicates by flashing the motorcycle's brake lamp, the conspicuity of the motorcycle increases, and the most effective low conspicuity countermeasures are LED lamps.

### **Low Conspicuity of a Motorcycle**

The low conspicuity of a motorcycle as a major causal factor in motorcycle accidents has been recognized since Martin L. Reiss and Joseph A. Haley studied the problem in 1968 (Olson, Halstead-Nusslock, & Sivak, 1981). Rößger et al. (2011) suggest the final level of conspicuity of a motorcycle is the result of sensory and cognitive elements of the automobile operator's visual behavior. They further suggest the

cognitive elements of visual behavior are the dominant factors in the determination of a motorcycle's conspicuity. These cognitive factors are directly related to the visual detection performance time of the automobile operator to initially perceive a motorcycle in the field of view. These findings by Rößger et al. (2011) are supported by psychophysiology studies on visual behavior.

Motorcycle conspicuity studies have concluded automobile operators' inattention is a major contributing factor for multivehicle accidents involving a motorcycle (ACEM, 2009; Gershon, Ben-Asher, Shinar, 2012; Huang & Preston, 2004). Shinar (2007) summarized the contributing factors for multivehicle accidents involving a motorcycle as being related to the automobile operator's inability to maintain visual attention on the task of operating the automobile, and to the motorcycle's low conspicuity.

Lee, Wierwille, and Klauer (2002) concluded the leading cause of rear-end collisions is inattention, followed by distraction, and following the lead vehicle too closely. According to these authors, countermeasures used to capture the visual attention of the trailing automobile should include "flashing."

### **Motor Vehicle Rear-End Collisions**

Rear-end collisions have consistently accounted for 25 to 28% of all vehicle collisions, with 60% caused by driver inattention (Davoodi, Hamid, Arintono, Muniandy, & Faezi, 2011; Kennedy, Jentsch, & Smither, 2001; Lee, McGehee, Brown, & Reyers, 2002; Lee, Wierwille, & Klauer, 2002; Wierwille, Lee, & DeHart, 2005). Furthermore, in the United States, rear-end collisions account for 23% of all tow-away frontal type collisions, 27% of crashes with injuries, and 5% of all fatal crashes (Kennedy, et al., 2001; Kusano & Gabler, 2011).

The automobile operator's behavior of visually fixating on objects not related to traffic factors is the most significant predictor for determining if a near rear-end collision event evolves into an actual rear-end collision (Llaneras, Neurauter, & Perez, 2010). More briefly, the leading causes of rear-end collisions are inattention and distraction (Lee et al., 2002; Wierwille et al., 2005). The majority of rear-end collisions occur when the trailing vehicle is two seconds or less behind the lead vehicle (Dingus et al., 2006). Klauer et al. (2006) found a gaze of more than two seconds away from the forward view while operating an automobile increases risk of a rear-end collision by a factor of two. The Klauer study further found 60% of rear-end collisions are a result of the driver not viewing the forward roadway for an elapsed period extending up to six seconds. Wierwille, et al. (2009) used a six second cut-off time for participants who did not respond to the automotive LED brake lamp treatments while giving visual attention to the research vehicle's GPS.

### **Rear-End Collisions Involving Motorcycles**

According to the National Highway Traffic Safety Administration – Fatality Analysis Reporting System (NHTSA-FARS), from 1995 through 2012, an average of 127 motorcycle operators lost their lives annually when their motorcycle was rear-ended by a trailing vehicle. An analysis of NHTSA-FARS 2014 data for vehicle miles traveled during the period 2007-2011 indicates a motorcycle is 54% more likely to be involved in a fatality when rear-ended than all other vehicle types combined.

Rear-end collisions are the second leading cause of motorcycle accidents in the United States (Ohlhauser, Milloy, & Cair, 2011). According to Hurt et al. (1981), out of 900 motorcycle accident cases, 3.4% involved motorcycles that were rear-ended. In

Pennsylvania in 1975, rear-end collisions accounted for 9.2% of motorcycle accidents (Olson, Halstead-Nussloch, & Sivak, 1981).

From 1999 through 2000, the ACEM (2009) conducted a case control study of 921 motorcycle accidents in Germany, Netherlands, Spain, and Italy. The study, which included full accident reconstruction, showed accidents in which the motorcycle was rear-ended accounted for 2.7% of the cases. In the same study, the largest causal factor of 36.6% of the motorcycle accidents was shown to be low conspicuity of the motorcycle.

In a study by Gkritza, Zhang, and Hans (2010), 25% of two-vehicle motorcycle accidents occurring in Iowa from 2001 to 2008 were rear-end collisions. Of these, 40% involved a trailing automobile. Utilizing data maintained by the Iowa Department of Transportation, Shaheed, Zhang, Gkritza and Hans (2011) studied multivehicle accidents involving a motorcycle and found 11.7% of those accidents to be caused by an automobile rear-ending a motorcycle.

In an analysis of NHTSA-FARS data on 2,074 motorcycle crashes, Preusser, Williams, and Ulmer (1995) found in 6.4% of the cases, the motorcycle was rear-ended by an unimpeded trailing vehicle, and in 6.1% of the cases, the rear-end collision occurred while the motorcycle was stopped, or near stopped, on the highway.

In a review of motorcycle accidents from Europe and the United States, Noordzij, Forke, Brendicke, and Chinn (2001) found 5.7% of the cases to be the result of rear-end collisions. According to an analysis by Zador (1985), out of 6,425 multivehicle accidents involving a motorcycle, 9.31% were rear-end accidents with a motorcycle; and in an examination of motorcycle accidents in Japan, Nagayama, and colleagues (1979) found

3.2% of motor vehicle collisions to be cases of motorcycles being rear-ended by a trailing vehicle.

### **Motorcycle Lamp Flash Studies**

Tang (2003) evaluated the effectiveness of simultaneously flashing a motorcycle's dual rear turn indicator lamps when the brake lamp is activated to increase the conspicuity of a motorcycle. Tang (2003) concluded by flashing the dual rear turn indicator lamps in conjunction with the brake lamp, braking response time of the trailing vehicle was reduced by an average of 80 milliseconds. Tang (2003) further found in daylight and night-time traffic environments, the simultaneous flashing of the dual rear turn indicator lamps with the brake lamp resulted in faster brake response times of the trailing vehicle as compared to the traditional continuous running lamp condition of the dual rear turn indicator lamp.

Tang, Tsai, and Lee (2006) evaluated the influence on response times of flashing the dual rear turn indicator lamps in conjunction with the application of the brake lamp. They found flashing of the dual rear turn indicator lamps as compared to using the normal turn indicators, resulted in a statistically significant decrease of 122 milliseconds in the brake response time of the trailing vehicle compared to normal activation of the turn indicator lamp.

### **Effects of a Flashing Lamp on Conspicuity**

According to evidence in the literature, a flashing lamp, when compared to a continuous lamp, increases conspicuity. In an early study, Gerathewohl (1954) concluded that when engaged in complex psycho-motor tasks, without pre-attention or pre-knowledge of the stimulus, the effectiveness of a lamp as an indicator is not dependent on

the luminance of the lamp but rather on the conspicuity achieved by a series of lamp flashes. Furthermore, as contrast increased between the flashing lamp and its background, the significance of frequency decreased to a point of being insignificant. Itti and Koch (2001), referring to work done by Gottleb and colleagues (1998), concluded a flashing lamp will provoke saccadic eye movements toward the flashing lamp.

Using a driving simulator, Shaheed, Gkritza, and Marshall (2012) tested the effectiveness of a flashing motorcycle headlamp to increase the motorcycle's conspicuity. They concluded flashing the motorcycle's headlamps resulted in a significant increase in the motorcycle's conspicuity irrespective of the background environment. Furthermore, participants could detect the flashing motorcycle headlamp at greater distances as compared to the continuous state high beam lamp or daytime running lamp.

In earlier studies by Donne and Fulton (1985), Olson, Halstead-Nusslock, and Sivak (1979), and Smither and Torrez (2010), a flashing motorcycle headlamp was found to significantly improve the conspicuity of a motorcycle. More recently, Goodwin et al. (2013) also determined one method of increasing motorcycle conspicuity is the implementation of a flashing headlamp.

In evaluating the influence on conspicuity of flashing an automobile's tail lamp at 5 Hz, Llaneras, Neurauter, and Perez (2010) estimated rear-end collisions would be reduced by 5.1%, and the severity of rear-end collisions would also be reduced. Using an automobile appliqué, they had participants complete a secondary task while seated in the driver's seat of a static automobile.

In an examination of the flash patterns of lamps on emergency vehicles, a 4-hertz flash rate was found to convey a greater sense of urgency and cause greater intra-

vehicular distances, as compared to a 1 hertz flash rate (Turner, Wylde, Langham & Morrow, 2014). Turner et al. concluded the higher the flash rate frequency, the more detectable the source is to the observer, with an upper limit of 20 hertz. Above 20 hertz, the flash appears as a continuous light to the observer.

Wierwille et al. (2009) examined optimum visual attention-grabbing frequencies of automotive LED tail lamp assemblies in an outdoor uninformed static test which included the secondary task of programming a factory-installed GPS. The results showed visual attention-grabbing frequencies ranging from 4.25 to 6.5 hertz to be optimal. Based on subjective impression rankings by the participants, the researchers further concluded an 83.30 millisecond flash frequency sequence is the most effective for capturing the participants' visual attention when looking directly at the LED tail lamp assembly at 100 feet intravehicular distance. The flash frequency sequence incorporating the 83.30 millisecond flash frequency sequence had a higher subjective impression ranking compared to the continuous state LED tail lamp assembly, but was not significantly different.

The findings of Wierwille et al. (2009) are supported by Wierwille, Lee and DeHart (2003) who concluded a flashing incandescent lamp provides higher visual attention-grabbing capability compared to the incandescent lamp's continuous state condition. In a later study, Wierwille, Lee, and DeHart (2005) further found evidence while a flashing lamp increases conspicuity, a strong learning effect occurs because of repeated exposures to flashing lamps. The repeated exposures resulted in a decrease in the effect of a flashing lamp on conspicuity.

## **Effects of LED Lamps on Conspicuity**

Motor vehicle LED lamp technology allows for motor vehicle tail lamp designs to incorporate optimum visual attention-grabbing frequencies (Wierville, Lllaneras, & Neurauter, 2009). Advances in LED lamp technology have brought the use of these lamps to the forefront in the motorcycle manufacturing process (International Motorcycle Manufacturers Association, 2014). Compared to incandescent motor vehicle lamps, LED lamp usage has steadily increased due to features such as energy efficiencies, increased life span, increased conspicuity, and design advantages (IMMA, 2014; Hulick, Peterson, Godwin & Madhanl, 2004).

The most critical feature of an LED lamp is a quicker rise time compared to incandescent lamps (Hulick et al., 2004). According to Hulick, Peterson, Godwin, and Madhanl (2004), the quicker rise time of the LED brake lamp equates to a 20' advantage in braking distance at 60 mph, compared to an incandescent motor vehicle brake lamp. In Sivak, Flannagan, Sato, Traube, and Aoki (1993), an LED brake lamp on a passenger vehicle provided a 200-millisecond brake response time advantage as compared to standard incandescent and fast incandescent lamps. The advantage in braking distance caused by the motor vehicle LED brake lamp is due to the faster brake response time on the part of the operator of the trailing automobile (Hulick et al., 2004).

Motor vehicle LED lamps also provide a narrower wavelength range as compared to incandescent lamps, resulting in quicker recognition by the visual information processing system (Olson, 1987; Sivak, Flannagan, Sato, Traube, & Aoki, 1993). Olson (1987) found under all laboratory based conditions, participants responded more quickly to an LED lamp compared to an incandescent lamp.



## Summary

This study incorporates the two factors that have been identified by the literature as the major causal factors of multivehicle rear-end accidents in which the motorcycle is struck by a trailing automobile: the low conspicuity of the motorcycle and the inattention of the operator of the trailing automobile. By applying the findings of Wierwille et al. (2009) to a motorcycle LED brake lamp assembly, this study examines three brake lamp flash treatments to determine their effect on the conspicuity of a motorcycle appliqué and the capacity of the treatment to grab the visual attention of a distracted participant. The use of a flashing brake lamp to increase conspicuity is supported by a body of literature concludes flashing should be incorporated into countermeasures designed to interrupt the inattention of automobile operators of trailing vehicles.

In studies on the prevention of rear-end collisions, the literature also provides evidence supporting the importance of a visual stimulus has the capacity to capture an automobile operator's visual attention when the operator is not observing the road ahead. Many rear-end collisions, or near rear-end collisions, could be avoided if the trailing automobile operator's visual attention could be captured from 20 to 40 degrees off-axis from the forward view.

The literature supports the use of eye tracking methodology to advance the data collection methodology used by Wierwille et al. (2009). Further, the literature provides evidence eye tracking data provides qualitative and quantitative measures of attributes of conspicuity. Psycho-physiology studies on visual behavior provide support for interpreting the data generated by the mobile eye tracking system in this study.

Finally, regarding the response of the automobile operator, the literature provides evidence of the growing significance of texting while driving and the fact cell phones are now the leading cause of fatal crashes involving a distracted driver. Of those distracted driver fatal crashes, the majority are rear-end collisions where leading vehicles are stopping or have stopped on the road ahead.

## CHAPTER THREE

### METHODOLOGIES

#### **Study Overview**

This study measured the differences in participants' visual behaviors and their ranking of subjective impressions regarding the capacity of an LED brake lamp to draw their visual attention to a lamp mounted on a 1:1 scaled motorcycle appliqué. The LED brake lamp was subjected to three different treatments and the participant's visual behavior was distracted by a secondary task of texting to simulate real-life conditions. Data collection was completed using an outdoor, uninformed test format. Participants were not informed that the object of the study was to analyze their visual behavior while texting until data collection was completed. Nor was the participant given pre-knowledge or pre-attention of the existence of the motorcycle appliqué or of its spatial location. These pre-conditions are consistent with Engel's (1976) definition of conspicuity.

The qualitative and quantitative attributes of the conspicuity of the motorcycle appliqué was measured using eye tracking methodology. A Likert scale was used to collect subjective impressions and to provide a subjective measure of the cognitive effect of the LED brake lamp treatments.

#### **Rationale**

This study's design is based upon the premise that most automobile operators involved in rear-end collisions are not viewing the forward roadway at the time of the collision (Klauer et al., 2006). The most effective method of re-directing the automobile operator's visual attention to the forward view to prevent a potential collision, is through

oculomotor capture (Wierwille et al. 2009). Three different LED brake lamp treatments were administered at 20 degrees off axis vertically from the line of sight to the LED brake lamp to determine if the stimulus was strong enough to invoke oculomotor capture. This corresponds to Klauer et al. (2006) who found, to prevent many rear-end collisions, it is necessary to capture the attention of a distracted automobile operator who is trailing the motorcycle, from 20 to 40 degrees off-axis from the forward view.

Texting is now the leading cause of distraction in fatal crashes, with 32% of those crashes involving rear-end collisions (NHTSA, 2013). Given 20% of drivers admit to texting while driving, the study participants will be asked to text as a secondary task to create a distraction and thus simulate actual driving conditions.

## **Sources of Data**

### **Population**

The researcher recruited volunteer participants from employees working at the Sheetz distribution center and administrative complex located on 224 Sheetz Way, Claysburg Pennsylvania. Recruitment notices for the study were posted within the Sheetz complex by Sheetz management personnel. See Appendix A for content of the Sheetz employee recruitment notice.

Research studies have suggested dual licensed operators have significantly different visual behaviors as compared to single licensed operators. Therefore, participants in this study had to hold a valid motor vehicle operator's license endorsed only for automobiles. Dual licensed operators were excluded. Additional criteria for participation are the participant must be at least 18 years of age at the time of the study

and must have a cell phone to use for texting. A candidate had to meet all criteria to be included in this research study.

### **Sample Size**

A pilot study was conducted in an attempt to determine the appropriate sample size using a power level of 80%. G-power software was to be used to perform the calculations for the various power tests. There was no valid eye tracking data obtained from the pilot study and therefore the power analysis for the sample size could not be conducted.

### **Areas of Interest**

The areas of interest for eye tracking methodology is the areas of the stimulus that is relevant to the research question (Bojko, 2013). When the participants' visual fixations landed inside an area of interest, it was interpreted by this study as the participant having given the object of visual interest their visual attention. Defining the areas of interest is necessary for quantitative analysis in eye tracking methodology (Bokjo, 2013). This study established the motorcycle appliqué as the primary area of interest and the participants' phones as the secondary area of interest. This study established the motorcycle appliqué and the participants' cell phones as areas of interest by utilizing a framing element in the Argus Science ET Mobile analysis software. Padding, e.g. an area around the parameter of the target that is included in the area of interest, was incorporated by the researcher into each area of interest. Holmqvist et al. (2011) suggests, at a minimum, the areas of interest should include the relevant area of the stimulus (i.e, the 1:1 scaled motorcycle appliqué and the participants' cell phones) and should account for the accuracy of the eye tracker (Holmqvist et al.). Bokjo (2013) suggests a more liberal

addition of padding to account for inaccuracies associated with eye tracking. Following Holmqvist et al. and Bokjo, the areas of interest was established as the parameter of the objects of interest plus padding outward to the edge of the area of interest framing. Areas of interest for the motorcycle appliqué and cell phones required adjustments based on the effects of parallax. The padding areas, at a minimum, accounted for the 0.5 degrees' accuracy of the mobile eye tracker.

### **Equipment**

This study required the use of the following pieces of equipment and software:

#### **Static Research Vehicle**

A white 2015 Nissan Murano SUV was used as the static research vehicle in an outdoor data collection environment. It functioned as a static platform for the participants to observe the motorcycle appliqué. This vehicle was consistent with the use of an SUV by Wierville et al. (2009). The research vehicle was equipped with a DC to AC converter to provide 110-volt power to power test instruments. The vehicle was continuously idling from 10:00am to 6:00pm, with the emergency brake set.

#### **Static Research Support Vehicle**

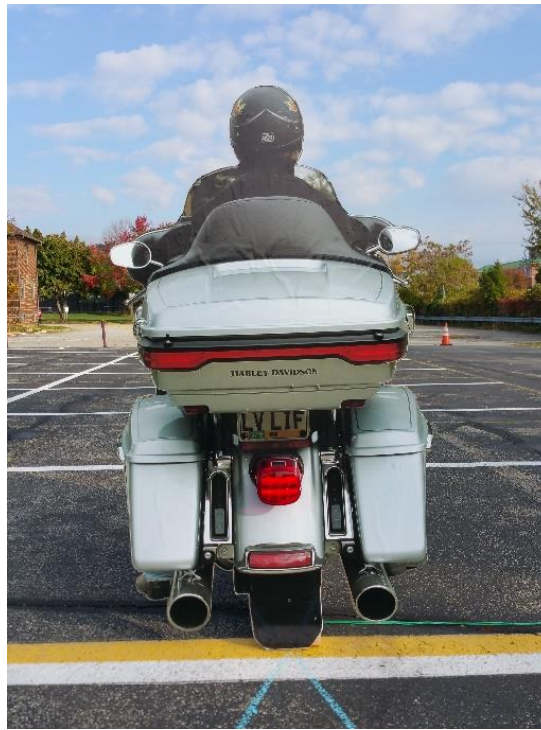
A black 2011 Nissan Titan was used as a support vehicle to provide 12-volt DC power to the secondary control panel and added visual clutter in an outdoor data collection environment. It functioned as a static vehicle parked adjacent to the motorcycle appliqué as if in real traffic. The static research support vehicle was equipped with a DC to AC converter to provide 110-volt power to maintain a charge on the 12-volt Harley Davidson battery powering the LED brake lamp. The vehicle was continuously idling from 10:00am to 6:00pm, with the emergency brake set.

### **Brake Lamp Flash Control Module**

A prototype multichannel, microprocessor-based, motorcycle brake flash control module designed and produced by Signal Dynamics Corporation, Jacksonville, FL was used to control the 83.30 and 117.50 millisecond flash frequency sequences of the LED brake lamp. The continuous state of the LED brake lamp was achieved by by-passing the control module.

### **Motorcycle Appliqué Brake Lamp Assembly**

A Harley Davidson Layback LED tail lamp assembly, part number 67800355, was used for the three LED brake lamp treatments. The LED tail lamp assembly was positioned on a 1:1 scaled motorcycle appliqué of a billet silver 2015 Harley Davidson Electra Glide Ultra Classic Low so the brake lamp was viewed by the participants as the brake lamp would be located on an actual motorcycle, as shown in figure 1.



*Figure 1. Motorcycle appliqué.*

This motorcycle was chosen as it was available for the research study. The LED brake lamp was energized by a Harley Davidson 12-volt battery, part number 66010-97C. The running LED lamp and the license plate LED lamp in the tail lamp assembly was not energized during the data collection periods. Based on findings from the pilot study, the running LED lamp and license plate LED lamp was not energized to maximize the potential for the LED brake lamp to achieve a visual behavior response from the participants. The photograph used to create the appliqué was taken using a Canon EOS Rebel T3 with a Canon EF-S 18-55 mm lens at a resolution of 4272 x 2848 pixels.

### **Portable Battery Charger**

The Nissan Titan support vehicle was equipped with a Car Quest CBC 2100 10-amp manual charger. The charger was used to maintain a full charge on the 12-volt Harley Davidson battery used to energize the LED tail lamp assemble.

### **Mobile Eye Tracking Glasses**

Argus Science's ET Mobile-3 eye tracker glasses, with a resolution of 640 x 480, was used to collect data on visual behavior. The Argus Science ET Mobile-3 eye tracking glasses record data at 60 hertz and has an accuracy of 0.5 visual degrees with a field of view of 60 total degrees horizontally and 55 total degrees vertically. The eye tracking glasses was set to record at  $\pm 30$  degrees from the horizontal line of sight axis and  $\pm 27.5$  degrees from the vertical line of sight axis (Argus Science LLC, 2016).

The Argus Science ET Mobile-3 has an intermediary window of 17 milliseconds measured as the time between sample data sets when there is no data being recorded. An intermediary window of 17 milliseconds results in a fixation duration error of  $\pm 8.5$



milliseconds. This is an acceptable magnitude of error in eye tracking methodology (Bojko, 2013).

**Calibration.** The researcher performed the Argus Science LLC ET Mobile-3 calibration procedure as described in Appendix B.

### **LED Brake Lamp Treatment Main Control Panel**

The researcher constructed a five-circuit electrical main control panel to control the LED brake lamp treatments. The main electrical control panel consisted of four control switches that controlled four relays on the secondary control panel. The relays were used to energized the motorcycle appliqué's LED brake lamp treatments. The main control panel utilized Leviton soft throw switches so the participant was not aware of the circuit being closed. See Appendix C for brake lamp control electrical schematic of the main and secondary control panel.

### **LED Brake Lamp Treatment Secondary Control Panel**

The secondary control panel consisted of the Signal Dynamics' brake lamp control module and four Novita RL44 12-volt, 30-amp relays. Relays controlled; (1) module input power, (2) the 83.30 millisecond flash frequency sequence, (3) the 117.50 millisecond flash frequency sequence, and (4) the continuous lamp. The secondary control panel was designed to the electrical layout of the wiring of the Harley Davidson brake lamp regarding wire gauge, power source, and wire length.

### **Graduated Hand Placement Scale**

This study used a fabricated graduated scale to locate each participant's hand relative to the top of the steering wheel. The scale was based on the participant's vertical eye location. The scale was used to position the participant's hand so that, at the

beginning of the data collection period, the participants' line of sight to their cell phone was at -20 degrees vertically from their horizontal line of sight to the motorcycle appliqué. The scale was removed from the steering wheel prior to commencing the data collection period so it does not interfere with the participants' phone manipulation.

### **Measuring Tape**

A reel type measuring tape was used to located the research vehicle 30 feet from the motorcycle appliqué. Measurement was taken from the center of the seat pan (front to back) of the research vehicle's driver's seat to the front of the motorcycle appliqué. Visual observation was used to center the motorcycle appliqué with the research vehicle's driver's seat.

### **Canopy**

The research vehicle was placed under a 10' x 10' canopy. The canopy was located so it would shield the research vehicle's front windshield from direct sunlight. The canopy was not visible from the driver's seat of the research vehicle during data collection.

### **AC/DC Converter and Charger**

The 2015 Nissan Murano SUV research vehicle and the Nissan Titan support vehicle were each equipped with a Schumacher 410-watt DC to AC converter to run test instruments and to maintain a charge on the battery powering the LED brake lamp.

### **Covered Motorcycle Parking Shelter**

A three-sided, roofed motorcycle parking shelter was used to provide a consistent background to view the motorcycle appliqué. The motorcycle appliqué was located at the front edge of the shelter during data collection.

## **Survey Instruments and Software Used**

### **Eye Tracker Data Analysis Software**

This study used an Argus Science's ET Analysis software to record and analyze the rank of the participants' visual fixations and their visual detection performance time.

**Areas of interest.** Using the Argus Science ET Analysis software, the researcher established the area surrounding the motorcycle appliqué and the area surrounding the participants' cell phone as the research studies areas of interest. The researcher used the rectangular drawing element to construct each of the areas of interest. There were no overlaps between the two areas of interest. Each area of interest was constructed using the object of interest plus a padding allowance.

### **Randomization Software**

This study used Research Randomizer on-line software available from [Researchrandomizer.org](http://Researchrandomizer.org). The software was used to randomly select the LED brake lamp treatment assigned to each participant.

## **Measures**

### **Independent Variable**

This study used one independent variable: the LED brake lamp treatment on the motorcycle appliqué. The participants were randomly presented with one of three LED brake lamp conditions: a continuous state lamp, an 83.5 millisecond flash rate, or a 117.50 millisecond flash rate. The flash rates were controlled by the researcher using a motorcycle brake lamp flash module made by Signal Dynamics Corporation.

## **Dependent Variables**

This study used four dependent variables: (a) the rank of the first visual fixation landing in the area of interest after initiation of the data collection period; (b) a Likert scale ranking of the participant's subjective impressions of the attention-getting capability of the LED brake lamp on the motorcycle appliqué, with 1 representing "not at all attention getting" to 8 representing "extremely attention getting;" (c) the visual detection performance time, measured in milliseconds, as the time from the start of the flash sequence to the time the first visual fixation lands in the area of interest; and (d) the total visual fixation duration time, measured in milliseconds, for all visual fixations that land inside the area of interest over the data collection period.

## **Sample Periods**

For the all three treatments (continuous state, the 83.30 millisecond flash sequence, and the 117.50 millisecond flash frequency sequence), the data collection period was initiated when the LED brake lamp is illuminated. The duration of the sample period was as follows: (1) for the continuous lamp 1.386 seconds, (2) for the 83.30 millisecond flash sequence 1.386 seconds, and (3) for the 117.50 millisecond flash sequence 1.787 seconds. With video recordings at 60 frames per second, the 1.386 and 1.787 second data collection periods are equivalent to 83 and 107 frames of video, respectively.

For the 83.30 and 117.50 millisecond flash frequency sequences, the sample period was based on the time to complete the flash sequence, an 80-millisecond period for the subject to complete a saccade from their cell phone to the area of interest and an additional 300 milliseconds for the creation of a fixation within the motorcycle appliqué's

area of interest. According to Holmqvist et al. the maximum time to complete a saccade is 80 milliseconds, and the maximum time of a fixation is 300 milliseconds. Further, the sample period for the continuous brake lamp is based on Theeuwes and Belopolsky (2012) where subjects being studied for oculomotor capture were given 1000 milliseconds to detect a continuous lamp. During the sample periods, the research vehicle and the appliqué were static, with the subject and appliqué being separated by 30 feet.

### **Research Site**

The research was conducted in the employee parking lot at the Sheetz Corporation's terminal and administrative complex located at 242 Sheetz Way, Claysburg, Pennsylvania. The researcher constructed the data collection environment as depicted in Figure 1. Data collection was performed from 10:00am to 6:00pm. The use of the morning through mid-day for data collection is consistent with Wierwille et al. (2009). The research vehicle was staged so the participant, when seated in the vehicle, viewed the appliqué of the motorcycle at 0 degrees horizontally from the center line of the driver's seat. The motorcycle appliqué was viewed by the participants in a northerly direction. The research vehicle orientation was consistent with Wierwille et al. (2009).

Using the center line of the research vehicle's steering wheel and driver's seat, the researcher positioned the motorcycle appliqué at 0 degrees horizontally at 30 feet in front of the center of the driver's seat. The researcher determined the eye position of the participant using a measuring tape. Based on the participants' eye position, the researcher determined the participant's cell phone position so that the participant viewed their cell

phone at -20 degrees from the vertically and 0 degrees horizontally at the beginning of the data collection period.

### **Test Procedure**

During data collection, the research vehicle and the research support vehicle were idling with emergency brakes set. The Sheetz employee lunchroom was used to stage participants. Upon the participants' arrival at the lunchroom, the research assistant provided a copy of the informed consent to the participant and instructed them to read the informed consent. See Appendix D Research Study Informed Consent. A research assistant then instructed the participant would need to sign the informed consent in the research vehicle if they were to participate in the study. The research assistant used text messages to inform the researcher that a participant was available for testing. Staging participants in the lunchroom prevented the participants from observing the study site prior to being tested and revealing the true purpose of the study. Once the researcher was ready for a participant, the researcher text messaged the research assistant to direct the participant to the research vehicle. Once at the research site, the researcher confirmed their age and the status of their motor vehicle operator's license endorsement by checking their automobile operator's license. The researcher then reviewed the informed consent form, obtain a signature, and give a copy of the form to the participant. The participant was then positioned into the driver's seat of the static research vehicle and the researcher occupied the front passenger's seat. The participant was permitted to relocate the driver's seat but the steering wheel location will remain consistent through data collection tests. The researcher then explained the testing procedure and requested permission to place the mobile eye tracking glasses on the participant. With permission, the researcher placed

the mobile eye tracking glasses on the participant and performed the calibration procedure for the mobile eye tracking glasses as described in Appendix B.

Upon successful completion of the calibration procedure, the researcher prepared the participant for data collection as described in Appendix E. With the participant seated in the research vehicle, the researcher measures the participant's vertical eye location relative to the interior roof of the vehicle. Based upon the eye location, and position of the driver's seat, the researcher used the graduated measuring scale to instruct the participant as to where to locate their cell phone relative to the top of the steering wheel. This method to position the cell phone provided for a consistent cell phone location across the participants, e.g. -20 degrees vertically from the horizontal line of sight to the motorcycle appliqué and 0 degrees horizontally. With the participant's hand in the pre-determined location, the researcher instructed the participant to keep their visual attention on their cell phone through the entire text messaging task. The researcher further informed the participant how they would be queued to start texting the phrase "Mary had a little lamp." As soon as the participant began texting, the researcher activated one of the three test treatments via a remote main control panel located inside the static research vehicle. The activation of the LED brake lamp initiated the beginning of the data collection period. When the brake lamp was energized by the researcher, the illuminated brake lamp was captured by the mobile eye tracker's forward-looking camera. An examination of the 60-hertz mobile eye tracker video recordings was conducted by the researcher to determine which data sets fell within the sample period assigned to the LED brake lamp treatment. The data collection period for each test period was identified by

visual observation of the video frames. During data analysis, the research parsed the excess frames from the video using Argus Science ET Mobile software.



*Figure 2.* Data collection set-up.

The participants were not aware of the pending activation of the LED brake lamp and the researcher took care to operate the remote main control panel in such a manner the participant was not aware of the researcher's activity. After the researcher terminated the recording, the researcher instructed the participant to stop texting and the test period was ended. The mobile eye tracker recorded data at 60 sets per second. The continuous brake lamp and 83.30 millisecond flash frequency sequence used 83 frames as the data collection period. The 117.50 millisecond flash frequency sequence used 107 frames as the data collection period.

After collecting the data on the participant's visual behavior, the researcher asked the participants to rank their subjective impressions of the LED brake lamp's capacity to direct their visual attention from their cell phone to the motorcycle appliqué. The



participant was presented with a Likert Scale for the subjective impression ranking as described in Appendix F. After the study was completed, the participant was given a verbal and written explanation of the true purpose of the study. See Appendix G. This ended the trial.

### **Descriptive Data Analysis**

For similarly distributed data, the median rank of the participants' first visual fixation landing in the motorcycle appliqué's area of interest was to be reported for the three LED brake lamp conditions: continuous state, flash rate of 83.30 milliseconds, and flash rate of 117.50 milliseconds. Because there were only oculomotor responses to the 83.30 flash frequency sequence, the analysis of the median rank of the participants' first visual fixation landing in the motorcycle appliqué's area of interest was not conducted. Subjective impression ranking data was similarly distributed data. Therefore, the median rank of the participant's subjective impression ranking of the LED brake lamp was reported. Participants used a 1 to 8 Likert scale to rank their subjective impressions of the LED brake lamp treatment's ability to capture their visual attention. The means and range were also reported for each of the three LED brake lamp conditions.

For continuous dependent variables, the number of cases, the mean, the standard deviation, and the lower and upper boundaries of the 95% confidence interval could not be reported for each of the three LED brake lamp conditions: continuous state, flash rate of 83.30 milliseconds, and flash rate of 117.50 milliseconds.

The Wilks' Lambda, F value, the p value, and Partial Eta Squared value were not reported for the vector that was to compare responses across the three conditions of the motorcycle appliqué's LED brake lamp. The continuous dependent variables were not

reported due to oculomotor responses only being achieved by the 83.30 millisecond flash frequency sequence.

## **Inferential Statistical Test**

### **Kruskal-Wallis H Test Summary**

The Kruskal-Wallis H test is a nonparametric test and was used to determine if there were statistically significant differences in the ordinal dependent variable when measured across the three groups of the independent variable. The dependent ordinal variables used in this procedure was the rank of the first visual fixation landing in the motorcycle appliqué's area of interest and the participant's subjective impression ranking using a Likert scale for the brake lamp's capacity to capture their visual attention. An alpha level of .05 was used to determine significance. IBM SPSS Statistics Version 24 was used to perform these calculations. The rank of the first visual fixation landing in the motorcycle appliqué's area of interest was not reported due to oculomotor responses only being achieved by the 83.30 millisecond flash frequency sequence.

### **Kruskal-Wallis H Test Assumptions**

Kruskal-Wallis H Test assumptions are: (a) one dependent variable measured on a ratio, interval, or ordinal level; (b) one independent variable that consists of two or more categorical, independent groups; (c) independence of observation, and (d) a determination can be made regarding the shape of the distribution of dependent variable data for each of the independent variable levels. If the distribution for dependent variable data across the three LED brake lamp levels of the independent variable do not have the same shape, the Kruskal-Wallis H test hypothesis compares means rather than median ranks.

The assumption for one dependent variable measured on an ordinal level was met by the study's design. The measure of a visual fixation is an ordinal variable (Holmqvist et al., 2011). The Likert scale, used for subjective impression ranking, is an ordinal variable.

The assumption of one independent variable that consists of two or more categorical, independent groups was met by the study's design. This study used three levels for the brake lamp condition. The assumption of independence of observation was met by the study's design. Each participant made an observation of only one level of the independent variable.

The assumption there can be a determination regarding the shape of the dependent variable was completed by visual examination of box plots. The examination determined if the ordinal dependent variable data was similarly distributed across the three levels of the independent variable. The distribution of the ordinal dependent variable data was found to be similarly shaped. Therefore, the Kruskal-Wallis H test procedure was used to determine if there was a statistically significant difference in the median rank across the three levels of the independent variable. If the ordinal dependent variable data would have been dissimilarly shaped across the three levels, the Kruskal-Wallis H test procedure would have used the mean ranking across the three levels of the independent variable.

### **Median Rank of First Visual Fixation Landing on the Motorcycle Appliqué**

**Test procedure.** The Kruskal-Wallis test was to be used to determine if there were significant differences in the median rank of the participants' first visual fixation landing in the motorcycle appliqué's area of interest, based upon the motorcycle

appliqué's LED brake lamp treatment conditions (continuous state, flash rate of 83.30 milliseconds, and flash rate of 117.50 milliseconds).

The rank of the first visual fixation landing in the motorcycle appliqué's area of interest was not analyzed due to oculomotor responses only being achieved by the 83.30 millisecond flash frequency sequence.

### **Kruskal-Wallis H Test Hypotheses**

The hypothesis tested was:

$H_{O1}$ : The median rank of the first visual fixation landing in the motorcycle appliqué's area of interest over the data collection period across the three levels of the motorcycle appliqué's LED brake lamp are equal.

$H_{A1}$ : The median rank of the first visual fixation landing in the motorcycle appliqué's area of interest over the data collection period across the three levels of the motorcycle appliqué's LED brake lamp are not equal.

The median rank of the first visual fixation landing in the motorcycle appliqué's area of interest was not analyzed due to oculomotor responses only being achieved by the 83.30 millisecond flash frequency sequence.

### **Subjective Impression Rankings for Oculomotor Capture**

**Test procedure.** The Kruskal-Wallis test was used to determine if there were significant differences in participants' rankings of their subjective impressions of the oculomotor capture capacity of the LED brake lamp based upon the three treatment conditions. The participants' subjective impression ranking was recorded on a Likert scale in which 1 = not at all attention getting, and 8 = extremely attention getting. The participants recorded their subjective impression rankings proceeding the uniformed

segment of the data collection period. Before the subjective impression data collection, participants were instructed per Appendix E.

### **Kruskal-Wallis H Test Hypotheses**

The hypothesis tested was be:

H<sub>O2</sub>: The median rank of the participant's subjective impression of the oculomotor capture capacity of the LED brake lamp across the three levels are equal.

H<sub>A2</sub>: The median rank of the participant's subjective impression of the oculomotor capture capacity of the LED brake lamp across the three levels are not equal.

The distributions were determined to be similar. Therefore, the hypotheses tested median rankings rather mean rankings. The Kruskal-Wallis H test was significant for the pilot study data. A Dunn's procedure was used for the post hoc analysis. The Dunn's procedure incorporated the Bonferroni adjustment.

### **One-Way MANOVA Test Summary**

The One-Way MANOVA test procedure was to be used to determine if there is significance in the group mean vectors of the dependent variables across two or more continuous dependent variables when there is one categorical independent variable. The continuous dependent variables used in this test procedure were the total visual fixation duration time in the motorcycle appliqué's area of interest and the visual detection performance time.

An alpha level of .05 was to be used to determine significance. IBM SPSS Statistics Version 24.0 was to be used to perform these calculations. The continuous dependent variables were not analyzed due to oculomotor responses only being achieved by the 83.30 millisecond flash frequency sequence.

## **One-Way MANOVA Test Assumptions**

One-Way MANOVA test assumptions are: (a) there is one independent variable that is categorical across two or more groups; (b) two or more dependent variables measured at a ratio or interval level; (c) multivariate normality; (d) no univariate outliers; (e) no multivariate outliers; (f) a linear relationship between the dependent variables for each group of the independent variable; (g) a between-group homogeneity of variance; (h) a homogeneity of variance co-variance matrices; (i) no multi-collinearity; (j) independence of observation; and (k) adequate sample size.

The assumption for one independent variable that is categorical with two or more groups was met by the study's design. This study's independent variable representing the three levels of the LED brake lamp was a between-group independent categorical variable.

The assumption of two or more dependent variables that are measured at a ratio or interval level was met by the study's design in that the dependent variables for visual detection performance time and total visual fixation duration time in the motorcycle appliqué's area of interest are ratio variables. Both ratio dependent variables were measurements of time in milliseconds. Shapiro-Wilk was to be used to test for univariate normality of the dependent variable data for each of the independent variable levels. If the assumption of univariate normality did not hold,  $p < .05$ , all dependent variable data would have been transformed and re-examined. If there was univariate normality, multivariate normality would have been assumed.

The assumption that there are no univariate outliers was to be tested using box plots. Those cases containing a univariate outlier would have been removed from the

analysis. Multivariate outliers were to be tested by using the Mahalanobis Distance Test. Cases where a Mahalanobis Distance value of 13.82 or greater would have been identified as outliers and those cases would have been removed from the analysis.

The assumption that there is a linear relationship between the dependent variables for each level of the independent variable was to be tested using a scatter plot matrix for each group of the independent variable. A visual examination of the scatter plot matrix would have been conducted to determine if there was a linear relationship between the dependent variable data for each level of the independent variable levels. If a visual examination of the scatter plot matrices indicated this assumption failed, all dependent variable data would have been transformed and re-examined.

The assumption that there is no multi-collinearity between dependent variable data was to be tested using Pearson correlation coefficients. Positive correlation of  $\geq .9$  would have been considered a highly-correlated variable and would therefore fail this assumption. Highly-correlated dependent variables would have been removed from the analysis.

The assumption of between-group homogeneity of variance was to be tested using Levene's Test of Equality of Error Variances. If Levene's Test was not significant,  $p > .05$ , then the assumption would have been met. If the assumption of homogeneity of variances was not met,  $p < .05$ , all dependent variable data would have been transformed and re-examined.

The assumption of homogeneity of variance co-variance matrices was to be tested using the Box's M Test of homogeneity of variance co-variance matrices. If the Box's M Test was not statistically significant ( $p > .001$ ), the assumption holds. If the assumption

did not hold,  $p < .001$ , all dependent variable data would have been transformed and re-examined.

The assumption of independence of observation was met by the study's design. Each participant only participated in one level of the independent variable and only ranked subjective impressions for the level of the independent variable the participant observed.

The assumption of an adequate sample size was to be met by the pilot study establishing the population size of the three independent groups of participants using a power level of 80%. By the study's design, the three independent groups of participants were to be of equal size. Because the pilot study did not generate any valid cases, the power analysis of the pilot study data was not conducted.

### **One-Way MANOVA Test Procedure Hypotheses**

The hypothesis tested were to be:

H<sub>03</sub>: There is no significance in the group mean vectors of the dependent variable across the three levels of the motorcycle appliqué's LED brake lamp levels.

H<sub>A3</sub>: There is significance in the group mean vectors of the dependent variable across the three levels of the motorcycle appliqué's LED brake lamp levels.

**Test procedure.** The One-Way MANOVA test was to be used to determine if there are significant differences in the vector across the motorcycle appliqué's LED brake lamp conditions (continuous state, flash rate of 83.30 milliseconds, and flash rate of 117.50 milliseconds). For cases where no visual fixation landed in the motorcycle appliqué's area of interest during the data collection period, the subject's visual performance data was removed from this analysis.



If the One-Way MANOVA was significant, ANOVAs would have been performed to determine where the significance lies within the dependent variables. If the ANOVAs were significant, post hoc analysis would have been performed using Tukey's HSD test. An alpha level of .05 was to be used to determine significance in all tests.

For tests of between-subject effects, the degrees of freedom, mean squared, Partial Eta Squared, and F value were to be reported. The partial Eta Squared was to be used to determine the ratio of variance accounted for by the main effect. If there was significance, the partial Eta Squared would have been used to determine the ratio of variance accounted for by the between-subjects effects.

If the data failed to meet the assumptions of the One-Way MANOVA, then appropriate non-parametric tests would have been performed. The One-Way MANOVA analysis was not conducted due to oculomotor responses being achieved only by the 83.30 millisecond flash frequency sequence.

## CHAPTER FOUR

### DATA

#### **Pilot Study**

A pilot study was conducted using the band practice parking lot located on the campus of Indiana University of Pennsylvania, Indiana, PA. The purpose of the pilot study was to confirm the research methods proposed in this study are valid. There were 51 participants in the pilot study, resulting in 49 sets of eye tracking data (one video file became corrupted and one case failed to record). There were 51 subjective impression rankings completed for the LED brake lamp treatment's ability to capture the participants' visual attention. An examination of the 49 sets of video data concluded pupillary tracking was lost in 24 of the cases. Of the 25 cases where eye tracking was maintained, 74.1% of the cases found the participants displayed a visual behavior of continuously changing their visual attention between their phone and the forward view. This visual behavior would be expected if the participants were operating the research vehicle in live traffic. In 7.4% of the 24 eye tracked cases the motorcycle appliqué was not in the field of view of the eye tracking glasses' forward-looking camera.

#### **Pilot Study Results**

An analysis to determine the presence of a statistically significant differences of the first visual fixation landing within the motorcycle appliqué's area of increase across the three LED brake lamp treatments using the Kruskal-Wallis H test, and the proposed analysis of the group mean vector across the three LED brake lamp treatments using a One-Way MANOVA test were not conducted because the pilot study resulted in no valid eye tracking cases. The researcher concluded there were no valid cases because the pilot

study did not provide a method to determine the location of the participants' visual attention at the beginning of the data collection period.

At the end of each eye tracking test, pilot study participants completed a subjective ranking of the brake lamp's capacity to capture the participant's visual attention was recorded using a Likert scale, with 1 being "Not at all attention getting," to 8 being "Extremely attention getting." A copy of the instrument used to collect the data appears in Appendix F. The participants ranked the LED brake lamp treatment they were exposed to during the eye tracking test. For the subjective impression ranking, the LED brake lamp was presented one time to the participant.

Using IBM SPSS version 24, an analysis of the pilot study's participants' subjective impression rankings was conducted. The mean rankings for the 83.30 millisecond flash frequency sequence, the 117.50 millisecond flash frequency sequence, and the continuous condition were 5.72, 5.13, and 4.58, respectively. The overall mean was 5.15. The most attention-grabbing treatment was the 83.30 millisecond flash frequency sequence, followed by the 117.50 millisecond flash frequency sequence, with the continuous receiving the lowest subjective impression ranking. The order of the median was the same as the means, with the 83.30 millisecond flash frequency sequence achieving the highest median. The average median was above the 4.5 neutral ranking. While the 83.30 millisecond flash frequency sequence received the highest average mean, no participant ranked that treatment as an 8. The continuous condition, which had the lowest mean ranking, received one 8 ranking. Table 1 summarizes the descriptive statistics for the pilot study subjective impression rankings.

Table 1

*Pilot Study Descriptive Summary*

<u>Flash Frequency Sequence in milliseconds</u>	<u>N</u>	<u>Mean</u>	<u>Median</u>	<u>Range</u>
83.30	18	5.72	5.50	3-7
117.50	15	5.13	5.00	4-7
Continuous	18	4.58	4.00	4-8
Total	51	5.15	5.00	3-8

A Kruskal-Wallis H test was conducted for the pilot study participants' subjective impression rankings to determine if there were statistically significant difference across the three levels of LED brake lamp treatments; (1) 83.30 millisecond flash frequency sequence, (2) 117.50 millisecond flash frequency sequence, and (3) the continuous condition. By visual observation of the box plots, it was determined the data were similar across the three treatments. Median subjective impression rankings across the three LED brake lamp treatments were statistically significantly different between treatments, Kruskal-Wallis H = 9.30,  $p = 0.01$ .

Post hoc test for means was conducted using pairwise comparisons using Dunn's procedure with a Bonferroni correction for multiple comparisons. Post hoc test indicated there was a statistically significant difference between the means of the continuous condition of the LED brake lamp (Median = 4.58) and the 83.30 millisecond flash frequency sequence (Median = 5.72),  $p = 0.01$ . There was no statistically significant difference in the means between the continuous brake lamp condition and the 117.50 millisecond flash frequency sequence (5.13) or between the 117.50 and 83.30 millisecond flash frequency sequences. Table 2 summarizes post hoc testing of the pilot study results.

Table 2

*Pilot Study Post Hoc Test Summary*

<u>Flash Freq. Sequence in milliseconds</u>	<u>p</u>	<u>Adjusted p</u>
Continuous – 117.50	0.17	0.48
Continuous – 83.30	0.00	0.01
117.50 – 83.30	0.13	0.40

**Modifications to Methods Resulting From the Pilot Study Findings**

Several changes were made to the research methodology as the result of the pilot study findings. A review of the video data with an engineer from Argus Science identified the following problems with the pilot study’s data collection methodology:

- Direct sunlight reflecting from the research vehicle’s windshield was the likely cause of the high number of cases where pupillary tracking was lost during data collection.
- No instructions were provided to the participant regarding where to direct their visual attention at the start of the data collection period resulting in the participants’ visual attention being off their cell phone at the beginning of the data collection period.
- The participants’ phone was not identified as an area of interest which did not permit the software to track visual fixations landing on the phone nor confirm the participant was looking at their phone at the beginning of the data collection period.
- In many of the cases, at a 100-foot intravehicular distance between the research vehicle and motorcycle appliqué it was difficult to determine, by

visual observation of the video, as to when the brake lamp was energized resulting in uncertainty as to which video frame started the data collection period.

- In many of the cases, the participants repeatedly looked downward at their phone and then upward to a forward view resulting in the participants looking towards the motorcycle appliqué by nature of this visual behavior.
- The background of the motorcycle appliqué was inconsistent with several participants' videos containing traffic and people.
- The brake lamp was energized from the research vehicle which required 220 feet of electrical cable resulting in a voltage drop not consistent with the motorcycle's electrical system used for the brake lamp assembly used in the study.
- Calibration target locations at 100 feet did not provide for adequate eye rotation which may have influenced the eye track data.

To correct these pilot study issues; (1) the research vehicle was placed under a canopy to prevent the windshield from being exposed to direct sunlight reducing the likelihood of loss of pupillary tracking, (2) the participants were given instructions to maintain visual attention on their phone during the data collection period, (3) the participants' phone was identified as an area of interest allowing for analysis and tracking of visual fixations landing on the phone; (4) the intravehicular distance was reduced to 30 feet to allow for the identification, by visual observation, of the video frame where the brake lamp became energized starting the data collection period, (5) the participants were

instructed they were not to act as if they are driving the vehicle in live traffic and maintain visual attention on their phone, (6) a three-sided motorcycle parking shelter was used as a back drop to provide a consistent background, (7) a secondary electrical control panel was incorporated into the electrical system of the LED brake lamp permitted the electrical wiring length and wire size of a motorcycle to be duplicated, (8) calibration distance was reduced to 20 feet using a single point method as describe in Appendix B.

Comparing the pilot study to the study conducted at the Sheetz complex, these corrective actions resulted in; (1) lost pupillary tracking being reduced to 16.7%, (2) the ability to determine brake lamp activation by visual observation of the eye tracking video increased to 100%, (3) in 93.3% of the cases where pupillary tracking was not lost the participants' visual attention was on their cell phone at the beginning of the data collection period, (4) the primary Purkinje reflection vector and pupillary location was confirmed in 100% of the calibration procedures, and; (5) voltage drop was reduced from 0.29% to 0.02%, which replicates the motorcycle, based on calculations.

### **Dissertation Data Overview**

Incorporating the modifications identified above, a second study was conducted using 55 participants who were employees of the Sheetz Corporation or Sheetz Corporation vendors, henceforward referred to as the *second study*. The second study resulted in 42 valid cases. Data analysis on the eye tracking variables was conducted on the 42 valid cases from the second study. Data on 13 participants were not analyzed due to: (1) loss of pupillary tracking data for nine participants; (2) the first visual fixation of two participants were outside either interest area at the beginning of the data collection period; (3) one participant was looking at the motorcycle appliqué when the data

collection period began, and (4) a data recording failure for one participant. Table 3 summarizes the second study cases by LED brake lamp treatment.

After the second study’s data collection period, all 55 participants completed a subjective impression ranking of the LED brake lamp treatment’s ability to capture their visual attention. The participants ranked the treatment they were exposed to during the eye tracking test.

Table 3

*Second Study Cases by LED Brake Lamp Treatment*

<u>Flash Frequency Sequence in milliseconds</u>	<u>Total Cases</u>	<u>Valid Cases</u>
83.30	20	16
117.50	18	15
Continuous	17	11
Total	55	42

**Kruskal-Wallis Analysis of the First Visual Fixation on the Motorcycle Appliqué**

An analysis to determine the presence of a statistically significant difference in the first visual fixation landing on the motorcycle appliqué’s area of interest existed across the three LED brake lamp treatments (a Kruskal-Wallis H test) was proposed but could not be conducted because only one treatment, the 83.30 millisecond flash frequency sequence, had valid cases. Table 4 shows the second study’s scan paths for the 42 valid cases.

Of the 42 valid cases, ET Mobile software analysis indicated only three participants displayed visual behavior indicative of oculomotor capture in response to exposure to the 83.30 millisecond flash frequency treatment. All three participants landed



at least one visual fixation on the motorcycle appliqué in response to the 83.30 millisecond flash frequency sequence. Two of these participants landed their first visual fixation on their phones before redirecting their visual attention to the motorcycle appliqué. The other participant landed their first visual fixation on the motorcycle appliqué.

Visual fixations per participant ranged from 1 to 6, with a total of 145 visual fixations being recorded across the 42 valid cases. Of the 145 visual fixations, 97.2% landed within the participants' phone's area of interest, 2.1% landed within the motorcycle's appliqué's area of interest, and 0.7% landed outside either of the two areas of interest. For the single case where a visual fixation was landed outside either area of interest, the scan path started with the first visual fixation landing within the phone's area of interest. Therefore, the data for this participant was considered as being valid.

Because the second study's data for the first visual fixation landing within the motorcycle appliqué's area of interest did not meet the assumptions of the Kruskal-Wallis H test, it was not performed. Thus, the hypothesis could not be tested.

Table 4

*Second Study Scan Paths for Valid Cases*

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<u>Participant</u>	<u>Scan Path Sequence</u>
7	P, P, P, P
9	P
10	P, P, P
11	P, P, P, P
12	P, P

13	P, P, P, P, P
14	P, P, P, P, P
16	P, P
17	P, P, P
18	P, P, P, P
19	P, P, P
20	P, P, P, P, P, P
21	P, P, O, P
22	P, P
23	P, P, P, P, P
24	P, P, P
25	P
26	P, P, P
27	P, P, P
28	P, P, P, P
29	P, P, P, P, P
30	P, P, M, M
31	P
32	P
33	P
35	P, P
36	M, P, P
37	P, P, P

38	P, P, P
40	P, P, P, P
41	P, P, P
42	P, P, P, P, P
43	P, P, P
44	P, P, P
45	P, P, P, P, P, P
46	P, P, P, P
48	P, P, P, P, P
50	P, P, P
51	P, P
52	P, P, P, P
53	P, P, P, P, P
54	P, P, P, M

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*Note:* *P* = Phone, *M* = Motorcycle appliqué, *O* = Fixation was outside phone's or motorcycle appliqué's area of interest

### **Subjective Impression Rankings of the LED Brake Lamp Treatments**

The subjective ranking of the brake lamp's capacity to capture the participant's visual attention was obtained using a Likert scale, with 1 being "Not at all attention getting," to 8 being "Extremely attention getting." Participants ranked their impressions after a single observation of the same LED brake lamp treatment to which they had been exposed during the data collection period. Prior to observing the LED brake lamp treatment for their subjective impression ranking, participants were instructed to act as if they were driving the research vehicle with their vision forward directed at the

motorcycle appliqué. The researcher informed the participants their subjective impression of the brake lamp's ability to capture their visual attention would be based on a single activation of the LED brake lamp.

### **Kruskal-Wallis Analysis of the Subjective Impression Rankings**

A Kruskal-Wallis H test was used to evaluate the hypothesis that the median rank of the participants' subjective impressions of the oculomotor capture capacity of the LED brake lamp is equal across the three levels. An analysis of the subjective impression rankings was conducted using IBM SPSS version 24 to determine if there was a significant difference across the three LED brake lamp treatments: (1) 83.30 milliseconds flash frequency sequence; (2) 117.50 millisecond flash frequency sequence; and (3) the continuous state. By visual examination of the box plots, the data distribution across the three treatments was determined to be similar. The analysis concluded the subjective impression rankings across the three LED brake lamp treatments were not statistically significant (median = 4.75, Kruskal-Wallis H = 4.938,  $p = .085$ ). See Table 5 a descriptive summary.

The average ranking for both flashing sequences was higher than the continuous condition of the lamp. The faster cycle of the two flashing sequences (the 83.30 millisecond flash frequency sequence) had the highest subjective impression ranking.

Of the three LED brake lamp treatments, 20 participants were exposed to the 83.30 millisecond flash sequence, 18 to the 117.50 millisecond flash sequence, and 17 to the continuous condition. The average subjective impression ranking of all the treatments was 5.76. The average subjective impression ranking for the 83.30 and 117.5 millisecond flash frequency sequence, and the continuous condition were 6.32, 5.75, and

5.09, respectively. See Table 5. The 83.30 millisecond flash frequency sequence achieved the highest subjective impression ranking. The continuous condition of the LED brake lamp received the lowest mean subjective impression ranking and had the lowest median.

The results indicate there is no statistically significant difference in subjective impression rankings across the three brake lamp treatments regarding the LED brake lamp's capacity to achieve oculomotor capture.

Table 5

*Second Study Descriptive Summary*

Flash Frequency Sequence in milliseconds	N	Mean	Median	Range
83.30	20	6.32	6.00	2-8
117.50	18	5.75	6.00	3.5-8
Continuous	17	5.09	5.00	2-8
Total	55	5.76	6.00	2-8

**One-Way MANOVA Analysis of the Group Mean Vector**

An analysis to determine the presence of a statistically significant difference in a group mean vector across the three LED brake lamp treatments (the One-Way MANOVA test) was proposed but not conducted because only one treatment, the 83.30 millisecond flash frequency sequence, had valid cases.

## CHAPTER FIVE

### DISCUSSION

#### **Study Overview**

The purpose of this study was to use mobile eye tracking methodology to examine the effect on a motorcycle appliqué's conspicuity to determine if oculomotor capture could be achieved by three LED brake lamp treatments: (1) 83.30 millisecond flash frequency sequence, (2) 117.50 millisecond flash frequency sequence, and (3) the continuous state.

Wierwille et al. (2009) tested automotive LED brake lamp assemblies consisting of a left lamp, a right lamp, and a center high mounted lamp. This study's design applied Wierwille's findings for effective attention-grabbing flash frequencies into the design of a module that controlled a single motorcycle LED brake lamp assembly.

The module used in this study consisted of two circuits. One circuit caused the motorcycle LED brake lamp to flash at 6.00 hertz, with six on-off segments, using a 50% duty cycle, e.g. on period and off period are equal. The other circuit caused the motorcycle LED brake lamp to flash at 4.25 hertz, with six on-off segments, using a 50% duty cycle.

Wierwille et al. (2009) study on automotive tail lamp assemblies suggested the best attention-grabbing flash frequencies were in the range of 4.25 to 6.00 hertz, with the 6.00 hertz being the optimal flash frequency based on their subjective impression rankings. Wierwille's 4.25 hertz flash frequency sequence is equivalent to the 117.50 millisecond flash frequency, and their 6.00 hertz flash frequency sequence is equivalent to the 83.30 millisecond flash frequency sequence, the two flashing frequencies used in

this study. These two flashing frequencies represent each end of the Wierville's frequency range as stated above.

Results from the pilot study provided evidence of the difficulties related to conducting mobile eye tracking studies in an outdoor environment. With 51 participants in the pilot study, there were no valid eye tracking cases. The pilot study resulted in the completion of 51 subjective impression rankings for the LED brake lamp treatment's ability to capture the participants' visual attention at an intravehicular distance of 100 feet.

### **Eye Tracking Data**

With deficiencies identified in the pilot study corrected, a second study was conducted at the Sheetz complex resulting in 42 (76.36%) of the 55 cases being valid with regards to the eye tracking data. Of the 42 valid second study cases, only three cases responded to an LED brake lamp treatment. All three responses were to the 83.30 millisecond flash frequency sequence. Due to a lack of responses to the different brake lamp treatments, statistical analysis could not be performed.

Similarly, Wierville et al. (2009) experienced a low number of participants responding to their automotive brake lamp treatments. Unlike Wierville, that assigned a default visual performance detection value of six seconds to participants that failed to respond to an LED brake lamp treatment, this study did not use a default value for participants that did not respond. If the participant did not respond in this study, their visual performance data was not considered valid and the case was removed from the study (only regarding to visual performance data).

Neither Wierville et al. (2009), the pilot study, or the second study had responses to the continuous condition of the brake lamp. Weirville and the second study achieved responses to the treatments that used flashing lamps. However, Wierville and the pilot study could not confirm the location of the participants' visual attention at the beginning of the data collection period. Weirville assumed visual attention was being paid to their first target, the GPS, at the beginning of their data collection period. The pilot study did not assume the participants' visual attention was being paid to their phone. Thus, all pilot study cases were not considered valid.

Only the second study generated valid eye tracking cases, with only 6.8% of the valid eye tracking cases responding across the three LED brake lamp treatments. Literature suggest the low response rate to the LED brake lamp is due to the phone's ability to maintain visual attention and to the increased cognitive aspect of visual behavior brought about by verbal instructions.

Weirville et al. (2009) and the second study had limited responses to the LED brake lamp treatments. Wierville noted the low number of participants responding to the brake lamp treatments was "unexpected". Based on the findings from Wierville, that used three automotive LED brake lamp assemblies in their treatments, the failure of this study's single motorcycle LED brake lamp to cause an oculomotor response should have been expected.

In examining the effects of texting while driving, Fitch et al. (2011) found a phone had the ability to keep the visual attention of even experienced phone users (while driving) resulting in these experienced driving being at increased risk of an accident due to texting while driving.



The pilot study provided evidence without giving the participants instructions to maintain visual attention on their phone; visual fixations could be landed on the motorcycle appliqué by the intentional shifting of the participants' visual attention between their phone and the forward view, rather than by oculomotor response to the LED brake lamp treatments. The participants at the second study were given verbal instructions to keep their visual attention directed towards their phone during the texting task.

Providing participants in the second study with verbal instructions to maintain their visual attention on their phones while texting resulted in 93.33% of the valid eye tracking cases (where pupillary tracking was not lost) beginning the data collection period with their visual attention directed within the phone's area of interest. Griffin and Bock (2000) found evidence of the influence of verbal instructions on visual behavior. Griffin and Bock (2000) findings suggest the participants' visual fixations will follow the order of the objects as described by verbal instructions, rather than following the guidance of the relative level of conspicuity of the objects.

### **Pilot Study Subjective Impression Rankings**

Subjective impression ranking data was used to answer the question: Is there a statistically significant difference in the rankings of participants' subjective impression of the LED brake lamp to capture their visual attention based upon the types of LED brake lamp treatments?

For the pilot study, the overall mean and median rankings of subjective impressions were higher than the neutral subject impression ranking of 4.5. The highest mean and median rankings of subjective impressions were achieved by the 83.30

millisecond flash frequency sequence. This placed the overall mean subjective impression ranking of the pilot study slightly less than “*quite attention getting*” on the Likert scale. The overall median subjective impression ranking achieved a ranking at the midpoint between “*moderate level of attention getting*” and “*quite attention getting*”. However, the 83.30 millisecond flash frequency sequence failed to evoke enough responses to allow for data analysis.

The analysis of the pilot study’s data for the subjective impression ranking of the LED brake lamp’s ability to capture the participants’ visual attention indicated that there is a statistically significant difference in the means across the 83.30 millisecond flash frequency and the continuous condition. For the pilot study data, there were no statistically significant differences across any other LED brake lamp treatment comparisons. Another inconsistency is the pilot study’s subjective impression ranking order for the LED brake lamp treatment’s subjective impression rankings did not follow the same ranking order of the automotive LED tail lamp assemblies (that used the same flash frequencies) tested in Wierwille.

Wierwille et al. (2009) did not find a statistically significant difference across their automotive tail lamp treatments; (1) continuous condition for outboard LED lamps with a center high mounted LED brake lamp flashing at 83.30 milliseconds, (2) outboard LED lamps flashing at 117.50 milliseconds, and (3) continuous condition for all LED lamps.

This study was modeled after Wierwille et al. (2009) regarding; (1) use of a 4.25 and 6.00 hertz flash as a test frequency, (2) pilot study’s intravehicular distance of 100-feet, and (3) 1 to 8 Likert scaled used to rank subjective impressions. Therefore,

comparison of this study's findings to Wierville's findings should be made with caution due to the substantial differences across the test designs. Wierville used three LED brake lamp assemblies laid out over a full-size automobile appliqué; (1) a left outboard LED assembly, (2) a right outboard LED assembly, and (3) a center high mounted brake lamp assembly. The left and right outboard assemblies used six LED lamp fixtures, with the center high mount assembly using three fixtures. Further, Wierville used alternating flash patterns within their three LED tail lamp assemblies in combination with a lamp in the continuous condition. This study used a single LED brake lamp assembly, consisting of only one fixture, affixed to a full-size motorcycle appliqué. These test design differences could explain the inconsistent findings between the pilot study and Wierville regarding the subjective impression rankings.

### **Second Study Subjective Impression Rankings**

Like the pilot study, subjective impression ranking data from the second study were used to answer the question: Is there a statistically significant difference in the rankings of participants' subjective impression of the LED brake lamp to capture their visual attention based upon the types of LED brake lamp treatments? However, the second study reduced the intravehicular distance from the 100 feet used in the pilot study to 30 feet. The reduction in the intravehicular distance was necessary so the researcher could identify, by visual examination, the eye tracking video frame where the LED brake lamp was energized. With the reduction in intravehicular distance, the video frame where the brake lamp was energized could be identified by visual observation for all valid cases.

In the second study, the overall mean subjective impression ranking of the LED brake lamp treatment to capture the participants' visual attention followed the same pattern as the pilot study. Both had the 83.30 millisecond flash frequency sequence achieving the highest mean subjective impression ranking, followed by the 117.5 millisecond flash frequency, then the continuous condition.

The second study's overall mean and median subjective impression rankings were higher than the neutral subject impression ranking of 4.5. The second study's overall mean placed the subjective impression ranking slightly higher than "*quite attention getting*" on the Likert scale.

In the second study, the 83.30 and 117.50 millisecond flash frequency sequences tied for the highest median rank. The overall median subjective impression ranking achieved a ranking of "*quite attention getting*". Only the 83.30 millisecond flash frequency sequence achieved a response and did not receive enough responses to allow for data analysis.

The analysis of the second study's data for the subjective impression ranking of the LED brake lamp's ability to capture the participants' visual attention indicated there is no statistically significant difference in the means across any of the LED brake lamp treatments. This is inconsistent with the pilot study that found a significant difference between the 83.30 millisecond flash frequency sequence and the continuous condition of the LED brake lamp.

The pilot study and second study followed the same order for subjective impression rankings. The 83.30 millisecond flash frequency sequence with the highest rank and the continuous condition with the lowest rank. In comparing the means across

the studies, an expected reduction in subjective impression rankings occurred when comparing the means for each treatment level, e.g. each treatment had a lower subjective impression ranking at the 100-foot intravehicular distance when compared to same treatment at a 30-foot intravehicular distance. The subjective ratings were higher across the three treatments for the 30-foot intravehicular distance when compared to the 100-foot intravehicular distance.

Decreasing the intravehicular distance may have contributed to the differences in the subjective impression rankings across the pilot study and second study. Also, small numbers of cases in each study may have contributed to the differences in the statistical significances when comparing the pilot study to the second study. A comparison across 83.30 flash frequency sequence to the continuous condition for the subjective impression ranking's mean, median and range may indicate the potential influence of low case numbers. For the pilot study and second study, the means were slightly greater than the medians, with the medians being in the middle of the range. The mean and median for the continuous condition in the second study followed this same pattern. However, the median for the continuous condition in the pilot was at the lower boundary of the subjective impression ranking range.

### **Conclusions**

Based on the findings of the pilot study and second study, it is concluded that:

- Using the test conditions in this study, the three different brake lamp configurations tested in this study were not very effective in drawing participants' eyes from their phones during texting to the motorcycle brake lamp. This could be due to several reasons including the verbal directions given to the participants

at the beginning of the study, the design of the brake lamps, design of the brake lamp control module, the amount of attention required of subjects to perform the texting task, and the study setup using a stationary vehicle and motorcycle appliqué.

- This study provided similar results with regards to the ratings of subjective impressions of the three different brake lamp conditions when comparing the results from the pilot study to those in the second study. In both studies, overall, participants ranked the 83.3 ms flash rate highest and the continuous brake lamp lowest. While one study identified significantly different rankings and the other not, this inconsistency could be due to sample sizes and differences in the intravehicular distances. In addition, decreasing the distance between the participants and the brake lamps appears to have resulted in higher subjective rankings across all three treatments.

### **Recommendations for Future Studies**

The single LED brake lamp assembly used in this study consisted of 12 LED housed in a single assembly. The use of the fender and tour pack LED brake lamp assemblies as a treatment may provide the visual stimulus needed to evoke oculomotor responses across the LED brake lamp treatments.

At an intravehicular distance of 30 feet, the second study found only the 83.30 millisecond flash frequency sequence, the faster of the two flashing sequences tested, achieved oculomotor response. Research supports the faster the flash cycle, up to 20 hertz where the flash appears to become a continuous lamp, the more likely the flash will

capture the participant's visual attention (Turner, Wylde, Langham, & Morrow, 2014). Therefore, it is recommended future studies use flash sequences faster than 6.00 hertz.

At 30 feet, the motorcycle appliqué was extremely life-like. Numerous participants thought the appliqué was a real motorcycle. In the second study, the motorcycle appliqué was placed in front of a three-sided motorcycle parking shed provided a consistent background against which the appliqué was viewed by the participants. On the motorcycle, the LED brake lamp assembly used in this study is located under the tour pack. Placing the LED brake lamp under the tour pack built into the appliqué would further increase the life-likeness of the appliqué and provide for a more consistent environmental condition for the LED brake lamp.

The pilot study identified direct sunlight reflections on the windshield of the research vehicle for causing loss of pupillary tracking in many cases during data collection. The second study corrected direct sunlight windshield reflections by placing the research vehicle under a portable canopy. The canopy could not be seen while in an operator's position, looking forward, from the research vehicle's driver's seat. However, the canopy did permit direct sunlight to enter the research vehicle through the side and rear windows. Of the nine eye tracking data sets where pupillary tracking was lost during the data collection period, direct sunlight entering through the driver's side window was the likely cause for the loss of pupillary tracking.

It is recommended future studies implement methods to prevent direct sunlight from entering the research vehicle while maintaining an unobstructed forward view, e.g. the participant cannot see the canopy when looking forward.

At the conclusion of the studies participants provided recommendations regarding improvements to the LED brake lamp to increase the potential to achieve oculomotor capture. The most common participant recommendation was to have the LED brake lamp create a sense of motion. Other recommendations included using faster flash cycles, more lamps, larger lamps, and brighter lamps.



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## Appendix A

### Sheetz Employee Recruiting Notice

#### Sheetz Employees Wanted for Vehicle Safety Research Study

Date: March 10, 2017

- Jeff Krupa is a PhD candidate in the Safety Sciences Department, Indiana University of Pennsylvania.
- Sheetz has agreed to support Jeff's vehicle safety research study by allowing him to use a section of a parking lot at Sheetz's Claysburg terminal/administrative complex.
- Sheetz employees are encouraged to support this study by participating in the study.
- Mr. Krupa is conducting research on visual behavior while texting using a stationary vehicle.
- The study will require the person to wear a pair of high-tech eye tracking glasses.
- If you wear contacts or prescription glasses you can still participate in the study.
- To participate in the study, the individual must meet all the following criteria:
  1. Hold a valid motor vehicle operator's license that is not endorsed for motorcycles.
  2. Have a cell phone that you use for texting.
  3. Be at least 18 years of age at the time of the study.
- Participation in the research study takes about 15 minutes.
- No vehicles move during the test.
- **IF YOU WANT TO PARTICIPATE IN THIS RESEARCH STUDY, PLEASE CONTACT:**

**STEPHANIE GREINER**

Researcher Contact: email: j.a.krupa@iup.edu, Phone: 814.512.5112.

IUP Faculty Contact: Dr. Christopher Janicak, 136 Sally Johnson Hall  
Phone: 724.357.3274, email: cjanicak@iup.edu

**THIS PROJECT HAS BEEN APPROVED BY THE INDIANA UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS (PHONE 724.357.7730)**



## Appendix B

### Calibration Procedure for Argus Science Eye Tracking Glasses

The Argus Science LLC ET Mobile-3 eye tracking glasses will be pre- and post-calibrated for each participant. The research will follow Argus Science's recommended procedure for calibration. Calibration will be performed with the participant seated in the stationary research vehicle that will be oriented and staged in the location to be used for visual behavior data collection.

The researcher will position the participant in the driver's seat of the static research vehicle and then will be seated in the front passenger's seat. The participant will then don the Argus Science ET Mobile-3 eye tracking glasses with the researcher assisting as necessary.

Using Argus Science's Results-Pro software, the researcher will confirm the proper location of the three Purkinje reflections and that the Argus Science's Results-Pro software has successfully identified the outer edge of the participant's pupil. If necessary, the research will adjust the monocle to achieve proper fit.

To begin calibration, the researcher will instruct the participant to rest their chin on the top of the research vehicle's steering wheel and use their hands to stabilize their head. The participant's head is to remain in this position during the entire calibration procedure.

Next, the researcher will instruct the participant to gaze at one of three non-linear calibration targets. Per the recommendation of Argus Science, the gaze is to be a minimum duration of 500 milliseconds per calibration target. Using the Argus Science's

Results-Pro software the researcher will view the streaming gaze data from the Argus Science ET Mobile-3 eye tracking glasses and will indicate the actual location of the calibration target by clicking on the target on the laptop screen. The Argus Science's Results-Pro software will calculate the accuracy and precision of the Argus Science ET Mobile-3 eye tracking glasses based on the location of the participant's visual fixations versus the actual target location as indicated by the researcher.

The researcher will have the participant progress through all three non-linear calibration targets repeating the process used for the first target.

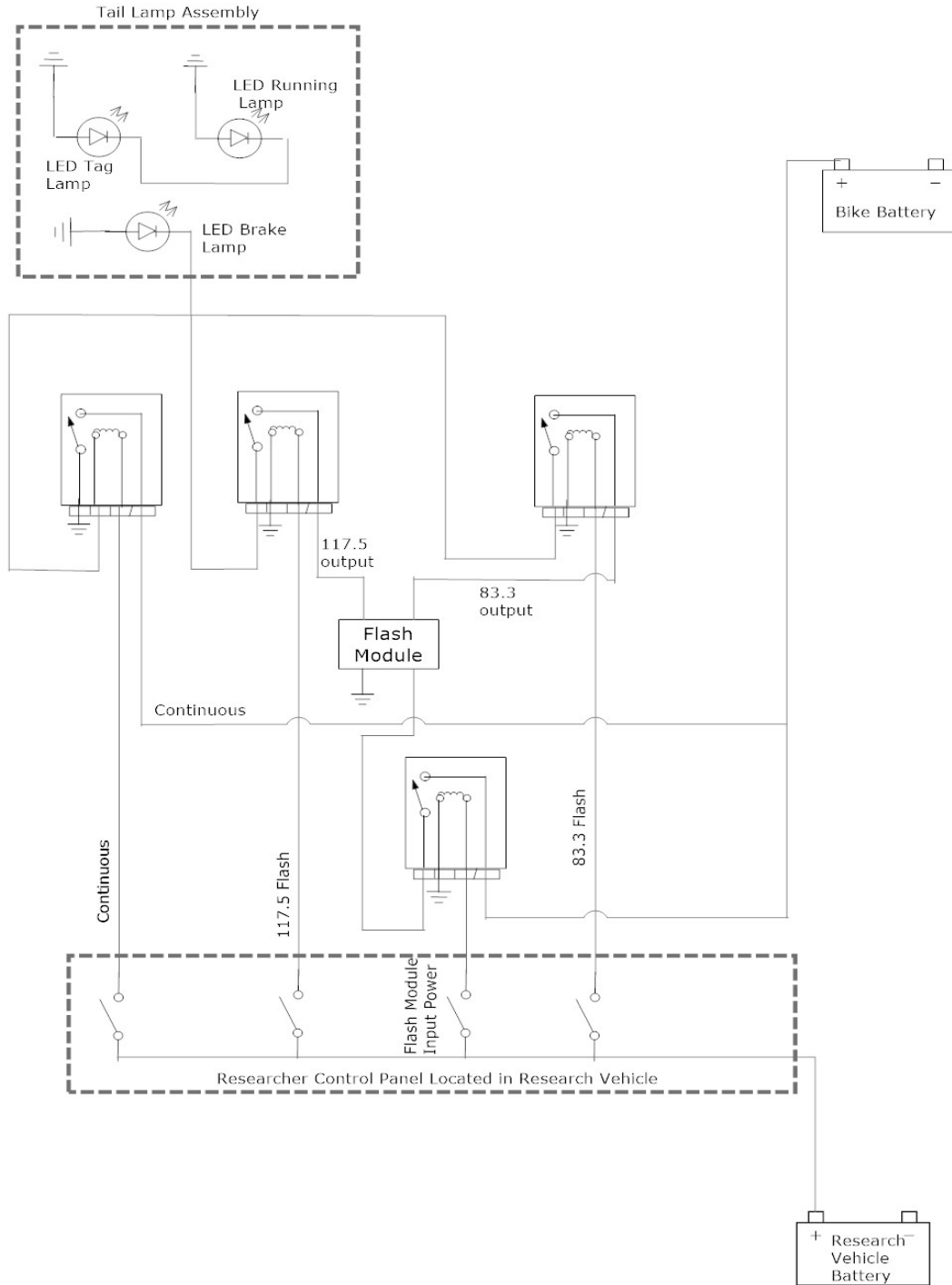
Calibration is achieved when a minimum of 95% of the calibration targets pass the accuracy and precision tests as calculated by the Argus Science's Results-Pro software. Given that the calibration procedure uses three calibration targets, accuracy and precision is achieved when the participant passes all three calibration targets.

Acceptable accuracy is 95% of the participant's visual fixations falling within 0.5 visual degrees of the actual target. Acceptable precision is 95% of the participant's visual fixations clustered inside the participant's focal point, not exceeding 0.5 degrees vertical (total of one degree) and 0.5 degrees horizontal (total of one degree) from the participant's focal point.

Once calibration is achieved, the researcher will proceed to prepare the participant for data collection as describe in Appendix E.

# Appendix C

## Brake Lamp Control Panels Electrical Schematic



## Appendix D

### Research Study Informed Consent Form

This Research Study Consent form will be printed on department letterhead

Page 1 of 2 – Research Study Informed Consent Form

Researcher: Jeff Krupa, Ph.D. Candidate, Safety Sciences Department

Contact Information for Researcher: [j.a.krupa@iup.edu](mailto:j.a.krupa@iup.edu); phone: 814.512.5112

Faculty Advisor: Dr. Christopher Janicak, Professor, Department of Safety Sciences,

Phone: 724.357.3274, email: [cjanicak@iup.edu](mailto:cjanicak@iup.edu)

Responsible Institution: Indiana University of Pennsylvania, Indiana, PA

Research Study Title: This study uses a uniformed test design. Title withheld.

You are invited to participate in this visual behavior research study. The following information is provided to help you to make an informed decision as to whether or not to participate. If you have any questions, please do not hesitate to ask. You are eligible to participate in this study because you hold a motor vehicle operator's license endorsed only for the operations of an automobile; you have a cell phone that you text with; and you are at least 18 years of age at the time of the study.

This study will be conducted in the employee parking lot of the Sheetz terminal complex located at 242 Sheetz Way, Claysburg, PA and will require about 30 minutes of your time. You must bring your cell phone to the research site.

When you report to the research study site, the researcher will explain that the research study is to examine visual behavior while text messaging in a stationary automobile. The researcher will also go over the informed consent and ask if you have any questions and if you understand the information contained in the informed consent form. The researcher will answer your questions and then ask you to sign the form. You will be provided with a copy of the consent form.

After signing the form, the researcher will have you occupy the driver's seat of a stationary automobile. The researcher will position you in the vehicle according to the study's protocol and then he will occupy the front passenger's seat. You will then proceed through the calibration of the eye tracking glasses and an explanation of the data collection procedures.

After the data collection period has ended, the researcher will present you with a survey to rate your subjective impressions regarding an element of the study. Once you complete the rating survey, the researcher will give you a written explanation of the research study. This will signal the end of the research study.

Your participation in this study is voluntary. You are free to decide not to participate in this study or to withdraw from the study at any time without adversely affecting your relationship with the investigator or Indiana University of Pennsylvania. Your decision will not result in any loss of benefits that you are otherwise entitled. If you choose to participate, you may withdraw at any time by notifying the researcher or study director. Upon your request to withdraw, all information pertaining to you will be destroyed.

If you choose to participate, all information will be held in strict confidence and will have no bearing on your academic standing or services you receive from the University. Your signed informed consent will be kept by the researcher for a period of not less than three years. The data generated by your participation, including the eye tracking video recordings, will only be identified by a "Participant ID #".

The data collected during this study will be analyzed by the researcher, along with data gathered from other participants. The data collected by the researcher, along with the research study's findings, may be publicly released in the form of final reports, publications, or other forms of media. The study's findings and data may be released individually or in summary with that of other participants. The data or information released by the researcher will be in a format that will not reveal the participants' personal information.

The mobile eye tracking glasses you will wear contain a forward-looking video camera. The video camera records the participant's visual field of view. The video camera does not record images of your face. However, the video recording may contain images of your hands.

The risks of participating in this study are minimal. Mobile eye tracking glasses track your pupillary position using a light source to illuminate your right eye. The manufacturer of the mobile eye tracking glasses states they have investigated the risk of the particular light source used by the glasses and found that it poses minimal risk to the person. Mobile eye tracking glasses are commonly used in this type of study, and is the preferred method to collect data on visual behavior.

In regard to the safety of the mobile eye tracking glasses, the manufacturer further stated that they have had no reported issues with any type of safety event with the Mobile Eye product line, which has been on the market since 2004.

This study is being funded by the researcher. If you are willing to participate in the study, please sign the statement below and give it to the researcher. This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (Phone: 724-357-7730).

**VOLUNTARY CONSENT:**

I have read and understand the information on the form and I consent to volunteer to be a participant in this study. I understand that my responses are completely confidential and that I have the right to withdraw at any time. I have received an unsigned copy of this informed consent to keep in my possession.

Participant's Name (PRINT): \_\_\_\_\_

Participant's Signature: \_\_\_\_\_

Date: \_\_\_\_\_

## Appendix E

### Participant Data Collection Preparation Procedure

The researcher will instruct the participant that they must remain seated in a straight upright position with their lower back against the back of the driver's seat during the time that the participant is engaged text messaging. After being seated in the driver's seat, the participant will be informed by the researcher that there will be no verbal communications during the time that the participant is engaged in text messaging.

The researcher will inform the participant that the researcher will take a measurement to identify the vertical location of the participant's eyes using a tape measure and a base point located on the interior side of the research vehicle's roof. Based on the vertical height of the participant's eyes, the researcher will instruct the participant as to their cell phone location on the graduated hand placement scale affixed to the steering wheel so that the participant views their cell phone at -20 degrees vertically and 0 degree horizontally from their line of sight axis to the brake lamp.

The researcher will instruct the participant to place a hand on the steering wheel and to hold their cell phone with their other hand, at the pre-determined position on the graduated hand placement scale. With the cell phone properly located, the researcher will instruct the participant to keep their visual attention directed at the text message characters being typed on their phone and that their visual attention should remain on the text characters while texting the entire message. The research will then instruct the subject to text the phrase: "Mary had a little lamb whose fleece was white as snow."

As soon as the participant begins to text, the researcher will activate the research brake lamp in one of the three conditions. The researcher will allow the subject to complete the phase. The researcher will then stop eye tracker data recording.

Once the visual behavior data collection period is complete, the researcher will have the participant remain in the driver's seat and remove the eye tracking glasses. The participant will be presented with a Likert scale for ranking their subjective impression of the brake lamp's capacity to capture their visual attention. See Appendix F for the Likert scale and the subjective impression rating procedure.

Completion of the Likert scale ends the participant's participation in the study. At that time, the researcher will give the participant a copy of Appendix G that explains the true purpose of the study.

## Appendix F

### Likert Scale for Subjective Impression Ranking

Page 1 of 2

Researcher: Jeff Krupa, Ph.D. Candidate, Safety Sciences Department

Contact Information for Researcher: email: j.a.krupa@iup.edu; phone: 814.512.5112

Faculty Advisor: Dr. Christopher Janicak, Professor, Department of Safety Sciences, phone: 724.357.3274

When the visual behavior data collection period is complete, the researcher will instruct the participant to remain in the driver's seat and will direct the participant's attention to the brake lamp (not activated). The researcher will inform the participant that the researcher is going to activate the brake lamp with the purpose of having the participant rate their subjective impression of the brake lamp's capacity to draw their visual attention from their cell phone while they were texting, and onto the brake lamp. The researcher will then give the participant the Likert scale and review the format of the scale for recording subjective impressions.

Prior to activating the brake lamp, the researcher will inform the participant that the subjective impression rating consists of only one observation of the brake lamp. After that, the participant will be asked to rate their impression of the experience using the Likert scale.

To initiate the collection of the subjective impression data, the researcher will instruct the participant to gaze at the brake lamp and then confirm the participant's gaze location using streaming data from the mobile eye tracking glasses. With the participant's gaze directed at the brake lamp, the researcher will activate the lamp in the same condition as that used to collect the visual behavior data. After the presentation of the LED brake lamp treatment, the researcher will state, "Based on your observation of the LED brake lamp and using the Likert scale provided to you, what is your subjective impression of the brake lamp's capacity to draw your visual attention off of your cell phone and onto the brake lamp while you were texting?"



**Instructions to the Participant:** Circle the number on the scale that best describes your subjective impression of the brake lamp’s capacity to draw your attention away from your cell phone and onto the brake lamp while you were texting.

<b>Oculomotor Capture Capacity Rating</b>			
Participant ID# (to be completed by the researcher):			
Description	Scale	Viewer’s Reaction	
Not at all <i>attention getting</i>	1	{ I would never direct my visual attention to this brake lamp.	None
	1.5		
Inconsequential level of <i>attention getting</i>	2	{ It is near certain that I would never direct my visual attention to this brake lamp.	Little Bit
	2.5		
Minor level of <i>attention getting</i>	3	{ There is a much greater chance that I would not direct my visual attention to this brake lamp than direct my visual attention to this brake lamp.	
	3.5		
Small level of <i>attention getting</i>	4	{ There is a slightly greater chance that I would not direct my visual attention to this brake lamp than direct my visual attention to this brake lamp.	
Neutral Level of <i>attention getting</i>	4.5		
Moderate level of <i>attention getting</i>	5	{ There is a slightly greater chance that I would direct my visual attention to this brake lamp than not direct my visual attention to this brake lamp.	A Lot
	5.5		
Quite <i>attention getting</i>	6	{ There is a much greater chance that I would direct my visual attention to this brake lamp than not direct my visual attention to this brake lamp.	
	6.5		
Extensive level of <i>attention getting</i>	7	{ It is near certain that I would direct my visual attention to this brake lamp.	Fully
	7.5		
Extremely <i>attention getting</i>	8	{ I would always direct my visual attention to this brake lamp.	

## Appendix G

### Explanation of Research Study's Purpose

**To the Participant:** First, I want to thank you for your time and effort to participate in this research. Although you were informed that the study involves visual behavior while texting in a static automobile, the actual purpose of the research was intentionally withheld from you. If you had been given information on the purpose of the research prior to participating, it may have changed your visual behavior and the results would have been compromised.

This research is being done in an attempt to understand what effect a flashing motorcycle LED brake lamp may have on an observer's visual behavior. The lamp was activated at two specific rates (83.30 milliseconds and 117.50 milliseconds) and the continuous state condition of a standard brake lamp. I will analyze the collected data to determine if any of the brake lamp flash patterns significantly increase the conspicuity of the full-size cutout of the motorcycle that you saw in front of the vehicle you occupied.

Over 200 motorcycle operators are killed each year when their motorcycles are rear-ended by automobiles. The primary cause of the rear-end collisions is inattentiveness of the automobile operator. This research may lead to changes in motorcycle brake lamp design and in motor vehicle safety codes that could save lives. Your voluntary participation in this study is very much valued.

Kind regards,

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