Implications of Red Signal Countdown Timers on Visual Attention of Oregon Drivers

by
Amy Wyman

A THESIS

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degree of

Honors Baccalaureate of Science in Civil Engineering
(Honors Scholar)

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AN ABSTRACT OF THE THESIS OF

Amy Wyman for the degree of Honors Baccalaureate of Science in Civil Engineering presented on March 14, 2016. Title: Implications of Red Signal Countdown Timers on Visual Attention of Oregon Drivers.

Abstract approved:

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David S. Hurwitz

Red Signal Countdown Timers (RSCTs) are devices placed at intersections to inform drivers of the time remaining on a red indication before it turns green, typically to improve intersection efficiency. This study examines the visual attention of Oregon drivers to circular red (CR) indications with RSCTs as compared to standard CR indications to determine how RSCTs impact intersection safety and efficiency. Second, it examines the variation in driver visual attention according to the duration of the red indication. Average fixation duration (AFD) data for 24 licensed Oregon drivers of varying age and driving experience was collected in a driving simulator experiment, using eye tracking equipment. Participants drove an experimental course of intersections with a combination of standard CR and CR with RSCT indications of 20, 40, and 60-second durations. RSCTs counted down the last 10 seconds of the red phase for each duration of red indication. Results show that the average median AFD of drivers was 0.24 seconds for a standard CR indication and 0.34 seconds for a CR indication with RSCT. There was no statistically significant difference between standard circular red or circular red with RSCT indications of varying duration ($p<0.05$).

Key Words: visual attention, driving simulator, traffic signal countdown timers, traffic control devices, red signal countdown timers

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Amy Wyman, Author

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Table of Contents

List of Tables

List of Figures

1 INTRODUCTION

Traffic Signal Countdown Timers (TSCTs) are devices placed at intersections to inform drivers of an impending signal change, much like a Pedestrian Countdown Timer alerts a pedestrian to the amount of time remaining to cross an intersection. There are three main types of TSCTs, each of which counts down the amount of time remaining on the signal phase that it is named for: Green Signal Countdown Timers (GSCTs), Yellow Signal Countdown Timers (YSCTs), and Red Signal Countdown Timers (RSCTs). TSCTs appear in a variety of forms, all of which include a countdown display incorporated into a traffic light. These signals are used throughout the world to regulate traffic flow through signalized intersections; however, they are not currently used in the US.

Typically, GSCTs and YSCTs are implemented to improve intersection safety and RSCTs are implemented to improve intersection efficiency. However, several studies show that GSCTs and YSCTs actually reduce intersection safety, increasing aggressive driving behavior and extending the dilemma zone. As such, the Federal Highway Administration (FHWA) has banned the implementation of GSCTs and YSCTs in the United States. This study focuses on the implications of RSCTs on intersections in the United States, specifically among Oregon drivers. Previous studies on RSCTs show that RSCTs have the potential to significantly reduce start-up lost time and headways at intersections. Studies also show that RSCTs may negatively impact intersection safety by increasing the occurrence of early-start behavior among drivers, in which drivers anticipate the signal change and begin to proceed through the intersection prior to the onset of the green phase.

This study aims to contribute to an understanding of how drivers react to RSCTs by examining differences in the driver's visual attention to the RSCT as compared to a standard red traffic signal at the same intersection. The study also examines how drivers' visual attention changes according to the duration of the red signal. For each case, average driver fixation durations were recorded and analyzed using a driving simulator study to develop a better understanding of the impacts RSCTs have on intersection safety and efficiency.

2 LITERATURE REVIEW

This literature review examines previous research on topics important to the study of how visual attention patterns of Oregon drivers at signalized intersections vary depending on the presence and duration of Red Signal Countdown Timers (RSCTs). The first section of this literature review provides an overview of the study of visual attention, describing what it is, how it is measured, and how it pertains to the driving task. The second section describes how drivers behave at signalized intersections and defines some common measures used to quantify intersection efficiency. The final section focuses specifically on the use of, driver opinion of, and implications of RSCTs through review of studies conducted in the U.S. and abroad.

2.1 Visual Attention and the Driving Task

2.1.1 What is visual attention?

We, as humans, cannot hope to process the entirety of information our sight provides us with. There is simply too much. The information that humans do process--that which we are aware of--is that which we attend to. This provides a basis for the two main principles of visual attention: humans can only process a limited amount of information. That which we find irrelevant we filter out (Chun and Wolfe, 2005; Desimone and Duncan, 1995). This process is sometimes also referred to as information shedding.

2.1.2 Bottom-Up vs. Top-Down Attention

Psychologists propose that there are two main types of visual attention: top-down (endogenous) attention and bottom-up (exogenous) attention. Top-down attention is goal-driven. A subject practicing top-down attention will often be pointedly looking for something in their surroundings, such as a person they are supposed to meet in a crowded place. Because top-down attention is motivated by semantics, a person has control over where they direct their attention (Chun and Wolfe, 2005).

Bottom-up (exogenous) attention is driven by external stimuli. Humans do not have control over bottom-up attention. In this case, the physical features of an object draw attention by how much they stand out from surrounding objects. A bright red stop sign, for example, draws attention because its color contrasts with its surroundings to make it salient. In traffic engineering, this phenomenon is often termed "conspicuity," which is defined as "the probability that the device will be noticed" (FHWA 2013). However, subjects can often quickly forget about static objects, such as a sign. This is not the case with dynamic stimuli. Dynamic stimuli, such as flashing lights, perceived motion and other 'abrupt visual onsets,' can capture attention quickly and hold it--even when subjects attempt to ignore the stimulus (Chun and Wolfe, 2005).

Bottom-up attention manifests itself in novelty and in long-term learned importance, as well (Desimone and Duncan, 1995). In a field of homogenous objects and one non-homogenous object--which may be exactly the same as the other objects, just orientated differently--it is easier to find the object that stands out because it is novel. Novel objects may also demand greater attention durations, as opposed to "familiar" objects, which subjects can examine more quickly (Wang, Cavanagh, & Green, 1994). At the same time, events of importance that re-occur over a long period of time can draw attention from out-of-the-blue (Reicher et al., 1976). A good example of this is the "cocktail party phenomenon." A subject engrossed in a conversation may automatically tune into a different conversation across the room when they hear their name spoken, even if they cannot recall anything else that was said (Moray, 1959).

2.1.3 Modern Attention Models

In the past, psychologists viewed visual attention as a "high-speed mental spotlight" that illuminates each object, one-by-one, in a visual field (Desimone and Duncan, 1995). Modern psychology, however, depicts visual attention as a constant competition between objects in a visual field and a constant competition between top-down and bottom-up attention. This competition is biased towards those objects which give the viewer information most relevant to their current behavior, such as driving (Desimone and Duncan, 1995).

Wickens et al. (2001) developed a model for visual attention which addresses both its top-down and bottom-up components. The model they produced is called the Saliency Effort Expectancy Value (SEEV) model. It predicts the probability that an area of interest (AOI) will draw attention, with each letter standing for a different key component of attention. The first two terms in the name of this model refer to bottom-up traits of attention. Saliency refers to the physical properties of an event that make it stand out. Effort refers to both the physical distance between the previous AOI and the current AOI, as well as the required mental effort to switch between tasks. The last two terms refer to top-down traits of attention. Expectancy denotes how likely the subject believes an event of importance will occur at a particular location. Value denotes how much importance the subject places on a particular event. In this model, the occurrence of salient events, value of an event, and expectancy of an event all motivate attention allocation to an AOI, while effort inhibits it.

S	E	E	V
Saliency	Effort	Expectancy	Value
Bottom-Up		Top-Down	

Figure 1: The SEEV Model

Wickens et al. (2001) tested their model in a study examining the difference in visual search patterns between experienced and novice pilots. The study found that, compared to the top-down characteristics value and expectancy, salience and effort played minimal roles in the pilots' visual search patterns. Therefore, the researchers concluded that top-down traits are more important than bottom-up traits for predicting how subjects will allocate their visual attention. They also hypothesized that, because of the general nature of their testing, the model can be applied to more general scenarios such as the driving task.

2.1.4 Change Blindness

Change blindness, or inattention blindness, is one particularly important, common phenomenon of visual attention which occurs when a subject fails to detect some change occurring within their visual field (Mancero et al., 2007). Research suggests that humans succeed at efficiently gathering "the gist" of a scene, yet perform poorly in remembering details from one scene to the next (Simons and Levin, 1997). Simons and Levin (1997) found that when studying photographs, subjects missed nearly 70% of changes made to the photographs occurring during their eye movements. The details that subjects do remember tend to relate closely to the scene's center of interest and thus have the highest relevance to the scene's overall semantic meaning. When changes occur to these details, the subject will more likely notice them. This suggests that semantics, and therefore top-down attention characteristics, are necessary for change detection. When the overall meaning is the same, subjects assume two scenes are the same. This is necessary according to the previously-mentioned phenomenon of information shedding (Simons and Levin, 1997).

Mancero et al. (2007) identified five common properties to all forms of change blindness. These include the rate the change occurs at, the eccentricity of the change, the proximity of the change to the subject's current fixation, the significance of the change, and the relevance of the change to the subject's search. The authors suggest that designers must take into account each of these properties when they design visual interfaces to reduce change blindness.

2.1.5 What are the links between attention and eye movement?

Multiple studies support a close connection between visual attention and eye movement, including (Itti and Koch, 2001; Engbert and Kliegl, 2003; Doshi and Trivedi, 2012; Desmond and Duncan, 1995). According to Irwin et al. (2004), people generally focus their gaze on the current object of attention. Thus, researchers consider tracking subject gaze patterns appropriate as a measure of visual attention (Velichkovsky et al., 2003).

Current research suggests that eye tracking can be used to differentiate between top-down and bottom-up attention paid to an object. Doshi and Trivedi (2012) propose that abrupt onset events--bottom-up events--draw a different pattern of eye and head movement as compared to top-down attention shifts. In the case of a top-down attention shift, the subject often undergoes preparatory head movements before eye movement.

Velichkovsky et al. (2003) used a driving simulator to study gaze pattern differences between preattentive and attentive, top-down attention-controlled processing. They designed a study in which they presented subjects with two potential hazards: a red traffic light and a pedestrian. The researchers determined that eye tracking could demonstrate direction and level of attention and that visual fixations "seem to be the most direct manifestations of visual attention." The study found that attentive processing leads to longer fixation durations and that, upon presentation of a hazard, fixation durations significantly increased. According to the researchers, the presentation of a hazard drew strong and reliable fixations quickly and fixation duration increased by 100% or more. The study also found that this reaction remained stable over time, even as familiarity with the hazards increased.

However, multiple researchers suggest that eye movements do not catch all items that subjects pay attention to. This is a phenomenon known as covert visual attention, in which subjects pay attention to items without displaying eye movements (Engbert and Kliegl, 2003). Similarly, Desimone and Duncan (1995) suggest that even though a subject may hold their gaze at an item of fixation, items within the visual field competing for attention with the current item of fixation provide interference that eye movements cannot measure.

2.1.6 What role does attention play in the driving task?

Visual attention plays a major role in the driving task. According to the Highway Capacity Manual 2010 (HCM 2010), 90% of the information that a driver receives is visual. To get from one place to the next, drivers must be aware of their surroundings at all times. This involves taking in relevant information about events in the environment, processing this information, and then making informed decisions about this information. The term perception-reaction time is often used to quantify how quickly drivers carry out these steps, which in turn represents how fast a driver will be able to respond to an emergency situation (HCM 2000). Thus, visual attention has important safety and efficiency implications on the driving task.

Driver Distraction: Theory, Effects, and Mitigation (2009) uses three categories to describe how external stimuli can distract drivers: through involuntary capture of visual attention by way of object saliency, through involuntary capture of mental attention, and through voluntary direction of attention away from the driving task. Objects which have an "abrupt onset," such as flashing lights, capture attention quickly. This is why they are used on certain traffic signals and emergency vehicles. Traffic designers limit the use of dynamic, salient objects such as flashing lights so that they do not detract from more important signals (Horberry and Edquist, 218).

Konstantopolous et al. (2010) performed a driving simulator study which demonstrates the use of eye tracking to identify how drivers allocate their visual attention. Researchers used a driving simulator to determine how experienced driving instructors' search patterns compared to those of inexperienced, learning drivers. They had each subject drive three routes: a day route, a night route, and a rainy route. Those who had greater driving experience, the instructors, displayed significant differences in their glance patterns than those of the inexperienced drivers. Results showed that experienced drivers have more efficient search strategies in which they allocate attention to more areas of interest using shorter fixation times. They also demonstrate a broader search pattern with fixations spread more widely across the driving scene, meaning that the experienced drivers can gather more information about their environment. This has important implications for safety and for education of learning drivers. Because experienced drivers can more quickly and completely gather information about their surroundings, they are less likely to miss important information which could, for example, allow them to act sooner to prevent a crash.

Cassavaugh et al. (2013) tested the validity of the SEEV model when applied to the driving task. In particular, the researchers hoped to determine whether the SEEV model could accurately predict how drivers allocate their attention to items, such as traffic signals, in their visual field and outside of the vehicle. The study found that the SEEV model successfully predicted driver attention when areas of interest were "spatially mutually exclusive", such as areas of interest inside the vehicle as compared to outside the vehicle. However, the SEEV model did not successfully predict driver attention allocation at intersections with non-hazard events.

A 2009 study conducted by Galpin et al. examined the phenomenon of change blindness as it pertains to the driving task. The study aimed to determine whether drivers were more likely to notice changes to targets in a driving scenario based on the event relevance to safety and to the driving task. They tested three factors thought to contribute to change blindness: the proximity of a subject's current fixation to the change, a subject's experience driving, and the semantic relevance of the change. First, researchers noted high levels of change blindness among their subjects. Researchers found that drivers were more likely to notice a semantically relevant change, that driving experience did not seem to have an effect on change blindness, and that change detection occurred most often at the left and right extremes of the screen, with less attention paid to the center.

2.2 Driver Behavior at Signalized Intersections

Understanding how drivers behave at signalized intersections and how traffic authorities evaluate intersection safety and efficiency is critical to analyzing the influence of Traffic Signal Countdown Timers (TSCTs) on drivers and intersections. This section provides a description of typical driver behavior at signalized intersections, descriptions of several measures of intersection efficiency, and definitions of important terminology related to both.

2.2.1 Headway

At a red traffic signal, cars approaching an intersection slow down and stop, forming a queue behind the stop line. When the light turns green, these cars begin to proceed through the intersection. According to the Highway Capacity Manual (HCM) 2010, the time it takes, in seconds, for the front wheels of each vehicle to cross the stop line with respect to the preceding vehicle is referred to as the headway for that vehicle.

The headway for the first vehicle in the queue is calculated as the time it takes for the vehicle's front wheels to cross the stop line, since there is no preceding vehicle. This is often the longest headway because the driver must first notice the signal change and react by accelerating their vehicle past the stop line. The time it takes for a driver to detect and react to a change is known as the perception-reaction time (HCM, 2010).

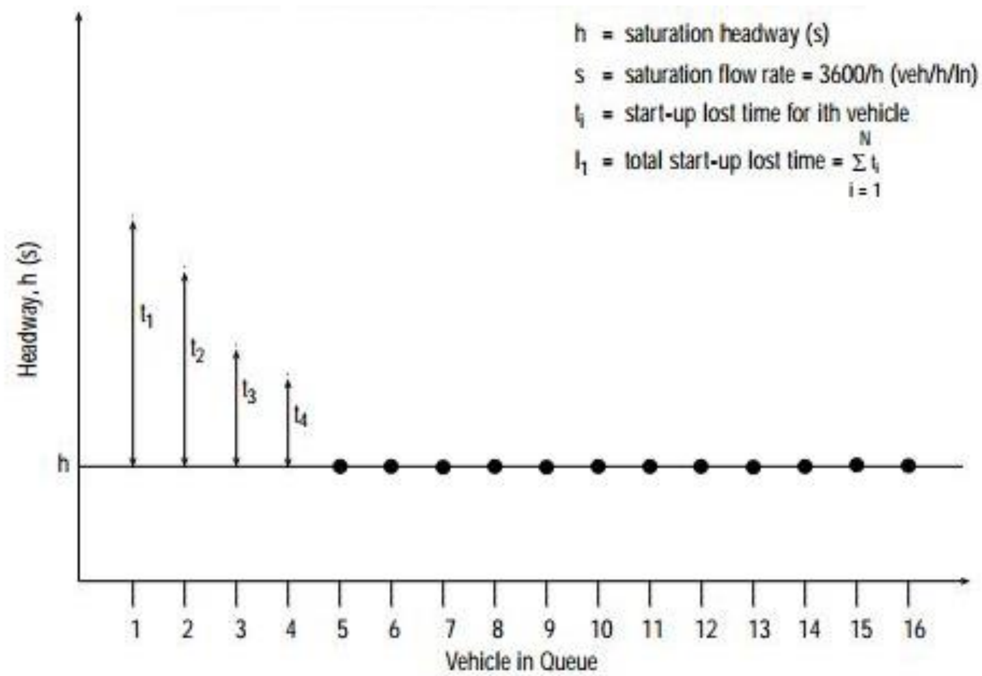


Figure 2: Headway and Start-Up Lost Time (HCM, 2000)

The headway for the second vehicle, and all following vehicles, is calculated as the time between when the front wheels of the preceding vehicle and the front wheels of the current vehicle cross the stop line. When the light turns green, the time it takes for the second vehicle to notice the change and react can occur while the first vehicle reacts, which means that the second vehicle can accelerate to a greater speed by the time it crosses the stop line. Therefore, the headway for the second vehicle is usually less than that for the first, the third vehicle's headway is less than the second, and the fourth vehicle's is less than the third. However, after the fourth vehicle crosses the stop line, the headways for the following vehicles remain fairly constant and vehicles progress through the intersection at a steady speed. This is because the effects of the drivers' "start-up reaction and acceleration has dissipated" (HCM, 2010). At this point, the queue has reached saturation headway and the vehicles have fully accelerated by the time they reach the curb line (Sharma et al., 2009). Typically, saturation headway ranges between 1.8 and 2.4 seconds (HCM, 2010). Limanond et al. (2009) suggest several factors that account for this variance, including driving culture, congestion, driver age, and time of day.

2.2.2 Lost time

Lost time refers to the duration in which no vehicles pass through the intersection. There are two times at which this occurs: the onset of a green light, the termination of the yellow light, and a period for which all signals display red. At the end of the yellow indication, drivers slow and stop. The time between when they stop and when the all-red phase terminates is the clearance lost time. For this study, we are primarily concerned with start-up lost time. Start-up lost time refers to the time lost when the first few vehicles in a queue travel with headways greater than the saturation headway because of their perception-reaction times. Typically, start-up lost times range from 1.0 second to 2.0 seconds (HCM, 2010).

2.2.3 Early-Start Ratio

The early-start ratio refers to the percentage of vehicles stopped at a red light which, upon anticipation of the change to green, begin to cross the intersection before the light has changed (Chiou and Chang, 2010). Early starts compromise intersection safety by increasing the chances of a right-angle collision with other vehicles committing a red light violation at the onset of red.

2.3 Traffic Signal Countdown Timers

2.3.1 Description of TSCTs

Traffic Signal Countdown Timers (TSCTs) are devices placed at signalized intersections which inform drivers of the seconds remaining until a traffic signal changes. Although there are many different styles of TSCTs in use throughout the world, all of them include some sort of countdown display on or next to a traffic light. The following figure displays an example of two TSCTs.

Figure 3: Red and Green Traffic Signal Countdown Timers (Islam et al., 2014)

There are three common types of TSCTs: Green Signal Countdown Timers (GSCTs), Yellow Signal Countdown Timers (YSCTs), and Red Signal Countdown Timers (RSCTs). A GSCT counts down the time remaining on a green signal and a YSCT counts down the time remaining on a yellow signal. GSCTs and YSCTs aim to improve intersection safety by giving drivers advanced warning that they will soon need to stop. An RSCT counts down time remaining until the light turns green. RSCTs aim to improve intersection efficiency by reducing start-up lost time at the onset of green since drivers have warning as to when they need to react (Chen et al., 2009). One or any combination of these three types of TSCTs can be employed alongside a pre-timed traffic light. For the purpose of this study, this literature review places special emphasis on research pertaining to RSCTs.

2.3.2 TSCT Usage in the US

TSCTs do not yet exist in the United States. The 2009 Manual on Uniform Traffic Control Devices (MUTCD, 2009) prohibits the use of GSCTs and YSCTs:

Section 4D.26 of the 2009 MUTCD specifically prohibits flashing green, vehicular countdown displays, or other similar displays intended to display a 'pre-yellow.'

The Frequently Asked Questions page of the MUTCD's website elaborates on this decision:

Each time displays such as these have been tried, it was found that they lengthened the "dilemma zone" in which drivers are unsure whether to stop or proceed, they encouraged more drivers to unreasonably speed up to "beat the light," and the increased aggressive driving behavior caused more crashes to occur than was the case without the advance indication of the change to yellow....FHWA does not believe it is appropriate to allow experimentation or to consider including any such pre-yellow signal displays for vehicular traffic control signals in the MUTCD.

Although the use of RSCTs is not expressly prohibited by the MUTCD, RSCTs have not been implemented in the US. One reason behind this is signal timing. TSCTs can only be implemented at fixed-time signals, for which the time for each signal phase is pre-determined. Many signalized intersections in the US use actuated signal timing, in which the time for each signal phase is determined in real-time by traffic demand (Chen et al., 2009).

Regardless of the type of TSCT, very little research actually exists on how drivers in the US react to TSCTs. In 1965, the city of Abilene, Texas, experimentally introduced a device to count down the time remaining on a yellow signal (Times Magazine, 1966). The device began counting before the onset and for the entire duration of the yellow phase. Over the 8 months that the timer was installed, traffic crashes reportedly decreased by 44% and drivers reportedly slowed down to stop instead of speeding through the light. Because of this success, the city of Houston, Texas planned to install more countdown timers. However, traffic authorities never implemented the countdown timers and few tests have been conducted since.

2.3.3 TSCT Usage Internationally

Though not currently implemented in the United States, TSCTs experience widespread use across parts of Europe and East Asia (Huang et al., 2014). One factor explaining this discrepancy is signal timing: in parts of the world where TSCTs are implemented, the use of fixed-time signals to manage traffic flow through intersections is more common. Therefore, considerable bodies of research examining the effects of GSCTs, YSCTs, and RSCTs on driver behavior at intersections in these countries exist--particularly studies from China, Malaysia, and Thailand. Often, these studies focus on two important intersection traits: safety and efficiency. GSCTs are most often implemented in the hopes of improving intersection safety, while RSCTs are often implemented in the hopes of improving intersection efficiency.

TSCTs vary tremendously in form between the countries that use them, although they all serve the same function of alerting a driver to an impending signal change within a certain period of time. An alternative form of the GSCT is the Flashing Green. Countries such as Cambodia, Israel, Mexico, Austria, Estonia, Latvia, Lithuania, Turkey, and Russia use a flashing green signal to indicate that the green signal phase is about to end (Koll et al., 2004), giving drivers more warning that they will soon need to stop. These are used most often on high-speed roads and aim to increase intersection safety.

Other countries, such as Austria, Denmark, Germany, Iceland, Sweden, Poland, Switzerland, United Kingdom, Argentina, Columbia, Paraguay, Israel, Pakistan, and Hong Kong, employ a variation of an RSCT at intersections. In these countries, traffic displays show a red and yellow signal together briefly before the termination of the red phase to warn drivers that the light is about to change from red to green (Islam et al., 2014). Traffic authorities hope to improve intersection efficiency with this advance warning, believing that it will enable drivers to react more quickly at the onset of the green phase and therefore reduce the start-up lost time.

International studies examining the effects of implementing TSCTs all tend to suggest that drivers favor the idea of TSCT implementation, particularly the implementation of the GSCT (Factor et al., 2012; Rijavec et al., 2013). However, studies about the effects of GSCTs produce more mixed results. Many suggest that GSCT implementation produces negligible results or decreases intersection safety. Many also suggest that, despite driver preference, RSCTs produce more useful results than GSCTs and deserver greater consideration. Studies examining the results of RSCT implementation are more consistent, finding that the RSCT provides intersections with significant efficiency benefits.

2.3.4 RSCT Research on Intersection Efficiency

Studies internationally and in the US consistently find that the implementation of an RSCT at a signalized intersection improves intersection efficiency. Li et al. (2014) found that a driver's perception-reaction time decreased from 2.12 to 1.48 seconds in the presence of Countdown Timers, suggesting that RSCTs make drivers more attentive to a signal change and suggesting considerable savings in terms of start-up lost time.

A driving simulator study by Oregon State University researchers tested how Oregon drivers reacted to the presence and duration of RSCTs (Islam et al., 2014). Each subject drove a virtual route in which they were presented with 20-second, 40-second, and 60-second duration RSCTs at intersections. The study determined that the presence of an RSCT decreased vehicle headway by a mean of 0.72 seconds. The study also found that, although there didn't seem to be any difference in vehicle headway between the 20 and 40-second durations, there was a significant difference in headway between the 20 and 60-second durations. The researchers propose that this difference can be attributed to driver distraction: at low-volume intersections, drivers most often encounter red signals lasting between 20 and 40 seconds. Therefore, drivers pay more attention to the signal when the signal's duration is below 40 seconds and less attention as duration increases.

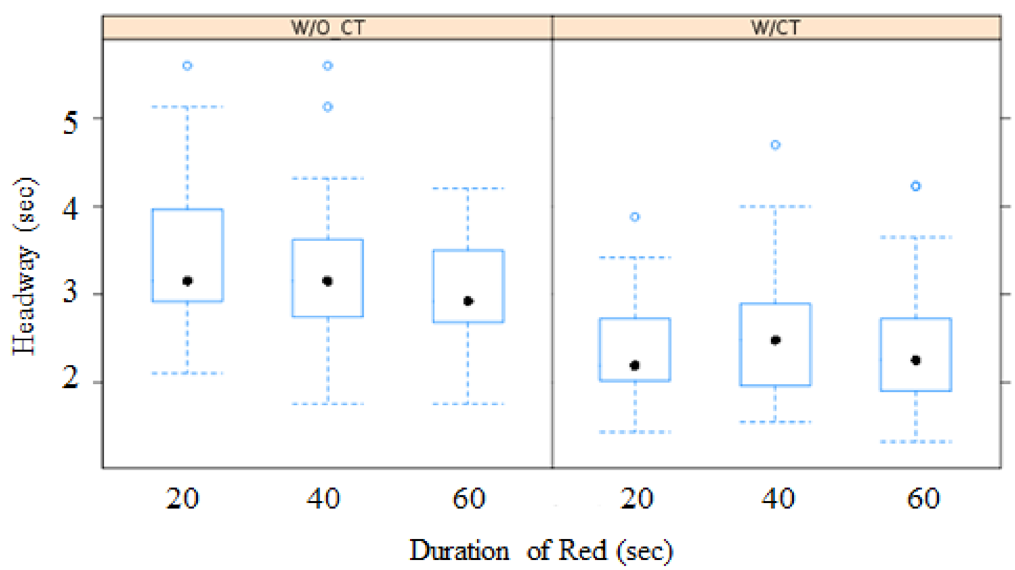


Figure 4: First Vehicle Headway (Islam et al., 2014)

Chiou and Chang (2010) conducted a study at one intersection in Taiwan to investigate the impact of an RSCT on intersection efficiency over an extended duration of several months. Using video footage, they analyzed driver behavior at the intersection before the implementation of the RSCT, 1.5 months after RSCT implementation, 3 months after, and 4.5 months after implementation. The researchers collected data on Friday mornings to keep their results consistent. They found that implementing an RSCT reduces both the headway of the first few vehicles in the queue and the saturation headway at 4.5 months after implementation. The researchers concluded that RSCTs improve intersection efficiency, and from their consecutive study on GSCTs, determined that RSCTs were more beneficial than GSCTs.

Liu et al. (2012) investigated the effects of RSCTs at seven different intersections in China on start-up lost time and saturation headway. Contrary to Chiou and Chang (2010), they found that the RSCTs had a negligible effect on saturation headway. However, the study did find that RSCTs significantly reduced start-up lost time by an average of 0.6 seconds per cycle for protected left-turn movements and 2.25 seconds for through movements, meaning that the RSCTs increased the throughput of the intersection by about one vehicle per cycle. Wenboa et al. (2013) support this study's results, finding from their analysis of an intersection in Guangzhou, China, that the RSCT reduced headway by 0.2 to 0.7 seconds and improved capacity by over 5%. Similar to Chiou and Chang (2010), Wenboa et al. (2013) found that the RSCT did decrease saturation headway and increased the saturation flow rate by 10-20%.

Finally, a study of a Bangkok intersection with an RSCT installed showed significant improvements to intersection efficiency. Limanond et al. (2009) found that, although the RSCT had little effect on saturation headway, the RSCT had a very significant effect on start-up lost time. The RSCT reduced start-up lost time by 1.00 to 1.92 seconds per cycle, resulting in a 17 to 32% time saving.

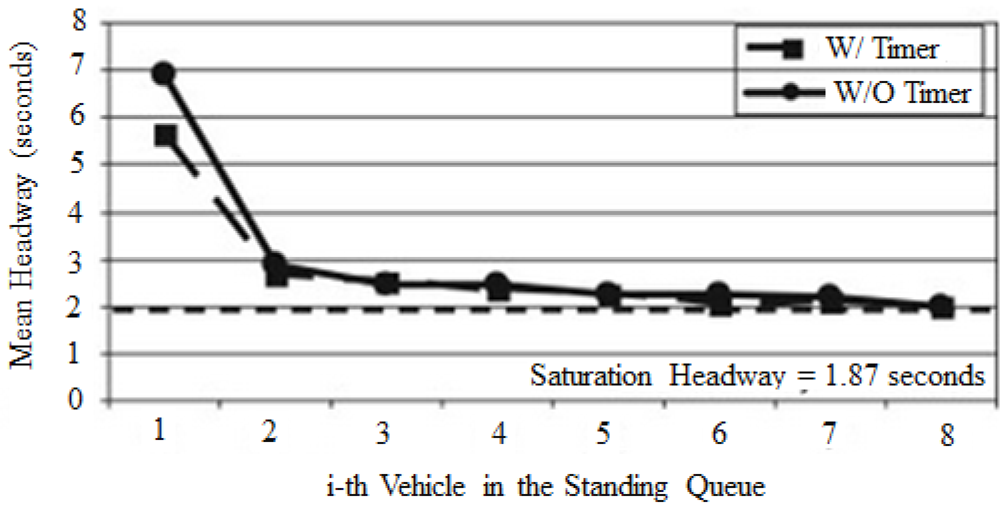


Figure 5: Headway With and Without Presence of an RSCT (Limanond et al., 2009)

2.3.5 RSCT Research on Intersection Safety

Although RSCTs are primarily introduced to improve intersection efficiency, one must also take into account their impact on safety. The primary concern about RSCT implementation is that they increase the risk of an early-start. An early-start occurs when a driver commits a red light violation by anticipating the change to green and proceeding before the signal actually changes. Sharma (2011) found evidence for this upon analysis of one intersection with an RSCT installed in Chennai, India. According to this study, red light violations at the onset of green showed a statistically significant increase from prior values, particularly for two-wheel vehicles as compared to cars. Rijavec et al. (2013) found that upon implementation of a TSCT at two intersections in Greece, early start violations increased to 24%, compared to pre-implementation values of 1%. On the other hand, Chiou and Chang (2010) found that the early-start ratio initially decreased at an intersection with an RSCT, although by 4.5 months after implementation of the RSCT, the early-start ratio returned to its before-implementation values.

2.3.6 Driver Opinion of RSCTs

Studies universally suggest that drivers favor the implementation of RSCTs. Islam et al. (2014) found that 98% of subjects participating in a driving simulator study on

GSCTs and RSCTs favored the implementation of a TSCT. Limanond et al. (2010) performed an extensive survey on local drivers who encountered an RSCT at a Bangkok intersection. The survey found that over half of local drivers said that the RSCT "relieved frustration caused by stopping for uncertain amounts of time during the red phase." Yu and Lu (2014) confirmed these results.

The results of the Limanond et al. (2010) study also suggest that drivers appreciate the RSCT because it keeps them aware of how long they have to perform other tasks before the light changes. Based on these results, the researchers propose that RSCTs minimize driver inattention to signal changes and suggest that more research needs to be performed to validate their suggestions. Hurwitz et al. (2013) supports this hypothesis, suggesting that longer red lights result in more distracted drivers, which in turn results in a longer reaction time to the onset of a green signal.

2.4 Summary

Considerable research exists on visual attention and its relevance to the driving task, driver behavior at signalized intersections, and on the implications of internationally-implemented TSCTs.

Review of this research reveals several key gaps. First, very little research exists on how drivers attend to traffic signals, such as TSCTs, regardless of where they are implemented. Second, very little research exists on how drivers in the US react to TSCTs. Although international research can show US researchers what to expect upon domestic implementation of a TSCT, it is necessary to perform more testing on the US driver reaction to TSCTs. Driving culture can vary dramatically with geography, creating potential for significant variance in results from country to country. Finally, this literature reveals a significant lack of research questioning how signal duration affects driver attention to the signal.

3 METHODOLOGY

The experimental design for this study, including its underlying research questions, methods used to collect data, and an overview of participant demographics are described herein. A statement of unique contribution to research in a field is also included as required for the University Honors College (UHC) thesis.

3.1 Research Questions

As described in the literature review (Chapter 2), the RSCT demonstrates significant potential for increasing intersection efficiency. Analysis of driver visual attention to different durations of circular red indications with RSCTs as compared to traditional circular red (CR) indications can further shed some light on how and why RSCTs impact intersection efficiency. Several research questions were developed to investigate how RSCTs impact driver visual attention. They are:

1) How does the duration and frequency of driver fixations on traffic signal heads vary with and without RSCTs?
2) How does the duration and frequency of driver fixations on traffic signal heads with RSCTs vary between red indications of 20, 40, and 60-second duration?

3.2 Driving Simulator

Because RSCTs have not been implemented throughout the US, no possibility of conducting a field study of driver visual attention to RSCTs exists. Therefore, a driving simulator study was performed as an alternative. A driving simulator study is a multi-stage human-in-the-loop experiment comprised of IRB approval, the design of the simulator test tracks, beta testing of those initial designs, iterative improvement, and finally, full subject participation.

For this experiment, drivers were asked to traverse virtual roadways including both intersections with and without TSCTs. Although the test tracks included both RSCTs and GSCTs, only RSCTs are considered for the purposes of this study. The design of the virtual environment and data collection were performed in the OSU Driving Simulator, which is described in the following section.

3.2.1 OSU Driving Simulator

The OSU driving simulator consists of a fully functional full-size 2009 Ford Fusion cab operated from a computer workstation out of sight of the driving simulator. The cab body is mounted on an electric pitch motion system, which allows for onset cues during acceleration and braking events.

The cab is surrounded by screens upon which the simulated environment is projected. As shown in Figure 6, three ceiling-mounted projectors produce a 180 degree front view and a fourth projects to a rear screen, which is displayed in the driver's rear-view mirror. Two side mirrors have embedded LCD displays that permit the driver to see both rear sides. The cab instrument includes a steering control loading system that accurately represents steering torques based on speed and steering angle.

The driving simulator computer system consists of a quad core host that runs the "SimCreator" Software (Realtime Technologies, Inc.). The high-fidelity simulator can capture and output highly accurate performance data such as speed, position, braking, and acceleration. The data update rate for the graphics is 60 Hz.

Figure 6: OSU Driving Simulator

The virtual test tracks that subjects drive are developed using Internet Scene Assembler (ISA) software, which uses Java Script-based sensors on the test tracks to change the signal indication and display dynamic objects, such as TSCTs, based on the subject vehicle's presence.

3.2.2 Experiment-Specific Test Track Design

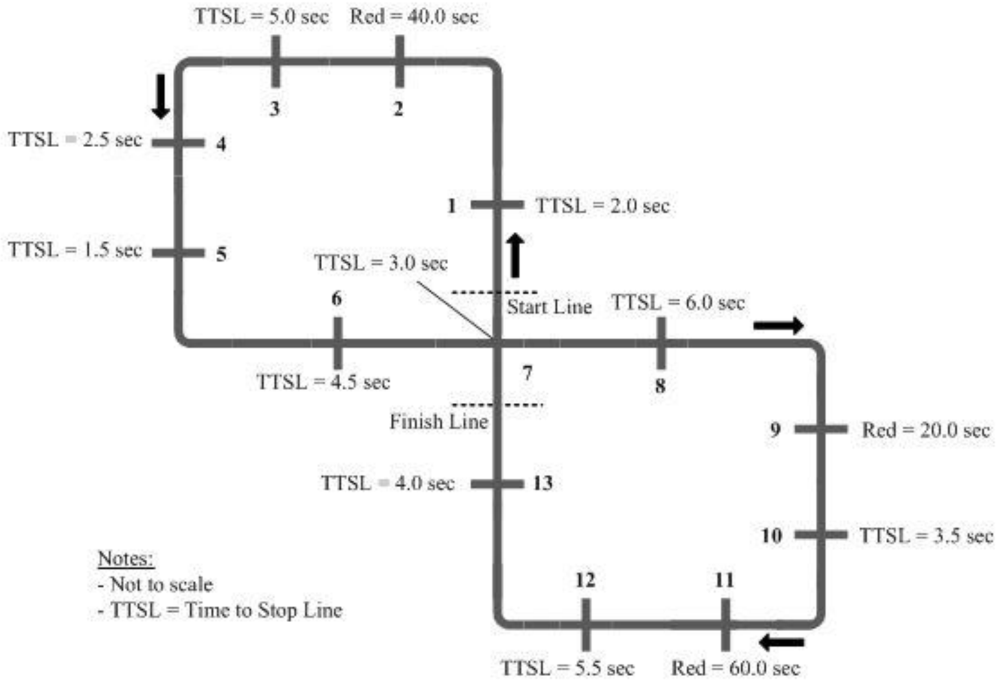
For this experiment, TSCT triggering sensors were placed at a distance upstream from an intersection. The signal change took place when the vehicle was at a desired distance from the intersection, measured in terms of Time To Stop Line (TTSL). TTSL is the amount of time, in seconds, it takes for a vehicle travelling at a given speed to reach the stop line. The following parameters were recorded at roughly 10 Hz (10 times a second) throughout the entire duration of the experiment:

- Time – To map the change in speed and acceleration with the change in signal indication or TSCT display.
- Signal Indication – To correlate driver response with respect to the change in signal indication or TSCT display.
- Instantaneous Speed – To identify changes in speed in response to the GSCT display.
- Instantaneous Position – To estimate the headways and distance upstream from the stop line.
- Instantaneous Acceleration/Deceleration – To identify any acceleration or deceleration in response to the GSCT display.

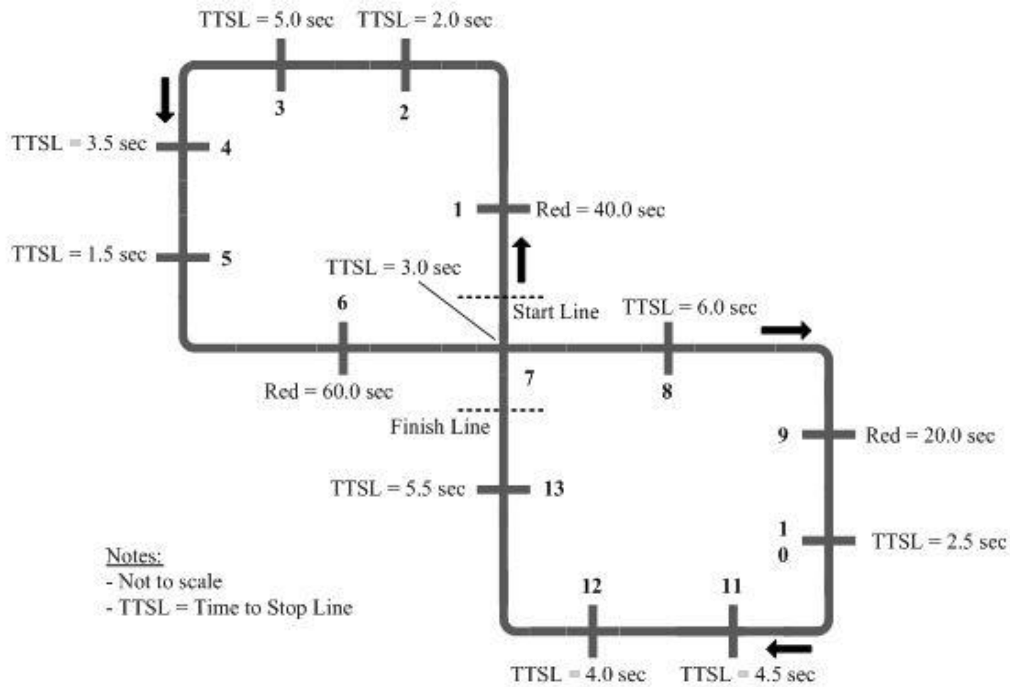
For all intersections where an RSCT accompanied a CR indication, the RSCT counted down the last ten seconds of the red phase regardless of the phase duration. When RSCTs of 20, 40, and 60-second duration are referenced within this document, this is referring to CR indications of 20, 40, and 60-second durations accompanied by RSCTs counting down the last ten seconds of the red phase.

3.3 Driving Simulator Scenario Layout

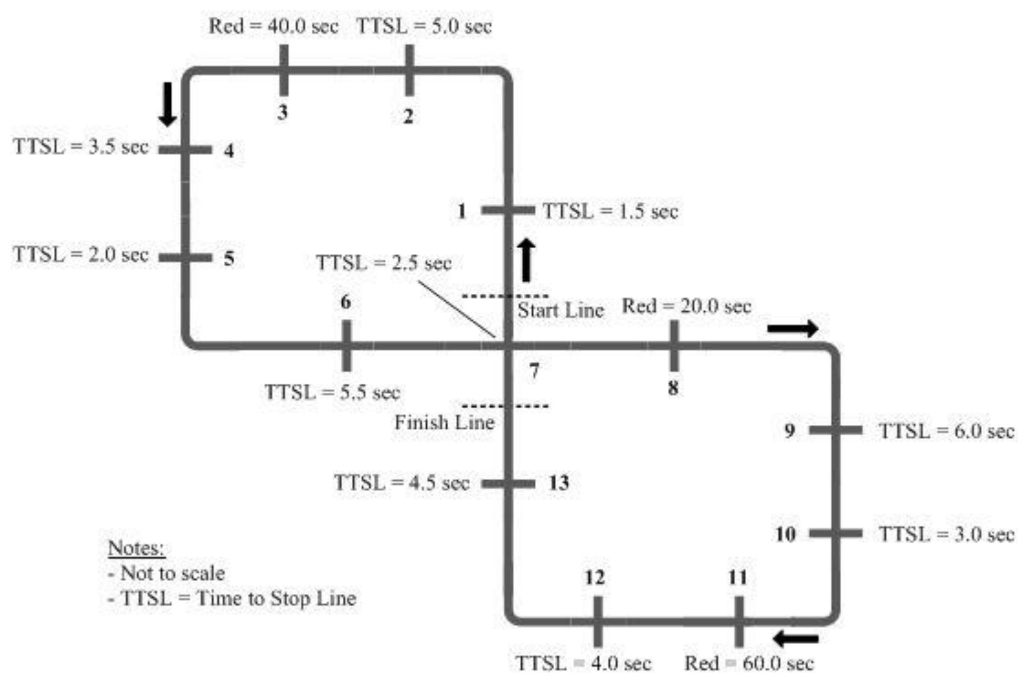
Participants were assigned one of four test track layouts: A, B, C, or D (Figure 7). Participants then drove two test tracks corresponding to their assigned layout, which differed only by the type of traffic signal used. The first test track included a combination of 20, 40, and 60-second duration CR indications at traditional traffic signals. The second test track included a combination of RSCTs of 20, 40, and 60-second duration and GSCTs corresponding to their equivalents in the first track. In the second test track, each RSCT test scenario was separated by at least two additional intersections so that subjects were not required to stop at successive intersections. GSCTs and RSCTs were combined in the same track to minimize the number of test tracks that subjects had to drive.



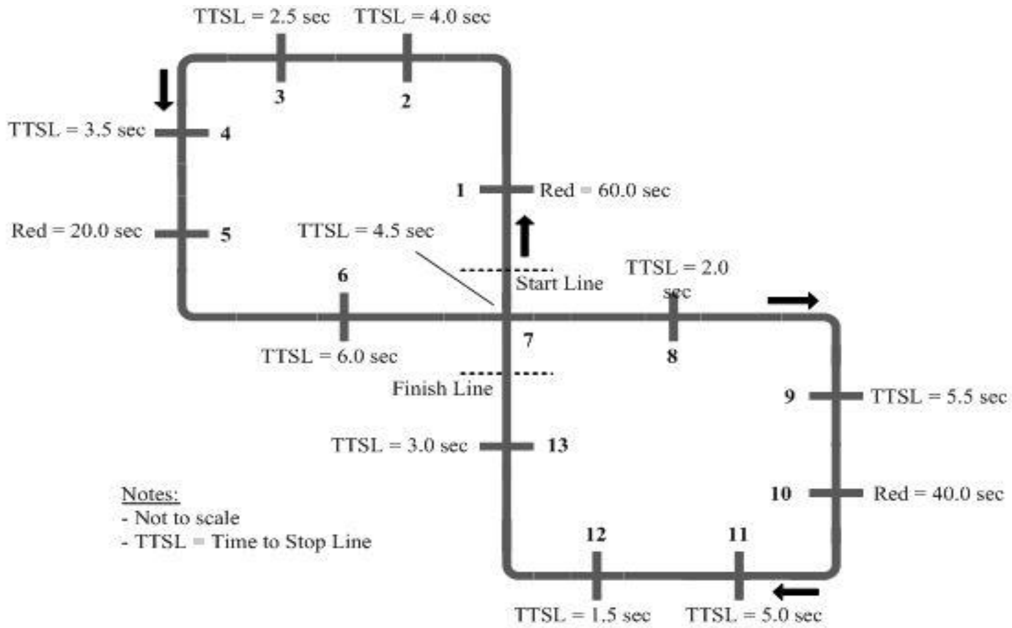
i) Configuration - A



ii) Configuration - B



iii) Configuration - C



iv) Configuration - D

Figure 7: Test Track Layouts A, B, C, and D

The following characteristics were the same for all test tracks:

- The posted speed was 35 mph and remained constant throughout each track
- The roadway was divided with one lane going each direction
- The track length was approximately 6.25 km, meaning each test subject drove approximately 12.50 km in total between the two test tracks

3.4 Experimental Procedure

A total of 67 individuals from Corvallis and the surrounding community were selected to participate in this study. Researchers recruited only licensed Oregon drivers with at least one year of driving experience for the study to restrict the population of interest to Oregon residents. In addition, participants needed to meet the following requirements:

1. Have no significant visual impairment
2. Have had no participation in a driving simulator study in the prior two years

Before participants drove the experimental tracks, they were provided with an informed consent document, informed of the potential for simulator sickness, and given the opportunity to ask clarifying questions. Following this, each participant drove a short three to five-minute test track to screen for simulator sickness. Simulator sickness is a phenomenon similar to motion sickness which can lead to headache, nausea, dizziness, sweating, and vomiting. If the participant experienced no signs of simulator sickness, they were outfitted with eye-tracking equipment and proceeded forward with the experiment. Participants were allowed to drop out of the experiment at any time.

Eye-tracking equipment was calibrated by mapping the participant's pupil to fixation points projected on the screen directly in front of the vehicle. An example of the eye-tracking calibration screen is presented in Figure 8.

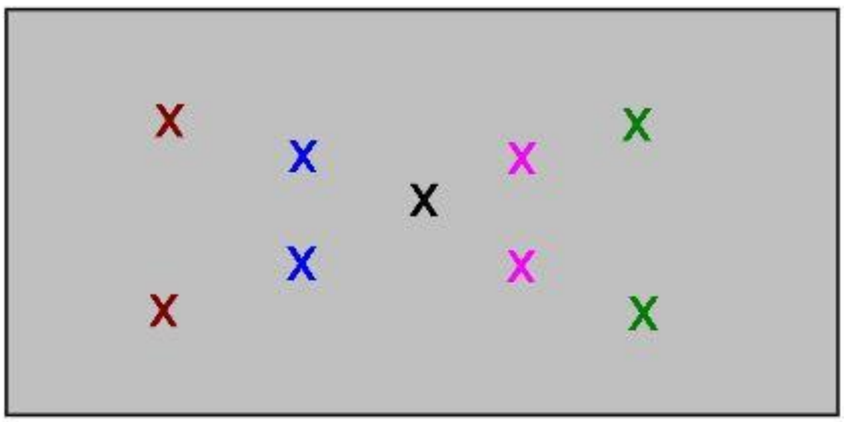


Figure 8: Eye-tracking Calibration Screen

Following calibration of the eye-tracking equipment, participants drove two experimental tracks according to their scenario layout.

3.5 Participants

Of the initial 67 participants, 12 participants experienced simulator sickness at various stages of the experiment. Responses recorded from subjects who experienced simulator sickness were excluded from the original data set prior to analysis. Of the remaining participants, some were unable to be properly outfitted with calibrated eye-tracking equipment. These participants yielded no eye-tracking data. Of those that were successfully outfitted with calibrated eye-tracking equipment, 24 participants with high quality eye-tracking data remained. This means the eye-tracking equipment for these 24 participants was able to record participants' eye movements with good consistency and accuracy which was suitable for analysis. For the purposes of this study, only data from these 24 participants is considered.

Information on gender, age, and level of education was collected on each of the 24 participants. Of the 24 participants, 16 were male and eight were female. The average age was approximately 27 years, with a minimum age of 20 years and a maximum age of 67 years. Level of education ranged from a high school diploma to a master's degree, with the majority of participants falling into the "some college" category. Table 1 summarizes the participant demographics recorded for this study.

Table 1: Participant Demographics

Demographic	Possible Response		Number of Participants
Gender	Male		16
	Female		8
Highest Level of Education	High School Diploma		3
	Some College		10
	Associates Degree		2
	4-year Degree		4
	Master's Degree		5
	PhD Degree		0
Age	**Minimum**	**Average**	**Maximum**
	20	27.33	67

3.6 Measurement of Eye Glance Data

Eye-tracking data was collected using the Mobile Eye-XG platform from Applied Science Laboratories (ASL). The Mobile Eye-XG platform allows a subject to have both unconstrained eye movement and unconstrained head movement during data collection and while driving via special glasses (Figure 9). The platform generates a sampling rate of 30 Hz and an accuracy of 0.5 to 1.0 degree. The subject's gaze is calculated by correlating the subject's pupil position and the reflection of three infrared lights on the eyeball.

Eye movement is comprised of fixations and saccades. Fixations are points that the subject focuses on for a short period of time. The Mobile Eye-XG system records a fixation when the subject's eyes have paused in a certain position for more than 100 milliseconds. Saccades are rapid eye movements between points. Mobile Eye-XG does not record saccades directly and instead calculates them based on dwell time between fixations.

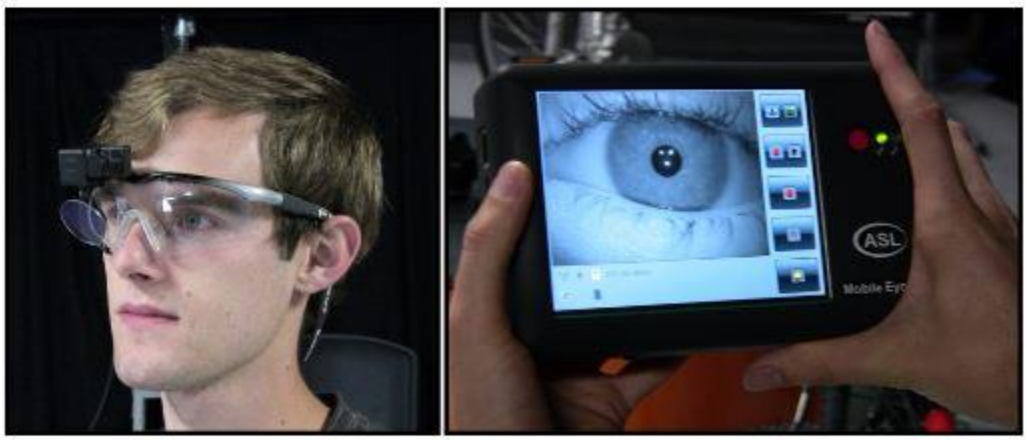


Figure 9: OSU Researcher Demonstrating the Mobile Eye XG Glasses and Mobile Recording Unit

The number and duration of fixations the subject's eyes made on RSCTs of 20, 40, and 60-second durations and on standard CR indications were recorded and compared using data compiled through ASL ResultsPlus data analysis software. Saccades were not examined for the purposes of this study.

3.6.1 ASL ResultsPlus Software

ASL ResultsPlus software, which accompanies the Mobile Eye-XG platform, was used to extract useful data on the number and duration of fixations that drivers made while driving a test track which pertained only to areas of interest (AOIs) defined by the researcher. The AOIs defined for this study include every RSCT of 20, 40, and 60-second duration and standard CR indications of 20, 40, and 60-second duration.

Areas of interest (AOIs) were defined after collection of video data by drawing a rectangle around the AOI and altering it accordingly for every five frames of data where the AOI appeared. An explanation of why AOIs were re-defined every five frames is given in Section 3.6.2. Figure 10 demonstrates the process of defining AOIs.

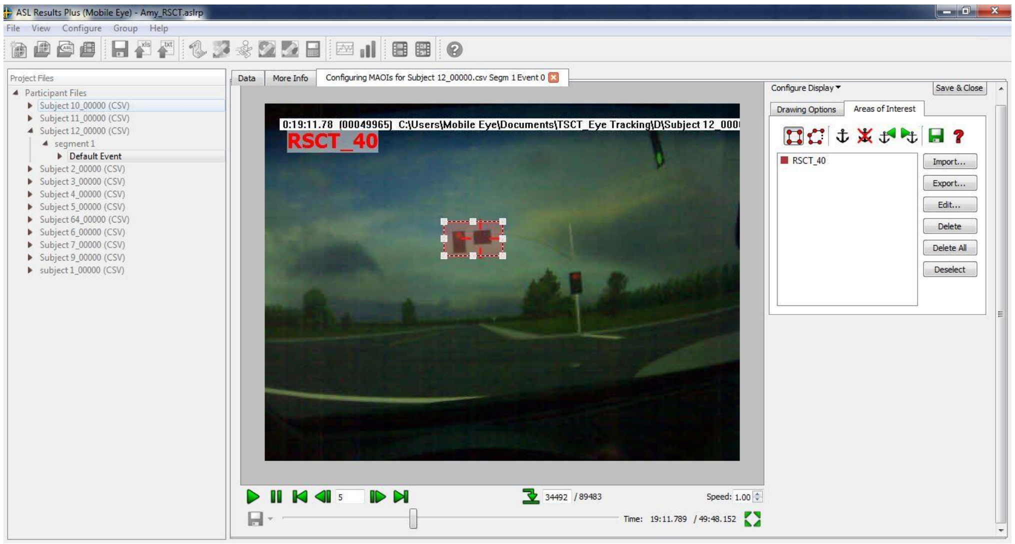


Figure 10: Defining AOIs with ASL ResultsPlus Software

Once each AOI was defined or re-defined for every five frames of video data, ASL ResultsPlus computed the number of fixations on that AOI by summing the number of times the subject directed their gaze within that region. ASL ResultsPlus computes fixation duration by calculating the amount of time the subject's gaze remains within the AOI before moving elsewhere. Figure 10 demonstrates what constitutes a fixation event. The red crosshair in the figure shows the focus of the subject's gaze, while the rectangle specifies the AOI. When the crosshair passes within the closed rectangle, the event counts as a fixation.

3.6.2 Choosing an Interval between Re-Definition of AOIs

Data was tested for differences between re-defining AOIs at every two, five, and ten frames. Table 2 shows how average fixation duration varies when AOIs are re-defined at every two, five, and ten frames at one intersection for one subject. As the number of frames between re-definition increased, the recorded average fixation duration increased. Five frames was chosen as the standard for this study to balance efficiency and accuracy. Five frames is also the most common interval between re-definition of AOIs used for eye-tracking analysis in the OSU Driving Simulator Lab.

Table 2: Response of Average Fixation Duration to the Variation of Frame Re-Definition Interval

Interval Between Re-Definition of AOIs (frames)	2	5	10
Average Fixation Duration (s)	0.347	0.358	0.366

3.7 UHC Thesis Unique Contribution

The data collection described in this chapter was originally performed by Mohammad Rabiul Islam, PhD in Civil Engineering 14'. He was studying the implications of RSCT and GSCT devices on intersection efficiency and safety by analyzing vehicle position data captured by the driving simulator. He was also studying driver comprehension and preferences towards TSCTs using survey data.

The unique contribution of this UHC thesis is an analysis of driver visual attention to RSCTs using eye tracking data collected by Islam for his study on intersection efficiency and safety, but never reduced or analyzed. This thesis works to determine how driver visual attention to RSCTs varies by RSCT duration, presence, and participant demographics. In addition, it works to further explain the results of the RSCT portion of Islam's 2014 study. The effort represents many hours of data extraction, statistical analysis, and interpretation of results.

4 RESULTS AND ANALYSIS

The following chapter presents the results of this study and describes the statistical methods used to analyze those results. The dependent variables include the average fixation durations (AFDs) measured for CR indications of 20, 40, and 60-second duration with and without RSCTs for 24 participants. This chapter begins with a discussion of summary statistics for the data sets with and without RSCTs. It is followed by a discussion of the normality of the datasets and subsequent statistical comparisons. For brevity, CR indications with RSCTs are referenced just as “RSCTs” in this chapter. Regardless of duration of CR indications tested, an accompanying RSCT counted down only the last 10 seconds of the red duration.

4.1 Data Reduction and Analysis

Following the reduction of data using ASL ResultsPlus software as described in Chapter 3, data was exported for each subject in text file format and imported into Microsoft Excel. Using Excel, the data was filtered and organized to create one spreadsheet of data highlighting the independent and dependent variables of interest across all subjects: AFD for CR indications without RSCTs of 20, 40, and 60-second duration and for RSCTs of 20, 40, and 60-second duration, a total of six individual scenarios. The datasets were abbreviated as CR without RSTCs, “CR”, or CR with RSCTs, “RSCT”, preceding the signal duration (20, 40, or 60 seconds). Datasets are referenced by this naming convention in this chapter and those that follow.

After data was compiled in Excel, data was imported from Excel into the statistical analysis software R. A combination of R and Excel was used for the final statistical analysis, which involved developing boxplots and histograms for the data, testing data for normality, and performing comparison tests between datasets.

4.2 Average Fixation Duration of CR Indication Datasets

Summary statistics for AFD data for CR indications of 20, 40, and 60-second duration were computed and are presented graphically with boxplots. Boxplots are chosen to represent the distribution of the data because they show variability, central tendency, and skewness. The following boxplots were created in R, with the whiskers extending to the most extreme data point which is not more than 1.5 times the interquartile range. Outliers, data points lying outside 1.5 times the interquartile range, are marked with a circle.

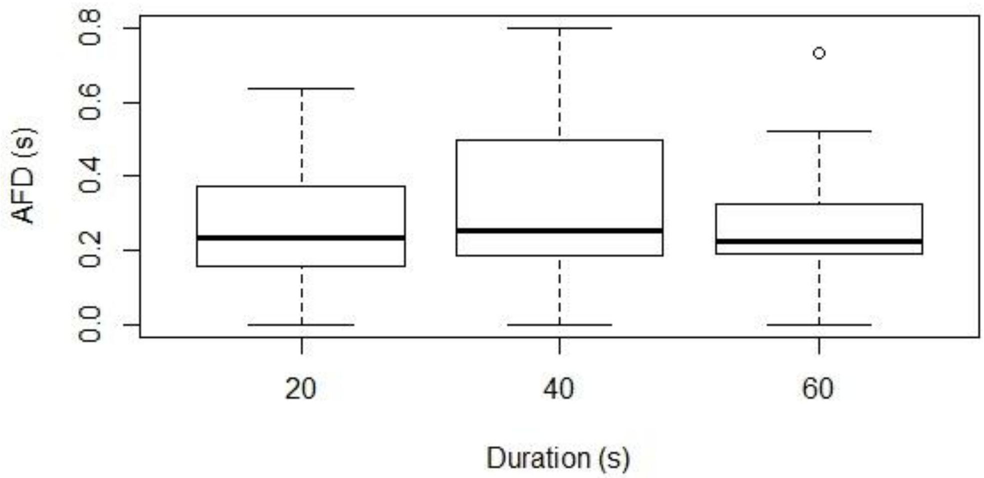


Figure 11: AFD Data for CR Signals of 20, 40, and 60-second Duration

Figure 11 indicates that each CR dataset is skewed right, with the majority of AFD observations concentrated between 0 and approximately 0.25 seconds. The median AFD for each duration of CR dataset is approximately the same, between 0.23 and 0.26 seconds. The CR dataset with 40-second duration has the highest median AFD by a small margin and the largest spread.

In addition to the highest median AFD, the 40-second duration CR dataset also has the highest mean AFD. Table 3 gives the summary statistics for each CR dataset to supplement Figure 11. The 40-second CR dataset shows the highest discrepancy between the median and mean and similarly, the highest standard deviation.

Table 3: Characteristics of 20, 40, and 60-second Duration CR Datasets

Dataset	**Median**	**Mean**	**Minimum**	**Maximum**	**Std Dev**
CR_20	0.24	0.24	0	0.64	0.17
CR_40	0.25	0.34	0	0.80	0.21
CR_60	0.23	0.27	0	0.73	0.16

4.3 Average Fixation Duration of RSCT Datasets

Summary statistics for AFD data of RSCTs of 20, 40, and 60-second duration were computed and are presented graphically using boxplots. Boxplots were developed in R using the same methods as those used to create the boxplots for the CR datasets.

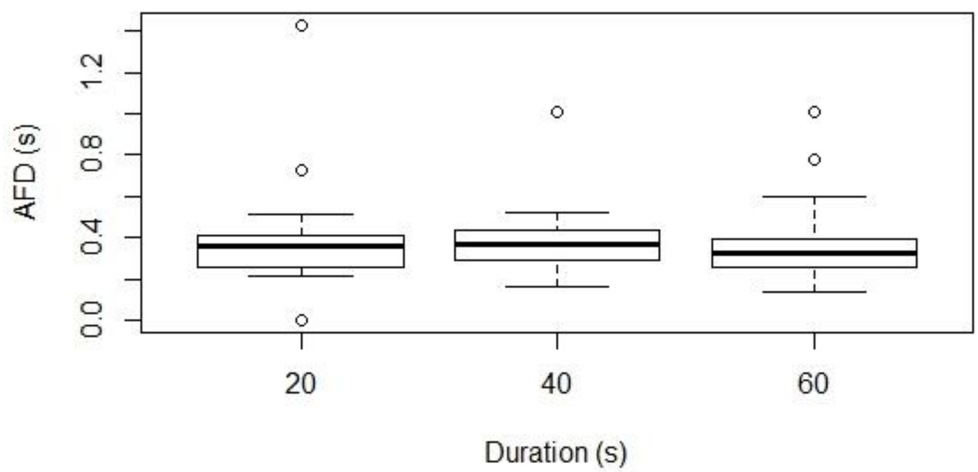


Figure 12: AFD Data for RSCTs of 20, 40, and 60-second Durations

Figure 12 shows that AFDs recorded for RSCTs of 20, 40, and 60-second duration do not follow similar patterns of skewness. However, the median AFDs recorded for each duration of RSCT are very similar, between 0.32 and 0.37 seconds. Similar to the CR datasets, the median AFD of the RSCT of 40-second duration is slightly higher than that of the 20-second and 60-second duration RSCT datasets.

Table 4 shows the specific summary statistics computed using R for RSCTs of 20, 40, and 60-second duration that are not explicitly shown by Figure 12. The mean AFDs computed for each duration of RSCT, all of which are higher than the median AFDs by no more than 0.004 seconds, follow the same pattern expressed by the median AFDs.

Table 4: Characteristics of 20, 40, and 60-second Duration RSCT Datasets

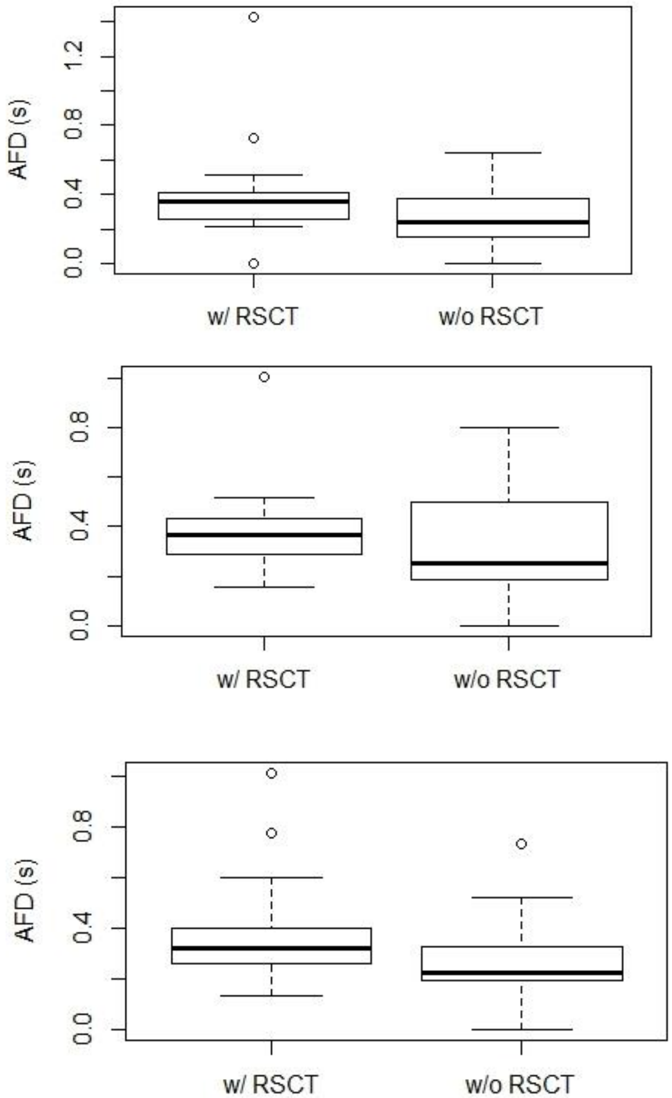
Dataset	**Median**	**Mean**	**Minimum**	**Maximum**	**Std Dev**
RSCT_20	0.35	0.38	0.00	1.43	0.27
RSCT_40	0.36	0.38	0.16	1.01	0.16
RSCT_60	0.32	0.37	0.14	1.01	0.20

4.4 Comparison of Data by Indication Duration

Regardless of indication type (CR or RSCT), a signal of 40-second duration had the highest median and mean AFD. However, the difference between median AFDs of differing durations for each signal type was marginal—never more than a few hundreds of a second. Although the CR indication of 40-second duration had the highest standard deviation among the three CR datasets, the RSCT indication of 40-second duration had the lowest standard deviation among the RSCT datasets.

4.5 Comparison of Data by Indication Type

Regardless of signal duration, the RSCT indication type yielded the largest median AFDs, which were approximately 0.1 seconds higher than the CR AFDs of corresponding duration. The following section breaks out boxplots by indication duration for ease of comparison and discusses what differences exist between different indication types using the same duration of red.



(a)

(b)

(c)

Figure 13: Signal of 20-Second Duration (a), 40-Second Duration (b), and 60-Second Duration (c)

Figure 13 shows how the CR datasets yield consistently lower median AFD values, yet have a generally larger range of values which are not considered outliers. RSCT datasets generally have a more limited range of non-outlying values, but more outliers.

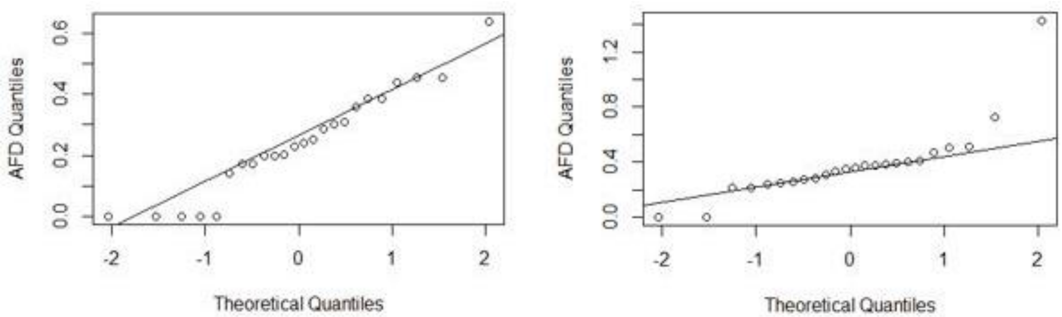
Standard deviations of the CR and RSCT datasets range from 0.16 to 0.27. The standard deviations of the CR datasets are lower than those of the RSCT datasets by approximately 0.1, with the exception of the 40-second duration CR and RSCT datasets. In this case, the CR dataset has a higher standard deviation by approximately 0.1.

4.6 Testing for Normality

Before datasets can be compared via statistical tests such as the t-test or f-test, data must be tested for normality. Data was visualized for normality by plotting each dataset on a normalized quantile-quantile plot and further examined using a Shapiro-Wilk test with a 95% confidence threshold.

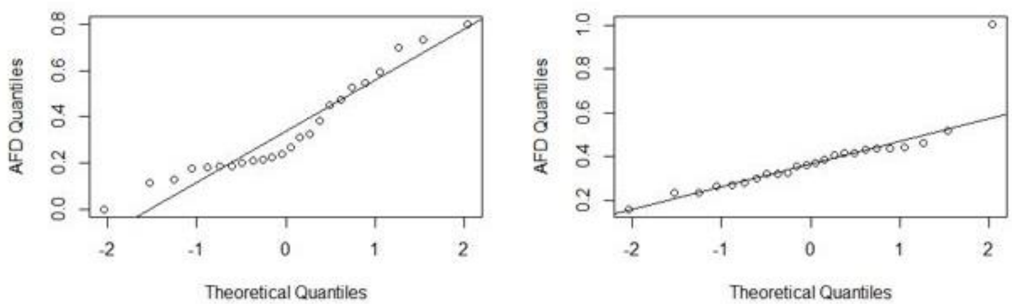
4.6.1 Quantile-Quantile Plots

Figure 14, Figure 15, and Figure 16 show the normalized quantile-quantile plots constructed for CR and RSCT indications of 20, 40, and 60-second duration and the best-fit lines generated by R for each dataset.



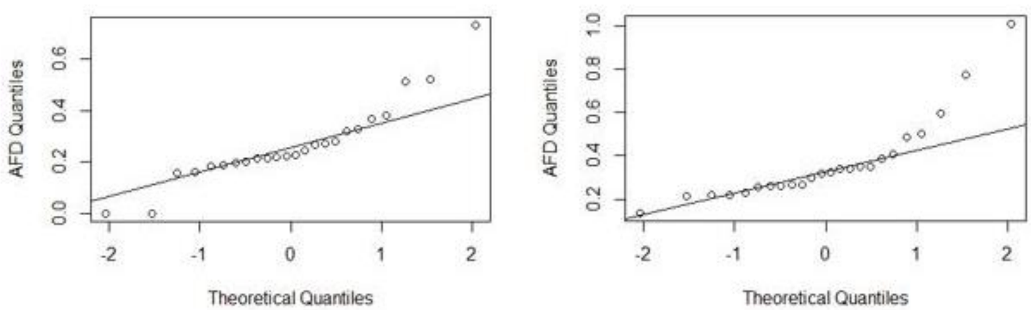
(a) **(b)**

Figure 14: Normalized Quantile-Quantile Plots for 20-second Duration CR (a) and RSCT (b) Datasets



(a) **(b)**

Figure 15: Normalized Quantile-Quantile Plots for 40-second CR (a) and RSCT (b) Datasets



(a) **(b)**

Figure 16: Normalized Quantile-Quantile Plots for 60-second Duration CR (a) and RSCT (b) Datasets

Table 5 shows the slope, y-intercept, and R^2 values pertaining to the best-fit lines generated for the corresponding normalized quantile-quantile plots in Excel. If a dataset follows a normal distribution, the slope of the best-fit line generated for its corresponding normalized quantile-quantile plot should be close to the standard deviation for that dataset. The y-intercept of the same best-fit line matches the mean of the dataset.

Table 5: Key Values for Quantile-Quantile Plot Best-Fit Lines

Dataset	y-intercept	Mean	R^2 value	Slope	Std Dev
RSCT_20	0.38	0.38	0.72	0.23	0.27
RSCT_40	0.38	0.38	0.73	0.14	0.16
RSCT_60	0.37	0.37	0.78	0.17	0.20
CR_20	0.24	0.24	0.95	0.17	0.17
CR_40	0.34	0.34	0.92	0.21	0.21
CR_60	0.27	0.27	0.88	0.15	0.16

Table 5 shows that the y-intercept of the best-fit line generated to describe the quantile-quantile plot matches the mean exactly for all datasets, which is the expected result for a normal distribution. It also shows that the slope of the best-fit line generated for the quantile-quantile plot for all datasets is generally close to the standard deviation of each dataset, the expected result for a normal distribution. The slope and standard deviation match almost exactly for all CR datasets. For the RSCT datasets, the slope and standard deviation differ by approximately 0.02 to 0.04. R^2 values are high for all datasets, in particular for the CR datasets. An R^2 value of 1 corresponds to a perfect fit.

4.6.2 Shapiro-Wilk Test

To further examine the normality of the datasets, a Shapiro-Wilk test with a 95% confidence threshold was performed on each dataset. Table 6 shows the Shapiro-Wilk test results for CR and RSCT indications of 20, 40, and 60-second durations. A p-value of less than 0.05 indicates that a dataset does not follow a normal distribution. However, a p-value greater than 0.05 does not prove that a dataset is normally distributed.

Table 6: Shapiro-Wilk Test Results for AFD of 20, 40, and 60-Second RSCT and CR Signal Datasets

Dataset	**p-value**
RSCT_20	< 0.001
RSCT_40	< 0.001
RSCT_60	< 0.001
CR_20	0.220
CR_40	0.053
CR_60	0.016

The Shapiro-Wilk tests performed on each dataset suggest that all datasets, with the exception of the 20 and 40-second duration CR datasets, do not follow a normal distribution.

4.6.3 Determination of Best-Fit Distribution

The Shapiro-Wilk test results and the quantile-quantile plots presented in the preceding section suggest that the CR and RSCT datasets may conform to a non-normal distribution. To determine the best-fit distribution for the datasets, Cullen and Frey graphs were generated for each of the six datasets in R. A Cullen and Frey graph uses the kurtosis and square of skewness of a dataset to suggest what distribution may best fit a dataset. Figure 17 and Figure 18 show the Cullen and Frey graphs for CR indication datasets of 20 and 40-second duration.

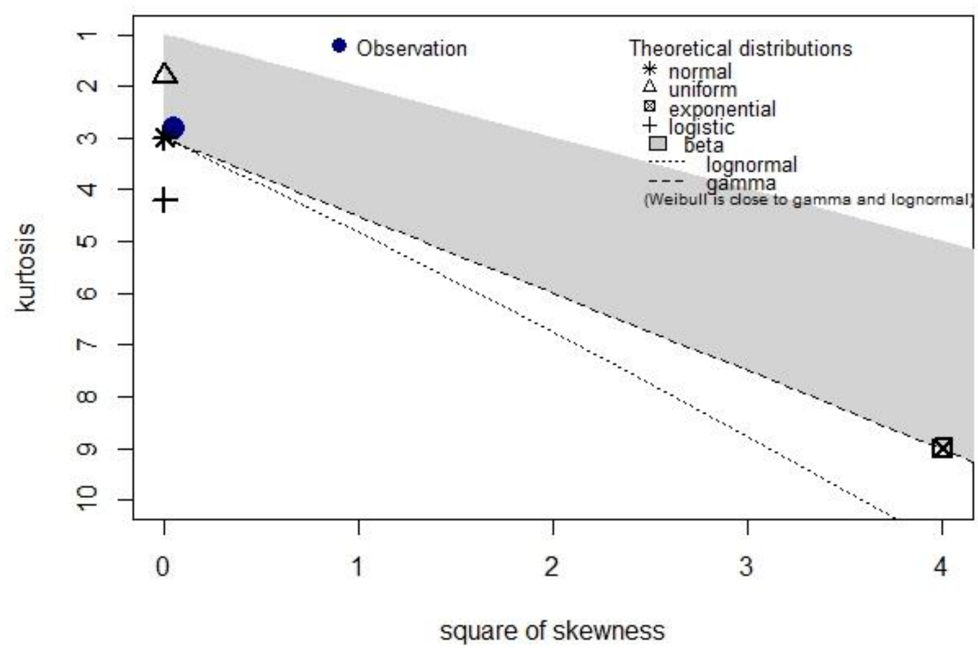


Figure 17: Cullen and Frey Graph of CR 0f 20-second Duration

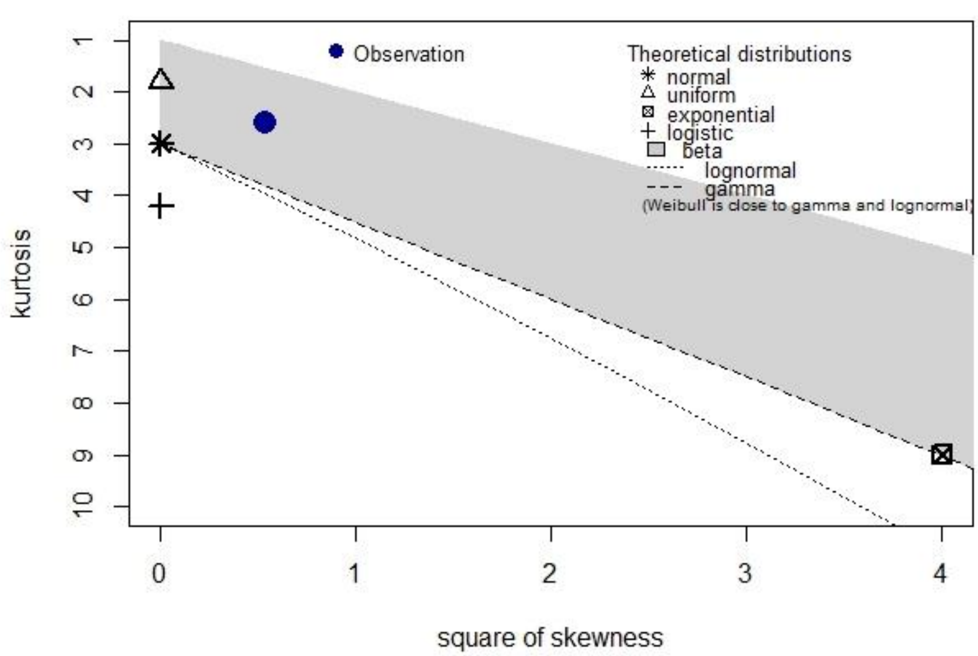


Figure 18: Cullen and Frey Graph of CR of 40-second Duration

Following with the statistical analysis presented in the preceding section, the Cullen and Frey graphs plot the CR of 20 and 40-second duration datasets, the closest of all the datasets to the normal distribution. Figure 19 presents the Cullen and Frey graph for the CR of 60-second duration dataset, suggesting that it may fit a lognormal distribution best.

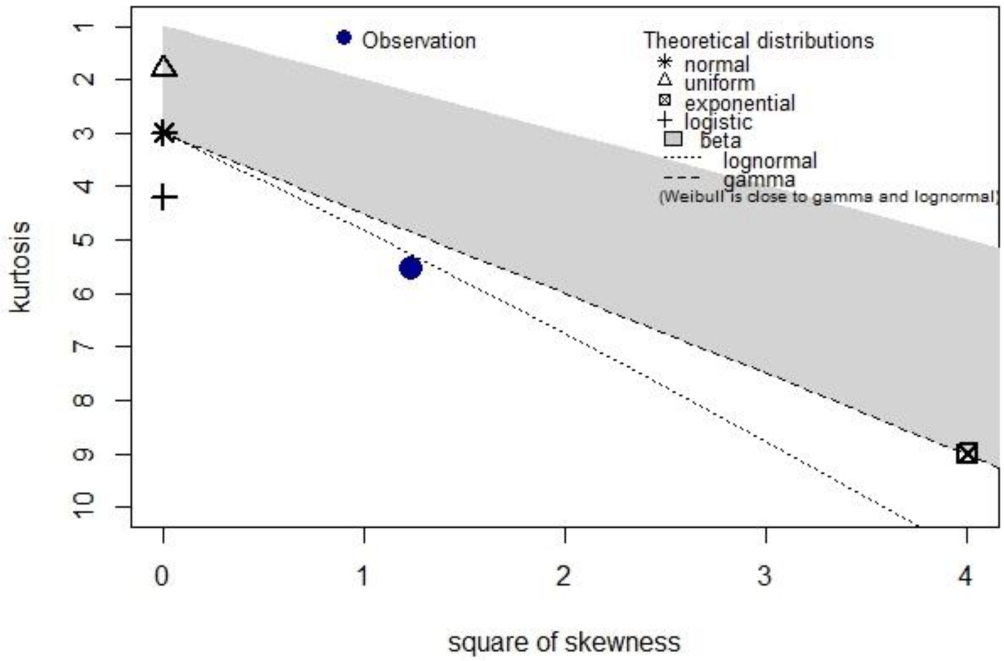


Figure 19: Cullen and Frey Graph of CR of 60-second Duration

While the CR datasets all plot with a square of skewness less than two and a kurtosis of less than six, the RSCT datasets all plot with a square of skewness greater than four and a kurtosis of greater than six. The Cullen and Frey graphs for the RSCT datasets of 20, 40, and 60-second duration are presented in Figure 20, Figure 21, and Figure 22.

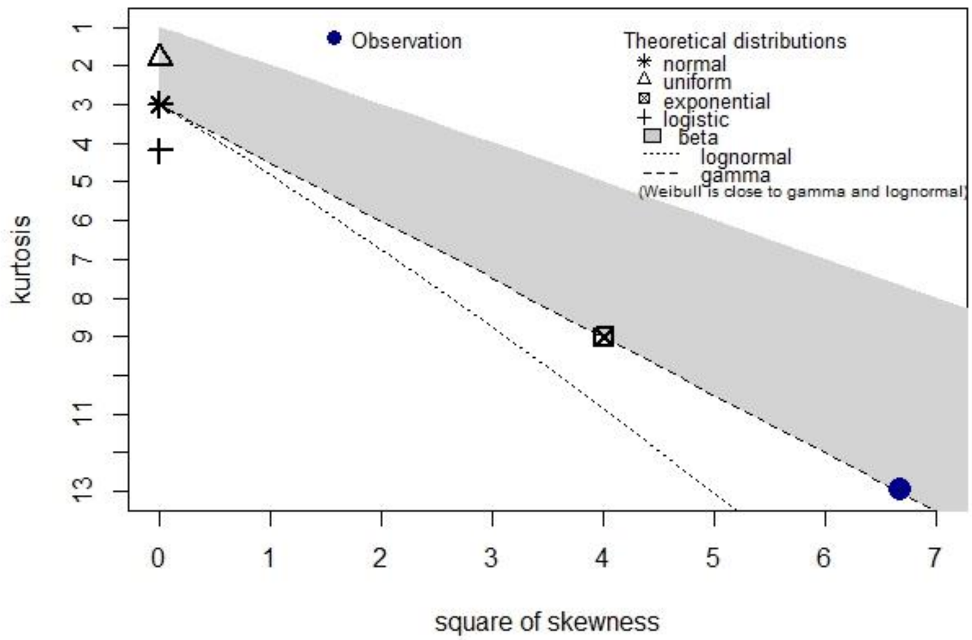


Figure 20: Cullen and Frey Graph of RSCT of 20-second Duration

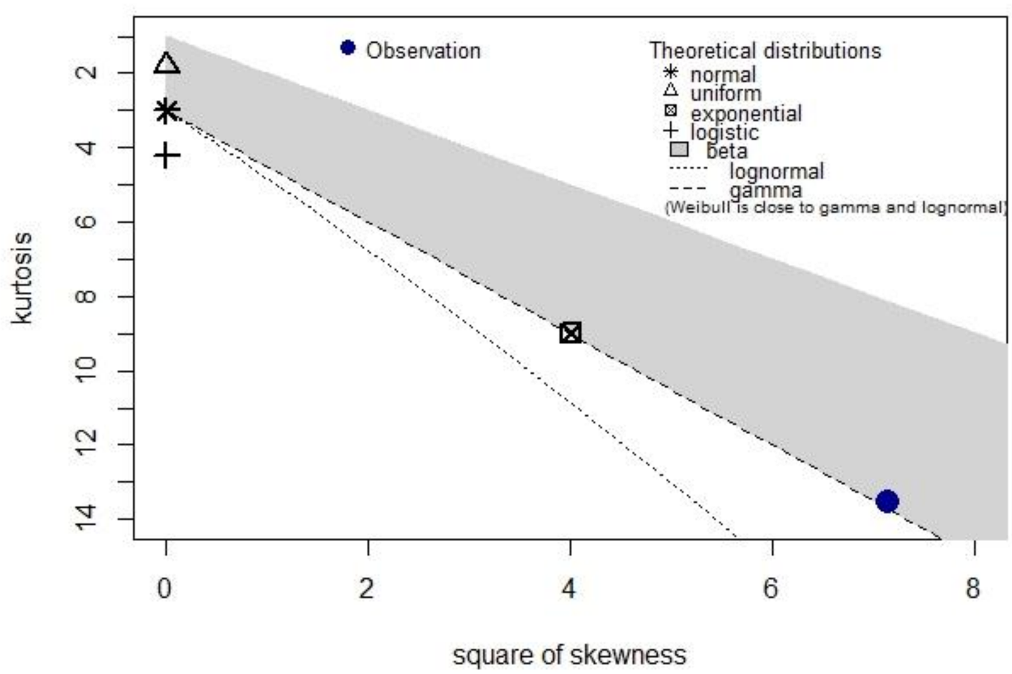


Figure 21: Cullen and Frey Graph of RSCT of 40-second Duration

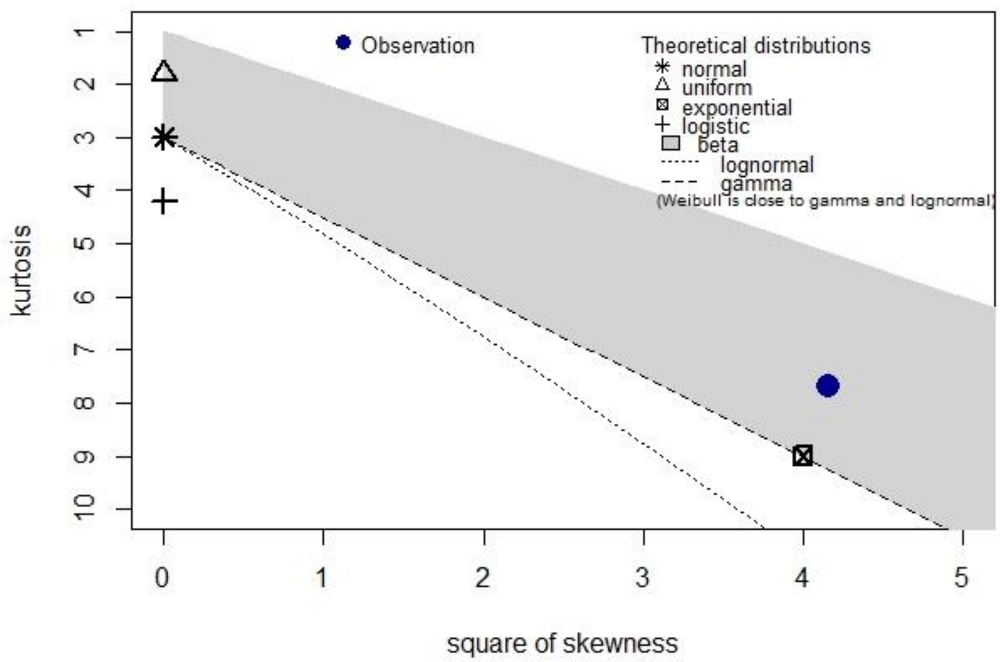


Figure 22: Cullen and Frey Graph of RSCT of 60-second Duration

The Cullen and Frey plots for the six datasets suggest that there is no one distribution which will describe all of the datasets well.

4.7 Statistical Comparison

Because the Cullen and Frey plots suggest that there is no single distribution which will describe each dataset well for the purposes of comparison, the datasets are treated as normal and compared using paired t-tests and f-tests. The following sections present the results of these tests, which compare indication type and indication duration.

4.7.1 Comparison of CR and RSCT Indications

Paired t-tests were performed comparing CR and RSCT datasets of the same duration. The results are presented in Table 7.

Table 7: Paired T-Test Comparing CR and RSCT Indications

Dataset 1	**Dataset 2**	**p-value**	**Significance**
RSCT_20	CR_20	0.01	Difference
RSCT_40	CR_40	0.30	No Difference
RSCT_60	CR_60	0.00	Difference

Table 7 shows that there is a statistical difference between CR and RSCT datasets of 20 and 60 seconds, while the datasets of 40-second duration show no statistical difference. Paired f-tests comparing the variance of the CR and RSCT datasets of the same duration were performed and are presented in Table 8.

Table 8: Paired F-Test Comparing CR and RSCT Indications

Dataset 1	**Dataset 2**	**p-value**	**Significance**
RSCT_20	CR_20	0.03	Difference
RSCT_40	CR_40	0.16	No Difference
RSCT_60	CR_60	0.32	No Difference

Table 8 shows that while there is a statistically significant difference in the variance between the CR and RSCT datasets of 20-second duration, there is no difference in the variance between the datasets of 40-second duration and the datasets of 60-second duration.

4.7.2 Comparison of CR Indications by Duration

Paired t-tests were performed comparing CR indications of different durations. The results are presented in Table 9.

Table 9: Paired T-Test Comparing CR Indications by Duration

Dataset 1	**Dataset 2**	**p-value**	**Significance**
CR_20	CR_40	0.05	Suggestive difference
CR_40	CR_60	0.05	Suggestive difference
CR_60	CR_20	0.28	No Difference

Table 9 shows that while there is no statistical difference between AFD data for CR indications of 20 and 60-second duration, there may be a statistical difference between CR indications of 20 and 40-second duration and CR indications of 40 and 60-second duration. Paired f-tests comparing the variance of CR indications of varying durations were performed and are presented in Table 10.

Table 10: Paired F-Test Comparing CR Indications by Duration

Dataset 1	**Dataset 2**	**p-value**	**Significance**
CR_20	CR_20	0.28	No Difference
CR_40	CR_60	0.15	No Difference
CR_60	CR_20	0.71	No Difference

Table 8 shows that there is no statistical difference between the variance of CR indications of 20, 40, and 60-second duration.

4.7.3 Comparison of RSCTs by Duration

Paired t-tests were performed comparing RSCT indications of different durations. The results are presented in Table 11.

Table 11: Paired T-Test Comparing RSCTs by Duration

Dataset 1	**Dataset 2**	**p-value**	**Significance**
RSCT_20	RSCT_40	0.90	No Difference
RSCT_40	RSCT_60	0.62	No Difference
RSCT_60	RSCT_20	0.78	No Difference

Table 11 shows with high confidence that there is no statistical difference between RSCT datasets of varying durations. Paired f-tests comparing the variance of RSCT datasets of varying duration were performed and are presented in Table 12.

Table 12: Paired F-Test Comparing RSCTs by Duration

Dataset 1	**Dataset 2**	**p-value**	**Significance**
RSCT_20	RSCT_40	0.01	Difference
RSCT_40	RSCT_60	0.33	No Difference
RSCT_60	RSCT_20	0.12	No Difference

Table 12 shows that there is no statistical difference between the variance of the RSCT of 40 and 60-second duration datasets and between the RSCT of 20 and 60-second duration datasets. However, there is a difference between the variance of the RSCT datasets of 20 and 40-second duration.

5 DISCUSSIONS AND CONCLUSIONS

The following chapter reviews the objectives of this study, summarizes its research findings, and suggests areas for future work.

5.1 Review of Research Objectives

The goal of this study was to shed light on how and why RSCT indications impact intersection efficiency. The following research questions were developed to guide this study:

> 1) How does the duration and frequency of driver fixations on traffic signal heads vary with and without RSCTs?
>
> 2) How does the duration and frequency of driver fixations on traffic signal heads vary between RSCTs with 20, 40, and 60-second duration red indications?

To answer these questions, eye tracking data was collected from 24 subjects out of a total 67 subjects who participated in an OSU driving simulator study (Islam, 2016). Only eye tracking data in which participant's eye movements were recorded with high consistency and accuracy were included in the analysis. Eye tracking data yielded average fixation durations for each subject on both standard CR indications and RSCTs. Average fixation duration was the primary variable examined for this study.

5.2 Research Findings

The study yielded the following results:

- There was a statistically significant difference in AFD between CR indication type for indications of 20 and 60-second duration. There was no difference between those of 40-second duration.
- There was no significant difference in AFD between standard CR indications of varying duration and no difference between RSCT indications of varying duration.
- For each indication type, the 40-second duration dataset had the greatest AFD by no more than several hundredths of a second.

- Of the standard CR indication datasets, the 40-second duration dataset showed the greatest variation in AFD. Of the RSCT datasets, the 40-second duration dataset showed the least variation.
- The average median AFD of the standard CR indications was 0.24 seconds.
- The average median AFD of the RSCT indications was 0.34 seconds.

5.3 Discussion

The results of this experiment show that there is a statistically significant difference in driver AFD between CR indications with and without RSCTs, with the exception of the 40-second duration indications. The results also show that there is little to no difference in driver AFD between various durations of each indication type. This suggests that it is necessary to test the influence of indication duration on driver AFD using a wider range of durations, including durations longer than 60-seconds.

The mean AFD for the standard CR indications was 0.24 seconds. The mean AFD for RSCT indications was 0.34 seconds, 0.1 seconds greater than that of the CR indication datasets. Existing literature suggests that 300 milliseconds is a typical value measured for an AFD, meaning that driver AFDs on CR indications with and without RSCTs are comparable to AFDs on other objects examined in existing literature, such as traffic signs. Little literature examining driver AFD on traffic signals, specifically, exists. Existing literature also suggests that longer AFDs correlate to more attentive processing (Velichkovsky et al., 2003), which, applied to this study, suggests that RSCT indications received more attention than those without RSCTs. This potentially has benefits for increasing intersection efficiency and negative effects on intersection safety.

A driver who pays more attention to a red indication will more likely be ready to proceed through the intersection on green than a driver who does not pay as much attention. This study shows that driver AFD to a RSCT indication was 0.1 seconds more than to a CR without RSCT, which accompanies Islam et al. (2016) finding's that RSCT indications decreased headway by 0.72 seconds, on average.

This experiment was a follow-up to the experiment performed by Islam et al. (2016), which determined that there was a significant difference in average first headway between indications of 20 and 60-second duration. The study attributed this difference to driver distraction. The study also proposed that drivers pay more attention to signals with a duration of less than 40-seconds and less attention as duration increases. The results of this study show that there was no statistically significant difference in driver attention as measured by AFD between RSCT indications of 20 and 60-second duration. Further, it shows that while AFD for the RSCT of 60-second duration was lower than that of the indication of 20-second duration, it was lower by only a few hundredths of a second. In sum, there was little correlation between the influence of CR duration on the visual attention of drivers considered in this study and the headway of lead vehicle considered by Islam et al. (2016).

In addition to efficiency, greater attention to a red indication has potential implications for driver safety. If a driver pays too much attention to the red indication, the driver may fail to pay attention to other items at an intersection that pose a safety hazard, such as a bike, pedestrian, or vehicle running a red light. The driver, knowing when the signal is going to turn green, may also “jump the red” and begin to proceed through the intersection before the light has turned green. This increases the chances of a right-angle collision with other vehicles proceeding through the intersection on red (Chiou and Chang, 2010). Sharma (2011) provided evidence that RSCTs increase this behavior. To determine the potential connection between driver fixation on an RSCT indication and early-start behavior, it would be useful in future work to compare driver early-start behavior with fixation data in the first two seconds before drivers proceed through the intersection.

5.4 Future Work

The research conducted for this study suggests that driver attention to a red indication varies based on indication type. Areas where future work could be performed include:

- How driver age, gender, and driving experience influence attention to the red indication.
- More extensive testing of driver attention to RSCTs and CR indications with a larger sample size and with track configurations that do not include GSCTs.

- More extensive testing on how the frame interval between redefinition of AOIs influences fixation data.
- Repeat the experiment with greater variation in indication duration (for example, test an indication of 120-second duration).
- Analyze driver fixation on the red indication in tandem with early-start-on-red behavior.
- Analyze driver fixation on RSCT indications in the first two seconds before that driver proceeds on green and compare with the driver's fixations on the intersection in front of them.

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