Influence of Texting on Driver Glance Patterns and Vehicular Lane Position on Horizontal Curves

by

Makenzie A. Ellett

A PROJECT

submitted to

Oregon State University

University Honors College

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Honors Baccalaureate of Science in Civil Engineering (Honors Scholar)

Presented: March 20th, 2015
Commencement June 2015

AN ABSTRACT OF THE THESIS OF

Makenzie A. Ellett for the degree of Honors Baccalaureate of Science in Civil Engineering presented on March 20th, 2015.

Title: Influence of Texting on Driver Glance Patterns and Vehicular Lane Position on Horizontal Curves

Abstract Approved: ____

David S. Hurwitz

The use of in-vehicle technologies, such as mobile phones, while driving has proliferated in recent years. Most notably, drivers are using mobile phones to send and receive text messages while operating a vehicle with increasing frequency. The act of texting while driving poses a significant threat not only to the driver, but also to passengers and adjacent road users. Texting requires the driver to take at least one hand off the wheel (motor distraction), their eyes off the roadway (visual distraction), and to read messages or conceive of responses (cognitive distraction) all of which can result in the performance degradation of the driving task. This research evaluated the effects of texting while driving, with particular focus on horizontal curves. The OSU Driving Simulator was used to record the lateral position of the vehicle and the glance patterns of the driver. Eighteen subjects drove an experimental course that included four billboards located at the beginning of horizontal curves and were asked to text the name of the animal whose picture appeared on each billboard. Driver glances at the mobile phone and the vehicle's corresponding lateral position were analyzed to determine their effects on the driving task. This study found that the deviation of lateral position increased for drivers who texted, and the longest single glances away from the road exceed 2.0 seconds in duration which is of critical concern since it is generally accepted that crash risk increases when glances exceed two seconds.

Key Words: Texting, Glance, Lateral Position, Simulator, Behavior

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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.

Makenzie A. Ellett, Author

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1 INTRODUCTION

The invention of mobile cellular devices (mobile phones) in 1983, followed by the arrival of the short message service (texting) in 1992, ushered in a new era in communication where subscribers could quickly and easily communicate with others from virtually anywhere *(CTIA, 2013)*. Most notably, subscribers are using their mobile phones to send and receive text messages while they are otherwise engaged in operating a vehicle. The act of texting while driving can simultaneously cause motor, visual, and cognitive distraction in order to read or write any message. According to the National Highway Traffic Safety Administration (NHTSA), the use of mobile devices while driving continues to increase, especially amongst younger drivers (*NHTSA, 2011)*, thus posing a safety risk for all roadway users.

Recently, many studies have evaluated the effects of texting while driving to determine its overall safety risk to the operator, and to adjacent roadway users. Additionally, research has been done to document the effects texting has on the driving behavior of subjects. Both naturalistic and simulator studies have been used to assess the changes in behavior, and increased crash risk. All research referenced within this study found that texting while driving negatively affected the driving task, to differing degrees.

This driving simulator study serves as a supplement to previous studies that have considered the effect text messaging has on driving performance, with an emphasis on texting while traversing horizontal curves. Glance frequency and duration towards the subject's mobile phone, as well as the corresponding lateral position of the vehicle while traversing the curve were recorded and analyzed to gain a better understanding of how significantly text messaging affects a driver's ability to safely operate the vehicle.

2 LITERATURE REVIEW

In this literature review the driving task, driving distractions, prevalence of mobile phone use, legality of texting while driving, and recent research related to text messaging while driving are discussed.

2.1 Definition of the Driving Task

The driving task incorporates the actions and thoughts directly related to operating a motor vehicle. The driving task is comprised of three subtasks: control, guidance, and navigation. A driver's focus is constantly switching from one task to another, as drivers are only able to concentrate on one source at a time. Each driving subtask requires a different level of decision-making, reaction, and focus depending on the scenario and in situ circumstances. The order of immediacy of these subtasks is exemplified in Figure 1.

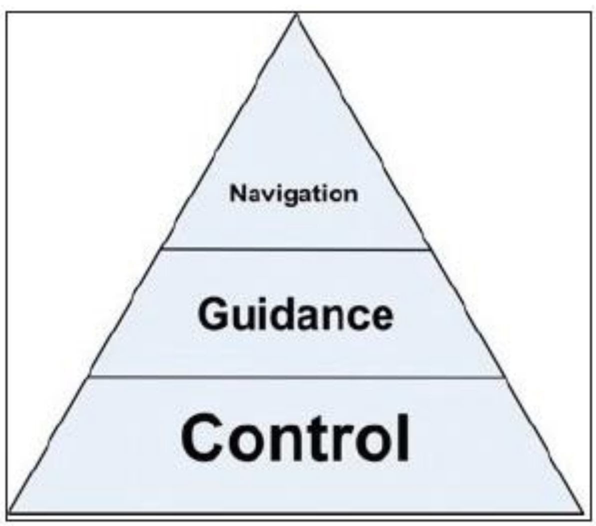


Figure 1: Driving Task Hierarchy (Lunenfeld and Alexander)

As seen from Figure 1 above, the least complex of the driving subtasks is control. The control subtask is defined by the Highway Safety Manual (HSM) as "keeping the vehicle at a desired speed and heading within the lane" *(2010)*. This task makes up the foundation of basic driving actions as it ensures that the car does not stray off of the road or into adjacent lanes, and that the vehicle is kept at a safe speed for the road conditions. Without control, the driving task would not be possible.

The next subtask of importance in the driving hierarchy is guidance, which requires a higher level of cognitive thinking than does the control task. Guidance is defined in the HSM as "safely interacting with other vehicles" (*2010)*. Interactions with other vehicles would include actions such as passing, merging, and following. Safe interactions are performed when the driver maintains a safe following distance, utilizes signaling devices, and obeys all traffic signs, signals, and rules.

The most complex subtask of driving is navigation, and it can only be done whilst both the control and guidance subtasks are being performed. Navigation is the act of "following a path from origin to destination," *(HSM, 2010)* essentially the process of travelling from one location to another. The navigation task is completed by utilizing guide and informational signs along the roadway as well as familiar landmarks located along a given route.

2.2 Distracted Driving

2.2.1 Categories of Distraction

Distracted driving includes a wide variety of tasks and activities that are performed by people who are operating a vehicle. The Center for Disease Control (CDC) defines distracted driving as "driving while doing another activity that takes your attention away from the driving," *(2013)*.

Typically, a distraction is any secondary event, activity, or object that commands attention away from the primary act of driving.

The broad definition of distracted driving can be disaggregated into three main categories of distraction as defined by the National Highway Traffic Safety Administration (NHTSA): visual, manual, and cognitive *(2013)*. These categories of distraction can occur individually or simultaneously.

A visual distraction is a task or event that requires the driver to take his or her eyes off of the roadway for any amount of time, as indicated by Figure 2. When the driver is not looking at the road the navigation and guidance aspects of the driving task are compromised and the driver is no longer aware of their surroundings or their position on the roadway. An example of a visual distraction would be the driver turning to look at a passenger in the backseat, or the driver glancing at an animal on the side of the roadway. *(NHTSA, 2013)*

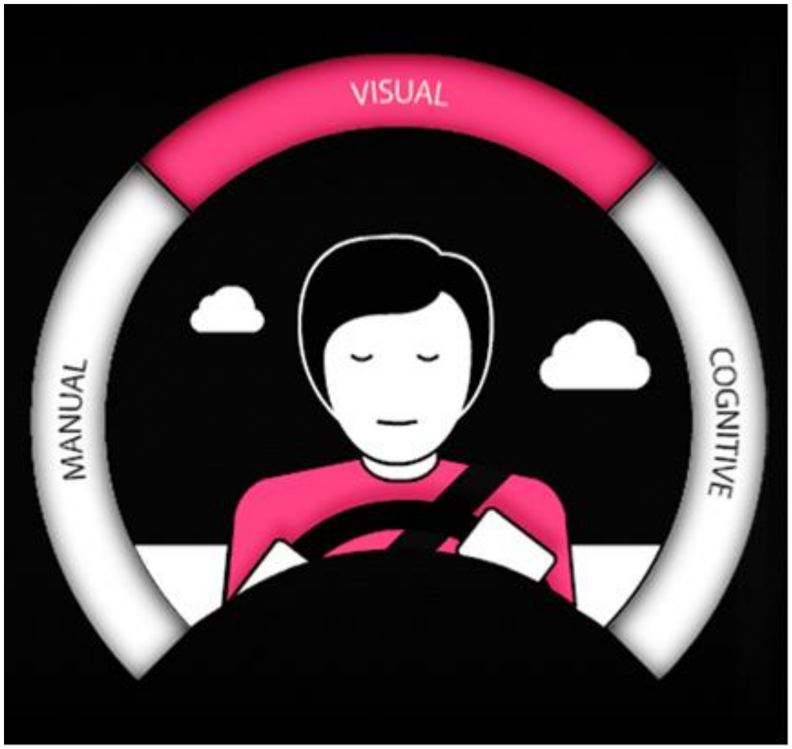


Figure 2: Graphic of a Visual Distraction in the Vehicle

A manual distraction is any event that requires a physical response by the driver. This distraction type is characterized by the driver taking one or both hands off the steering wheel of the vehicle (Figure 3). By removing a hand, or hands, from the steering wheel the driver is shifting attention away from control of the car and thereby putting the car at an increased risk of crashing. Common distractions characterized as manual include the act of a driver reaching over to adjust a setting on the middle console, or reaching to place something into a purse or bag. *(NHTSA, 2013)*

Figure 3: Graphic of Manual Distraction in the Vehicle

The third category of distraction, cognitive, is the most complex and multifaceted distraction category. However, this distraction type is also the most prevalent. A cognitive distraction is one that takes your mind off of the driving task. When the mind is engaged in some other activity the driving task is no longer of primary importance, and attention is shifted to the distractor. Cognitive distractions include daydreaming, the driver thinking about his or her workday, planning, etc. as shown by Figure 4. Cognitive distractions are often considered more dangerous because often the driver does not realize that their attention is not on their driving and as such does not make adjustments to the driving task to increase safety. *(NHTSA, 2013)*

Figure 4: Graphic of Cognitive Distraction in the Vehicle

While visual, manual, and cognitive distractions can occur independently it is commonplace that these distraction types will occur simultaneously in some combination. For example, eating while driving is a common activity, but the act of eating requires motor action and cognitive thought to successfully bring the food to your mouth and so incorporates both of these distraction types. Another example would be the act of reading directions while driving which incorporates both visual and cognitive distractions to both read the words and process their meaning. A third common example is that of a driver talking on a mobile phone while driving. This distractor requires that the driver remove a hand from the steering wheel to hold the mobile phone, and shift some measure of cognitive thought to the content of the conversation.

2.2.2 Texting and Driving

Texting while driving, demonstrated in Figure 5, is widely considered to be among the worst distraction activities that a driver can engage in. The reason for the increased crash risk associated with texting while driving can be explained using the aforementioned distraction categories. The act of sending or receiving a text message requires that the driver's hand be removed from the steering wheel to hold the cell phone, resulting in a manual distraction. Texting while driving encompasses a visual distraction since the driver's eyes are focused on reading or writing a text message. Finally, the driver's cognitive thought must be attentive on reading or composing a text message and fully comprehending its content rather than the operation of the vehicle. Therefore, texting while driving incorporates all three areas of distraction into one complex activity, highly compromising the overall driving task. *(NHTSA, 2013)*

Figure 5: Texting While Driving (Forsyth)

2.3 Mobile Device Usage

2.3.1 A History of Mobile Phones

Cell phones are a relatively new technology. According to *CTIA – The Wireless Association* experimental cellular systems were being tested in the Chicago and Washington D.C./Baltimore beginning in 1977. Then in October of 1983 the first commercial cellular system began operating in Chicago *(CTIA)*. The idea of a cellular device was intriguing because it gave users flexibility in where calls could be placed. The same year that the commercial cellular system began operating, Motorola introduced the "DynaTAC mobile telephone unit", the first mobile radiotelephone available to consumers. The 1983 Motorola DynaTAC 8000x phone had only one hour of talk time, weighed 1.75 pounds, stood 13 inches high, and cost $3,995 *(Ha, 2010)*. In comparison, the newest Motorola mobile phone, the 2013 Motorola Moto X lasts for over six hours of battery life (including talk time, internet use, gaming, text and picture messaging), weighs only 0.3 pounds, stands at 5.1 inches tall, and costs $199 (*Spoonauer, 2013*). These two devices can be seen in Figure 6.

Figure 6: 1983 DynaTAC 8000x (Left; Kennedy, 2013); 2013 Motorola Moto X (Right; Saleem, 2013)

Since their release, the popularity of mobile cellular devices has grown exponentially. Two years after the first DynaTAC mobile phone was released, there were a little over 340,000 cell phone subscribers. By 1992, the number of cellular subscribers had reached ten million. In 2000, only seventeen years after the introduction of commercial cellular systems, the number of subscribers surpassed 100 million or 38% of the United States population. Less than thirty years after the first mobile phone was introduced into society (2012), there are more than 326.4 million cellular phone subscribers in the United States alone. All indications show that these numbers are expected to continue growing, as shown in Figure 7 *(CTIA, 2012)*. According to a report compiled by The Nielsen Company entitled *The Mobile Consumer: A Global Snapshot*, 94% of people in the United States ages 16 and over own a mobile device as of February 2013 *(Nielson, 2013)*.

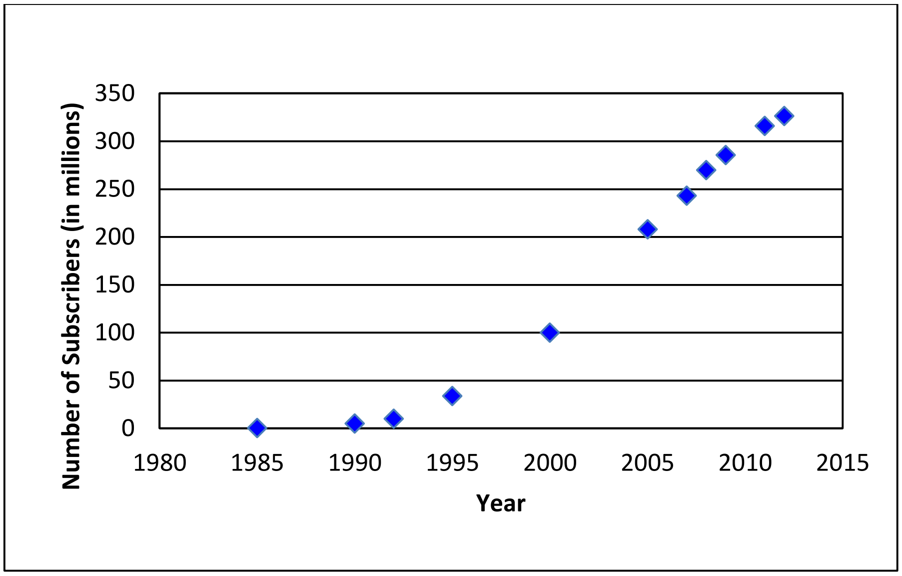


Figure 7: Number of Cell Phone Subscribers in the United States

2.3.2 A History of Short Message Service

In 1992, one of the most innovative cell phone features was introduced: short message service (SMS). This service still remains as the most popular cell phone feature today, although it is most often termed "text messaging". The world's first commercial SMS was sent from the personal computer of Neil Papworth, an engineer for the *Sema Group* based in the United Kingdom, to the mobile phone of his colleague Richard Jarvis. The text message was sent on December 3, 1992 over the Vodafone network, and contained the simple message "Merry Christmas" *(Shannon, 2007)*. Soon after, the SMS technology was being offered to cellular subscribers worldwide. Originally, cellular phones were not equipped for sending messages composed of text. However, once the SMS technology was implemented, cellular phones were adapted so that text messages could be sent between mobile phones.

Soon, the number of text messages being sent and received in the United States began rising faster than the number of cellular subscribers. Initially, SMS was being used in very limited capacities by consumers. However, as mobile phones were adapted to support text messaging, more wireless providers offered text messaging services and popularity again grew exponentially. This sudden rise in demand is generally attributed to younger generations, who recognized the ease and convenience of SMS conversations, and have since adopted texting as a standard form of communication. In 1997, soon after the concept of text messaging evolved, only about 40,000 SMS messages were being sent per day in the United States. By 2005, the number of text messages sent per day had risen to 222 million. And 20 years after that first simple text message (in 2012), more than six billion text messages are being sent on a daily basis in the United States alone. The number of text messages being sent within the United States has exponentially increased since 1997 as indicated in Figure 8. *(CTIA, 2012)*

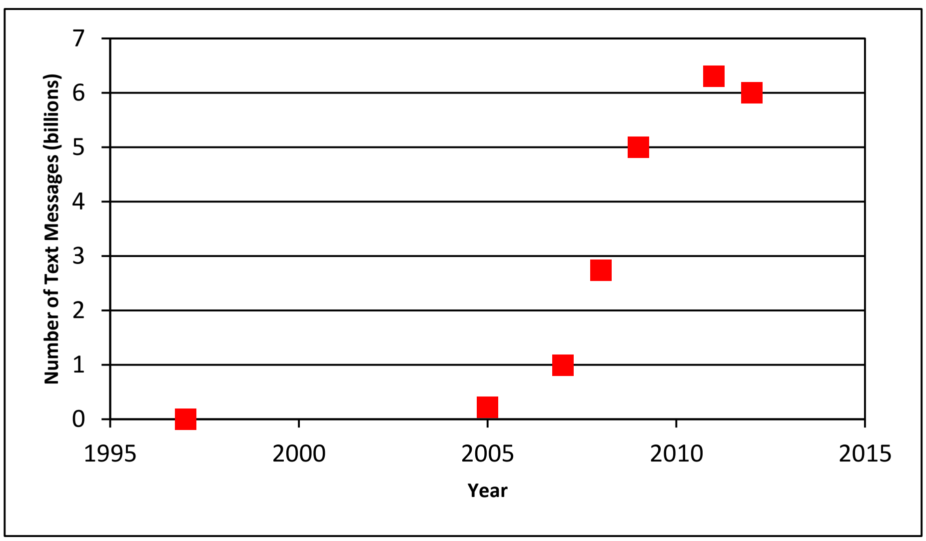


Figure 8: Number of Text Messages Sent Per Day in the United States

2.4 Safety of Texting and Driving

The convenience of text messaging means that consumers can converse with people from almost anywhere, even their car. Early on, research studies began observing a link between talking on a cell phone and driving performance. For example, as early as 1997 a Canadian research team led by Donald Redelmeier and Robert Tibshirani found that talking on a mobile phone quadrupled a driver's crash risk *(Redelmeier, et al.)*. However, texting was still a new technology, not used considerably, and associated with no known risk. Only relatively recently, have crash risks been associated specifically with text messaging while driving.

In 2009, Olson et al. performed a naturalistic study to determine the relative risks associated with various distractors for drivers operating commercial motor vehicles. This comprehensive study found that texting was by far the riskiest behavior associated with driving. The researchers outfitted commercial vehicles with instrumentation to record the driver, the roadway, and all sensory applications to the vehicle (i.e. braking, accelerating, steering, etc.). The purpose of the naturalistic study was to better understand how the drivers would react in their normal working environment. For the purposes of this study, texting was classified as a "complex tertiary task"; defined as an activity completely extraneous to the driving task that requires the driver to glance away from the roadway multiple times. The results of this study indicated that the act of texting while driving increases a driver's chances of being in a crash by 23.24 times. In comparison, a driver conversing on a hand-held mobile phone only increases their crash risk 1.04 times. *(Olson, et al., 2009)*

However, even with new data that indicates the extremely high risk of texting while driving, the number of people who send and receive messages while operating a vehicle is increasing. A

2011 report focusing on *Driver Electronic Device Use* as a part of the National Occupant Protection Use Survey (NOPUS), sponsored by NHTSA, indicates trends in mobile device usage while operating vehicles. Between 2010 and 2011 the *Driver Electronic Device Use* surveys show an increase in the observation of manipulations of mobile devices. For all drivers, the percentage of people who are operating mobile devices while driving has increased significantly from 0.9% in 2010 to 1.30% in 2011, a 0.4% rise. While the group of drivers aged 25-69 show a slightly smaller increase than the overall group, rising from 0.8% to 1.10%, younger drivers showed a substantial increase in the manipulation of mobile devices while driving. From 2010 to 2011 the percentage of drivers aged 16-24 who visibly handled mobile devices increased from 1.5% to 3.7%, an increase of 2.2% which is over five times greater than the overall rise in the use of hand-held devices whilst driving. *(NHTSA)*

Table 1: Percentage of Population Observed Manipulating Hand-Held Devices

Driver Type	2010	2011
All Drivers	0.90%	1.30%
Age 25-69	0.80%	1.10%
Age 16-24	1.50%	3.70%

The 2012 National Survey on Distracted Driving Attitudes and Behaviors (NSDDAB), by Schroeder et al., questioned drivers about their use of mobile phones while driving. The responses indicated that 14.3% of all drivers admit to text messaging while driving, an increase from 12% in 2010. The two biggest age groups that acknowledged texting and driving were the 16-20 and the 21-24 age groups, who had 71.1% and 69.2%, respectively, of respondents confirm the use of a mobile phone to text while operating a vehicle. Additionally, this survey asked respondents how they choose to send text messages while they are driving. 43.5% of people said that they wait for a red light or a stop sign to send their message, while over a third of the respondents (35.3%) admitted that they will continue to drive while texting. Both of these actions are critically unsafe as they impact the driving task. Only 14% of those surveyed indicated that they will either pull over to a safe location to send a text message, or hand the mobile phone to a passenger who can safely send a message. *(Schroeder, et al., 2012)*

2.5 Legality of Texting and Driving

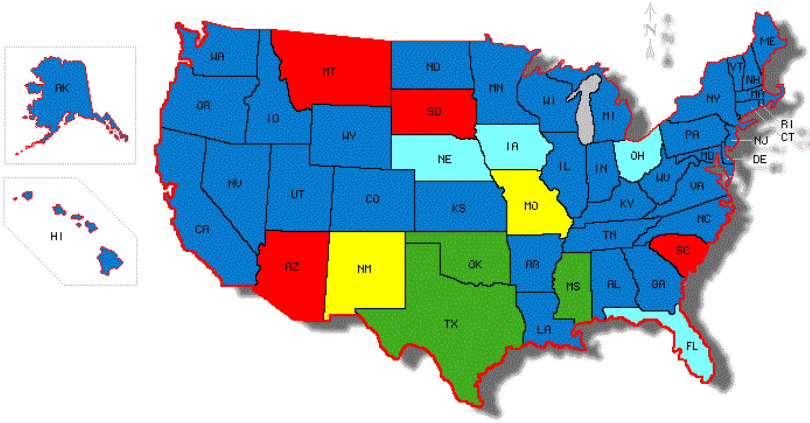
In 1997, research, such as that of Redelmeier and Tibshirani, on the use of mobile phones while driving began correlating their use behind the wheel to an increased crash risk. In response to observations of higher crash risks, *CTIA – The Wireless Association* introduced the first advertisement campaign against distracted driving. This anti-distracted driving movement was based on the slogan "Safety – Your Most Important Call", and sought to educate drivers about the risks associated with talking on a mobile phone while driving *(CTIA, 2012)*. Later, individual states began implementing their own laws restricting the use of mobile phones while driving. However, there are no outright bans of mobile phone use while driving, and texting was not originally included in laws. The first law limiting texting while driving was enacted in Washington in May 2007 and encompasses a complete ban *(GHSA, 2013)*.

2.5.1 National Trends

Many states followed Washington's lead in enacting laws against texting and driving, including Oregon in 2010. In total, 41 states now completely ban texting while driving. Of these 41 states with no texting laws, bans against texting while driving are primary laws in 37 states and secondary laws in four *(Distraction.gov, 2013)*. A primary law is one where a police officer can issue a ticket to the driver without any other additional traffic offense occurring. In contrast, with a secondary law the officer must be pulling the driver over for a primary violation and can only cite the driver for texting if noticed after the stop. Florida, Iowa, Nebraska, and Ohio currently define their texting while driving law as secondary *(GHSA, 2013).*

The nine states that do not have total texting bans when driving include Arizona, Missouri, Mississippi, Montana, New Mexico, Oklahoma, South Carolina, South Dakota, and Texas. Although these states do not fully ban texting while driving, most have enacted limitations for certain drivers. Since younger drivers are at a higher risk for crashes, and more likely to text while driving they are often targeted by text messaging bans as a component of graduated licensing practices. Mississippi, New Mexico, Oklahoma, and Texas enacted primary laws that prohibit novice drivers, defined as a driver licensed for less than a year, from text messaging while driving. Similarly, Missouri passed a primarily enforced law that bans texting for all drivers 21 years of age or younger. Additionally, in Mississippi, Oklahoma, and Texas it is illegal for school bus drivers to text while performing their duties. *(Distraction.gov, 2013)*

In total 46 states have laws that limit texting while driving; either completely banning texting for all drivers or prohibiting certain drivers from texting while operating a vehicle. Currently, only Arizona, Montana, South Carolina, and South Dakota have no laws restricting texting while driving for drivers. As of now the only federal law referencing texting and driving, Executive Order 13513, was enacted in 2009 and prohibits text messaging for federal employees who are operating a government vehicle or on official government business. There are no plans to make texting and driving a federal issue, each state is able to decide for itself how to react to distracted driving issues. *(Distraction.gov, 2013)*



LEGEND

No Ban

Total Ban (Primary Law)

Total Ban (Secondary Law)

Partial Ban (School Bus & Novice Drivers)

Partial Ban (Novice Drivers only)

Figure 9: Laws Regarding Texting While Driving By State

2.5.2 State Of Oregon Laws

The state of Oregon's law eliminating texting while driving took effect on January 1st, 2010. The law completely prohibits texting while driving for all drivers, unless they are using a voice-activated technology that is hands-free; the law also includes a ban for talking on a handheld mobile phone while driving *(Rubin, 2009)*.

A study by Hurwitz et al. compared driver distractions in Lawrence, Kansas, Corvallis, Oregon, and Logan, Utah *(2013)*. Overall, drivers in Kansas and Utah were twice as likely to be distracted than those in Oregon. Furthermore, Utah had the highest incidence of mobile phone distractions, over four times that of Oregon. Overall, of the three states Oregon had the lowest proportion of distracted drivers, and drivers who were distracted by use of a mobile phone.

Table 2: Comparative Distraction Percentages for Kansas, Utah, and Oregon

States	OVERALL DISTRACTION (%)		TYPES OF OBSERVED DISTRACTIONS (%)				
	Not Distracted	Distracted	Talking	Cell Phone	Dashboard	Eating/Smoking	Other
Kansas	**75.4**	**24.6**	9.3	**4.3**	1.9	3.9	5.2
Utah	**78.4**	**21.6**	10.3	**8.5**	0.6	0.4	1.7
Oregon	**87.8**	**12.2**	4.1	**2**	1.4	1.3	3.4

Still, in the state of Oregon, the number of fatal crashes associated with distracted drivers has risen from 12 in 2009 to 15 in 2011 even with the passing of the cell phone law. Although, officials believe that mobile phone related crashes are underreported so the actual numbers are higher *(Snow, 2013)*. Additionally, since the inception of Oregon's original mobile phone law in 2009, the number of citations for using a cellular device has risen from 9,848 in 2009 to 22,892 in 2012, an increase of 133%. The rise in distraction-related fatalities and traffic citations for mobile phone use indicates that an increasing amount of drivers are manipulating a mobile phone while driving *(Snow, 2013)*.

To combat this rise in cell phone use, and specifically texting, while operating a vehicle, Oregon lawmakers are looking into raising the fine for texting while driving. The minimum fine for texting while driving in Oregon is $142 *(DrivingLaws.org, 2013)*. Currently the maximum fine for texting while driving is $250. Senate President Peter Courtney, of Salem, introduced Senate Bill 9 which moves to double the current maximum fine to $500, effectively moving texting while driving from a Class D to a Class C violation. The bill has begun to move, and is set to come before the Oregon Legislature soon *(Esteve, 2013)*.

Overall, people in the United States overwhelmingly support laws against texting while driving. According to the 2012 NSDDAB, 94% of people are in favor of laws banning texting while driving. On average, the respondents supported a fine of $279 for texting while operating a vehicle. *(NSDDAB)*

2.6 Driver Behavior

Driver behavior forms a basis for determining appropriate and effective transportation safety measures. The behavior of drivers varies from person to person, but general distributions of performance can be approximated over large populations, and as such it is possible to formulate conclusions concerning changes in driver behavior when alternate tasks are introduced. Distraction tasks have been shown to have significantly detrimental effects on driver behavior.

The 2012 NSDDAB questioned drivers about their perceived difference in behavior when texting and driving compared with driving undistracted. Respondents listed changes such as being less aware of surroundings (24.3%), decreasing speed (21.2%), drifting out of their lane (10.9%), and decreasing distance from lead vehicle (0.7%). However, an astounding one third of people (32.9%) believe that there is no difference in their driving when they are engaged in a texting task.

When conversely asked if they feel comfortable as a passenger in a vehicle where the driver is texting 92.2% of the respondents acknowledged that they feel at least “somewhat uncomfortable”. Then, when asked to list their top five unsafe driver activities, those surveyed listed “reading text messages” and “sending text messages” in fourth and fifth place behind “watching a movie”, “using a laptop”, and “reading a book”. The NSDDAB survey also found that 99% of people acknowledge that they feel at least “a little less safe” when riding with a driver who is text messaging. These results seem to indicate that, although most people consider themselves able to text and drive safely, they do understand the inherent risks associated with this task.

Recently, studies have been undertaken to determine the aspects of driver behavior that are most affected by text messaging. These research studies have seen significant changes in driver speed *(Reed et al., 2008)*, reaction times *(Ranney et al., 2011)*, following distance *(Drews et al., 2009)*, lane position *(Hosking et al., 2006)*, and glance patterns *(Klauer et al., 2006)*. Of primary concern to this research project is the deviation in lateral position and effects on a driver's visual search task.

2.6.1 Speed

According to the HSM, a driver's speed choice is based on perceptual cues, such as peripheral vision and noise level, as well as road message cues like regulatory speed limit signs and the alignment of the road *(HSM, 2010)*. When a driver is focused on their mobile phone to read or write a text message, these cues are lost.

A simulator study of novice drivers' texting with alphanumeric keypads, completed in 2008 by Reed et al., found a significant decrease in speed when the subjects were texting compared to a baseline drive. When driving without distraction the subjects traveled at an average speed of 84 mph, but when completing the same course while texting drivers maintained an average speed of only 81 mph. In the 2012 NSDDAB survey, 21.2% of subjects acknowledged that they decreased their speed. It is thought that by decreasing speed drivers are attempting to compensate for their increased distraction, either consciously or subconsciously.

2.6.2 Reaction Time

A driver's reaction time is defined as the time from the detection of a stimulus to the commencement of a response *(HSM, 2010)*. The perception-reaction time (PRT) interval can be split into three steps: detection, decision, and response. The first step, detection, is when the details of the stimulus are determined for recognition by the driver. Next, a mental decision is made by the driver in response to perception and recognition of the stimulus. Finally, a physical reaction is initiated based upon the driver's decision and the response time interval is completed. All three of these steps can vary in time depending on the intricacy of the stimulus, with more complex stimuli generating longer response times. Additionally, researchers have discovered a perception related phenomenon termed "inattention blindness" where a subject who is focusing their attention on a particular task fails to notice an unexpected event, which greatly affects the guidance aspect of the driving task *(AAA, 2008)*. According to the 2012 NSDDAB, drivers do recognize that by engaging in a text messaging task they are not as aware of what is occurring on the roadway.

Numerous simulator studies have looked at the effects of text messaging on the PRTs of drivers. One of these studies, completed by Drews et al. in 2009, had drivers travel along a tangent roadway with varying traffic flow while following a pace car programmed to brake at random intervals. Compared with baseline PRTs, the participants' responsive braking times were 0.2 seconds slower when texting. Previously, Reed et al. (2008) had tested novice drivers' PRTs while traversing two loops. The drivers were asked to depress the clutch pedal when a short auditory tone (lasting 0.45 seconds) was heard. Reed et al. also found an increase of approximately 0.2 seconds in driver reaction time between the control drive (1.05 sec) and the experimental drive with texting (1.25 seconds). The 0.2 seconds increase in reaction times was statistically significant in both studies, indicating an increase in crash risk. Incidentally, Drews et al. observed a six fold increase in collisions during the text messaging drive versus the controlled drive.

Another simulator study conducted by Ranney et al. (2011) compared the distraction potential of texting while driving to the distraction potential of tuning the vehicle's radio. Radio tuning is representative of a generally acceptable level of distraction, and any task that is found to be more distracting is considered unsafe to perform while driving. Texting while driving was found to have the highest level of distraction potential; greater than dialing a number, calling a phone contact, and inputting a destination. This simulator study had subjects drive along a tangent roadway with light oncoming traffic, responding to text message phrases that were missing one or multiple words. During the drive, a red circle appeared at one of six locations every 3-5 seconds. Subjects were asked to press a button in response to the appearance of these visual targets. A significant decrease in the proportion of targets correctly detected was found between the tertiary tasks of radio tuning and text messaging. When tuning their radios drivers responded correctly 86% of the time, compared to text messaging where drivers were correct only 76% of the time. The increased number of missed detection cues can be attributed to inattention blindness exhibited by drivers focusing on the texting task.

2.6.3 Following Distance

Following distance is a measure of the longitudinal distance between the lead vehicle and the following vehicle. A safe following distance should allow for sufficient driver reaction time. Following too closely is defined by Federal Motor Carrier Safety Administration (FMCSA) as "situations in which one vehicle is following another vehicle so closely that even if the following driver is attentive to the actions of the vehicle ahead, they could not avoid a collision in the circumstance when the driver in front brakes suddenly," *(FMCSA, 2013)*. According to the NSDDAB, a majority of drivers believe that text messaging has no effect on their following distance, although a small percentage acknowledges that when distracted they will decrease their following distance *(2012)*.

In the simulator study performed by Drews et al. (2009), several changes in following distance were observed for drivers on a tangent roadway. On average, the following distance of the text messaging driver significantly increased compared to baseline driving according to an ANOVA performed by the researchers. However, the researchers simultaneously observed instances of smaller following distances during the experimental drive versus the control drive. While it is apparent that drivers actually attempted to increase their following distance from the lead vehicle to compensate for distraction caused by the texting task, overall their total variability in following distance was increased according to an ANOVA analysis. This greater variability is indicative of decreased control of the following vehicle when text messaging.

2.6.4 Lateral Position

Lateral position measures a vehicle's lane position relative to the median or edge lines of the roadway. The standard deviation of lateral position (SDLP) is generally used to measure vehicular control. The SDLP records the amount of "weaving" of the vehicle as a measure of lateral position changes, as exhibited by Figure 10. As vehicle control decreases, the corresponding SDLP values increase (*Verster et al., 2011)*. As a driver exhibits greater deviation in lateral position there is an increased risk of lane departures by the vehicle either onto roadway shoulders or into adjacent lanes, thus posing a greater crash threat. Since it is a standard measure, multiple studies have explored the effects of text messaging while driving on vehicle SDLP.

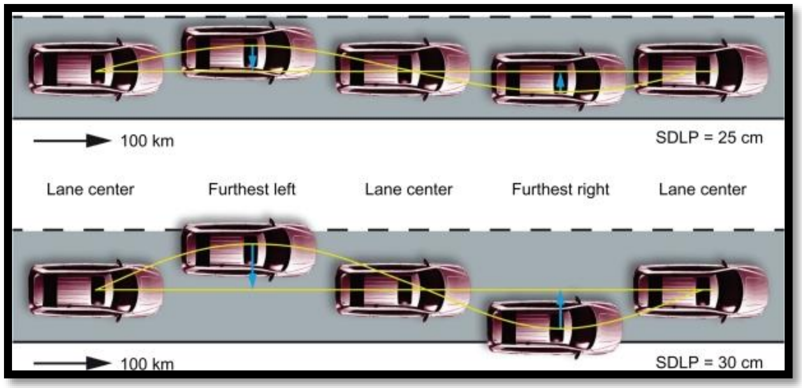


Figure 10: Measuring Standard Deviation of Lateral Position (Verster et al., 2011)

A simulator study led by Hosking et al. (2006) tested novice drivers along a tangent roadway with set events occurring along the drive. They found that the subjects' exhibited a 70% increase in the variability of lane position when texting versus baseline driving. A more recent simulator study *(Ranney et al., 2011)* had subjects respond to text messages with a missing word, and then compared the text messaging drive to a drive in which the subjects tuned their radio (radio tuning representing the level of acceptable distraction). When tuning the radio subjects exhibited an average SDLP of approximately 0.95 ft. When responding to text messages the average SDLP increased significantly to 1.2 ft. In addition the average frequency of lane departures increased between the radio tuning and text messaging tasks, from 0.75 to 2.25 within a 2.5 minute drive. Reed et al. (2008) ran novice drivers through a simulator study that included different driving scenarios. One scenario was a car following task (identified as section three in the report) in which a significantly increased mean SDLP was observed across participants. They found that the mean SDLP during the control drive was 0.69 meters, but during the texting drive the measurement increased to 0.74 meters. Additionally, the total number of vehicle departures from the lane observed during the car following task increased from zero during the control drive to 18 when the participants were asked to complete text messages.

The study conducted by Reed et al. (2008) also included a section with two loops. When traversing the curves section the subjects' mean SDLP while writing text messages doubled from a baseline of 0.25 to 0.5 meters; indicating a significant increase. Through further study, Reed et al. determined the frequency of lane excursions, defined as any occasion in which an edge of the vehicle departed from the driving lane. There were significant increases for both writing and reading text messages compared to control scenarios when traversing the loops section; an increase from 4 to 42 while writing, and 8 to 18 when reading.

Recently, a naturalistic study by Cooper et al. (2011) on a tangent roadway found significant changes in SDLP during the text messaging condition. The drivers traveled one part of a course that was open and another part that was bounded by evenly-spaced barrels. While the SDLP increased for both conditions compared to the baseline drive, there was a noticeable decrease in SDLP through the bounded roadway section when compared to the open section. These results indicate that the drivers understood that more control was needed in the closed sections to avoid crashing into the barrels.

2.6.5 Glance Patterns

According to the HSM, 90% of the information a driver uses comes from visual cues. The visual search task of a driver depends upon an active search of the changing roadway and requires continuous collection and absorption of information. There are multiple aspects of the visual search task, including visual acuity, contrast sensitivity, peripheral vision, and the useful field of view. *(HSM, 2010)*

Visual acuity describes the acuteness of vision, mainly the driver's ability to locate and perceive object details at a distance. Measurements of visual acuity are commonly used as assessments for overall vision. For example, in order to be eligible for licensure, a driver must pass a Snellen Letter Chart test with 20/40 vision *(Precision Vision, 2013)*. The ability to discern lighting and luminescence differences between an object and its background is the driver's contrast sensitivity. In other words, contrast sensitivity allows a driver to easily pick out the object of interest from the surroundings. A measure of peripheral vision is a driver's capacity to detect objects that are outside the area of accurate vision. Accurate vision only occurs at the very central area of focus of the eye, while peripheral vision includes the ability to observe stimuli in any direction. Peripheral vision does not have as great visual acuity as central vision, but it is sensitive enough to detect contrasts and movement of objects or events even when not looking in their direction. Finally, the useful field of view (FOV) describes a part of the visual field where stimuli can be detected, recognized, and understood without any head or eye movement. When stimuli are in the FOV, a driver response can be initiated in a timely manner using the PRT parameters. It is recognized that FOV narrows as the visual task becomes more demanding *(HSM, 2010)*.

When a driver is performing an activity unrelated to the driving task then attention is being divided between the two actions, impairing their visual search task. By focusing on another task, the driver is effectively narrowing their FOV and limiting the use of their peripheral vision. Texting while driving is considered a demanding visual task that can greatly affect driver vision. Besides requiring more visual attention, texting while driving also physically removes the driver's eyes from the roadway to glance at the mobile phone. Thus, the driver's ability to detect stimuli along the forward roadway (through visual acuity and contrast sensitivity) is also compromised. *(HSM, 2010)*

To determine the effects of distractions on the eye glance patterns of drivers, Klauer et al. (2006) analyzed driving data from the 100-Car Naturalistic Driving Study. This naturalistic study placed cameras in light, passenger vehicles to record the drivers' habits and actions preceding a safety-critical event. The study focused on a six second interval of events. The intervals were made up of five seconds prior to a precipitating crash factor, and 1 second following the precipitating crash factor. The safety-critical events were categorized as a "crash", "near crash", or "incident". These four event types were then compared against random baseline epochs from the datasets. This study analyzed the odds ratios for varying total glance durations within the six second intervals to determine their relative safety factors. The results showed that the more time drivers spent with their eyes off of the road correlated with higher odds ratios. Additionally, researchers isolated the glances away from the roadway that were a result of driver inattention resulting in a crash or near crash; thus excluding driver-related glances to check center, right, and left rear-view mirrors. The results in Table 3 indicate that while any amount of time the driver's eyes were off the roadway increased the risk of a crash. However, total time of eyes off roadway odds ratios were significant for glances greater than 2.0 seconds, and near significance for glances between 1.5 and 2.0 seconds long.

Table 3: Odds Ratios Associated with Eyes off of the Forward Roadway *(significant values indicated in bold)*

Total Eyes off Forward Roadway Time (seconds)	Odds Ratios	Lower Control Limit (LCL)	Upper Control Limit (UCL)
$t \leq 0.5$	1.13	0.67	1.92
$0.5 < t \leq 1.0$	1.12	0.79	1.59
$1.0 < t \leq 1.5$	1.14	0.79	1.65
$1.5 < t \leq 2.0$	1.41	0.98	2.04
$t > 2.0$	**2.27**	**1.79**	**2.86**

Additionally, Klauer et al. ran ANOVAs on the mean time of eyes off forward roadway compared between "crash", "near crash", "incident", and "baseline" event types within the six second intervals *(2006)*. T-test results found significance between each event type. The researchers found that the average driver baseline for time of eyes off forward roadway was 0.9 seconds, while during a "crash" event drivers spent an average of 1.85 seconds with their eyes off of the road. For an "incident" to occur it was observed that drivers looked away from the road for only 1.1 seconds, and for a "near crash" the time was increased to 1.3 seconds. By taking their eyes off of the roadway for only 18% of the interval time drivers were placing themselves at risk for an "incident", 22% of the time for a "near crash", and 31% of the time for a "crash".

Using the method outlined in Klauer et al. (2006), a similar study using commercial motor vehicles was completed by Olson et al. (2009). The same six second interval was utilized to differentiate between types of events and baseline epochs. However, the Olson et al. study included texting while driving as a distraction and performed a more detailed analysis of its effects on driving. Therefore, the mean duration of time a driver had their eyes off of the forward roadway while text messaging on a mobile phone was recorded and analyzed. Driver glance data without text messaging showed fixations of 1.2 seconds away from the roadway. A significant increase was reported when drivers were text messaging: an average of 4.0 seconds with no event occurring, and 4.6 seconds when a safety-critical event was involved. Thus, drivers who were text messaging spent at least 66% of the time with their eyes off of the forward roadway. This amount of time, when travelling at 55 mph, is equivalent to driving the length of a football field blind.

Two other simulator studies are worth mentioning as they also investigated the effects of text messaging on driver glance patterns. The 2011 study performed by Ranney et al. had subjects drive a course accompanied by light oncoming traffic, and their performance while text messaging was compared against that of tuning a radio (representing the level of acceptable driver distraction). The researchers found that the number of "long glances" significantly increased between the radio tuning and text messaging tasks. A "long glance" was defined as any fixation away from the roadway lasting for more than two seconds. On average, radio tuning required two long glances while text messaging necessitated 3.6 of these long glances. A previous study performed by Hosking et al. (2006) had novice drivers complete a simulated course that had eight set events occur throughout the drive. Researchers then looked at the overall effect of texting while driving as well as the differences between sending and receiving messages. When comparing the mean glance frequency a significant 100% increase from three glances to six glances was observed between the baseline and text messaging drives. Additionally, there was a significant increase in the mean glance duration when receiving messages (155%) and when sending messages (277%). Overall, drivers spent approximately 0.9 seconds glancing away from the road when texting, versus only 0.3 seconds when not text messaging. Finally, the proportion of time that the drivers spent with their eyes off of the forward roadway significantly increased between the text messaging and control drives. During the baseline run, drivers glanced away from the road (presumably for driving-related tasks) for approximately 10% of the time during each event. Then, when the subjects drove the course while text messaging, the researchers recorded them looking away from the road for an average of 40% of the time. The distraction caused by text messaging resulted in a fourfold increase from baseline standards.

2.7 Summary

Texting while driving is widely considered to be the riskiest activity performed by drivers *(Olsen et al., 2009)*. The act of texting while driving incorporates visual, manual, and cognitive distraction into one hazardous activity *(NHTSA, 2013)*. Since all three areas of distractions are encompassed by the act of texting while driving, the driving task is highly compromised during texting. When drivers are holding and looking at their mobile phones, and either reading or composing text messages they are not focused on the control, guidance, and navigation of the vehicle.

Additionally, the number of mobile phone subscribers and the number of text messages sent daily in the United States are continually increasing *(CTIA, 2012).* National surveys and studies show increased use of mobile phones by all categories of drivers. As the number of driver’s text messaging increases, the number of distraction-related crashes is also expected to increase. In order to combat these rising trends 46 states, including Oregon, have enacted at least a partial ban against texting while driving *(GHSA, 2013)*. Oregon is even looking at moving texting while driving from a Class D violation to a Class C, which raises the maximum fine from $250 to $500 *(Esteve, 2013)*.

Although the dangers of texting while driving were not initially recognized, numerous studies have been undertaken recently to determine the effects of text messaging on driver behavior. These naturalistic and driving simulator studies have shown that drivers engaging in a texting task significantly decrease their speed, increase their PRT, increase their variability in following distance (including both closer and greater observed distances), increase their SDLP, and take their eyes off of the roadway for longer periods of time resulting in more frequent lane departures. While these studies consistently show the dangers of texting while driving, the majority only focus on text messaging on tangent roadways. With an exception being Reed et al. (2008) who included two curves on their simulated course.

This study supplements the existing literature by investigating the effects of text messaging on drivers traversing horizontal curves. The SDLP and eye glance patterns of the driver will be analyzed to determine any changes between tangent roadways and curves. Additionally, this study will integrate the eye glance patterns and lateral position data to determine a correlation between frequency and duration of driver fixations on a mobile phone with changes in SDLP.

3 METHODOLOGY

This Chapter describes the specific research hypotheses of this study as well as the experimental methods implemented to address them. It also provides information about the OSU Driving Simulator, the ASL Mobile Eye XG, and the experimental design.

3.2 Research Hypotheses

The overarching goal of this research project is to improve our understanding of the impact of distracted driving, specifically texting while driving, on driver performance. Focusing the research on driver performance on horizontal curves while distracted increased the likelihood that maximum effects will be observed, thereby increasing the possibility of statistically significant findings. The following three hypotheses regarding driver performance while texting on a horizontal curve were developed to guide the research methodology:

1) H_0: *There is no difference in the duration and frequency of driver fixations on a mobile phone while completing a text messaging task between four horizontal curves.*

2) H_0: *There is no difference in the lateral position of a vehicle between baseline driving and driving while completing a text messaging task between four horizontal curves.*

3) H_0: *There is no difference in the lateral position of the vehicle before, during, or after the text messaging task between four horizontal curves.*

The first hypothesis tests the differences between the four curves and their associated billboards with regard to the participants' eye glance patterns. The second hypothesis compares the lateral position deviations of an experimental group versus a control group. Finally, the third hypothesis focuses on any statistical changes in the text messaging participants' lateral position before, during, and after traversing each curve.

3.2 OSU Driving Simulator

The OSU Driving Simulator is a high-fidelity motion base simulator. The simulator consists of a full 2009 Ford Fusion cab mounted on top of an electric pitch motion system with the driver's eye-point located at the center of the viewing volume. The pitch motion system accurately reflects acceleration and deceleration cues on tangent road segments. Three projectors are used to project a 180 degree front view and a fourth projector is used to display a rear image for the driver's center mirror. The two side mirrors also have embedded LCD displays. The vehicle cab instruments are fully functional and include a steering control loading system to accurately represent steering torques based on vehicle velocity and steering angle. The computer system consists of a quad core host running Realtime Technologies SimCreator Software with an update rate for the graphics of 60 Hz. The simulator software is capable of capturing and outputting performance measures such as instantaneous velocity, position, brake, acceleration, and time and space headways. The simulator is pictured in Figure 11 from the interior and exterior of the vehicle.

Figure 11: OSU Driving Simulator

Researchers build the environment and track subject drivers at the operations station shown in Figure 12, which is out of view from subjects within the vehicle.

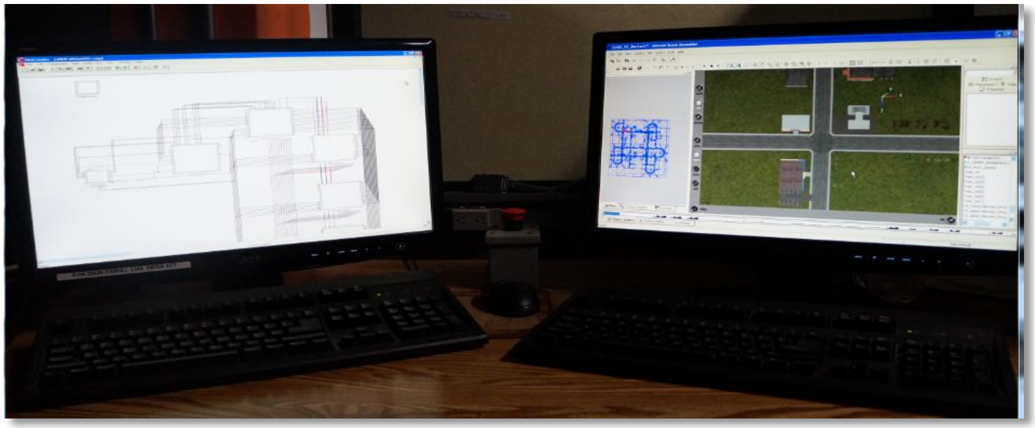


Figure 12: Driving Simulator Operator Workstation

3.3 Measurement of Eye Glance Data

Eye-tracking data was collected using the Mobile Eye-XG platform from Applied Science Laboratories (Figure 13). The advanced Mobile Eye-XG allows the subject to not only have unconstrained eye movement but also unconstrained head movement, generating a sampling rate of 30 Hz and an accuracy of 0.5 to 1.0 degree. The subject's gaze is calculated based on the correlation between the subject's pupil position and the reflection of three infrared lights on the eyeball. Eye movement consists of fixations and saccades. Fixations are considered points that are focused on during a short period of time and saccades are when the eye moves to another point. The Mobile Eye-XG system records a fixation when the subject's eyes have paused in a certain position for more than 100 milliseconds. Quick movements to another position, saccades, are not recorded directly but instead are calculated based on the dwell time between fixations.

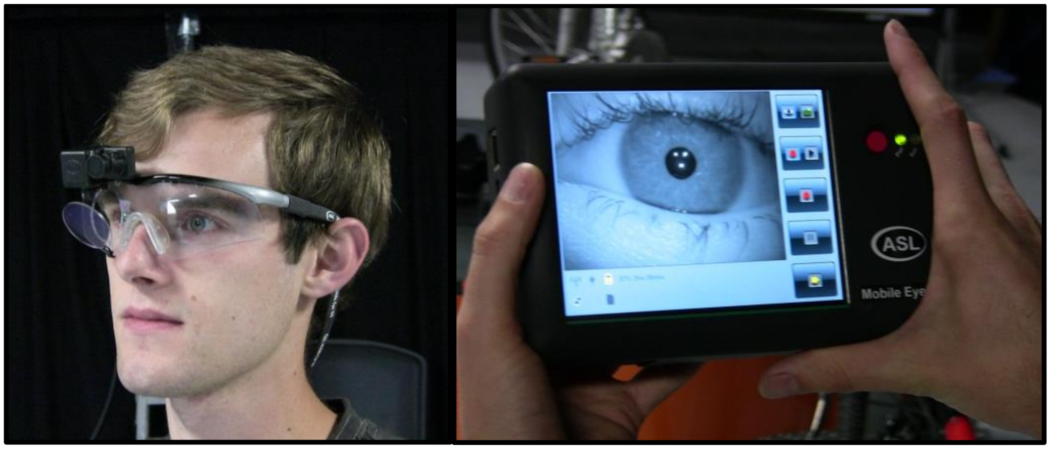


Figure 13: OSU Researcher Demonstrating Both the Mobile Eye XG Glasses and Mobile Recording Unit

The number and duration of fixations of the subject's eyes on their mobile phone were recorded and analyzed to aid in answering the aforementioned research objectives. For this study, the saccades were not analyzed due to the specific research questions being considered.

3.4 Scenario Layout

The experiment was designed using simulator software (Internet Scene Assembler, SimCreator, and Google Sketch-Up) and the OSU Driving Simulator was used to project the virtual environment around the driver. The purpose of this environment was to put drivers in situations in which observations could be made and measurements taken in a controlled and repeatable laboratory setting to help answer our specific experimental questions. The course was designed to take the subject between 10 and 15 minutes to complete. The entire experiment, including the consent process and post-drive questionnaire, lasted approximately 45 minutes. In an effort to reduce the chances of simulator sickness and other confounding variables, the driving scenario was built with no stops and no ambient traffic.

The course was designed to simulate a four-lane, divided, rural highway with travel in both directions. However, the ambient traffic was set to zero to minimize outside distractions. This experiment was originally designed for a study researching driver behavior in work zones. Therefore the driving scenario consisted of four work zones, two with a mobile barrier and two without a mobile barrier. The layout was designed as a continuous track, with a work zone located at each tangent section of the course. At each of the four corners, a billboard was placed to the right of the road. Figure 14, below, shows a plan view of the experimental test track. Each of the four work zones are identified as well as the four billboard locations.

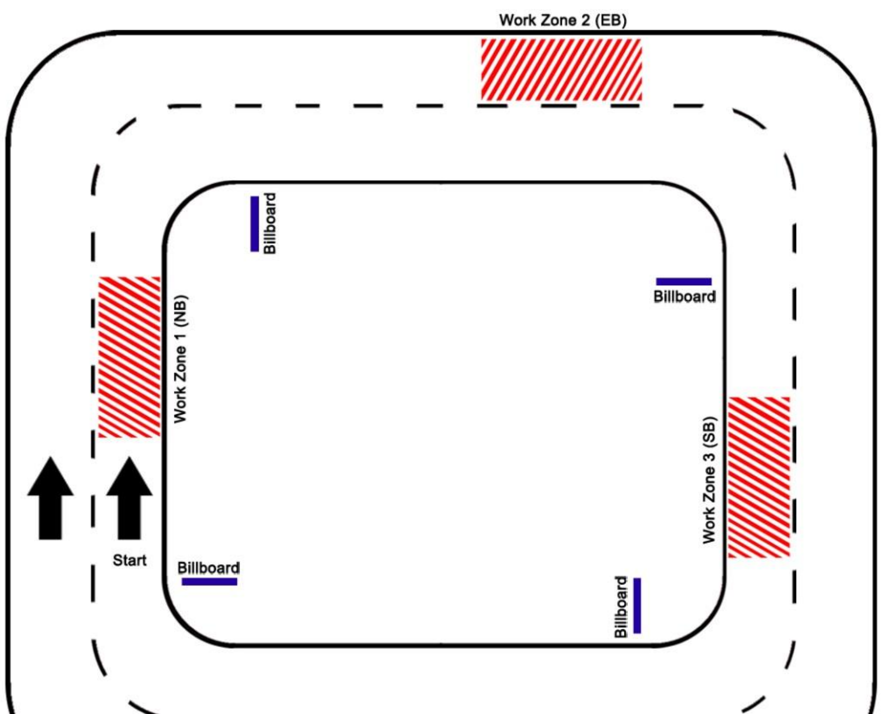


Figure 14: Aerial View of the Simulated Test Track (not to scale)

Each of the four billboards displayed a picture of a familiar animal, as indicated in Table 4. Figure 15, below, is an example of what the subjects saw as they entered into the curve.

Table 4: Image Description by Curve

Curve	1	2	3	4
Image	Cow	Cat	Eagle	Dog

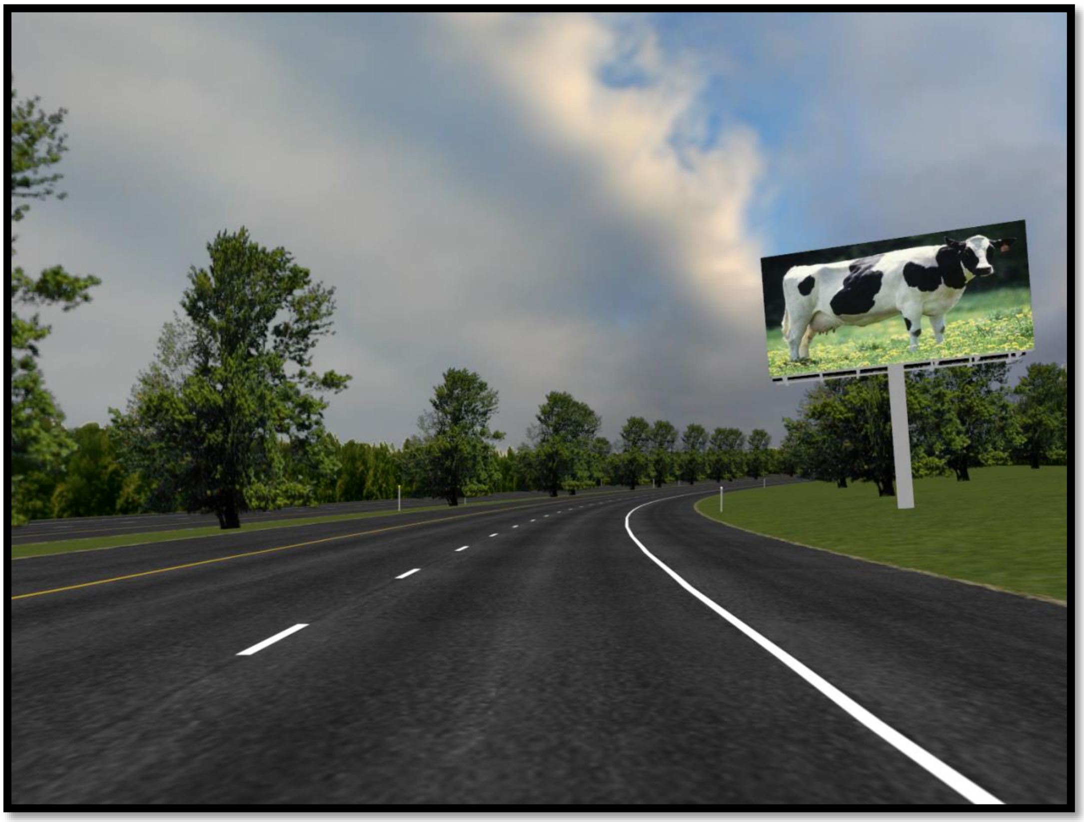


Figure 15: Example of Billboard Image

3.5 Experimental Procedure

Participants for this study were selected from the OSU and surrounding community. Participants were required to possess a valid driver's license, not have vision problems, and be physically and mentally capable of legally operating a vehicle. Participants also needed to be deemed competent to provide written informed consent.

Recruitment of participants was accomplished through the use of flyers posted around campus and emailed to different campus organizations, as well as announcements during transportation engineering classes. Interested participants were screened to ensure that they possess a valid driver license and were not prone to motion sickness.

Participants met a student researcher in the OSU Driving Simulator Office, located in room 206A of Graff Hall. They were then given the informed consent document, asked to read through it with the student researcher, and provided the opportunity to ask any clarifying questions. During this time, participants were also informed of the risk of simulator sickness, that they had no obligation to finish, and that they could stop participating in the experiment at any time without monetary penalty.

Upon entering the lab, participants were briefly introduced to the equipment being used in the experiment, fitted with the ASL Mobile Eye-XG equipment, and asked to position themselves in the driver's seat of the driving simulator. The subjects were informed about driving in the simulated environment, and instructed to behave as natural as possible while following all traffic laws as they normally would. Each participant was then given approximately three minutes to drive in a four-lane, divided, rural highway practice environment to become familiar with driving in the simulator and to assess the potential for simulator sickness.

If the participant completed the practice drive without signs of simulator sickness, the researchers calibrated the eye-tracking equipment by mapping the participant's pupil to fixation points projected on to the screen directly in front of the vehicle (Figure 16). If the equipment could not be properly calibrated, which was dependent upon eye positioning and other physical attributes, the equipment was removed and the subject was allowed to continue without it.

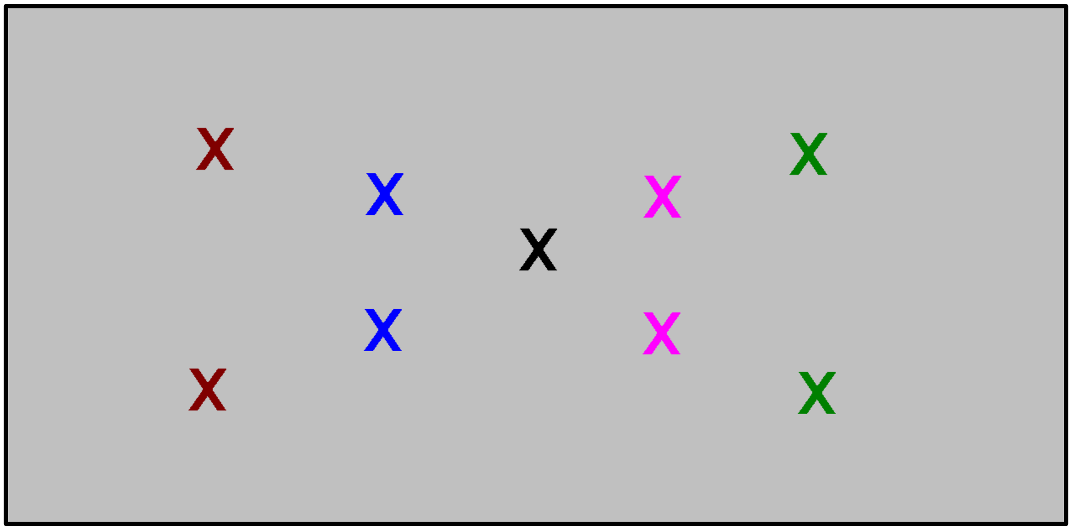


Figure 16: Eye-tracking calibration image

After calibration, participants were given further instructions on how to drive in the experimental scenario. Participants were reminded to behave as they normally would and to react to all traffic control devices in a manner consistent with their typical driving behavior. They were then given instructions on how to traverse the course and perform the texting task. After verbal confirmation of their understanding of the instructions, they were allowed to begin the experiment. Upon completion of the experiment, drivers were escorted back to the office where they completed a post-test questionnaire, received a $20 cash compensation for participating, and were debriefed on the purpose of the experiment.

3.6 UHC Thesis Unique Contribution

The experimental procedure described above was originally performed by Joshua Swake, MSCE 13', who was studying the influence of mobile work zone barriers on driver behavior. In order to reduce the likelihood that participants would deduce the primary research questions of the original study, and thereby potentially altering their driving behavior, they were asked to complete the texting tasks while traversing the horizontal curves of the experimental route. In post-experiment debriefing, nearly every driver supposed that the experiment was concerned with texting while driving.

The unique contribution of this UHC Thesis included the data extraction, reduction, and analysis of drivers' visual attention during the distractor test. This effort is significant, representing hundreds of hours working with the data acquisition system and statistical analysis tools.

3.7 Participants

A total of 40 participants with a balance of gender were enrolled to be used in the original experiment. However, four participants withdrew from the study due to simulator sickness. An effort was made to incorporate participants of all ages within a specified range of 18 to 75 years old, although it was expected that most participants would be OSU students.

Of the original 36 participants, only 22 were able to be properly outfitted with the calibrated eye-tracking equipment. For this study, the data from only those participants whose eye glance patterns could be consistently observed and measured were used with the corresponding measurements of the vehicle's lateral position. This resulted in data from 18 subjects being used in this current study. However, four of these participants made the decision to not engage in the act of texting while traversing the experimental course. Therefore, the 14 participants, gender unknown, whose eye glance patterns could be measured were treated as the experimental group, and the four participants who did not text were treated as a comparative control group.

Throughout both studies, information related to the participants was kept under double lock security in conformance with accepted IRB procedures. Each participant was randomly assigned a number to remove any uniquely identifiable information from the recorded data.

4 RESULTS

This Chapter presents the findings from the evaluation of participants' driving behaviors as observed in the OSU driving simulator. These findings explore the various aspects of the drivers' responses to visual images that prompted a text message reply while traversing horizontal curves in the experimental course. The results include eye glance patterns and deviations in the vehicle's lateral position in response to text messaging.

Of the original 36 subjects who drove the experimental course, 18 who were able to wear a calibrated eye tracking device are included in this study. Four of these participants did not attempt to text in response to the billboards, and are therefore treated as a control group. The other 14 subjects did respond to the visual cues by texting one of the researchers, and these participants are considered a treatment group.

4.1 Data Reduction

4.1.1 Research Hypotheses Review

The three hypotheses that were tested with this study are as follows:

1) ***H_0***: *There is no difference in the duration and frequency of driver fixations on a mobile phone while completing a text messaging task between four horizontal curves.*

2) ***H_0***: *There is no difference in the lateral position of a vehicle between baseline driving and driving while completing a text messaging task between four horizontal curves.*

3) ***H_0**: There is no difference in the lateral position of the vehicle before, during, or after the text messaging task between four horizontal curves.*

Based upon the available data from each of the 18 subjects' drive through the experimental course, the following list of questions was developed to act as dependent variables:

1) How often does the subject glance at their phone while traversing each curve?
2) What is the duration of the subject's glances at their phone while traversing each curve?
3) For what percentage of time the subject is traversing the curve is their eyes on their phone?
4) What is the SDLP of the vehicle as the subjects traverse each curve?

These dependent variables were used to test the research hypotheses for validation or rejection.

4.1.2 Reduction of Eye Glance Data

The ASL Mobile Eye-XG equipment records a digital video from the subject's point of view while driving the experimental course as well as measurements of fixations in the field of view. The two data streams are integrated into a single video showing where the driver is looking during the drive by overlaying a red crosshair on their fixation location. The researcher isolated the portions of each subject's video where they traversed each of the four curves. Using frame-by-frame analysis, the frequency and duration of glances was observed and recorded. In this way, the researcher was able to track the subject's eye glance patterns in increments of one tenth of a second.

4.1.3 Reduction of Lateral Position Data

Using default output data from the OSU Driving Simulator, each individual driver's key performance measures were saved as a CSV file. The CSV files of all of the subjects included in this study were compiled and exported into a Microsoft Excel spreadsheet. The data was organized by relative position along the course and time stamps. Next, the data was filtered to only include the performance measures of interest to this study: time stamp and lane position. The data was further aggregated by curve number.

4.2 Glance Statistics

The frequency and duration of a driver's glances at a mobile phone while driving is an important variable because it allows for the determination of how much time the driver is focused on the text messaging task as compared to the driving task. Only data from the 14 subjects who participated in the texting task are included in this section.

4.2.1 Average Frequency of Driver Fixations on Mobile Phone

The frequency with which each subject glanced at their mobile phone while attempting to complete the text messaging task and traversing the curve was observed from the video recordings. The distribution of the number of glances of each driver as they traversed Curves 1-4 are shown in the comparative box plots (Figure 17).

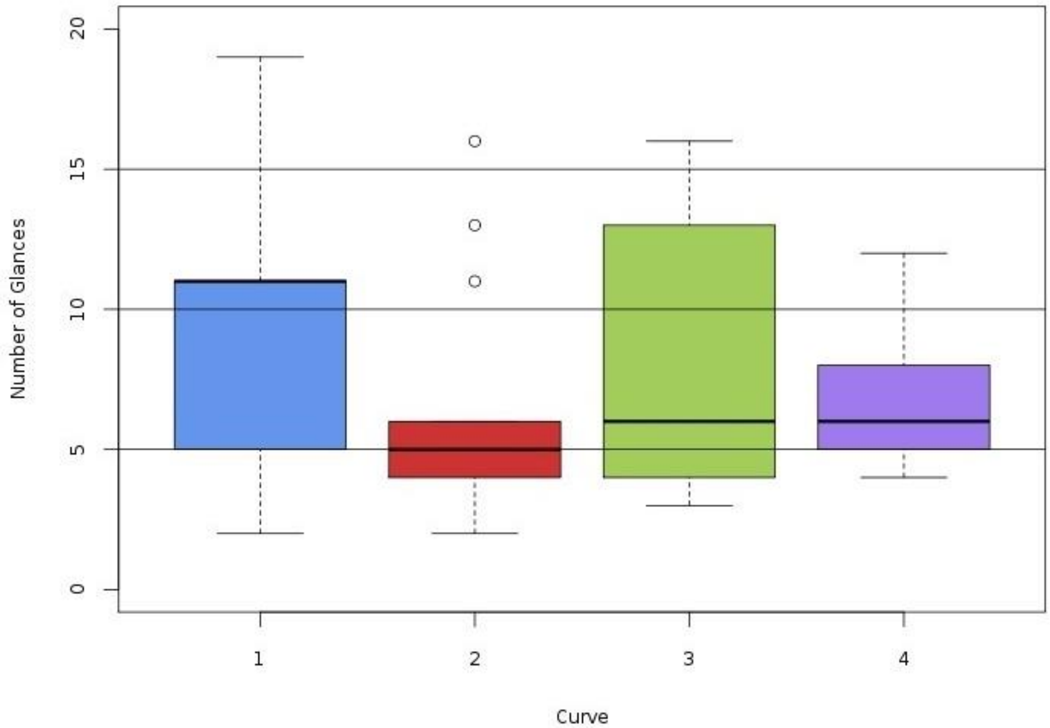


Figure 17: Frequency of driver fixations on mobile phone while texting

As shown by the modified box plot in Figure 17, the median number of glances was similar for Curves 2-4 with five to six, but higher for Curve 1 at approximately 11. Additionally, Curve 2 was the only curve to display any outliers in the glance frequency data. Curves 1 and 3 show larger ranges in data than Curves 2 and 4 (excluding any outliers). Curve 1 is most likely atypical due to it being the first curve the drivers traversed, and Curve 3 has a larger range due to the increased complexity of its text messaging cue ("eagle").

The average glance frequency was calculated for each curve, and documented in Figure 18 below. Error bars representing the 95% confidence intervals were calculated for each curve and included on the graphs. The 95% confidence interval defines an interval that contains the true mean with a statistical confidence of 95%.

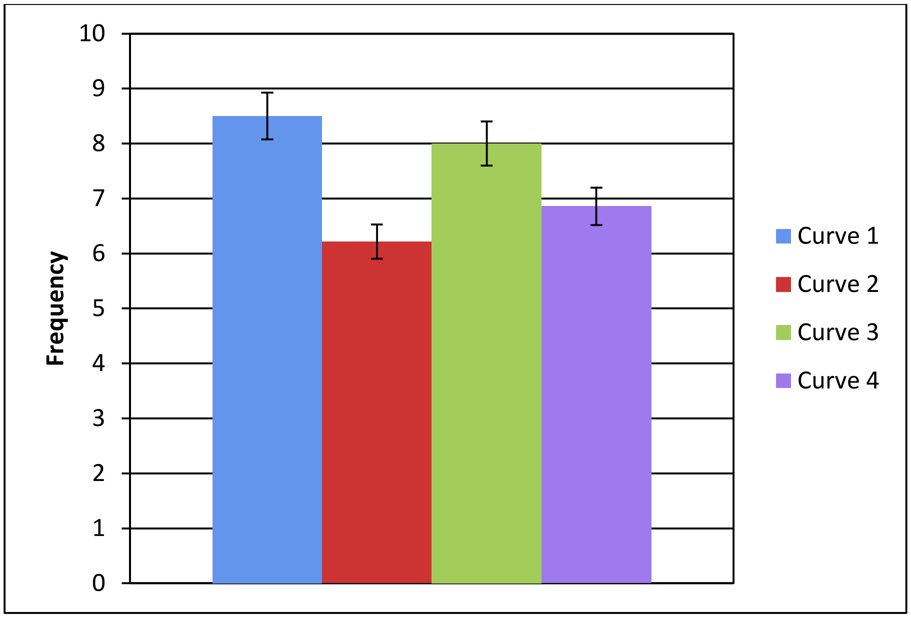


Figure 18: Average frequency and 95% CIs of driver fixations on mobile phone

As indicated by Figure 18, the average frequency of driver fixations was greatest for Curve 1 with 8.5, with Curve 3 having the second greatest frequency at 8 glances. Curve 2 had the lowest average number of driver glances at the mobile phone with 6.2. The average number of glances at the mobile phone exhibited on Curve 4 was approximately 6.9.

The average frequency of driver fixations on their mobile phones were analyzed for each curve pairing through a paired t-test with 95% confidence intervals. The paired t-tests were run in R and were adjusted for the multiple comparisons through the Benjamini and Yekutieli adjustment (Table 5).

Table 5: Statistical Summary Comparing Average Frequency of Fixations Between Curves

Average Frequency of Driver Fixations (sec)				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
8.500	6.214	8.000	6.857	**1 v 2**	**0.069**	**Suggestive**
				1 v 3	0.530	No
				1 v 4	0.150	No
				2 v 3	**0.035**	**Yes**
				2 v 4	0.323	No
				3 v 4	0.268	No

A statistically significant difference was found between the average fixation frequencies of Curve 2 and Curve 3. The statistical comparison between Curves 1 and 2 resulted in a suggestive significance, and all other curve pairings were found to have no significance between the average frequencies of driver fixations. The image subjects responded to in Curve 3, “eagle”, was the longest of the four words to be texted, and followed one of the simplest responses: “cat”. This increase in complexity may explain why there was statistical significance between Curve 2 and Curve 3, but not for any other pairing.

4.2.2 Maximum Frequency of Driver Fixations on Mobile Phone

The maximum number of times a driver looked at his/her phone was determined for each of the four curves with 95% confidence intervals (Figure 19).

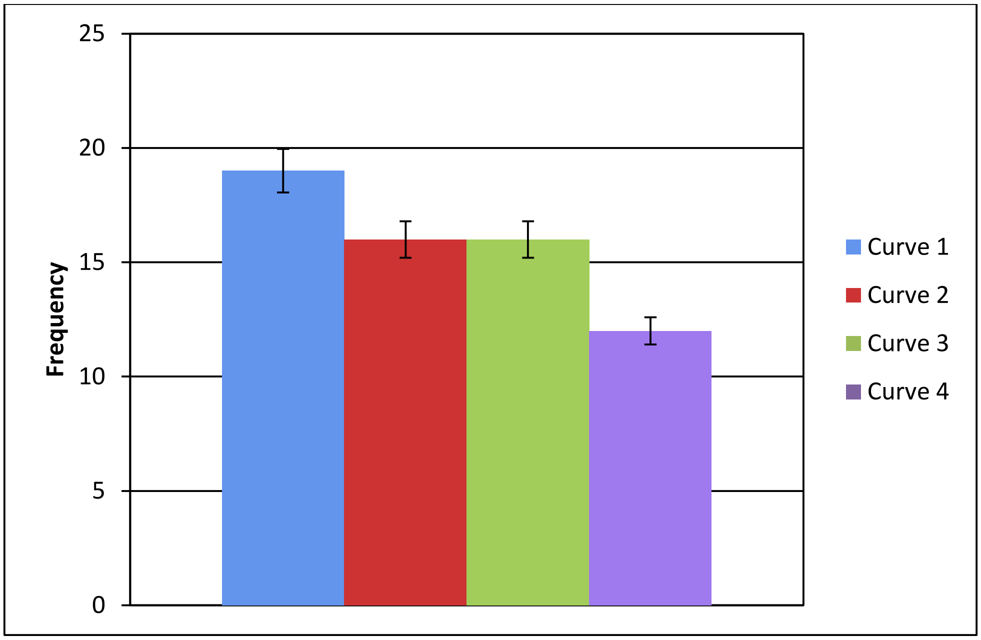


Figure 19: Maximum frequency and 95% CIs of fixations on mobile phone

The maximum frequency of fixations was equal for Curve 2 and Curve 3 with 16 glances. A driver exhibited the greatest frequency of glances on Curve 1 with 19, and the smallest maximum frequency was seen on Curve 4 with 12. It is noted, that the subject who was observed to have the greatest number of glances at their mobile phone was not the same subject for each curve. Overall, it appears that the maximum number of glances occurred while on Curve 1 due to a learning curve exhibited by the subjects, and decreased as they traversed the course through Curve 4 and became more comfortable texting while in the driving simulator.

4.2.3 Average Duration of Driver Fixations on Mobile Phone

Along with the frequency of glances observed for each subject, the duration of each fixation was measured and recorded by curve. The average fixation duration (AFD) was calculated for each subject, and the distribution of these averages is displayed in a modified box plot (Figure 20).

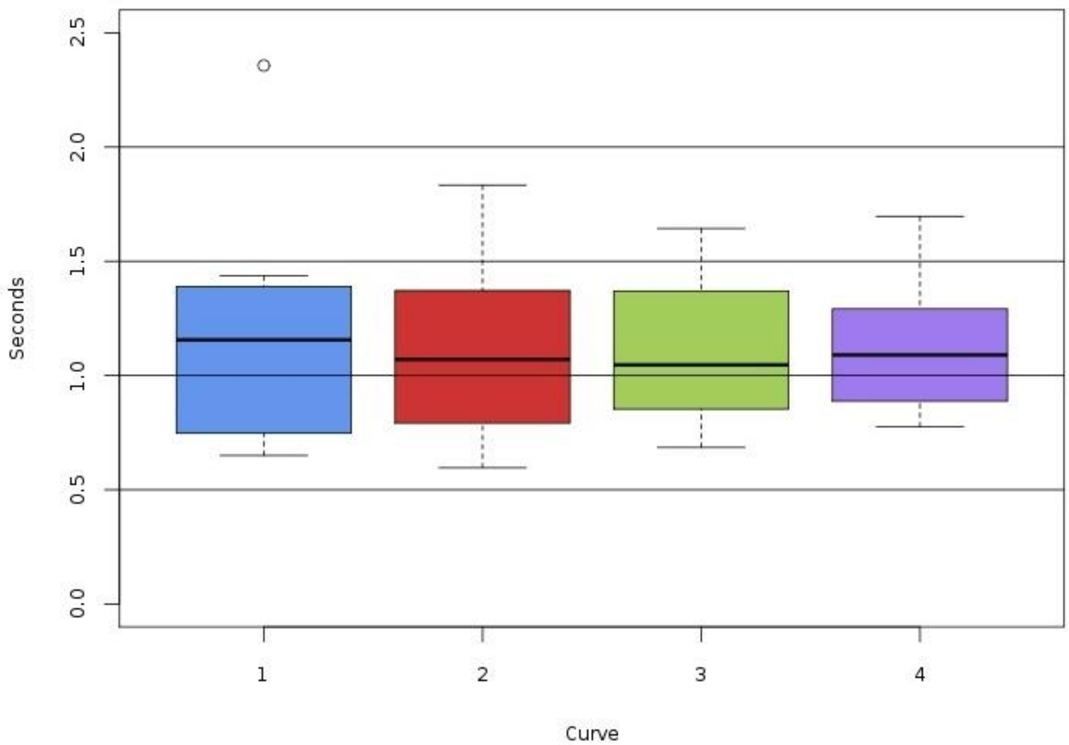


Figure 20: Average duration of fixation on mobile phone for each subject

The median fixation duration was consistent for each of the four curves. Curve 1 was the only curve to have an outlier data point. Additionally, excluding the outlier, Curve 1 had the smallest range of values while Curve 2 had the greatest range.

The mean fixation duration data of each subject were averaged together to produce an overall AFD for each of the four curves. The overall average for each curve was plotted with error bars representing the 95% confidence intervals in Figure 21, below.

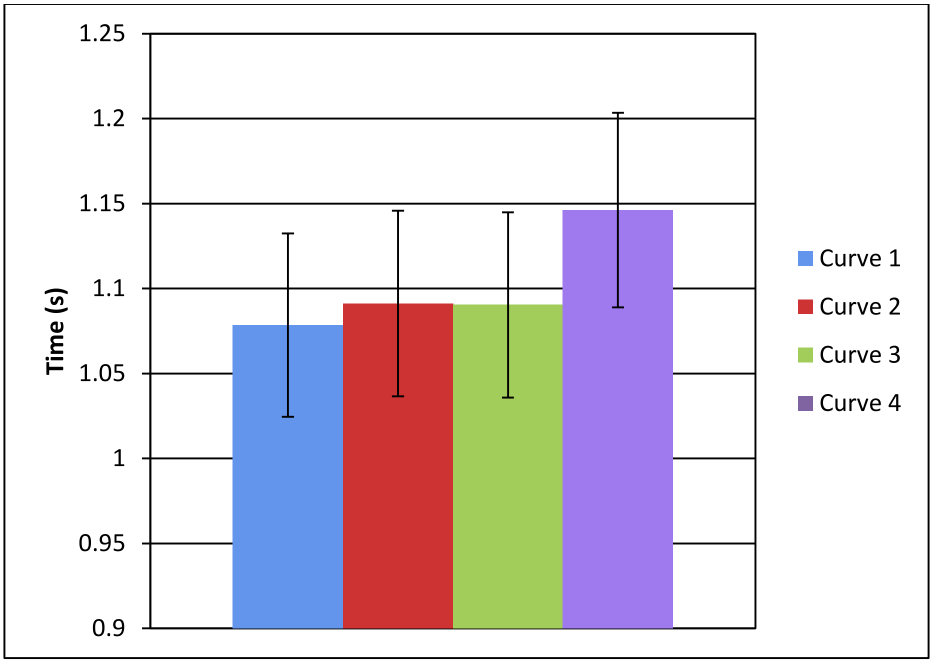


Figure 21: Average duration and 95% CIs of driver fixations on mobile phone

The average duration of driver fixations increased from Curve 1 through Curve 4. The average duration of each glance at a mobile phone was approximately equal between Curve 2 and Curve 3 at 1.09 sec. Curve 1 had the smallest average glance duration with 1.08 sec, while Curve 4 had the largest duration of approximately 1.15 sec. The largest difference in mean duration time, occurring between Curves 1 and 4, was 0.07 sec, indicating that the average duration of driver glances was similar between all of the curves.

The average duration of driver fixations on a mobile phone, as displayed in Figure 21, were run through a statistical paired t-test for each curve pairing.

Table 6: Statistical Summary Comparing Average Duration of Fixations Between Curves

Average Duration of Driver Fixations (sec)				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
1.078	1.091	1.090	1.146	1 v 2	0.731	No
				1 v 3	0.682	No
				1 v 4	0.833	No
				2 v 3	0.992	No
				2 v 4	0.537	No
				3 v 4	0.353	No

The results from Table 6 indicate that none of the comparisons of the average duration of glances at a mobile phone for Curves 1 through 4 were found to be statistically significant. This result suggests that the different image cues had no effect on how long drivers glanced at their mobile phones during any one fixation.

4.2.4 Maximum Duration of Driver Fixations on Mobile Phone

The maximum duration of fixation, or longest glance, observed for each subject as they responded to the text messaging cue was recorded for each curve. The distribution of the longest glances is shown in Figure 22 as modified box plots.

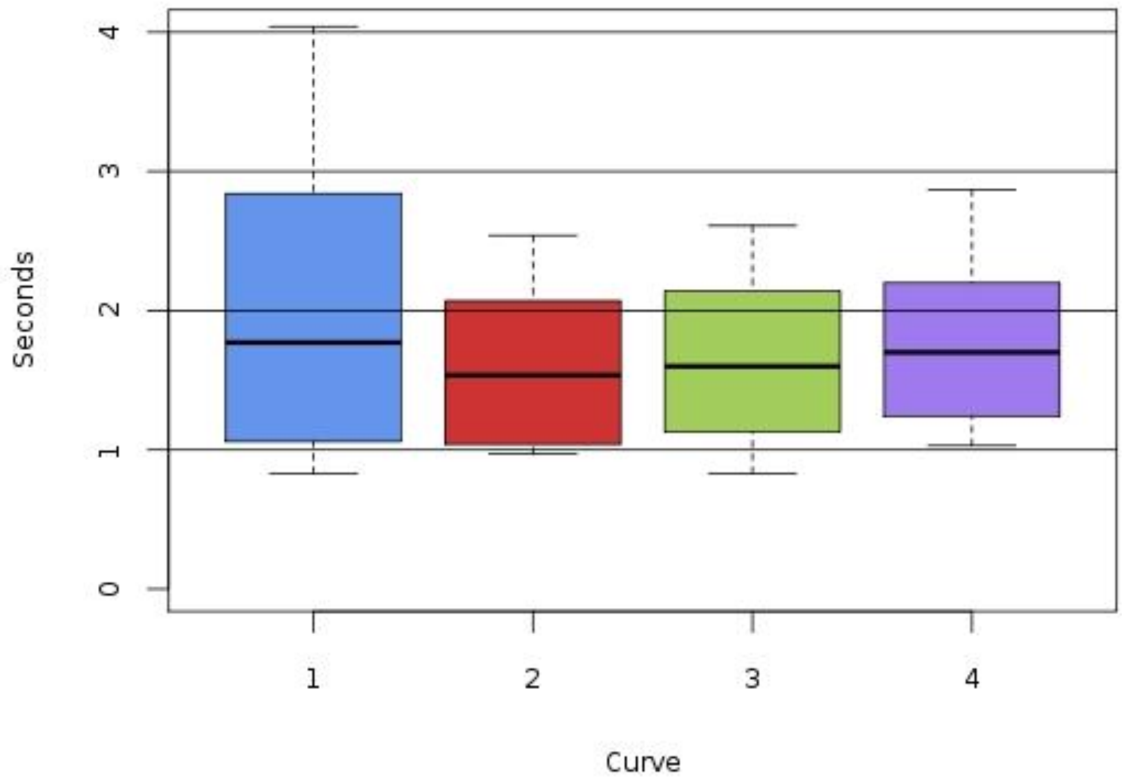


Figure 22: Maximum duration of driver fixations on mobile phone

The medians are similar for each of the four curves, which means that the average duration of the subjects' longest glances was consistent between each curve. However, Curve 1 shows a larger range in duration of the longest glances, while Curve 2 has the smallest range that is similar to those of Curves 3 and 4 as well. No outliers were recorded for any of the curves. Klauer et al. (2006) defined a glance away from the road for longer than two seconds as being very unsafe. In this study glances greater than two seconds were observed on all curves, 12 were observed on Curve 1, eight on Curve 3, and four were observed on both Curve 2 and Curve 4. It is likely that Curve 1 and Curve 3 had the most long glances due to the drivers' getting accustomed to texting while in the driving simulator for Curve 1, and the increased complexity of the text message ("eagle") for Curve 3.

The observed fixation of maximum duration was found for each of the four curves, and plotted with error bars showing the 95% confidence intervals (Figure 23). This data represents the overall longest glance exhibited by one of the 14 subjects in the treatment group, and it is noted that the glance of maximum duration was not completed by same subject for each curve.

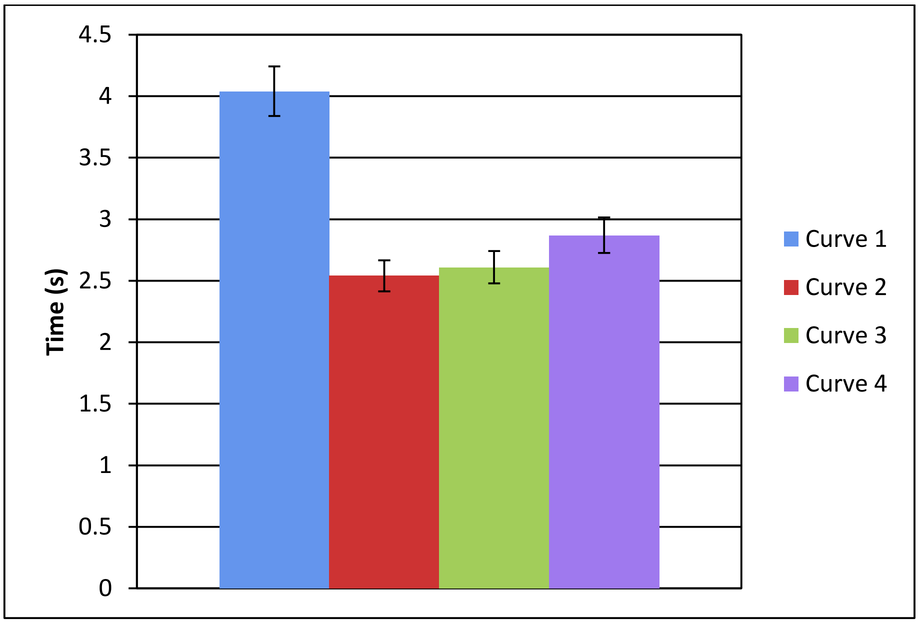


Figure 23: Maximum duration and 95% CIs of fixation on mobile phone

The longest recorded glance occurred while the driver traversed Curve 1. This glance lasted 4.04 sec. The glance of maximum duration for Curve 2 was the lowest of the four curves, lasting 2.54 sec. The maximum duration fixations for Curve 3 and Curve 4 were 2.61 sec and 2.87 sec, respectively. These fixations all represent dangerous glances away from the road strongly increasing the risk of crashes for the experimental subjects.

Based on the maximum fixation durations shown in Figure 23, a paired t-test was performed to check for significant differences between the curves (Table 7).

Table 7: Statistical Summary Comparing Maximum Duration of Fixations Between Curves

Maximum Duration of Driver Fixations (sec)				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
4.04	2.54	2.61	2.87	1 v 2	0.195	No
				1 v 3	0.270	No
				1 v 4	0.198	No
				2 v 3	0.540	No
				2 v 4	0.408	No
				3 v 4	0.766	No

According to the results of the paired t-test performed for each curve pairing, there was no significance between the maximum fixation durations.

4.2.5 Percentage of Time with Eyes Off Forward Roadway

The time that it took each driver to traverse the length of Curves 1 through 4 was recorded, as well as the total time each driver spent fixated on their mobile phone. With this data, the percentage of time each driver spent looking at his/her phone while travelling through the curve could be determined. The percentages of time with eyes off the forward roadway were split into four equal categories: 0-24%, 25-49%, 50-74%, and 75-100%. The number of drivers that fell within each for each individual curve is shown in Figure 24 below. Note that all curves record 14 drivers, except for Curve 1 that only has data for 13 drivers. This discrepancy is due to the fact that Subject 5 failed to text while traversing Curve 1, but did respond to the texting prompt for Curves 2 through 4.

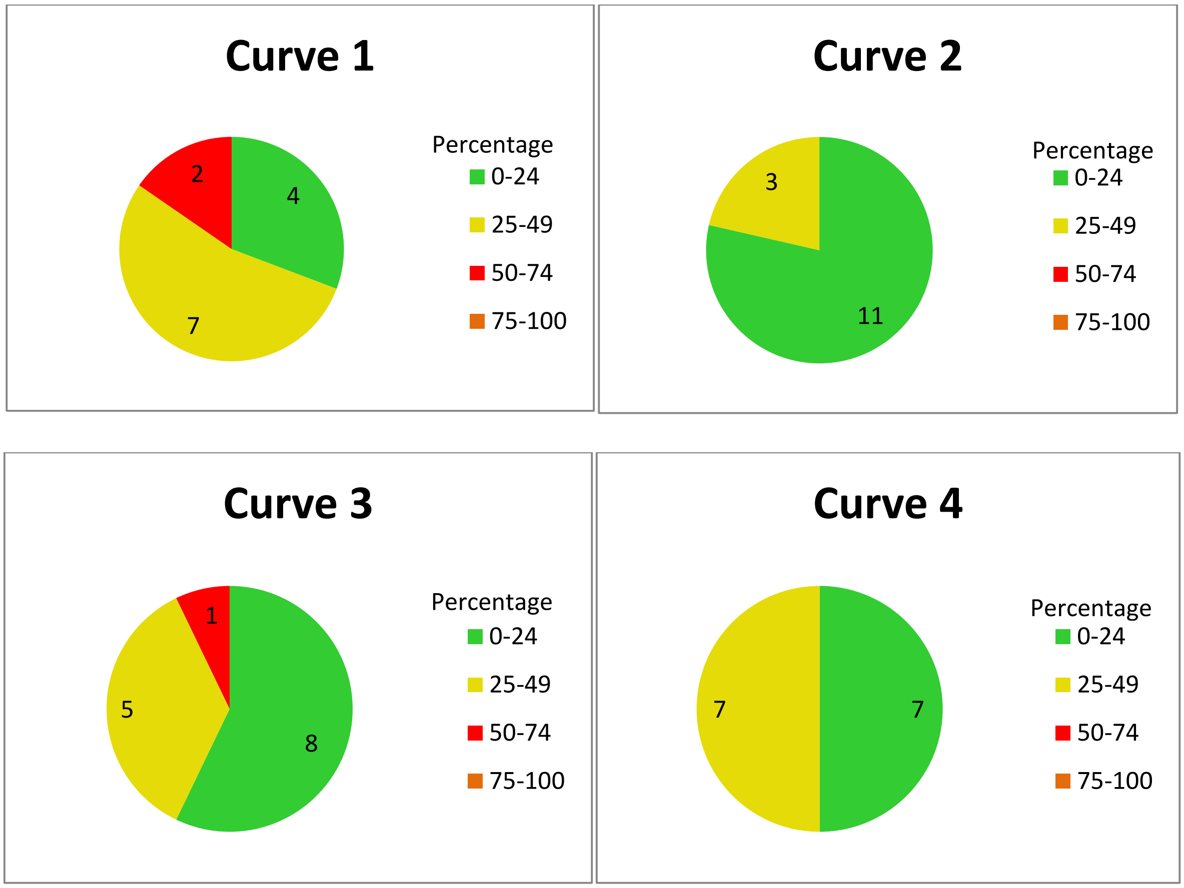


Figure 24: Percentage of time with eyes off roadway

Only while traversing Curves 1 and 3 do any drivers take their eyes off the road for 50-74% of the time, with two and one drivers respectively. This phenomenon could be attributed to a learning curve for the subjects attempting to text while driving the simulator for Curve 1, and for the increased complexity of the image (“eagle”) on Curve 3. At no point do any of the drivers look away from the road and at their phone for more than 74% of the time they are maneuvering through the curves. For Curves 2 and 3 the majority of drivers, 11 and eight respectively, looked at their phone for less than 25% of their time on the curve. On Curves 1 and 4, seven drivers fell into the 25-49% of time category.

The percentage of time each subject spent with their eyes off of the forward roadway for each curve was plotted as a modified box plot to show the overall distributions (Figure 25).

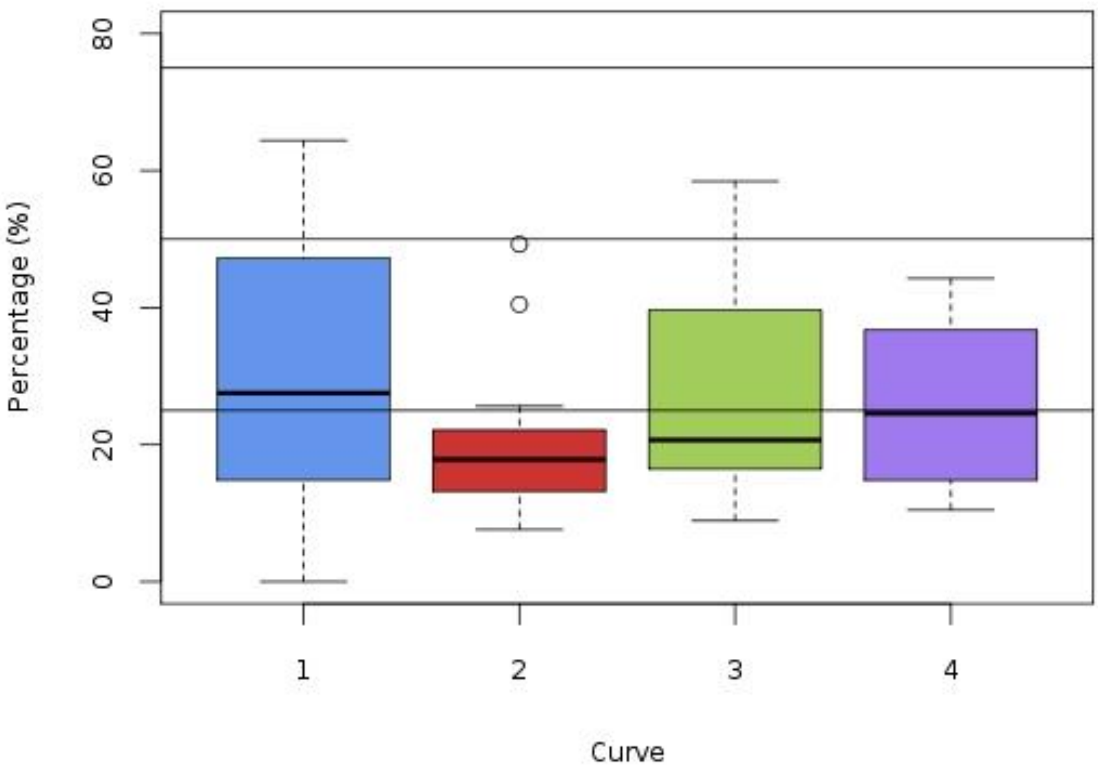


Figure 25: Average percentage of time with eyes off roadway

The median amount of time drivers spent with their eyes off of the forward roadway varied between the curves. Curve 1 had the highest median percentage with approximately 27%, while the lowest median percentage occurred on Curve 2 with 18%. Curves 3 and 4 fell in the middle with 20% and 25%, respectively. The only outliers occurred on Curve 2.

The average percentage of time drivers spent with their eyes off the forward roadway was averaged for each curve. These mean values were plotted with 95% confidence interval error bars (Figure 26).

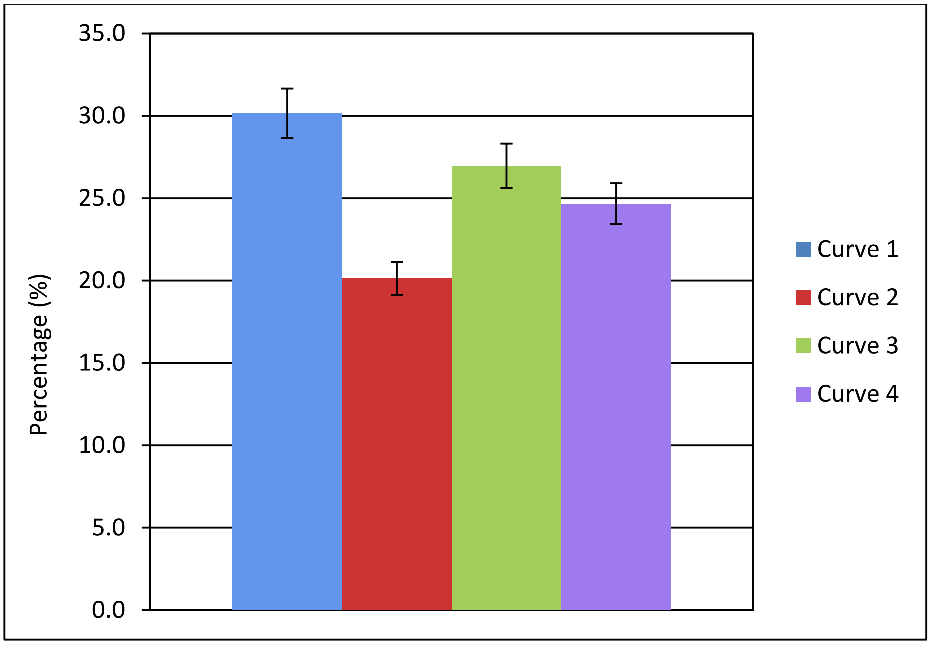


Figure 26: Average percentage of time with eyes off forward roadway with 95% CIs

On average drivers spent the longest time looking at their phones while maneuvering through Curve 1, spending 30.2% of the time with their eyes off the road. While traversing Curve 2, drivers spent the least amount of time with their eyes off the roadway, only 20.1% of the time. The average amount of time the drivers looked away from the road at their mobile phones while traversing the curves increased while travelling through Curve 3 to 27.0%, and then decreased for Curve 4 to 24.7%.

A paired t-test was performed on the data for the average percentage of time drivers spent with their eyes off the roadway to test for significance between the different means for each curve (Table 8).

Table 8: Statistical Summary of Percentage of Time of Eyes Off Roadway Between Curves

Average Percentage of Eyes off Forward Roadway				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
30.2	20.1	27	24.7	1 v 2	**0.062**	**Suggestive**
				1 v 3	0.589	No
				1 v 4	0.255	No
				2 v 3	**0.064**	**Suggestive**
				2 v 4	**0.056**	**Suggestive**
				3 v 4	0.547	No

The paired t-test found no significant comparisons between the average percentages of time the drivers spent with their eyes on their mobile phones for any of the four curves. However, the comparisons between Curves 1 and 2, Curves 2 and 3, and Curves 2 and 4 were suggestive of statistical significance. All of the suggestively significant results are related to the low percentage of eyes off forward roadway exhibited on Curve 2. While traversing Curve 2, subjects had to respond to the researcher with the word “cat”; this response was considered one of the simplest responses which could account for less time spent with the subjects’ eyes on their mobile phones.

4.2.6 Maximum Percentage of Time with Eyes Off Forward Roadway

As well as the average percentage of time drivers spent with their eyes away from the roadway, the maximum percentage of time a driver spent looking at their phone was recorded for each curve (Figure 27).

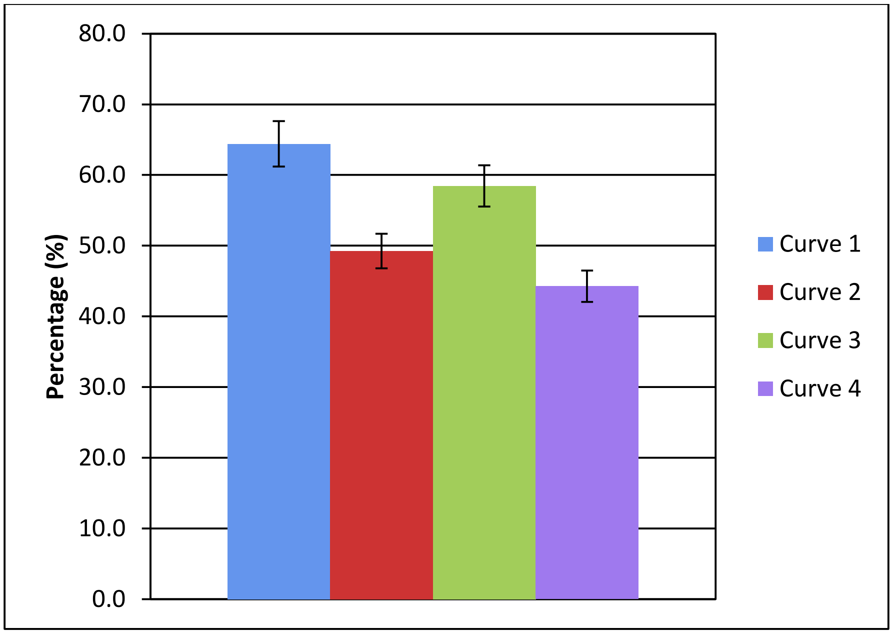


Figure 27: Maximum percentage of time with eyes on mobile phone

The largest percentage of total time a driver spent with their eyes off the road while traversing Curve 1, where 64.4% of the time was spent with the driver's eyes on their mobile phone. The maximum percentage value then decreased for Curve 2, increased for Curve 3, and reached its lowest time on Curve 4 with values of 49.3%, 58.4%, and 44.3% were recorded, respectively.

4.3 Lateral Position Statistics

The OSU driving simulator recorded the position of the vehicle throughout the subjects' drives. The lateral position of the vehicle was measured from a reference point (the left lane edge line). The SDLP as the vehicle traversed the curve was calculated. A vehicle's position is an important element of driving behavior because it can be used to determine the extent to which the driver is in control of the vehicle. Increases in the SDLP indicate that the driving task has been compromised. The lateral position data from 18 subjects was included in this section (14 participants who responded to the text messaging cues termed the "treatment" group, and four participants who did not text while).

4.3.1 Average Overall SDLP for Treatment and Control Conditions

The overall SDLP was calculated for both the treatment and control groups for each of the four curves. The overall SDLP is the calculation of the change in lateral position of the vehicle as the driver traverses the entirety of the curve. Figure 28 and Figure 29 show box plots recording the distribution of average overall SDLP for each subject, for the control and treatment conditions, respectively.

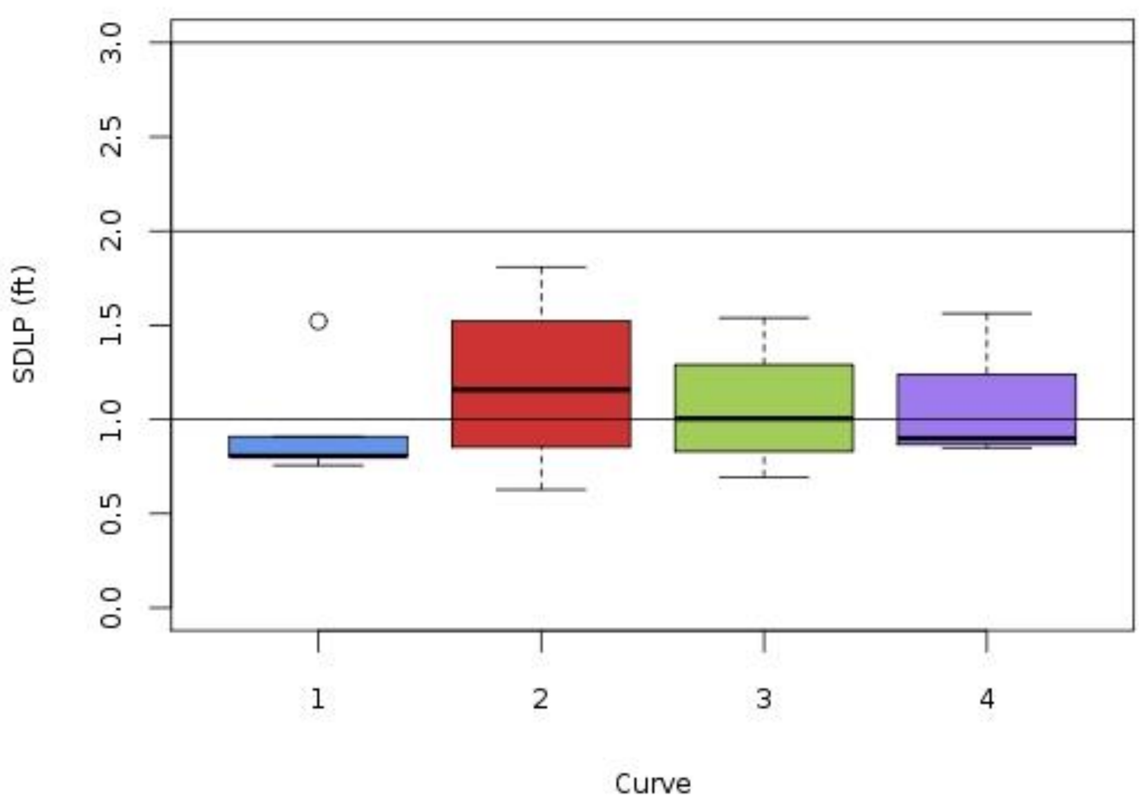


Figure 28: Overall SDLP for control condition

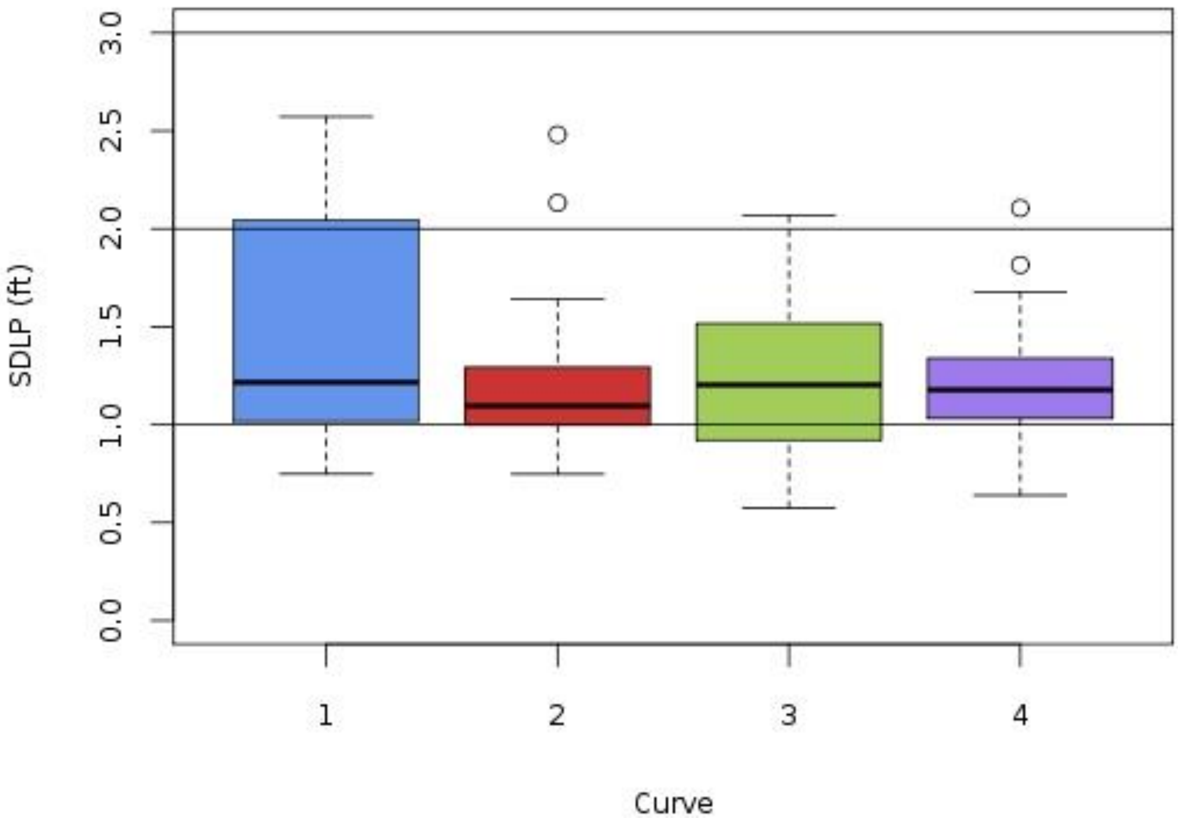


Figure 29: Overall SDLP for treatment condition

The medians are more variable within the control condition and consistent for each of the four curves with the treatment condition. However, while Figure 28 only shows one outlier along Curve 1, Figure 29 indicates four outlier data points, two on each of Curve 2 and Curve 4. This increase in outliers indicates that drivers had a higher SDLP while responding to the text messaging cues.

The overall SDLP numbers for each subject were averaged by curve to give an overall SDLP measure for the control and treatment condition on each of the four curves (Figure 30).

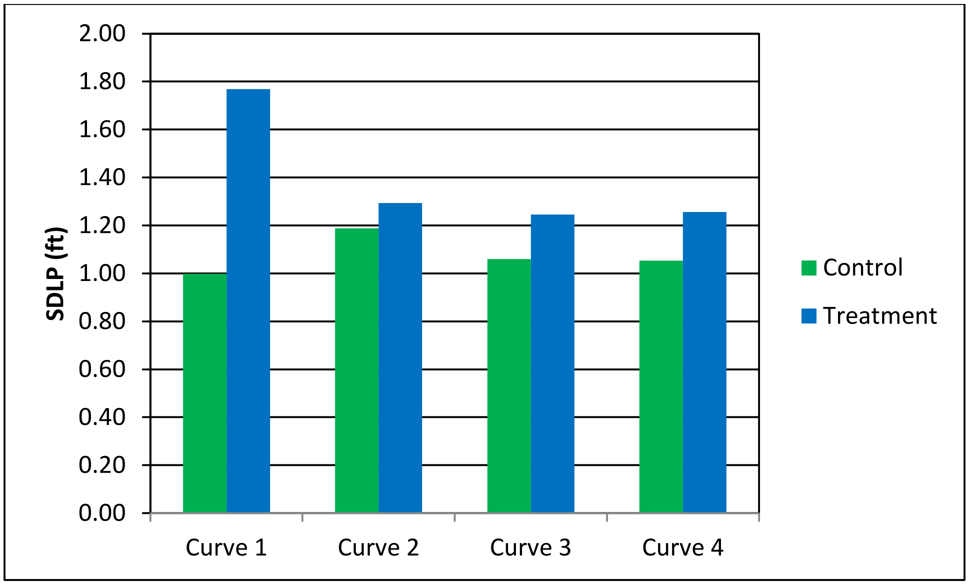


Figure 30: Average SDLP for control and treatment conditions for each curve

Each curve exhibits an increase in SDLP in the treatment condition as compared to the control condition. The largest observed increase in SDLP occurred for Curve 1, and the smallest increase was seen on Curve 2.

The lane position of the subject vehicle was recorded at each point along the curve, and these positions were plotted for the purpose of visual inspection between the treatment and control conditions (Figure 31).

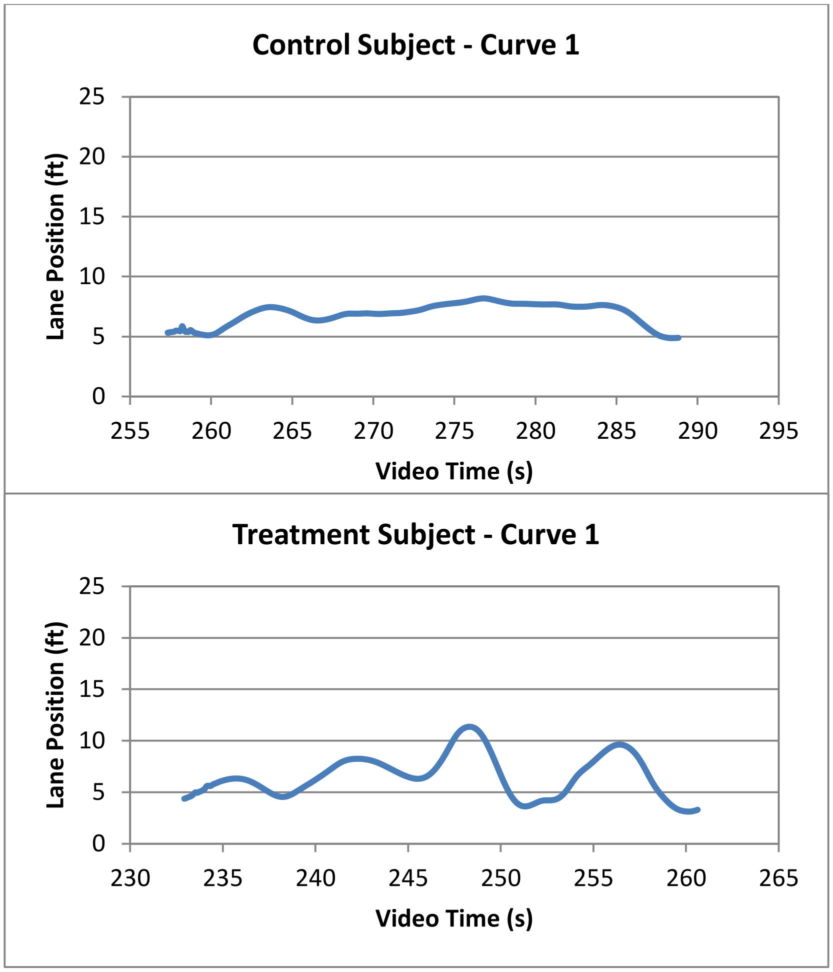


Figure 31: Visual comparison of lane position for Curve 1 for a control subject and a treatment subject

From an assortment of line graphs such as the ones shown above, the increase in SDLP between the control and treatment conditions can be seen. The vehicles of the drivers who responded to the text messaging cues exhibited more erratic lane positions while traversing the horizontal curves.

A statistical analysis was conducted on the overall SDLP data for both the control and treatment conditions. The paired t-test compared the average overall SDLP for each curve within each condition to check for statistical significance (Table 9 and Table 10).

Table 9: Statistical summary of average SDLP of control condition between curves

Average SDLP of Control Condition				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
1	1.19	1.06	1.05	1 v 2	0.26	No
				1 v 3	0.60	No
				1 v 4	0.12	No
				2 v 3	0.49	No
				2 v 4	0.36	No
				3 v 4	0.94	No

Table 10: Statistical summary of average SDLP of treatment condition between curves

Average SDLP of Treatment Condition				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
1.77	1.29	1.25	1.26	1 v 2	0.10	No
				1 v 3	0.16	No
				1 v 4	0.13	No
				2 v 3	0.80	No
				2 v 4	0.78	No
				3 v 4	0.94	No

All of the statistical tests recorded in Tables 9 and 10 failed to reach statistical significance. This lack of significance indicated that there was no statistically significant difference in SDLP for each curve within the respective experimental groups; which means that the different complexity of the text messaging cues did not affect the overall SDLP of the subjects.

4.3.2 Average Interval SDLP for Before, During, and After Conditions

The SDLP for three different intervals were recorded for the four curves. The three intervals were defined as “before”, “during”, and “after” as it related to the texting condition. The during interval varied in time between the subjects, and was identified as the time between the subject’s first glance and the last glance at their mobile phone. The distribution of the SDLP for each of the three aforementioned intervals are shown in Figures 32, 33, and 34 and organized by curve.

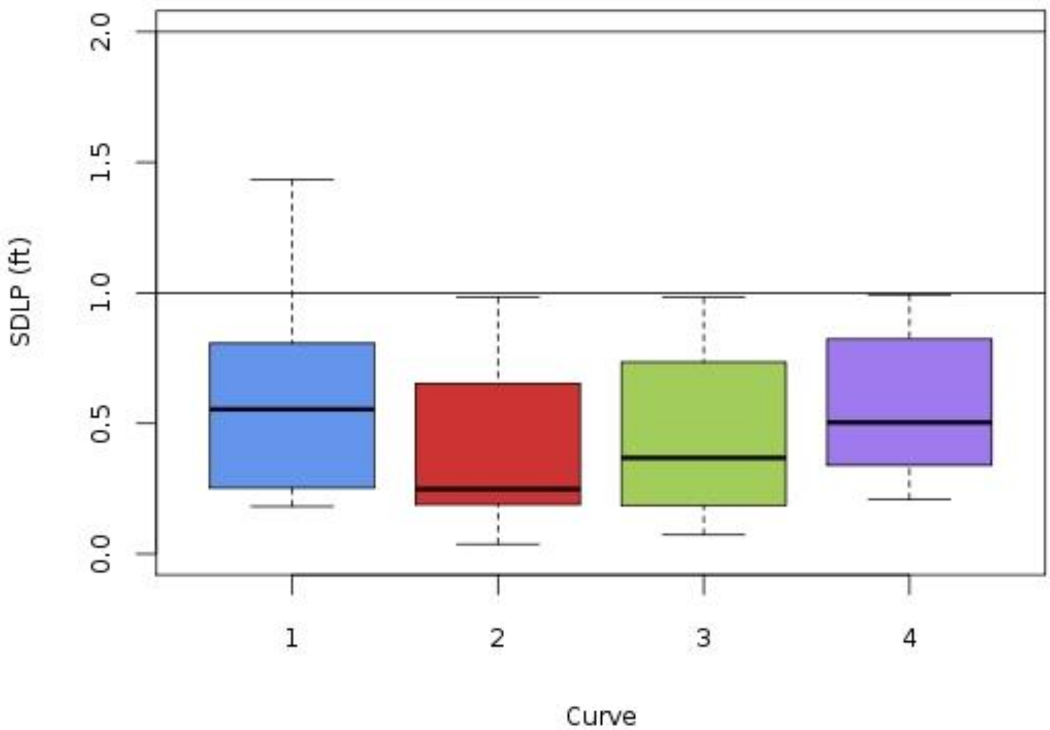


Figure 32: SDLP for before interval

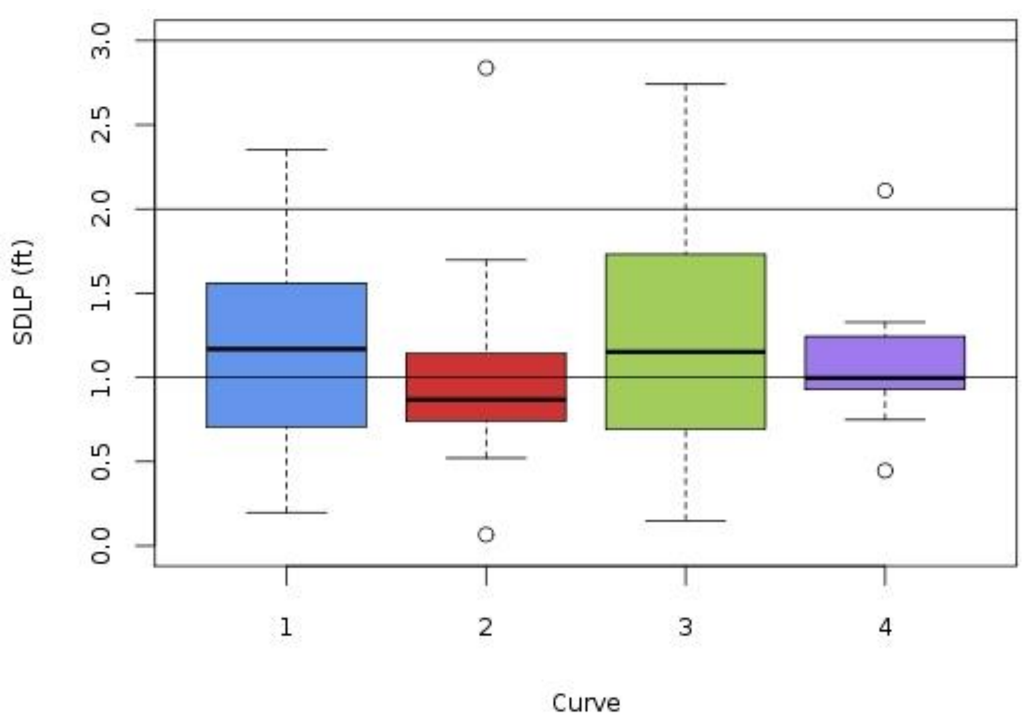


Figure 33: SDLP for during interval

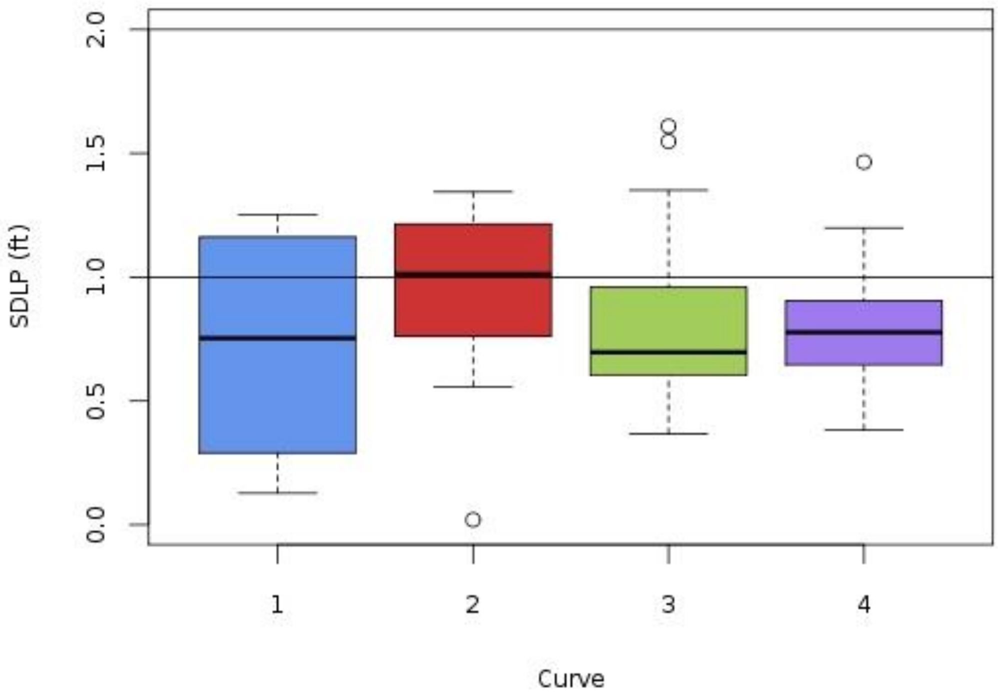


Figure 34: SDLP for after interval

As indicated by the figures above, the most consistent median SDLP was seen within the during interval, Figure 33. Additionally, no outliers were found in Figure 32 during the before interval indicating that no driver struggled to stay on course before sending a text message. Both Figures 33 and 34 show four outliers which indicates that subjects' SDLP was more variable during these intervals and sometimes exceeded normal bounds.

The subjects' SDLP for each interval, before, during, and after, were averaged together by curve (Figure 35).

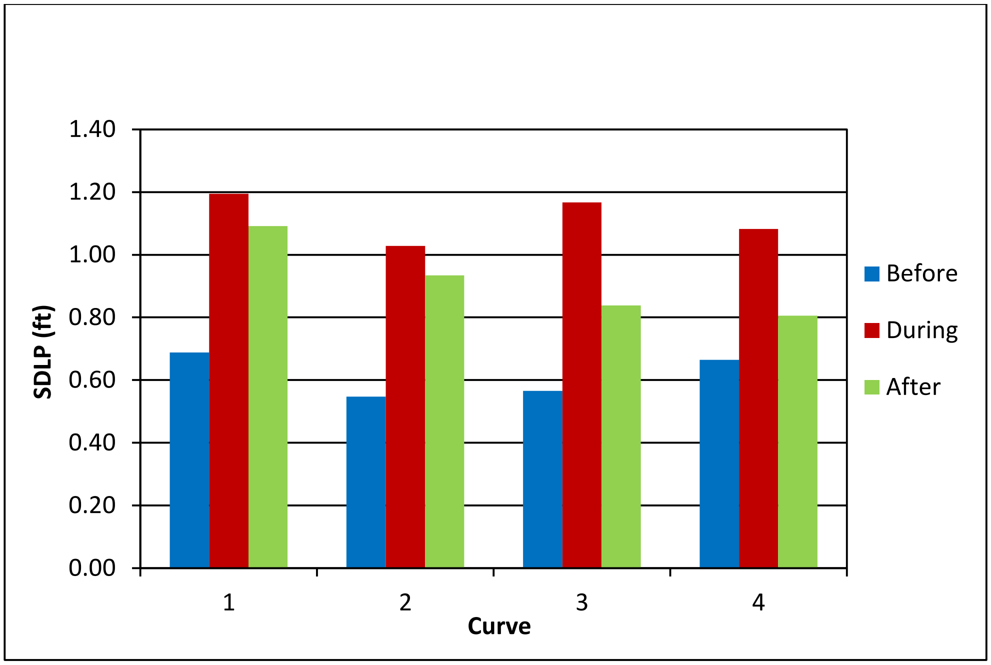


Figure 35: Average SDLP for before, during, and after intervals by curve

The highest SDLP for each of the four curves occurred in the during period. The lowest SDLP consistently occurred within the before period for each curve. The after period for each curve exhibited a greater SDLP than the before period, but less than that of the during interval.

To test for statistical significance in the average SDLP for each of the three intervals, a paired t-test was run on the data. These statistical tests compared the four curves within the before, during, and after intervals. Tables 11, 12, and 13 show the results of these tests for the before, during, and after intervals, respectively.

Table 11: Statistical summary of average SDLP of before interval between curves

Average SDLP of before Period				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
0.688	0.547	0.565	0.665	1 v 2	0.168	No
				1 v 3	0.274	No
				1 v 4	0.747	No
				2 v 3	0.949	No
				2 v 4	0.235	No
				3 v 4	0.168	No

Table 12: Statistical summary of average SDLP of during interval between curves

Average SDLP of during Period				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
1.195	1.028	1.167	1.083	1 v 2	0.598	No
				1 v 3	0.778	No
				1 v 4	0.586	No
				2 v 3	0.327	No
				2 v 4	0.785	No
				3 v 4	0.685	No

Table 13: Statistical summary of average SDLP of after interval between curves

Average SDLP of after Period				Curve	Paired T-test	
Curve 1	Curve 2	Curve 3	Curve 4		P-value	Significant
1.092	0.934	0.838	0.806	1 v 2	0.725	No
				1 v 3	0.675	No
				1 v 4	0.496	No
				2 v 3	0.677	No
				2 v 4	0.266	No
				3 v 4	0.804	No

The results shown in Tables 11, 12, and 13 indicate that no statistical significance was found in any of the paired t-Tests.

5 CONCLUSIONS

5.2 Review of Research Objectives

The aim of this research was to gain a better understanding of how drivers behave when text messaging while driving on a horizontal curve. More specifically, this research focused on the drivers' glance duration and frequency and the corresponding lateral position of the vehicle when completing a text messaging task. Three null hypotheses were tested in the OSU driving simulator:

1) ***H_0**: There is no difference in the duration and frequency of driver fixations on a mobile phone while completing a text messaging task between four horizontal curves.*

2) ***H_0**: There is no difference in the lateral position of a vehicle between baseline driving and driving while completing a text messaging task between four horizontal curves.*

3) ***H_0**: There is no difference in the lateral position of the vehicle before, during, or after the text messaging task between four horizontal curves.*

The following list of questions was developed to act as dependent variables to test the research hypotheses for validation or rejection:

1) How often does the subject glance at their phone while traversing each curve?
2) What is the duration of the subject's glances at their phone while traversing each curve?
3) For what percentage of time the subject is traversing the curve is their eyes on their phone?

4) What is the SDLP of the vehicle as the subjects traverse each curve?

Overall, data was obtained from 18 subjects who drove an experimental course in the OSU Driving Simulator. These 18 subjects were chosen from an original population of 40 subjects (Swake, 2014). Only data from those subjects whose eye glance patterns could be consistently observed and measured were used in this experiment. Of these 18 participants, four did not respond to the text messaging cues and were thus considered a control group.

5.2 Research Findings

The findings of this research effort are organized according to their corresponding research hypotheses.

5.2.1 Duration and Frequency of Driver Fixations

The detailed results of this objective can be found in Section 4.2 but the key outcomes include:

- A statistically significant difference in average frequency of driver fixations between Curves 2 and 3, and statistically suggestive difference between Curves 1 and 2.

The average frequency of driver fixations was greatest on Curve 1 with 8.5 sec, and smallest on Curve 2 with 6.2 sec. These results indicate that drivers found the text messaging cue on Curve 2 ("cat") to be the simplest, while Curve 3 ("eagle") was longer and thus more difficult, and the initial cue on Curve 1 ("cow") was unexpected.

- All four curves exhibited average driver fixation durations greater than one second.
- No statistical significance was found in comparison of the average duration of fixations between the four curves.

The largest difference in average durations between the four curves was 0.07 sec, occurring between Curves 1 and 4.

- No statistically significant difference was found between the maximum duration of fixations of the four curves.

These results suggest that the drivers' behavior remained consistent throughout the experiment regardless of the changing text messaging cues.

- The greatest duration of fixation was 4.04 sec and occurred on Curve 1.
- The smallest maximum duration of fixation was 2.54 sec and occurred on Curve 2.

These results indicate that on each of the four curves, glances greater than 2.5 sec were observed. Since Klauer et al. defined a very unsafe glance as one lasting 2.0 sec, it can be concluded that these glances are very dangerous to the driver and their surroundings.

- Statistically suggestive significance in the difference between the average percentages of time with eyes off roadway was found between Curves 1 and 2, Curves 2 and 3, and Curves 2 and 4.

Curve 2 exhibited the lowest average percentage of time with drivers' eyes off the forward roadway (20.1%), while all other means showed suggestive significance in comparison. Thus, these results suggest that drivers found the text messaging cue on Curve 2 ("cat") to be the simplest of the three, requiring less time to compose the text message. However, the other three cues did not require any significant difference in time with the drivers' eyes off the roadway while composing the message.

- No drivers spent longer than 75% of the time on the curve with their eyes off the roadway

- Three drivers spent between 50% to 74% of the time on the curve with their eyes off of the roadway (two on Curve 1 and one on Curve 2).
- Only on Curves 2 and 3 did the majority of drivers spend less than 25% of time with their eyes off the forward roadway.

5.2.2 Average SDLP of Treatment and Control Groups

The detailed results of this hypothesis can be found in Section 4.3.1, but some key outcomes include:

- No statistical difference in the average SDLP of the treatment group between the four curves.
- No statistical difference in the average SDLP of the control group between the four curves.

These results suggest that drivers demonstrated the same behavior on each of the four curves, regardless of the different text messaging cues.

- The treatment group exhibited increased SDLP compared to the control group on all four curves.

These results suggest that no matter what the text messaging cue was, those that responded had a greater variability in lane position throughout the duration of the curve than those who did not compose a text message while driving.

5.2.3 Average SDLP of Before, During, and After Intervals

The details results of this hypothesis can be found in Section 4.3.2, several key outcomes include:

- No statistical difference was found in the average SDLP of the before intervals between the four curves.
- No statistical difference was found in the average SDLP of the during intervals between the four curves.
- No statistical difference was found in the average SDLP of the after intervals between the four curves.

These results indicate that there was no difference in driver behavior in any of the intervals (before, during, and after) regardless of the difference in text messaging cues.

- On all four curves, the average SDLP was least for the before interval.
- On all four curves, the average SDLP was greatest for the during interval.

From these results, it can be concluded that a driver had the greatest control of the car before beginning to compose a text message and the worst control (corresponding to a greater SDLP) while writing and sending the text message. However, while the SDLP of the after interval was less than that of the during interval for all four curves, it was still consistently greater than that of the before interval. These results suggest that upon completing a texting task, the driver does not immediately regain full control of the vehicle, instead there is a period of time in which the driving task is still compromised.

5.3 Future Work

This research has provided insight to driver behavior when completing a text messaging task while driving on a horizontal curve. This research looked at the effects glance frequencies and durations, as well as SDLP have on driver behavior and control of the simulated vehicle. The results included here indicate that texting while driving has a degrading effect on the driving task. With that said, there is additional work that could further these results and this line of research:

- A larger, more diverse sample size could result in more specific conclusions relating the effects of age, gender, and driving experience.
- A larger sample size could result in statistical conclusions being drawn between the control and treatment groups.
- Analysis on the addition of ambient traffic could be performed.
- Varying the text messaging cues by category, complexity, or prompt-type to see their effects on driver behavior.
- Direct comparison of SDLP and glance patterns of drivers when texting on horizontal curves and tangent roadways.

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