ABSTRACT

Title of Dissertation: THE EFFECT OF CELLPHONE USAGE ON DRIVING PERFORMANCE USING AN EYE TRACKING SYSTEM AND A DRIVING SIMULATOR

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In 2016 the National Highway Traffic Safety Administration (NHTSA) reported that 10% of fatal crashes, 18% of injury crashes, and 16% of all police-reported motor vehicle crashes resulted from distracted driving. Thus distraction while driving is a major risk factor for road traffic crashes in the U.S. and the State of Maryland.

There are different types of distracted driving, usually categorized as those in which the source of distraction is internal (in-vehicle), such as using a mobile phone or tuning a radio, or external (out-of-vehicle) like looking at accidents, surrounding landscapes, or pedestrians. This study focuses on the different types of mobile phone distractions (hand-held, hands-free, voice commands, texting) and the effect they have on drivers' performance while driving on different road classes, to show that the potential risk to road safety is increasing rapidly as a result of the exponential growth in the use of

mobile phones in society.

Different studies from different countries suggest that the proportion of drivers using mobile phones has grown over the past decade, ranging from 1% to 11%. The use of hands-free mobile phones is likely to be higher, but this figure is more difficult to ascertain. In many countries the extent of this problem remains unknown, as data on mobile phone use is not routinely collected when a crash occurs.

Using a driving simulator and an eye tracking system, this study evaluates the driver's performance (speed, steering, brake, throttle, etc.) when distracted by a cellphone in a simulated road network that includes four different road classes: urban, highway, rural, and local - school zone. Forty participants drove six scenarios sequentially with a few minutes break between scenarios. There are no cellphone distractions in the first and last scenarios to benchmark the pure effect of distraction and capture and remove the effect of learning and/or fatigue. The second to fifth scenarios have hands-free, hand-held, voice command, and texting as the distracting element, respectively.

A total of over 960 simulator runs was collected and analyzed. Statistical analyses such as Kolmogorov-Smirnov test, ANOVA test, and Mann-Whitney U test were performed to find the effect of each distraction on driver performance.

The first and last scenarios were specifically evaluated to examine the effect of fatigue on a driver's performance. Since the results showed the effect of learning influences drivers' speed, another study was conducted to examine the impact of learning on the performance of drivers. Additionally, a distraction model was also designed in this research to show the relationship between distraction and some variables.

The statistical analysis of the results indicated; impaired performance of participants due to these distractions, is affected by other driving parameters such as; speed, steering and throttle. Based on the results of this analysis, increasing the complexity of the distraction will result in decreased speed. In other words, participants decreased their speed in all scenarios, on all roads, in the presence of an external distraction.

It is the author's hope that this study's findings will help to root out the issue of distracted driving, identify key effective factors, and ultimately identify factors associated with driving distraction to remove or mitigate this issue.

THE EFFECT OF CELLPHONE USAGE ON DRIVING PERFORMANCE USING AN EYE TRACKING SYSTEM AND A DRIVING SIMULATOR

By

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CHAPTER 1: Introduction

Driver distraction is an important risk factor for road traffic injuries. While there are different types of distractions, distracted driving usually refers to those within the vehicle, such as using a mobile phone, tuning the radio, using GPS, etc. This study focuses on the use of mobile phones while driving, to see the effect of cellphone usage on the performance of drivers, and to figure out which kind of phone usage is the riskiest and how much the exponential growth in the use of mobile phones is decreasing the safety of the roads. This study aims to categorize which type of cellphone usage has the most and least effect on driver performance by comparing different cellphone usage scenarios such as hands-free and texting, and it will also present countermeasures that are being used around the world to tackle this growing problem.

Different studies from various countries suggest that the proportion of drivers using mobile phones while driving has grown over the past decade, ranging from 1% to 11% (1). The use of hands-free mobile phones is likely to be higher. In many countries the extent of this problem remains unknown, as data on mobile phone use is not routinely collected when a crash occurs. In the United States, 6 out of 10 crashes among young drivers are caused by distraction. According to recent research (Figure 1) the most common factors of distraction are interacting with other passengers, using a cellphone, and looking at something in the vehicle. The most important factor, which ranked on top, is interacting with people, and the second most important factor is cellphone usage while driving.

Using phones may cause drivers to take their eyes off the road, or their hands off the steering wheel, as well as their minds off the road and the surrounding situation (1).

This type of distraction is known as cognitive distraction and appears to have the biggest impact on driving behavior. A growing body of evidence shows that the distraction caused by mobile phones can impair performance in a number of ways, e.g., longer reaction times (notably braking reaction time, but also reaction to traffic signals), impaired ability to stay in the correct lane, shorter following distances, and an overall reduction in awareness of the driving situation.

Figure 1 Distracted driving (photo credit by TeenDriving.AAA.com)

Using a phone for messaging during driving seems to have a detrimental impact on driving behavior. Text messaging is often a low-cost form of communication, and the increasing use of text messaging services among drivers makes it an important road safety concern. Young drivers are more likely to use a mobile phone while driving than are older drivers, and given their relative inexperience behind the wheel, they are particularly vulnerable to the effects of distraction. There are many types of distraction, such as talking to passengers, eating, working a navigation system, or talking or texting on a cellphone (2). Different distractions are presented in Figure 2 in a diagram format. These distracting tasks affect drivers in different ways and can be grouped into three categories:

1. Visually distracting: tasks that require the driver to look away from the road to visually get information.

2. Manually distracting: tasks that require the driver to take a hand or hands from the steering wheel.

3. Cognitively distracting: tasks that require the driver to think about something other than driving.

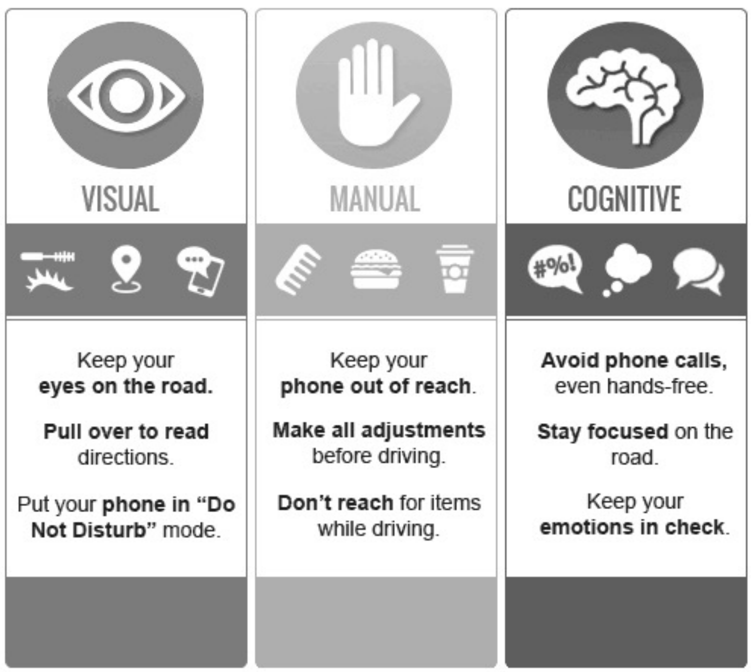

Figure 2 Types of distracted driving (photo credit by www.dmv.org)

All of these types of distractions can increase crash risks. In addition, how often and how long a driver is distracted affects their crash risk. For example, drivers who engage in a less distracting task but do so frequently or for long periods of time may increase their crash risk to levels comparable to a much more difficult task that is performed only briefly or less often (3).

The impact of using a mobile phone on crash risk is difficult to ascertain, but studies suggest that drivers using a mobile phone are approximately four times more likely to be involved in a crash (2). This increased risk appears to be similar for both hand-held and hands-free phones, suggesting that it is the cognitive distraction that results from being involved in a conversation on a mobile phone that has the most impact upon driving behavior, and thus crash risk (2).

The body of research looking at the risk associated with using cellphones while driving is growing rapidly. As a result, a number of countries are following approaches that have been known to be successful in addressing other key risk factors for road traffic injuries, such as increasing seat-belt use or reducing speed and drunk driving.

Nonetheless, to date the effectiveness of any of the above measures (increasing seat-belt use or reducing speed and drunk driving) on cellphone usage while driving—and more importantly, on crashes and injuries—has yet to be adequately documented. While there is some research on the effectiveness of rules and regulations on the use of mobile phones, the ability to sustain reduced levels of mobile phone use needs to be assessed. In addition, the possibility that laws banning only hand-held mobile phones may actually increase the use of hands-free phones needs to be evaluated, particularly since, as based on the available evidence, using a hands-free phone while driving appears to have a risk similar to using a hand-held one.

Although the evidence surrounding mobile phones as a risk factor for road traffic injuries is in its infancy compared to other aspects of road safety, this issue is a growing concern. Furthermore, while this research focuses on mobile phone use, it is important to recognize that mobile phone services are increasingly integrated with other applications (e.g., email and internet access via "smartphones" as well as apps). Information on the role of such uses in road traffic crashes, as well as on potential countermeasures, is therefore likely to evolve alongside the rapid technological changes taking place in this area. Governments need to be proactive and put in place measures to address mobile phone use among drivers, while simultaneously monitoring and evaluating the effects of these interventions. In this way the body of evidence in this area will grow, allowing future policy decisions to be grounded firmly in science.

1.1 Problem Statement

Distracted driving is a major source of crashes in the U.S. and the State of Maryland. Using a cellphone while driving caused an estimated 1.5 million car accidents in the U.S. in 2017 according to the National Safety Council. The National Highway Traffic Safety Administration (NHTSA) (3) reported that 10% of fatal crashes, 18% of injury crashes, and 16% of all police-reported motor vehicle traffic crashes were reported as distraction-affected crashes. Drivers between 21 and 29 use cellphones the most and are the most distracted.

In Maryland, approximately, 30,000 people per year are injured or killed due to distracted driving. Although the number of distracted driving crashes has been declining in the past few years, they account for 58% of all crashes and 46% of all fatal crashes in Maryland. About a quarter of the drivers involved in distracted driving crashes were between 21 and 29 years old. Nearly 57% of distracted drivers were male and about 80% of distracted driver fatalities were also male.

The effects of mobile phone use on driving behavior are relatively well researched, but the accuracy of studies varies considerably, and depends on the methods used and the conditions under which the studies were performed. Each of the approaches provides a slightly different perspective on the problem and no single approach can provide all the information needed to make policy decisions. It is the weight and convergence of the evidence from various approaches that provide the basis for informed decision-making.

Also, there is a lack of comprehensive study that compares all kinds of cellphone usage, especially with recent technologies such as voice to text or voice command that are designed to be more user friendly. This study tries to evaluate the distractions caused by a variety of mobile phone usage conditions (no call, messaging, voice command, hands-free call, hand-held call), and compares all of these by applying different statistical analyses that have not been applied so far according to the literature.

Additionally, this study develops a distraction statistical model, using sociodemographic characteristics and driving performance. Compared to previous research projects that have designed regression models, this research specifically examines speed and steering, and sets this factor together with age, race, and income in the model. These kinds of models help in legislators' decision-making, to root out the problem of driving distraction, identify key effective factors, and ultimately identify factors associated with driving distraction to remove or mitigate this issue.

1.2 Dissertation Objective

This study compares the effects of a variety of mobile phone usage conditions (no call, messaging, voice command, hands-free call, hand-held call) on simulated driving performance. One of the prominent tools to study human-related issues, specifically driver distraction, is a driving simulator. It is able to simulate a virtual driving environment and resemble real driving conditions (4, 5). This research is a comprehensive investigation of the effects of mobile phone usage while driving on drivers' performance. Driving performance is investigated on different road types (rural road, urban road, freeway, and school zone), and with different types of cellphone usage (hands-free call, hand-held call, texting, and voice command). In addition, the effect of fatigue on driving performance is studied and removed to find the pure effect of cellphone usage. Finally, a distraction statistical model is developed.

Here are some research questions that this study attempts to answer:

- Does using a cellphone deteriorate driving performance while driving?
- Which groups of people are more vulnerable to distraction (gender, age group, etc.)?
- What's the difference between hand-held, hands-free, texting, and voice command, in affecting drivers' performance?
- What's the difference between the performances of distracted drivers on different roads?
- How does fatigue and/or learning affect driving performance and how can we account for these effects?

CHAPTER 2: Literature Review

Every year, nearly 1.3 million people die and 50 million are injured as a result of road traffic crashes (6). Approximately 23% of all crashes and near-crashes are caused by distraction due to secondary tasks (7). These deaths and injuries have an immeasurable impact on families and communities as they tragically and irrevocably change people's lives. In addition to the huge emotional toll these injuries exact, they also cause considerable economic loss to casualties, their families and nations as a whole.

Relatively few studies have systematically examined the impact of more recent technologies on driver performance; for example, the effects of email (8, 9), text messaging (10) and MP3 players (11) on driver performance are less common than studies of cellphones and driving (12, 13).

Road traffic injuries affect all age groups, but their impact is particularly striking among the young—they are the leading cause of death worldwide among those 15–29 years old (14). Trends suggest that by 2030, road traffic injuries will rise from being the ninth-leading cause of death globally to become the fifth (14). This rise is particularly driven by the dramatic increase in motorization in a number of low- and middle-income countries—an increase that now demands improved road safety strategies and land-use planning.

A number of factors have been identified as affecting the likelihood of a road traffic injury, and limiting the exposure to these risk factors is critical to the success of efforts to reduce road traffic injuries. For example, there is now a large body of scientific research showing the increased risk of road traffic fatalities and injuries resulting from excessive or inappropriate speed, drunk driving, and non-use of seat-belts, child restraints or motorcycle helmets (15, 16). Over the past few decades, evaluation of programs around the world has helped provide a solid foundation of evidence-based solutions that policy-makers can draw upon in efforts to improve road safety within their countries.

Distraction in traffic is another risk and is becoming an increasing concern among policy-makers. Most research and attention in this area relates to driver distraction, largely because of drivers' increasing use of mobile phones and other technologies. However, the extent of the problem of driver distraction, including that created by mobile phones, and its contribution to risky driver behavior and road traffic crashes is not well known, even in countries with a good road safety record.

Furthermore, previous research has shown that distracted driving decreased drivers' performance in different ranges (17, 18). For example, drivers spent less time observing their instruments and mirrors when using a mobile phone while driving (19).

2.1 Distracted Driving

Driver distraction remains a poorly and inconsistently defined concept. Distraction is the diversion of attention away from activities critical for safe driving toward a competing activity (20).

When drivers are distracted, their attention is temporarily divided between what is often referred to as the "primary task" of driving and "secondary tasks" not related to driving; for example, during a mobile phone conversation a driver's cognitive (i.e., thinking) resources are being used to analyze both the driving situation (the primary task) and the conversation taking place (the secondary task). As a result, the driver's situational awareness, decision-making and driving performance are impaired. Driver distraction can be one of three types:

- Visual distraction is looking away from the road for a non-driving-related task.
- Cognitive distraction is reflecting on a subject of conversation as a result of talking on the phone rather than analyzing the road situation.
- Physical distraction happens when the driver holds or operates a device rather than steering with both hands or dials a mobile phone or leans over to tune a radio, which may lead to rotating the steering wheel.

More than one of these categories may occur at the same time, depending on the particular trigger.

It is important to know that driver distraction is generally thought to be different from driver inattention, or poorly allocated attention. Distracted driving occurs when some kind of triggering event external to the driver results in the driver shifting attention away from the driving task (e.g., a ringing mobile phone). The diversion in attention occurs because the driver is performing an additional task or is temporarily focusing on an object, event, or person not related to the primary driving task (21). Inattention while driving applies to any state or event that causes the driver to pay less attention to the task of driving; the inattention is not necessarily triggered by an event, for example, daydreaming (20, 22). The diversion of attention that occurs in distracted driving is also distinct from those impacts on driving performance that are attributable to a medical condition, alcohol or drug use, and/or fatigue.

Driver distraction can result from a number of sources that are internal or external to the vehicle.

In-vehicle (internal) distractions include eating, smoking, and talking (23, 24). However, it is the growing number of new electronic devices that are of most concern to those involved in road safety. These include systems that are not integrated into the car, also called "nomadic devices," such as mobile phones, laptops, and portable and non-integrated navigation or global positioning systems. While some of these systems, such as navigation systems and intelligent speed adaptation (ISA) systems, have the potential to help drivers in unfamiliar settings, they may also be a source of driver distraction (22, 25). Internal sources of distraction also include the growing number of communication technologies that are now integrated into vehicles, for example, the Bluetooth technologies and those that allow drivers to access their emails and the Internet.

Little data is available on the extent of the use of these in-vehicle sources of distraction or their effects on driving performance. Some studies show that using in-vehicle entertainment systems has detrimental effects on driving performance (23). Indeed, adjusting a radio, CD, or cassette player was found to be one of the major causes of distraction-related crashes in the United States, and while information on newer technological sources of distraction is lacking, similar negative effects on safety would be expected. This area probably will be the target of more research in the future (24, 25).

Thus, some of the main internal sources of distracted driving are:

- Interacting with passengers
- Adjusting radio, CD
- Dialing or texting on a mobile phone
- Eating or drinking
- Moving an object in the vehicle

- Talking on a mobile phone (24).

Some researchers suggest that the impact on driving performance of talking on a mobile phone is similar to that of holding a conversation with a passenger. However, other more recent studies suggest that there is a significant difference between these two situations, with a higher risk of distraction and effect on driving behavior for those using a mobile phone compared to those conversing with a passenger. Studies have shown that reaction times are slower among drivers talking on a phone than among those talking to a passenger (26). This appears to be because the passengers are more aware of the driving situation and road environment and can moderate, adapt, or delay the conversation during challenging driving circumstances, a phenomenon that does not occur during phone conversations (27, 28). However, this does not mean that a conversation with a passenger is not potentially distracting. Various studies have shown that young drivers' crash risk is significantly increased by the presence of similarly aged passengers in the vehicle (27, 29).

External distractions may arise when the driver looks at buildings, people, or situations outside the vehicle, as well as at billboards and other roadside advertising. Advertisements that are "successful" from a marketing perspective may be those that pose the most threat to driving behavior. Interest in this area has increased recently because advertisers are pressuring road authorities to allow video advertising (30, 31). A study comparing the distraction to drivers caused by static versus video billboard advertising found that video ads had a more detrimental effect on driving performance, suggesting the increased risk of this type of external distraction (32).

Police in most countries do not systematically report the use of a particular distracting activity, such as using a mobile phone, in crash reports, making it difficult to estimate the contribution distraction makes to crashes and the consequent danger it poses on the world's roads. Where police do include distraction information in crash reports, drivers are less likely to disclose their use of mobile phones as it can indicate fault, and thus data are likely to be underreported. Witness statements may also be unreliable (33). However, a selection of studies highlighted below indicates a growing body of evidence suggesting that distraction is an important contributor to road traffic crashes.

- An Australian study examined the role of self-reported driver distraction in serious road crashes resulting in hospital treatment and found that distraction was a contributing factor in 14% of crashes (34).
- In New Zealand, research suggests that distraction contributes to at least 10% of fatal crashes and 9% of injury crashes, with an estimated social cost of NZ$413 million in 2008 (approximately US$311 million). Young people are particularly likely to be involved in crashes related to driver distraction (35).
- Insurance companies in Colombia reported that distracted driving in 2006 caused 9% of all road traffic crashes. (36).
- In Spain, an estimated 37% of road traffic crashes in 2008 were related to driver distraction (37).
- In the Netherlands, the use of mobile phones while driving was responsible for 8.3% of the total number of dead and injured victims in 2004 (38).
- In Canada, national data from 2003–2007 show that 10.7% of all drivers killed or injured were distracted at the time of the crash (39).

- In the United States, driver distraction as a result of sources internal to the vehicle was estimated to be responsible for 11% of crashes nationwide that occurred between 2005 and 2007, although a smaller study involving 100 drivers found that driver involvement in secondary tasks contributed to 22% of all near crashes and crashes (40, 41). In 2008, driver distraction was reported to have been involved in 16% of all fatal crashes in the United States (42).
- In Great Britain, distraction was cited as a contributory factor in 2% of reported crashes. (43).

Estimating the relative contribution of different forms of distraction to road crashes is difficult. One study in New Zealand found that passenger distraction accounted for the highest number of collisions involving driver distraction: In fact, passenger distractions ranked higher than those related to telecommunications and entertainment systems combined (44). Similarly, it is important to consider not just the effect of the source of distraction upon driving behavior, but also the frequency and duration of the behavior. Thus, while talking on a mobile phone may have a less detrimental impact on driving behavior than text messaging, some studies in the United States suggest that the frequency and duration of mobile phone conversations while driving lead to a larger overall impact in terms of crashes: An estimated 1.4 million crashes result from mobile phone conversations relative to approximately 200,000 crashes that are believed to involve text messaging or sending emails (45, 46).

However, it should be noted that the difficulty of collecting data on texting may also mean these estimates are underreported.

2.2 Cellphone Use

Levels of ownership and use of mobile phones have risen exponentially over the past decade in all parts of the world. The diagram in Figure 3 shows the steady growth in the number of mobile phone subscriptions globally, reaching 67 per 100 inhabitants at the end of 2009.

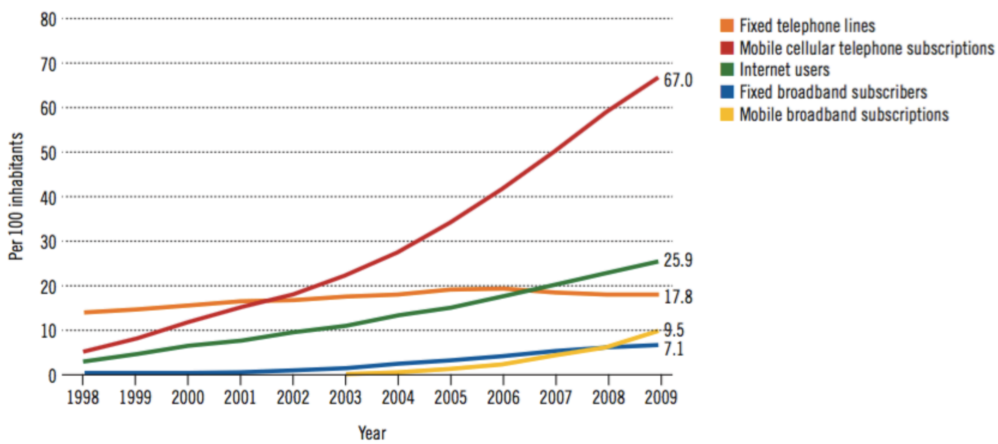

Figure 3 Global information and communication technology developments

Growth in mobile phone subscriptions is fastest in low- and middle-income countries where there are now twice as many mobile phone subscriptions as in high-income countries, reflecting the relative size of these markets. In contrast to most high-income countries, many low- and middle-income countries are going directly to the use of wireless technology for phone services, skipping landlines. Between 2008 and 2009 the use of mobile phones in developing countries exceeded 50% of the global population, reaching an estimated 57 per 100 inhabitants, while in high-income countries use has largely exceeded 100% (i.e., there is more than one mobile phone subscription for every inhabitant, including children and adults). The relatively low cost of mobile phone services and related devices in many parts of the world is likely to continue to drive the global market in mobile phone growth. Mobile phone use is greatest among the young, especially the 15–24 age group, while data suggest that those in the younger age group are also driving the demand for text messaging services (27). One study in Canada found that young people spend more than an hour every day talking on their mobile phones (compared to a global average of 27 minutes), with 49% using text messages on a weekly basis (27). It is important to note that the frequency of text messaging is likely to increase, as it is cheaper than talking on the phone.

The increasing use of mobile phones is part of the broader integration of information and communications technology worldwide, allowing an instant and continuous flow of information and social networking. Increasingly pervasive hand-held devices such as mobile and smartphones, MP3 players, iPods, and applications such as Facebook and Twitter, are, in many societies, drawing users into ever-deeper engagement. This trend is particularly prevalent among young people, but the distraction associated with the continual use of such devices has led to discussion about whether this excessive use is an addiction. Research suggests this behavior is like a compulsive-impulsive disorder, whereby an inability to access the services is associated with negative health consequences, including withdrawal and depression and other negative repercussions such as social isolation and fatigue (48). It is evident that such excessive use and possible dependency associated with these devices could compound their distractive potential, with a correspondingly detrimental effect upon driving behavior.

As mobile phone ownership rises rapidly worldwide, the use of mobile phones in vehicles is also increasingly common. Along with the growing use of hand-held mobile phones, new vehicles are being equipped with Bluetooth technology, facilitating voice activation and hands-free phone use.

A number of studies have tried to determine how many drivers use mobile phones while driving. For example, in a number of high-income countries (e.g., the United States, New Zealand, Australia, and some European countries), 60% to 70% of drivers report using a mobile phone at least sometimes while driving (27, 38, 49, 50). Some studies also try to assess the use of mobile phones at any given moment because it is not only use while driving, but also the length of use that impacts risk—the longer the use, the greater the risk. Most of these are self-reported or observational studies, or police records. These include:

• About 1% to 7% of observed drivers used mobile phones at any given moment during the day in Australia, the Netherlands, the United Kingdom and other European countries (27, 38, 49, 50). In the United States, 11% of vehicles observed had drivers using a mobile phone (22, 51).

• Another study in Canada found that 2.8% of drivers were using mobile phones at any given moment while driving in rural areas, but this figure was much higher (5.9%) in urban areas (52).

Young and novice drivers (below the age of 25) are a high-risk group for road traffic injuries and are greatly overrepresented in crash and traffic fatality statistics. For instance, within the Organization for Economic Co-operation and Development (OECD) countries, young drivers typically represent between 18% and 30% of all drivers killed, although people in the same age group only represent between 9% and 13% of the total populations in their countries (29). Studies from the United Kingdom, Australia, and New

Zealand show that male drivers under 30 are also more likely to use mobile phones while driving (27, 28). A United Kingdom study found that drivers under 30 were almost twice as likely to use a mobile phone as drivers over 30 (54). Heavy use of mobile phones could increase the high crash risk for these young drivers, who are more vulnerable to the effects of distraction given their relative inexperience behind the wheel.

2.3 Effects of a Call on Driving

As mentioned earlier, certain tasks considered essential for safe driving are referred to as "primary tasks." Others, such as using a mobile phone, constitute "secondary" tasks. Studies show that it is hard for drivers to carry out the primary tasks essential to driving a vehicle safely when they are involved in a secondary task. The result is that their driving performance deteriorates in a number of ways. The effects of mobile phone use on driving behavior are relatively well researched, but the accuracy of studies varies considerably, and depends on the methods used and the conditions under which the studies were performed.

As stated earlier, each of the approaches provides a slightly different perspective on the problem and no single approach can provide all the information needed to make policy decisions. It is the weight and convergence of the evidence from various approaches that provide the basis for informed decision-making.

Based on the literature, some other factors are important in determining the degree to which distraction affects driving behavior. These include:

2.3.1 Age

The effects of mobile phone conversations on driving performance are more extreme for both younger and older drivers. Younger drivers with less experience find it more difficult to divide their attention appropriately between driving and the secondary task of talking on the phone. Older drivers have decreased visual and cognitive capacities, which also make it more difficult for them to conduct two tasks concurrently, as manifested by an increased reaction time while driving (28, 54, 55).

2.3.2 Gender

Most research shows that men are more likely to use mobile phones while driving, but the impact of the distraction on driving behavior is unclear. Some studies suggest mobile phone use may have a greater impact on female driving behavior, particularly young female drivers, but others show no differences—this may be a result of age-related differences in the samples used in different studies (28, 56). A study on the effects of text messaging while driving found that male drivers were more likely to text while driving, but that impairment caused by text messaging was far more significant among female drivers. Male drivers were also less likely to reduce their speed while texting and driving (57).

2.3.3 Driver's Experience

Since many novice drivers are also young drivers, it is difficult to separate out the effects of age and experience on driving ability while using a mobile phone.

However, younger inexperienced drivers appear to be more susceptible to the effects of distraction on their driving performance: A new phase of cognitive development that takes place during adolescence makes young drivers more prone to distraction, potentially resulting in greater impacts on driving performance than for mature drivers (28).

2.3.4 Hand-held versus Hands-free

Another important factor that must be considered is that as the mobile phone market expands and technology becomes increasingly sophisticated, hands-free phones and other aids, such as voice activation and speed dialing, are being developed to reduce physical distractions associated with mobile phone use. Whether hands-free phone devices have less impact on driving behavior than hand-held phones has become the subject of increasing investigation. While hand-held phones have the physical distraction of being held to the ear, a number of studies show that using hands-free phones also negatively impacts various aspects of driving behavior—notably, an increased reaction time—that are similar to using a hand-held phone.

Using hands-free phones while driving leads to reduced visual monitoring of instruments in the car and the general traffic situation, and negatively impacts vehicle control (58). Studies suggest that hands-free phones are not safer than hand-held phones in terms of driving performance (27, 28). Although this may be counterintuitive, evidence showing that it is the cognitive distraction that has the most impact upon driving performance may explain why using a hands-free mobile phone may be as likely to cause a crash as using a hand-held mobile phone (27, 28). These conclusions are derived from epidemiological studies, meta-analyses, simulator studies, and reviews of the literature (27, 28).

2.4 Effects of Messaging on Driving

The effects on driving behavior of sending or receiving text messages are potentially critical. While there is still little research in this area, existing studies (mostly experimental) suggest that text messaging leads to increased cognitive demands in order to write text messages, physical distraction from holding the phone, and visual distraction from creating or reading messages—these in turn impact critical driving tasks. For instance, one experimental study found these results among drivers who were texting:

- The amount of time that drivers spent with their eyes off the road increased by up to 400% when retrieving and sending text messages.
- Drivers made 28% more lane excursions and 140% more incorrect lane changes when sending and receiving text messages; texting drivers did attempt to compensate for distraction by increasing their following distances or reducing their speed (59).

Another recent study in the United Kingdom of reaction times of young drivers, 17–24 years, who used their mobile phones to send and read text messages showed a decreased ability to stay in the correct lane, a reduced ability to maintain a safe distance from the vehicle ahead, and an increase in reaction time. In particular, sending text messages was found to reduce reaction time by 35%. An American study found that drivers of commercial vehicles who were texting while driving were 23 times more likely to be involved in a "safety-critical event" compared to a situation in which they were not texting while driving (60).

2.5 Driving Simulator

Driving simulators were designed to guide a great number of personnel in the tactical use of war machinery during the Second World War (61). In the 1960s, these devices were deployed in the research field to study driver behavior and performance interaction with the vehicle and the road environment (61). In 1975, thanks to the fast progression of what was state of the art in computer technology and visual displays, about 16 driving simulator devices were in use throughout the United States, using different techniques for the generation of the visual field, as well as two devices in Europe (62). Since 1985 the trend in the development of simulators has been to achieve the specific needs of a particular group, whether this is an automotive industry, a private research institute, or even a university.

Today the main applications of driving simulators are to investigate acceptability issues of innovative transport elements and evaluate the safety concept as well the transferability of the simulator results to the real world. Simulators have been applied as research aids in the transportation, psychology, and ergonomics fields and even in civil engineering. Their uses include testing the design of new tunnels; reviewing new in-vehicle navigation systems; evaluating driving behavior affected by alcohol, fatigue, or different devices (which is the area of this research); and testing ABS, 4-wheel drive, and vehicle interior design.

The highest benefit of simulator devices is that they can provide an integrally safe environment for driving research, which can be effortlessly and economically configured to examine a variety of human factors research problems. They also make it possible to manage experimental conditions over a wider variety than field-tests and can be easily transformed from one condition to another. Simulators are linked to computer systems, which can provide online data processing, formatting, and storage and the reduction and compact arrangement of data.

On the other hand, simulator devices provide an artificial setting that could never be the same as the real environment. For example, even in the very advanced simulators the lateral accelerations and longitudinal aspect are limited (63) and only parts of the extremely complicated transport system could be simulated until today. The differences between the real driving environment and the simulated setting may influence subjects' performance and behavior; therefore any performance measures observed in a driving simulator may vary from the same conditions or measures observed during real driving.

2.6 Eye Tracking System

Eye tracking systems are devices with more than a 100-year history of application in various scientific fields that involve analysis of human eye movements. Recording human visual activity as part of eye-tracking studies used specific activities. First research into human eye movements involved a typically invasive way of putting a lens with a special gap for the pupil on a subject's eye. Technological progress made it possible to change the way of gathering information about the movement of the eyes with a device mounted on the subject's head, like the device used during this study, allowing for completely non-invasive measurements by non-contact video observation of eye movement (64).

When considering the possibility of using eye-tracking devices in studies related to road traffic, it is necessary to refer to both the practical and theoretical aspects of their use. Research conducted at the Motor Transport Institute shows a high potential for such application of eye tracking systems from both of those standpoints. Eye-tracking devices are supported by numerous different theories of the cognitive science concerning the relationship between visual stimuli and mental functions of humans. There are lots of studies that indicate eye tracking systems have helped to develop better research with stronger results.

First and foremost is a study performed by NHTSA in 2011 (65), in which eye-tracking devices were examined in terms of the possibility of studying gaze data of motorcycle riders. The results of this study were described as positive. Despite the fact the research was designed to identify possibilities of using eye-trackers for studies, it showed that eye-trackers could be successfully used even on a motorcycle during a real-world traffic drive. In that context, research using mobile eye-trackers in cars seems to be even more feasible and reasonable. The results of these studies indicate a basis from which to prepare real-traffic eye-tracking experiments.

Other research, which is important due to the study subject, was prepared in 2010 by the Department of Traffic and Engineering Psychology of Technology University in Chemnitz (TU). A driving simulator and eye tracking system were used. The drivers were tasked with driving through a T-intersection and turning right, while different conditions of traffic occurred (66).

The TU research was used to examine features of traffic and road design, which could be matched to driver behavior in the intersection. Measurements were made regarding driver behavior and vehicle reactions, and speed while approaching as well as turning right at the four intersection types was computed. During the analysis of the results, the researcher used the SEEV (Salience, Effort, Expectancy, Value) model of allocation of visual attention in comparison of traffic situations in which drivers were tested. Additionally, the drivers' waiting times at the intersections and time gaps when the drivers turned right were examined.

Tests were made on 40 drivers (26 male and 14 female) ranging from 19 to 55 years.

The TU study confirmed, according to the SEEV model, that the higher the event rate of task-relevant information (higher traffic density) the more it grabs the driver's attention and directs it to that source of information. Lower event rate conditions result in lower "interest" from the driver. Also, it was observed that a second Area of Interest is likely to change the gaze direction of the driver significantly only when the first (main) source of information (vehicles from the left side) had a lower event rate.

As indicated, especially by the latter example, eye-trackers are successfully used in road traffic studies both in car simulators and real-world traffic-based types of research. The range of received data could be very wide, depending on the needs of the experiment and the study subject.

2.7 Statistical Model

Statistical modeling is a procedure that uses data and probability to estimate and predict outcomes. Each statistical model includes several predictors. These factors are variables that are likely to impact future outcomes. After data is collected, then a statistical model is formulated (67). This statistical model may engage a simple linear calculation, or it may be more complex like a neural network, plotted out by complex software. As extra data becomes available, the statistical model is revised or validated.

Statistical models are often correlated with many applications in many fields and research areas. One of the most common uses of predictive modeling is in transportation studies, particularly in behavioral research, which have connections to reactions of people (68).

Although it may be tempting to consider that huge data makes statistical models more true and accurate, according to the literature, after a certain number of data, feeding additional data into a statistical model does not increase accuracy of the model (69).

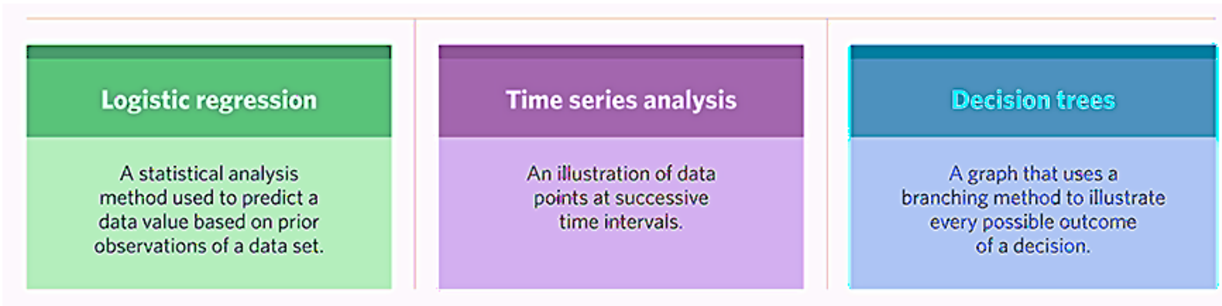

Figure 4 Statistical model methodologies

Once data is collected, the right model must be selected. Linear regression models are among the easiest forms of statistical models. Linear regression models basically take two variables that are correlated (one independent variable and the other a dependent variable). The model employs a best-fit line to the resultant data points (70). Figure 4 shows different statistical model descriptions, including logistic regression, time series analysis, and decision trees. A logistic regression model, also known as logit model, is considered to model dichotomous result variables. In the logistic regression model the log odds of the results is demonstrated as a linear combination of the predictor factors or variables.

2.8 Normalization

Data that is not normalized may include data that is contained in one or more external factors that may reduce the accuracy of results in future. Depending on the field of study it could be bad for security reasons, disk space usage, integrity of data, speed of queries, and, maybe most importantly, data accuracy and efficiency. A database before normalization is one that has not been cleaned logically into pure data. Data should not be redundant, which means that the impurity and duplication of data should be kept to a minimum (71).

According to Merriam Webster the word of normalize means, “to make conform to or reduce to a norm or standard” (72). Normalization is a process of removing redundancies of data. It is a technique that is applied when restructuring or cleaning a dataset (71). Normalization is the statistical procedure of rearranging data so that it meets two important necessities: There is no redundancy of data, and data dependencies are logical. This process is vital for several objects, but mainly because it helps databases to clean and purify the data as much as possible, resulting in increased accuracy.

There are different methods to eliminate and arrange a new data, such as deduction, percentage, or min and max (73). In statistics, normalization have a range of meanings (74). In the simplest situations, this means modifying values collected on different scales to a notionally common scale. In some situations, normalization may refer to more complex modifications for which the aim is to bring the whole probability distributions of modified values into alignment. Other situations of normalization of values in educational assessment may aim to support distributions to a normal distribution. A different approach to normalization of data refers to the creation of new versions of data. The aim of this is that these normalized values consent the comparison of normalized data for different datasets in a way that removes the effects of certain external influences on primary data, exactly (75) what will be reviewed in detail in chapter 4.

There are three main purposes to normalize a data. The first is to minimize identical and duplicate data, the second is to purify and clean the data, and the third is to minimize or avoid data modification issues. A fourth purpose is to simplify queries (74).

CHAPTER 3: Methodology

This study is a pretest posttest experimental study that utilizes a high-fidelity full-scale driving simulator and an eye tracking system to study the effect of cellphone use on drivers' performance.

3.1 Participants

The 40 participants (16 female, 23 male) who participated in this study ranged in age from 18 to over 65, and they were all licensed drivers. After data cleanup, 36 of these cases were analyzed. All participants agreed to participate in the study as volunteers after reading and signing a consent form detailing the purpose and proceedings of the study.

3.2 Procedures

The participants were recruited to drive in the simulator environment while using their cellphones. Recruitment was performed via fliers distributed to schools and colleges and posted on social media such as Facebook, Twitter, and Craigslist. The participants' reaction, speed, acceleration, lane changing, car-following ability, eye and head movement, and crashes were recorded with different levels of cellphone usage: voice command, texting, and hand-held and hands-free talking. Two survey questionnaires were given to the participants to complete. The first questionnaire addressed their socioeconomic characteristics and their usage of and attitude toward distracting devices, which was sent to them prior to their driving experience.

The second questionnaire, given to them immediately after completing their driving, is about their experience and what they learned from it.

The recorded reactions, eye movement, crashes, and near crashes were analyzed by comparing each of the scenarios with speed, acceleration, position of the car, distance of the car from the car in front of it, and missing exits/turns when distracted. Also, the time that eyes are off of the road in each scenario, as determined from the eye tracking system, were analyzed. Each scenario will be discussed later in detail. Methodology will include t-test, ANOVA, U test, Kruskal-Wallis, and Friedman tests to compare driving distractions in each scenario. Also, a regression model will be employed to find the relationship between sociodemographic characteristics and driving distractions.

3.3 Equipment

Morgan State University owns two advanced, computer-based driving simulators. As Figure 4 shows, the simulator displays roads with features such as bridges, ramps, roadside objects, billboards, three-dimensional trees, and buildings, providing a realistic environment for drivers. Eye-tracking glasses record and track the movements of a driver's eyes and head as drivers are driving the simulator. Using an eye tracking system and the driving simulator helps track and record factors like movement of the eyes along with speed, acceleration, lane changing, brake and throttle, lane offsets, crashes, and near-crashes.

The simulator consists of hardware like that of a car: the cockpit, three surrounding monitors, acceleration and brake pedals, ignition key, safety seat belt, automatic transmission, hazard lights, and steering wheel. It uses the software VR-Design Studio made by Forum 8 Co. It is capable of creating and editing the entire map network elements including road alignments, intersection design, traffic signals, cross sections, roadside signs, terrain setup, and traffic generation. This system permits researchers to investigate driver behavior under several designed conditions. This simulator is capable of replicating driving tasks on different roads and scenarios, under different traffic conditions and composition, traffic information (e.g., VMS), and weather conditions (rain, fog, snow). It is also possible to simulate some features such as buildings and road networks with desired characteristics that are similar to the way they appear in the real world. The subjects are capable of choosing their own routes from the origin to the destination.

Figure 5 (a) Network in the simulator (b) Utilized driving simulator

As mentioned earlier the Tobii Pro Glasses 2 (Figure 6) records the eye and head movements of drivers while they are in the driving the simulator. Tobii Pro 2 is a wearable, head-mounted eye tracking glasses system that records the participant's gaze in real time while the person moves freely around an environment or situational scenario. The driving simulator test is supplemented by two survey questionnaires before (appendix A) and after driving (appendix B). IRB approval was received before human subjects were recruited. During the recruitment process, drivers' socioeconomic attributes and characteristics were collected via online surveys before the driving simulator session to ensure a diverse sample of participants who reflect the population. The second survey was collected immediately after the driving simulator to evaluate the effects of tests on drivers.

Figure 6 Pro Glasses 2 eye tracker (photo credit by Tobii Pro catalog)

3.4 Route Design

In the driving simulator, a realistic road network in Baltimore County just north of Baltimore City was developed (Figure 7). The route starts from Hampton Lane and continues to I-695, then Perring Parkway, and Taylor Avenue, and ends at Radar Avenue. It includes main roads, signs, trees, and buildings. Participants were asked to drive from the origin (yellow star) to the destination (blue star). As shown in Figure 7, they have four types of road based on their speed limits. These roads are: highway, urban, rural, and local (which is a school zone). The table below presents more information about these roads.

Table 1 Road types and characteristics

Road Type	**Road Name**	**Speed limit**	**Lanes per Direction**
Highway	I-695	88 km/hr	4
Urban Arterial	Perring	64 km/hr	3
Rural Road	Hampton	48 km/hr	2
Local Road (school zone)	Radar	40 km/hr	1

Six scenarios were developed to study the effect of different types of distractions—no cellphone usage, hand-held call, hands-free call, voice command, and text messaging— with specific questions for each scenario (appendix C) on driving performance. All of these scenarios are on a dry road in daylight with mild traffic, and each scenario takes about 15 min to complete. There are breaks between scenarios to reduce fatigue.

Figure 7 Realistic network map

3.5 Statistical Roadmap

As mentioned before six different scenarios were performed, and these are:

- S1 & S6: No cellphone (these are the same to evaluate the effect of learning)
- S2: Hand-held
- S3: Hand-free
- S4: Voice command

- S5: Texting

Figure 8 presents different types of analysis/description. Scenario 1 is the base scenario without any distraction to benchmark the study. Participants drove the scenarios in order. However, one might argue that participants' fatigue due to driving different scenarios would affect the results. Therefore, we added the no-distraction scenario as the last scenario to find and deduct the fatigue effect.

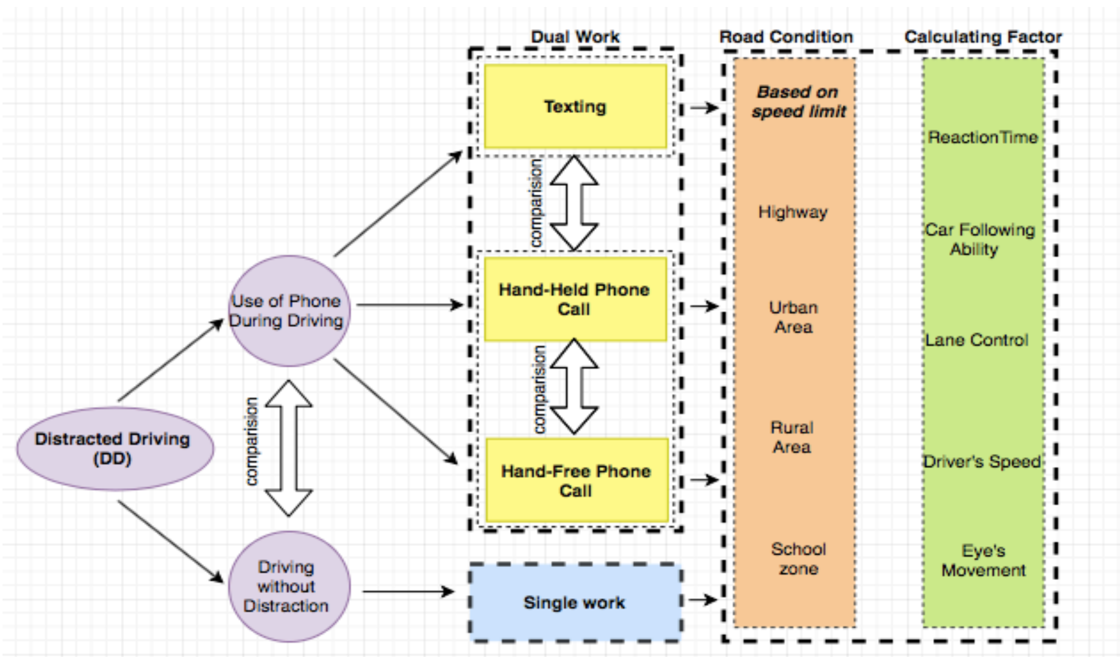

Figure 8 Conceptual diagram example of project analysis

To create these scenarios in each drive, at a specific distance in each road, a person called or texted the drivers and asked them specific questions which were different on different roads as presented in Appendix 3.

CHAPTER 4: Findings and Results

In order to fulfill the objectives of this research, different tests and analyses were applied in four different types of data, pre-survey, post-survey, eye tracking, and simulator.

4.1 Pre-Survey Data

In the following section, all data from pre-test surveys from 39 participants were analyzed.

The collected data were transferred to Excel and after data screening and cleaning, 36 participants remained. Then those data were transferred to IBM SPSS 24 and the frequency (percent) of quantitative data was evaluated. Table 2 presents sociodemographic characteristics from the pre-survey questionnaire.

Table 2 Demographic characteristics of participants

Characteristics		Frequency	Percent
Age (year)	18–20	4	10.3
	21–25	21	53.8
	26–30	5	12.8
	31–35	4	10.3
	36–45	4	10.3
	More than 55	1	2.6
Gender	Female	16	41.0
	Male	23	59.0
Ethnicity	Asian - Pacific	6	15.4
	African American	19	48.7
	Hispanic	1	2.6
	Other	8	20.5
	White	5	12.8
Education	Associate degree	3	7.7
	College graduate	8	20.5
	College student	13	33.3
	High school or less	11	28.2
	Post graduate	4	10.3
Employment	Unemployed	18	46.2

	Full time	12	30.8
	Part time	9	23.1
Income ($)	Less than 20K	16	41.0
	20K–30K	8	20.5
	30K–50K	5	12.8
	50K–75K	4	10.3
	75K–100K	1	2.6
	More than 100K	5	12.8
Family size	Less than 4	31	79.5
	4 or More	8	20.5

As presented in Figure 9, approximately 53% of participants are between the ages of 21 to 25 while about 2% of participants are older than 55. As shown in figure 10, 59% of participants are male and 41% are female.

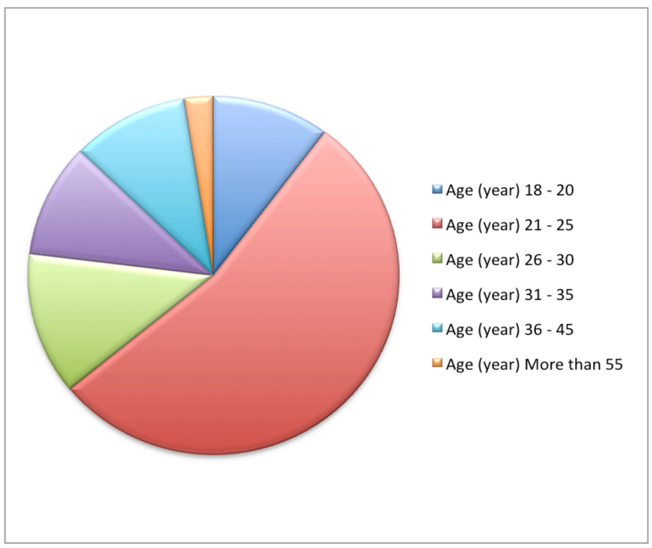

Figure 9 Population by age group

Figure 11 is population by ethnicity. People of varied ethnicity participated in this project; about 48% of them are African American, about 15% are Asian, 12% percent are white, 2% Hispanic, and 20% other races.

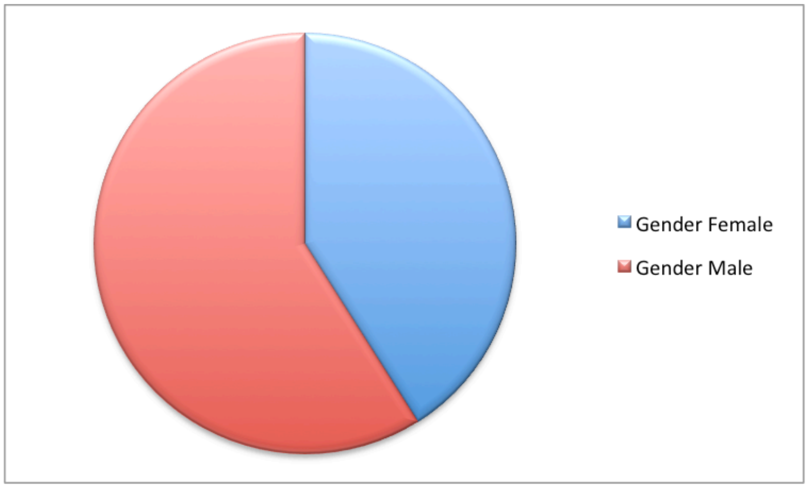

Figure 10 Population by gender

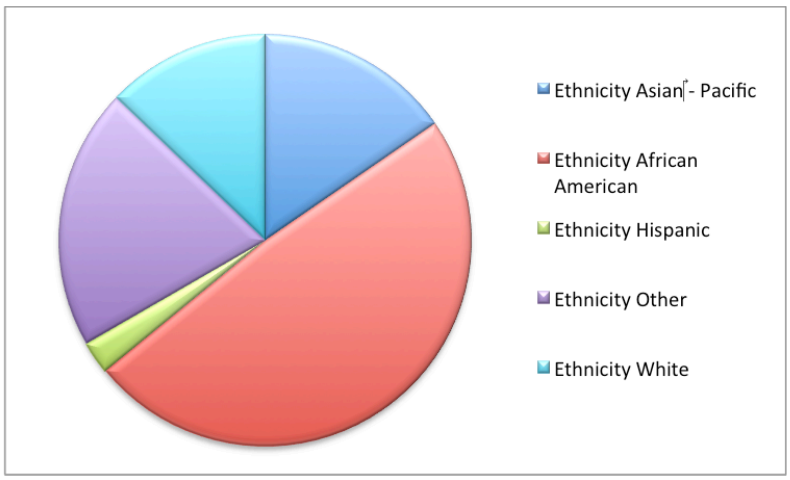

Figure 11 Population by ethnicity

Figure 12 details education; 33.3% of project participants are college students, 28% have a high school degree or less, 20.5% are graduate students, 10.3% are postgraduates, and 7.7% have an associate degree.

The analysis shows that most of participants, 46%, in this research are not employed, 30% are full-time workers, and 23% have part-time jobs (Figure 13).

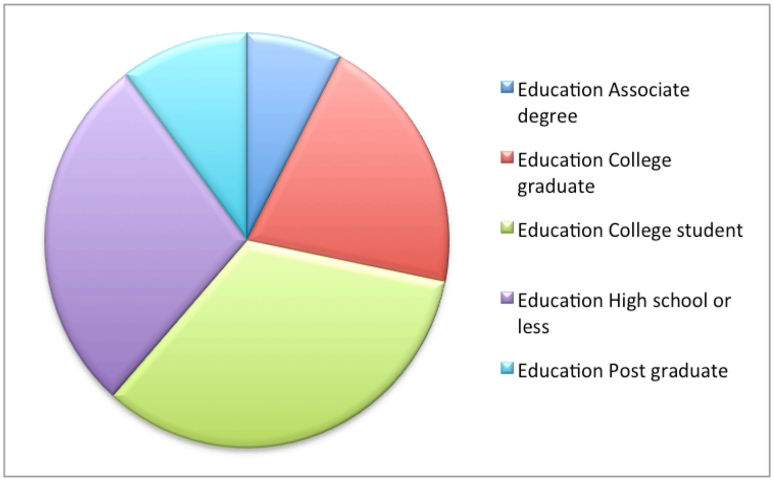

Figure 12 Population by education

Their annual income is shown in Figure 14; most of the participants, 41%, have an annual household income of less than $20K, 20% of participants have incomes between $20K and $30K, about 13% have incomes between $30K and $50K, about 12% have incomes of more than 100K, 10% have incomes between 50K to 75K, and, finally, 2% have incomes between 75K to 100K.

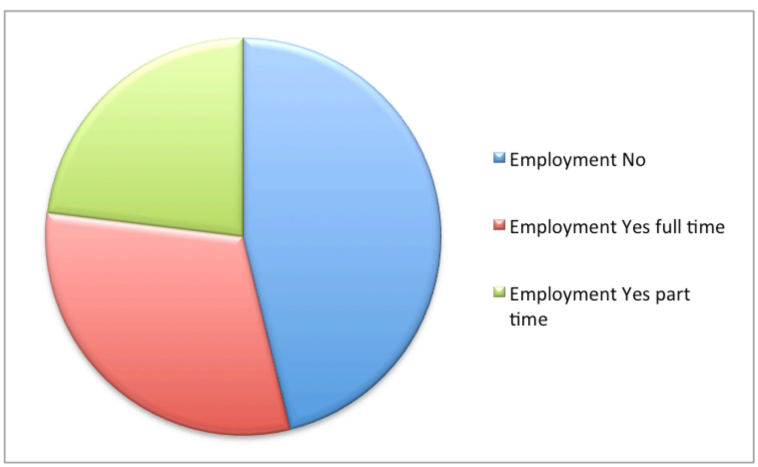

Figure 13 Population by employment

Most of the participants, 79%, have a family size of less than four people and the rest have more than four members in their family.

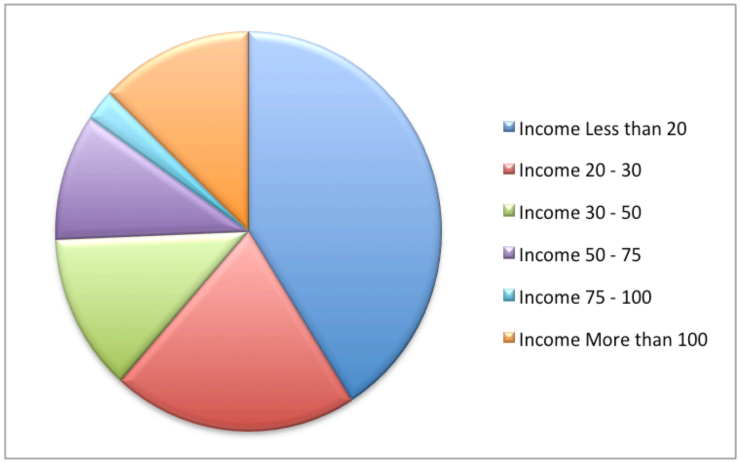

Figure 14 Population by income

Data analysis from the pre-simulator survey shows that 92% of participants in this research have a regular vehicle license, 5% have an all vehicles permit, and only 2% have no permit.

Some 69% of people have less than three cars in their family, 30% have three or more cars, and only 10% don't have a car.

Most of the participants, 76%, have been driving more than three years.

The average annual miles driven for 30% of participants were between 8,000 to 15,000 miles. Some 69% of participants did not use glasses and only about 30% did. Table 3 shows the driving history of participants.

Table 3 Driving history of participants

Variables		Frequency	Percent
Driving permit	No	1	2.6
	All vehicle	2	5.1
	Regular vehicle	36	92.3
Number of cars per houshold	Less than 3	27	69.2
	3 or More	12	30.8
Years of driving experience	Less than 1	4	10.3
	1–2	2	5.1

	2–3	3	7.7
	More than 3	30	76.9
Average annual driving distance (miles)	No car	5	12.8
	Less than 8,000	10	25.6
	8,000–15,000	12	30.8
	15,000–30,000	4	10.3
	More than 30,000	8	20.5
Driving distance per week (miles)	Less than 100	22	56.4
	101–200	11	28.2
	201–300	1	2.6
	301–400	3	7.7
	More than 400	2	5.1
Wearing glasses	No	27	69.2
	Yes	12	30.8

Since this project is simulator-based research, one important factor is motion sickness; according to data approximately 90% of participants don't get motion sickness, and only 2% experienced motion sickness while driving the car (Table 4).

Table 4 History of motion sickness

Vehicles	Frequency	Percent
No	35	89.7
Airplane	1	2.6
Boats	2	5.1
Cars	1	2.6

Most of the participants (about 61%) stated that the following factors do not distract them: accidents, animals, buildings, chatting, glare, joggers, merging, pedestrians, sharp exits, or signs. Table 5 offers more details.

Table 5 Frequency of distractive objects while driving

Objects	Frequency	Percent
Nothing	24	61.5
I don't know	1	2.6

Accidents	2	5.1
Animals	1	2.6
Buildings	1	2.6
Car accidents	1	2.6
Chatting	1	2.6
Signs	1	2.6
Glare	1	2.6
Joggers	1	2.6
Merging	1	2.6
Pedestrians	1	2.6
Sharp exits	1	2.6

Table 6 describes the frequency of social media use while driving. Instagram and Twitter are two social media apps that 7.7% of drivers always use while they are driving, but on the other hand only 2.6% always use Facebook and Snapchat while driving.

Table 6 Frequency of social media use while driving

Social media		Frequency	Percent
Facebook	Always	1	2.6
	Never	28	71.8
	Rarely	7	17.9
	Sometimes	3	7.7
Snapchat	Always	1	2.6
	Never	26	66.7
	Rarely	3	7.7
	Sometimes	9	23.1
Twitter	Always	3	7.7
	Never	34	87.2
	Rarely	1	2.6
	Sometimes	1	2.6
Instagram	Always	3	7.7
	Never	26	66.7
	Rarely	6	15.4
	Sometimes	4	10.3
Other	Never	33	84.6
	Rarely	6	15.4

As mentioned in the second chapter of this dissertation, cellphone usage is an important causative factor in distracted driving. Table 7 shows the usage of cellphone-related technologies while driving; voice to text is ranked first with 23%, followed by text to voice technology that is used by 7.7%. Two other phone-related technologies used while driving had the same percentage of 2.6.

Table 7 Frequency of cellphone-related technologies use while driving

Technology	Frequency	Percent
Headphone	1	2.6
None	23	59.4
N/A	1	2.6
Signal jammers	1	2.6
Text to voice	3	7.7
Voice to text	9	23.1
Text to voice/ Voice to text	1	2.6

Table 8 summarizes the survey questionnaire responses. According to the participants' answers, most of the drivers don't pull over first and then use their cellphone if they receive a call while they are driving. Also, the majority of participants stated that they feel confident that they don't experience any problem using their cellphone while driving.

Approximately 26% of the participants had a near-crash experience and 5% had crashes in the last three years due to using a cellphone while driving. Some 29% of the participants had friends or family who experienced crashes due to usage of cellphones while driving.

If drivers don't use any cellphones during their drive then more than half of them (59%) said that they are very confident that they do not make any mistakes while driving, but if they use some accessories, such as headsets, then the number of drivers confident of not making mistakes drops to 48%. On the other hand, if drivers use a cellphone freely or use technologies like voice to text, then only 35% of drivers feel very confident during their drive.

About 51% of participants mentioned that they never talk on a hand-held phone; 15% sometimes talk on their phone while they are driving. Some 46% don't text, but 23% sometimes text during their drive. About 79% never read or update their social media, and only 5% update their social media while driving. When it comes to games, 95% never play while driving, but 3% do. Some 77% of drivers never check email and 8% sometimes do while driving.

With regard to taking pictures, 53% reply never and 12% reply they sometimes take pictures with their phones while driving. But 25% of participants never and 59% sometimes use the cellphone's GPS while they are driving. Some 7.7% don't eat or drink while driving but 38.5% sometimes eat while driving. All the participants stated that they never shave or apply makeup while they are driving.

IOS, used by 41% of participants, is the most popular type of cellphone, followed by Android with 28%, then Windows, 5%, while 25% reported using other types during this project.

Table 8 Pre-simulation survey questionnaire data analysis

Item	Response category	Frequency	Percentage
If you need to text or answer/make a call, while you are driving, how likely is it that you pull over first and then use your cellphone?	Not at all	12	30.8
	Some what	7	17.9
	A great extent	8	20.5
	Very little	12	30.8
How confident are you that you would not experience any problem using your cell phone while you drive?	Confident	12	30.8
	Doubtful	3	7.7
	Neither	15	38.5
	Very confident	8	20.5
	Very doubtful	1	2.6
How many times have you experienced a near-crash experience due to using cell phone while you were driving in the last three years?	0	29	74.4
	1	6	15.4
	2	2	5.1
	3	1	2.6
	4	1	2.6
How many times have you experienced a crash due to using a cellphone while you were driving in the last three years?	0	37	94.9
	1	2	5.1
How many times have your friends or family members experienced an accident due to using a cellphone while they were driving in the last three years?	0	28	71.8
	1	5	12.8
	2	3	7.7
	3	1	2.6
	4	2	5.1
To what extent are you confident that YOU, driving in the following situations, would NOT experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.? [No cellphone while driving]	Confident	8	20.5
	Doubtful	4	10.3
	Neither	4	10.3
	Very confident	23	59.0
To what extent are you confident that YOU, driving in the following situations, would NOT experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.? [Using accessories such as headsets]	Confident	12	30.8
	Doubtful	2	5.1
	Neither	6	15.4
	Very confident	19	48.7
To what extent are you confident that YOU, driving in the following situations, would NOT experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.? [Technologies such as voice to text]	Confident	13	33.3
	Doubtful	4	10.3
	Neither	8	20.5
	Very confident	14	35.9
To what extent are you confident that YOU, driving in the following situations, would NOT	Confident	13	33.3
	Doubtful	6	15.4

experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.? [Using cellphone freely]	Neither	6	15.4
	Very confident	14	35.9
What kind of activities do you indulge in while driving? [Talk on the phone (hand held)]	Always	1	2.6
	Never	20	51.3
	Rarely	12	30.8
	Sometimes	6	15.4
What kind of activities do you indulge in while driving? [Text]	Never	18	46.2
	Rarely	12	30.8
	Sometimes	9	23.1
What kind of activities do you indulge in while driving? [Read/update Social Media]	Never	31	79.5
	Rarely	6	15.4
	Sometimes	2	5.1
What kind of activities do you indulge in while driving? [Play Games]	Never	37	94.9
	Rarely	1	2.6
	Sometimes	1	2.6
What kind of activities do you indulge in while driving? [Read/respond to Emails]	Always	1	2.6
	Never	30	76.9
	Rarely	5	12.8
	Sometimes	3	7.7
What kind of activities do you indulge in while driving? [Take pictures/record video]	Never	21	53.8
	Rarely	13	33.3
	Sometimes	5	12.8
What kind of activities do you indulge in while driving? [Follow GPS directions/reroute]	Always	10	25.6
	Never	3	7.7
	Rarely	3	7.7
	Sometimes	23	59.0
What kind of activities do you indulge in while driving? [Eat/Drink]	Always	3	7.7
	Never	7	17.9
	Rarely	14	35.9
	Sometimes	15	38.5
What kind of activities do you indulge in while driving? [Change Clothes]	Never	37	94.9
	Rarely	1	2.6
	Sometimes	1	2.6
What kind of activities do you indulge in while driving? [Shave]	Never	39	100
What kind of activities do you indulge in while driving? [Makeup]	Never	39	100
What type of phone are you using for this test?	Android	11	28.2
	IOS	16	41.0
	Windows	2	5.1
If your phone rings or you receive a text message while driving what is your response?	I will answer	4	10.3
	I will answer in a safer situation	13	33.3

	I will ignore it	8	20.5
	I will stop on shoulder	1	2.6
	My phone is set in automatic answer	3	7.7
	None	10	25.6

Moreover, about 8% stated that they set their phone to automatic answer, 33% of drivers will answer their phone in a safer situation if they get a call or text while driving, and 20% will ignore it. Only 10% of participants will answer their phone no matter what the situation is while they are driving.

4.2 Post-Survey Data

The post-survey questionnaire responses were transferred to Excel and after data screening, correcting missing data, grouping the quantitative data and converting them to qualitative data, and coding, 36 participants remained. Then those data were transported to IBM SPSS 24 and the frequency (percent) of quantitative data has been evaluated.

Table 9 presents the symptoms' frequency and severity after using the driving simulator. Some 42% of participants did not have general discomfort, 52% have no fatigue, 50% have no headache, 60% have no blurred vision, 73% have no salivation increase or decrease, 76% have no sweating symptom, 60% have no dizziness, and 76% have no nausea after driving the simulator.

Table 9 Symptoms frequency and severity after driving the simulator

Symptoms	Severity	Frequency	Percent
General Discomfort	No	16	42.1
	Slight	19	50
	Moderate	1	2.6
	Severe	2	5.3
Fatigue	No	20	52.6
	Slight	14	36.8
	Moderate	3	7.9
	Severe	1	2.6
Headache/Eyestrain	No	19	50
	Slight	13	34.2
	Moderate	5	13.2
	Severe	1	2.6
Blurred vision	No	23	60.5
	Slight	11	28.9
	Moderate	4	10.5
	Severe	0	0
Salivation increase/decrease	No	28	73.7
	Slight	8	21.1
	Moderate	1	2.6
	Severe	1	2.6
Sweating	No	29	76.3
	Slight	5	13.2
	Moderate	3	7.9
	Severe	1	2.6
Dizziness	No	23	60.5
	Slight	9	23.7
	Moderate	4	10.5
	Severe	2	5.3
Nausea	No	26	68.4
	Slight	7	18.4
	Moderate	3	7.9
	Severe	2	5.3

Furthermore, after testing, 37% of drivers stated that the driving simulator experience reduced to a great extent the likelihood of their using a cellphone while driving. Also 42% of participants think that they made more than three times the normal number of mistakes while they were driving the simulator.

Table 10 Post-survey data analysis

Items		Response category	Frequency	Percent
To what extent does this experience reduce the likelihood of you using a cellphone while driving?		Not at all	2	5.3
		Very little	8	21.1
		Somewhat	13	34.2
		Great extent	14	36.8
		Not applicable	1	2.6
How many times do you think you made a mistake (deviating from the destination, going through a red light, near-crash experience, crash, etc.) during the last simulation run?		None	3	7.9
		1	7	18.4
		2	12	31.6
		3 or more	16	42.1
Will you return for another simulation run using the driving simulator?		Yes	34	89.5
		No	4	10.5
To what extent are you confident that YOU, driving in the following situations, would NOT experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.?	No cellphone while driving	Very doubtful	1	2.6
		Doubtful	1	2.6
		Neither	4	10.5
		Confident	8	21.1
		Very confident	24	63.2
	Using accessories such as headsets	Very doubtful	2	5.3
		Doubtful	2	5.3
		Neither	4	10.5
		Confident	17	44.7
		Very confident	13	34.2
	Using technologies such as voice-to-text	Very doubtful	9	23.7
		Doubtful	9	23.7
		Neither	4	10.5
		Confident	11	28.9
		Very confident	5	13.2
	Using cellphone freely	Very doubtful	13	34.2
		Doubtful	6	15.8
		Neither	3	7.9
		Confident	10	26.3
		Very confident	6	15.8

Based on the post survey data analysis, 63% of drivers feel very safe and confident if they don’t use their cellphones, while 34% of drivers feel confident if they use accessories such as headsets, and 13% feel safe driving if they use technologies such as voice-to-text. Finally, only 15% feel very confident during the drive if they use cellphones freely.

4.3 Eye-Tracking Data

The eye-tracking videos were reviewed manually, and the collected data, which are the number and duration of events from 36 participants in the study, were extracted from six scenarios for four different roads. The event that was reviewed in this section is eyes off the road. After a transfer from the Excel Sheet to IBM SPSS 24, the data were analyzed in terms of how they are distributed. Further, central indicators and data analysis were computed and plotted to draw different chart or tables.

As noted before, the eye tracking system monitored eye movement’s data. Then the data have been gathered by manually reviewing the recorded videos when the eyes are off the road, in the interval of distraction.

4.3.1 Eyes off of the Road in different Scenarios

By examining the data from the eye tracking system and comparing different scenarios, it became clear that the complexity of distraction boosted the time of eyes off of the road. It means that, in the first and final scenarios (no cellphone scenarios), the eyes off of the road had the least amount of time, while this amount was the highest in texting as shown in Figure 15.

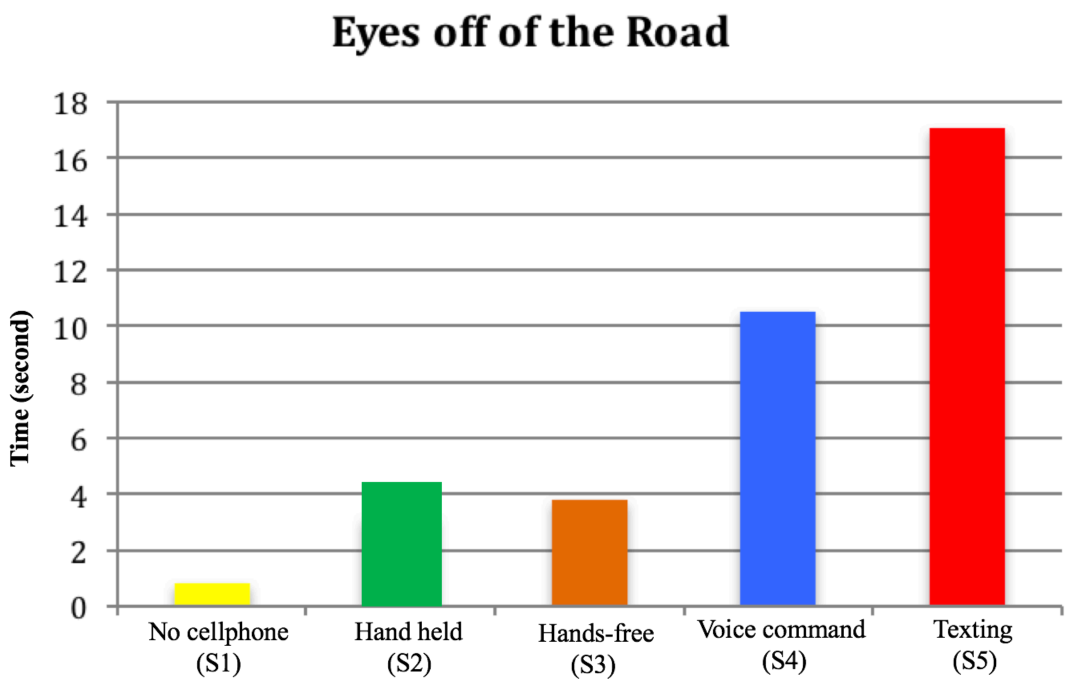

Figure 15 Eyes off of the road based on scenarios

It was also found that in the two major categories of call (hand-held and hands-free) and texting (voice command and texting) in which the technology was accompanied, the amount of time that eyes were off of the road is less than other distractive scenarios. For example, the use of voice command (Scenario 4) has reduced the average of duration of eyes off the road by seven seconds compared with the texting (Scenario 5). It should be noted that in later sections, the eyes off of the road were defined as a level of distraction.

The following figures show the time of eyes off of the road in each scenario. As presented in Figure 16, eyes off of the road in the first and last scenarios ranges from 0 to 3 seconds, while this amount increased in other scenarios. In hands-free calling the eyes off the road varies from 0 to about 9 seconds (Figure 17). This value was increased further from 0 to 20 seconds in hand-held talking. The eyes off of the road are between 0 and 25 seconds in voice command, and up to 37 seconds in the texting scenario. Figure 21 presents all scenarios in one chart.

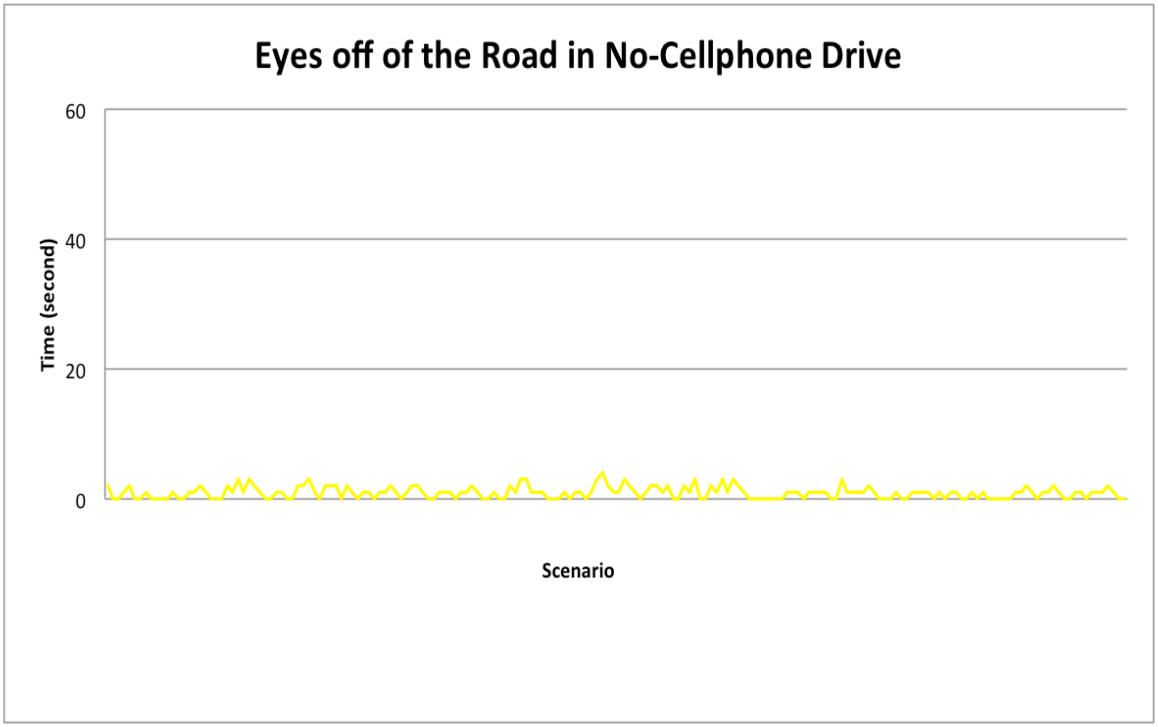

Figure 16 Eyes off of the road in cell-phone drive (S1)

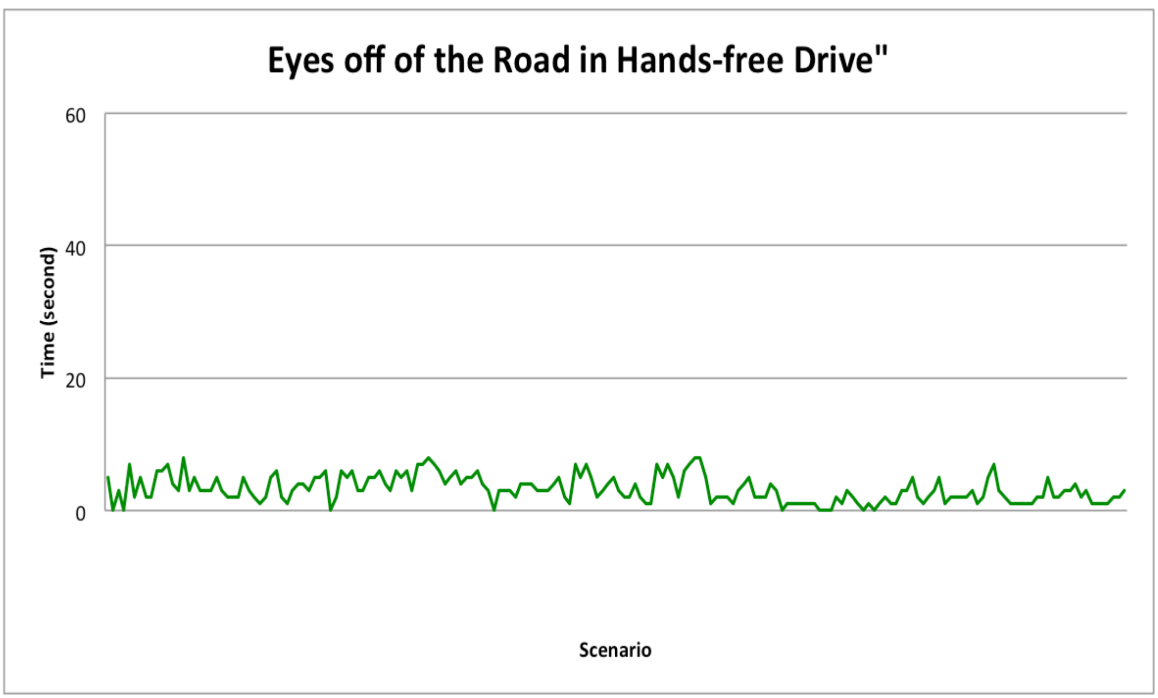

Figure 17 Eyes off of the road in hands-free drive (S2)

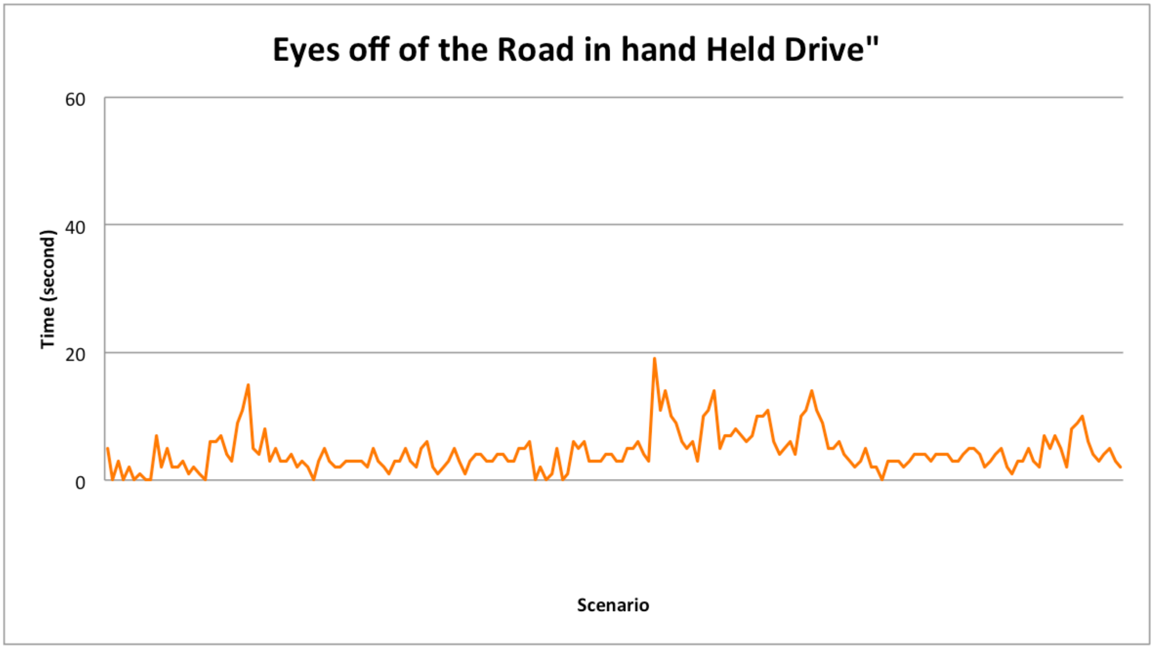

Figure 18 Eyes off of the road in hand held drive (S3)

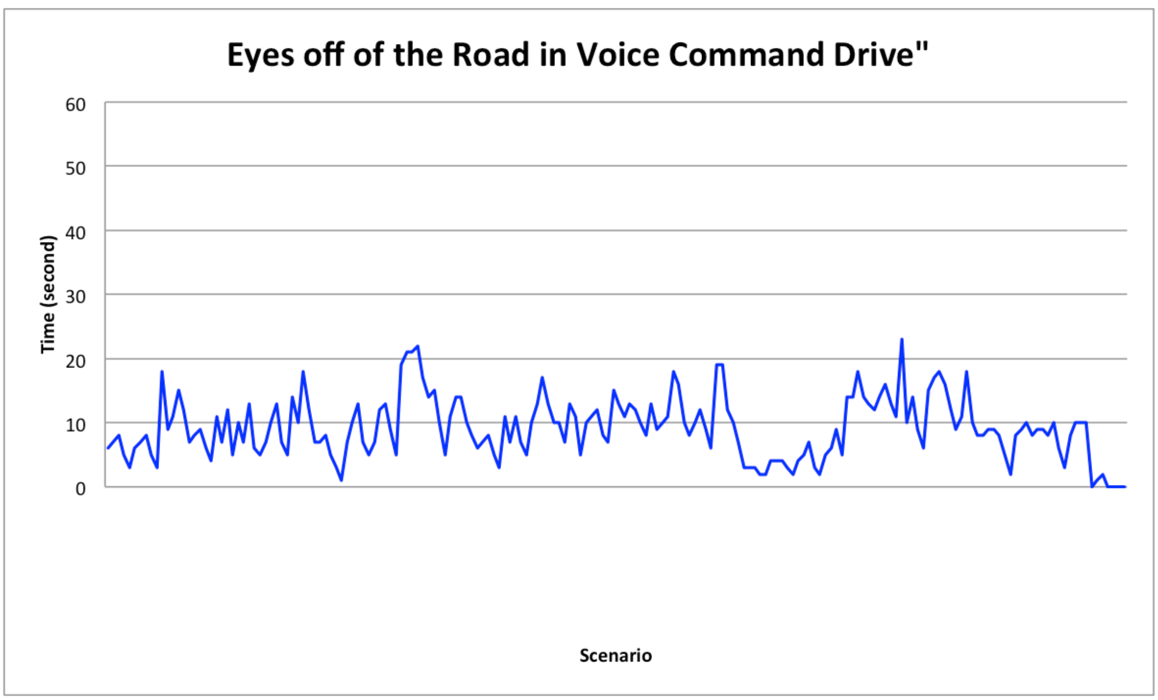

Figure 19 Eyes off of the road in voice command drive (S4)

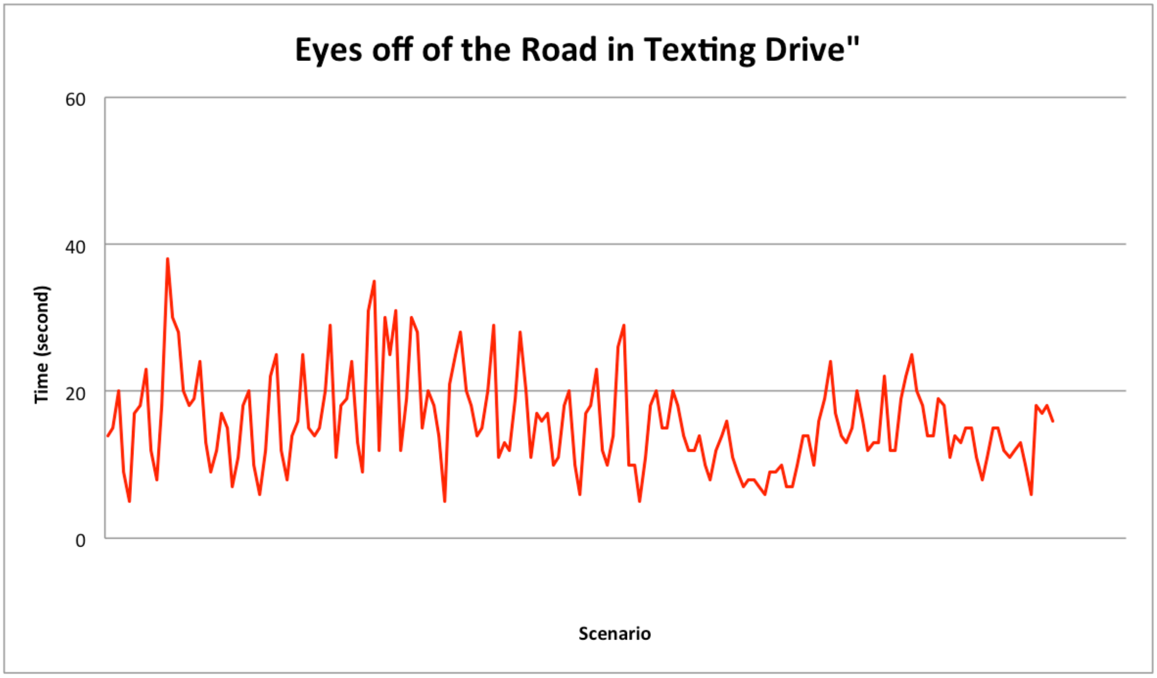

Figure 20 Eyes off of the road in texting drive (S5)

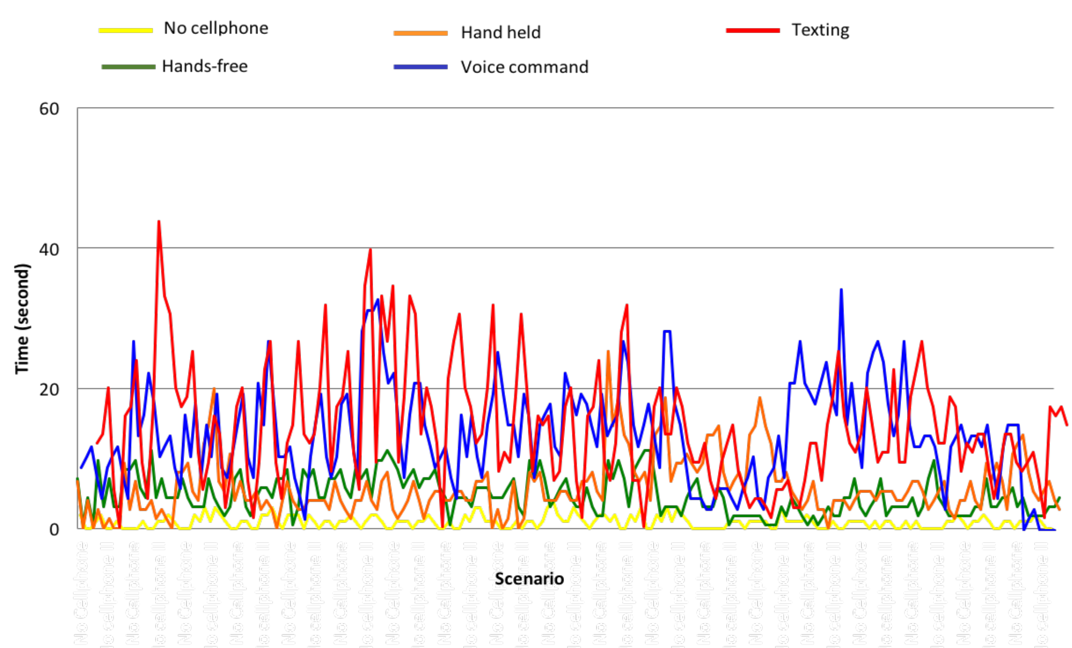

Figure 21 Combination of all scenarios

4.3.2 Eyes off of the Road on different Roads

This section examines the eyes off of the road on different roads (urban, highway, rural, and school zone). As shown in Figure 22, there is a correlation between the road class and the average time that eyes are off of the road.

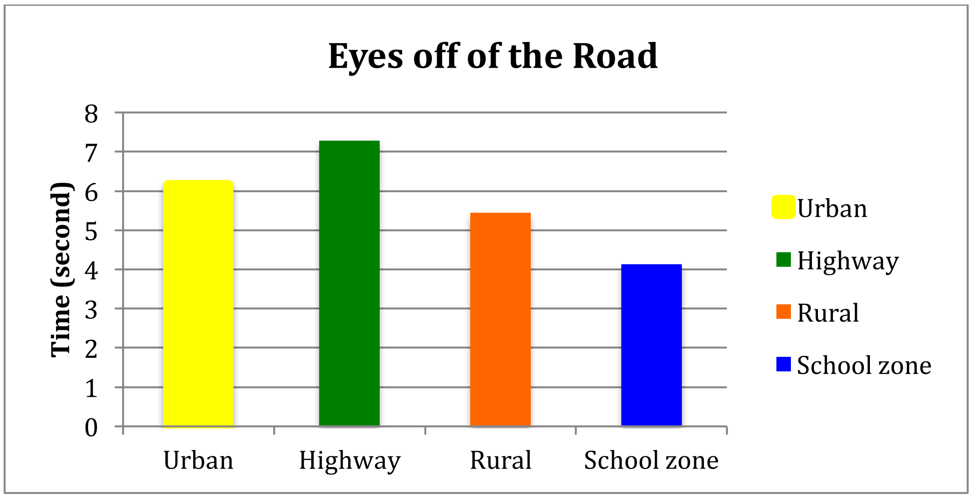

Figure 22 Eyes off road on different roads

The highway had the highest time off of the road, followed by urban, rural, and school zone. The reason could be the speed limit, traffic volume, or cognitive load.

4.4 Simulator Data

The first raw data from the simulator output for 36 participants was screened, and some variables such as average brake, throttle, lane changing, offset from lane center, and speed and acceleration (appendix D) in six different scenarios, for all four roads were calculated and reviewed. The aformentioned variables for all scenarios and roads were compared during the distraction period. Furthermore, the variables were compared for before, after, and during distractions.

As mentioned earlier, this study contains six different scenarios with four different road classes. In this section, various tests was applied to analyze and compare the effect of distraction on drivers. These tests are ANOVA (one way and two way), Kolmogorov-Smirnov, and Friedman test, and also at the end a statistical regression model was designed.

An ANOVA test is usually used to compare the mean of variables in more than two groups and a one-way ANOVA test compares the mean of one variable in each group but repeatedly.

The Kolmogorov-Smirnov test evaluates the distribution of these data. Consequently, if the distribution of data is not normal then description is possible with Median evaluation, and Friedman's repeated measurements will be a suitable statistical test for these analyses.

4.4.1 Fatigue and Tiredness

One of the initial questions at the beginning of this research was whether fatigue affects the performance of drivers. In this research scenarios have an ordered structure; however many studies run scenarios randomly, such as the study by Louisiana State University in 2014 (76). The LSU study participants were randomly assigned into three different types of phone call scenarios: no call, mundane call, and intense or emotional call to remove the effect of the fatigue and tiredness on the results of study. But this study is looking to capture the effect of fatigue, and puts all scenarios in an ordered setup for the entire process of data collection.

To find and capture this effect, the base scenario (no distraction) was run at the beginning (scenario 1) and at the end (scenario 6) of the experiment. The driving performances were compared between these two scenarios.

By comparing the results of the two data collection systems, the simulator and eye tracking systems, and comparing the two scenarios without distraction, scenario 1 and scenario 6, the frequency of events, such as not looking at the road, did not change. There was no significant change in driver performance-related variables such as brakes or throttle, or even steering, except the speed that increased in scenario 6 (figure 23).

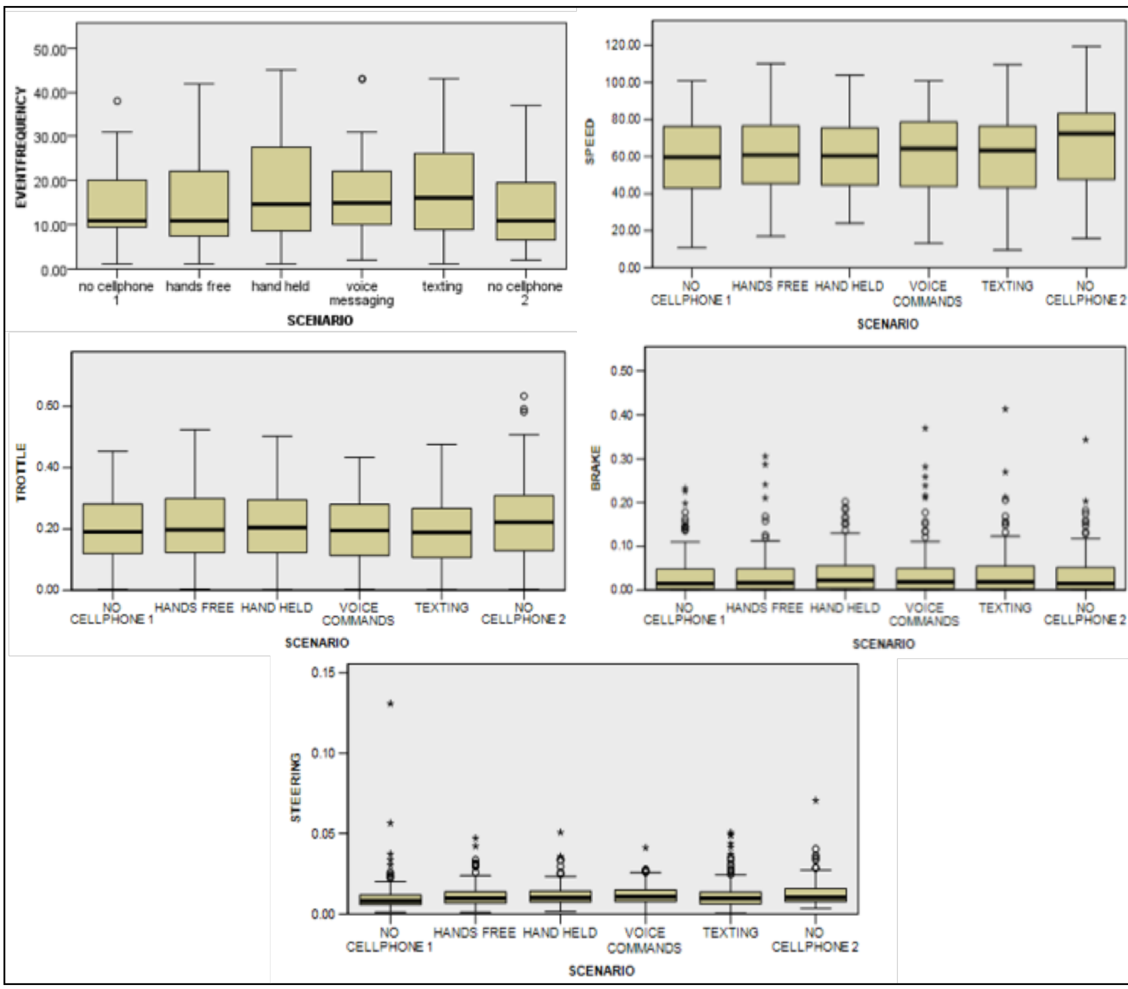

Figure 23 Plot box of different scenarios

Thus, it can be interpreted that repeatedly driving a route for about 1.5 hours with breaks in between 15-minue scenarios did not result in fatigue or tiredness; however the average speed increased, which likely can be attributed to factors such as familiarity with the road and the conditions of the test, or learning.

The learning can be considered a confounder, since there is no learning intervention, so each participant, based on his or her ability to concentrate, achieved this skill.

4.4.2 Learning

Figure 24 presents different roads with different segments. These segments are before, during, and after distraction. Five distraction points are shown with red arrow symbols on the map; all of these points are the starting point of distraction.

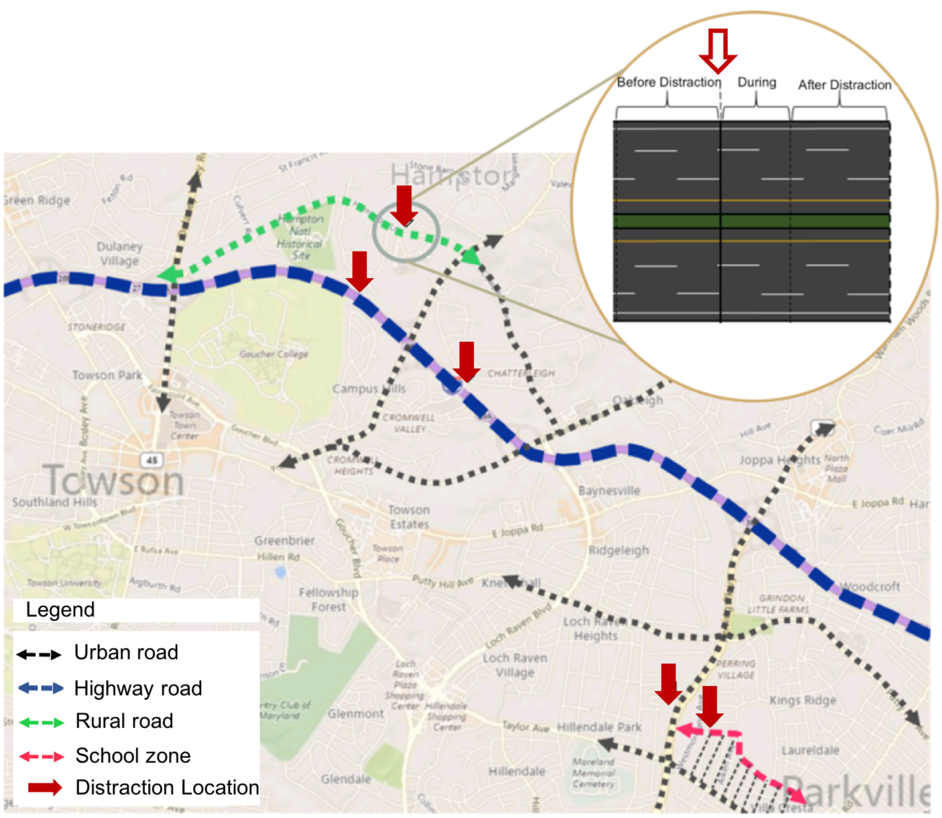

Figure 24 Location of distraction segments

Moreover, in each distraction area three different segments are defined, before distraction, during, and after distraction.

The information for each segment is presented in Table 11. Each segment has specific durations of time and distance based on the road and average of time in each segment that participants are driving; as mentioned, the starting point of the distraction during the distraction section is where the distraction has begun. Several videos have been seen and the average of distraction time was about 36 seconds in each road, and then based on the speed limit of each road the distraction area has been calculated.

Table 11 Distraction segments information

Road Type	Road Name	Distraction Area	After Distraction Area	Before Distraction Area	Speed limit	Distraction Time
Highway Road	I-695	880 m	880 m	880 m	88 km/hr	36 S
Urban Arterial	Perring	640 m	640 m	640 m	64 km/hr	36 S
Rural Road	Hampton	480 m	480 m	480 m	48 km/hr	36 S
Local Road (school zone)	Radar	400 m	400 m	400 m	40 km/hr	36 S

By examining the data from the simulator in the previous section, it was found that the learning factor influenced the performance (only speed) of the participants. The main focus of this study is to evaluate the effect of cellphones on drivers' performance, but to achieve this purpose the purifying of speed is required. Therefore, to subtract the effect of learning on speed data, the normalization process has been applied. As mentioned in Chapter 2, the normalization is the process of organizing and designing a new data for which redundant data is eliminated and only data related to the attribute is exported (77). There are different methods to eliminate and arrange a new data, such as deduction, percentage, or min and max (78). According to the literature different studies have applied different models of normalization in their methodology; one research in 2016 (78) used min and max normalization to eliminate the individual difference within each participant (73).

In this study to normalize the speed and remove the pure learning effect in each scenario, two steps have been taken: normalization process before distraction and normalization during distraction.

In the first step, ANOVA was performed to find the average speed differences between each two scenarios for the before-distraction segment. The difference between average speeds in the before-distraction segment of each scenario and its previous scenario was calculated; this number has been collected from the Post Hoc test. Afterward, to figure out if this method is proper or not, the calculated mean difference was deducted from the mean of speed for the before-distraction segment for each scenario. Figure 25 presents the normalization process before distraction. After the normalization, the average of speed in all scenarios is similar; that means the effect of learning has been removed.

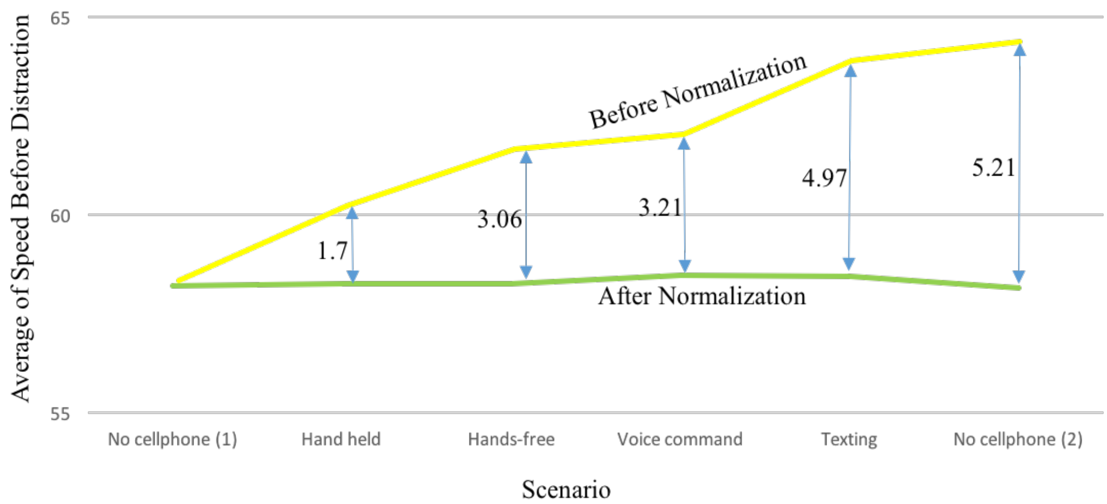

Figure 25 Deduction normalization method before distraction

As mentioned before different methods could be applied to normalize the speed, the percentage method, using percentage of mean difference (figure 26) or the deduction method, using the difference of mean. In this research the deduction normalization has been selected since its simpler and more convenient.

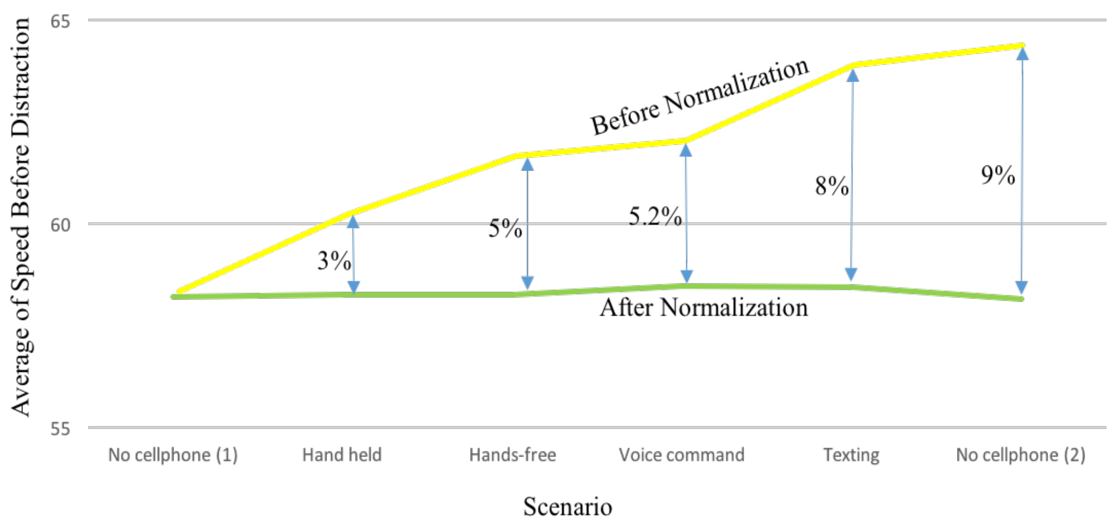

Figure 26 Percentage normalization method before distraction

By examining the normalization process before distraction, when distraction doesn't affect this data, it appears that this method is an appropriate way to exclude the learning effect on the during-distraction segment.

Consequently, in the second step the calculated mean difference of before distraction was deducted from the mean of speed during the distraction segment for each scenario. Figure 27 shows speed before and after normalization during distraction. The newly calculated speed is called normalized speed, which is presented in green in the figure below.

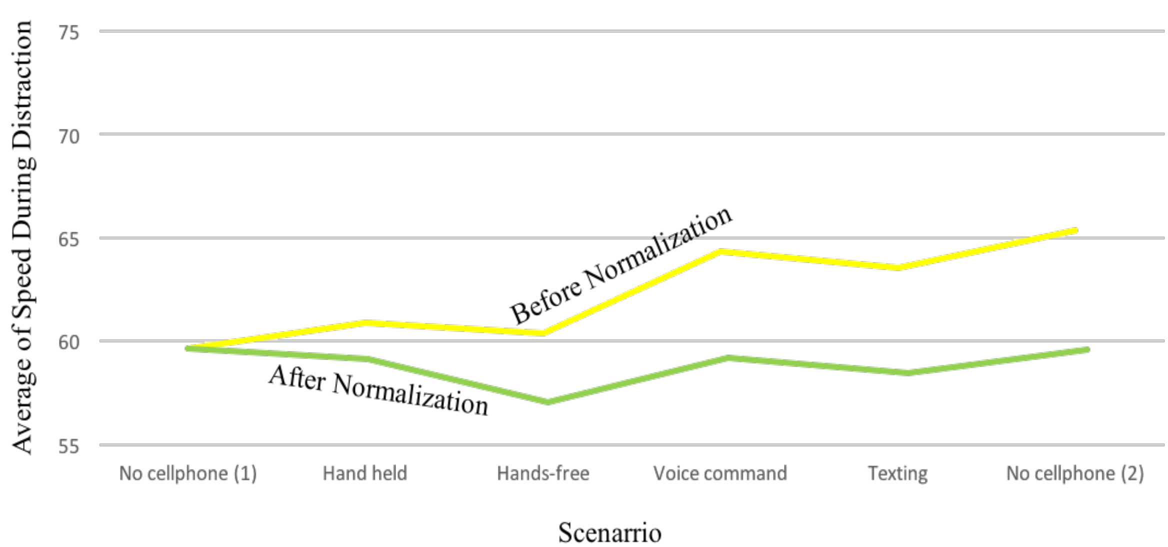

Figure 27 Normalization process during distraction

Table 12 presents average speeds of before, and during distraction before normalization and after normalization for each scenario. The mean of speed before normalization in the before- and during-distraction segments in scenario 1 and 6 is different, but after the normalization process it becomes the same.

Table 12 presents average speeds of before, and during distraction before normalization and after normalization for each scenario. The mean of speed before

normalization in the before- and during-distraction segments in scenario 1 and 6 is different, but after the normalization process it becomes the same.

After the normalization process and eliminating the effect of learning, another ANOVA was performed to find the average normalized speed and differences between each two scenarios for the during-distraction segment. Again the average speed of scenarios 1 and 6 became almost the same.

Table 12 Speed comparison before and aduring distraction

Scenarios		Mean of Speed Before Normalization	Deduction value (mean difference)	Mean of Speed After Normalization
No cellphone (1)	Speed before	58.2	0	58.2
	Speed during	59.65	0	59.65
Hand held	Speed before	59.97	1.7	58.27
	Speed during	60.9	1.7	59.2
Hands-free	Speed before	61.33	3.06	58.27
	Speed during	60.39	3.06	57.33
Voice command	Speed before	61.69	3.21	58.48
	Speed during	64.36	3.21	59.25
Texting	Speed before	63.43	4.97	58.46
	Speed during	63.56	4.97	58.59
No cellphone (2)	Speed before	63.87	5.21	58.16
	Speed during	65.36	5.21	59.6

Also the Post Hoc test presented in Table 13 verifies the claim, and the speed of scenario 1 and scenario 6 is not statistically different.

Therefore, in future sections, the normalized speed is utilized to compare drivers' distraction and performance in different scenarios and roads.

Table 13 Results of Post Hoc of speed during distraction after normalization

Scenario	Scenario	Sig.
No cell phone (1)	Hand-held	.991
	Hands-free	.056
	Voice command	1.000
	Texting	1.000
	No cellphone (2)	.235
Hand-held	No cellphone (1)	.991
	Hands-free	.995
	Voice command	.976
	Texting	.988
	No cellphone (2)	.960
Hands-free	No cellphone (1)	.056
	Hand-held	.995
	Voice command	.021
	Texting	.001
	No cellphone (2)	.202
Voice command	No cellphone (1)	1.000
	Hand-held	.976
	Hands-free	.021
	Texting	1.000
	No cellphone (2)	.326
Texting	No cellphone (1)	1.000
	Hand held	.988
	Hands-free	.001
	Voice command	1.000
	No cellphone (2)	.279
No cellphone (2)	No cellphone (1)	.235
	Hand-held	.960
	Hands-free	.202
	Voice command	.326
	Texting	.279

4.4.3 Scenario Comparison

Since it was determined in the analysis carried out in the previous section that the relationship between speed and distraction is statistically significant, in this section only average of normalized speed will be investigated. In order to find the percentage and difference of distraction between different scenarios, an ANOVA and post hoc Tukey were utilized. The result of the ANOVA test compares the average of normalized speed among different scenarios. As shown in the Table 14, in scenario 2 which is hand-held drive and scenario 5 which is texting drive, the average speed has declined more than the rest of the scenarios.

As shown in Table 14, there are two rows of green which represent the call categories and two yellow rows showing texting categories. It can be pointed out that when participants use technology (hands-free device, and voice command technology) they reduce their speeds less than when they do hand-held talking or texting. Moreover, Table 15 represents the multiple comparisons of average speed among different scenarios. The average speed in the hand-held scenario decreases by 0.45 km/hr compared to no distraction.

Table 14 Comparison of speed between scenarios

Scenario	N	Mean of speed
No cellphone	189	59.65
Hand-held	188	59.2
Hands-free	191	57.33
Voice command	181	59.25
Texting	175	58.59
Sig.		0.05

Table 15 Post Hoc results

Scenario	Scenario	Mean Difference
Hand-held	No cellphone	-0.45
	Hands-free	1.87
	Voice command	-0.05
	Texting	0.61
Hands-free	No cellphone	-2.32
	Hand-held	-1.87
	Voice command	-1.92
	Texting	-1.26
Voice command	No cellphone	-0.4
	Hand-held	0.05
	Hands-free	1.92
	Texting	0.66
Texting	No cellphone	-1.06
	Hand-held	-0.61
	Hands-free	1.26
	Voice command	-0.66

Also, the average speed in the hands-free scenario decreases by 2.32 km/hr compared to no cellphone usage while driving. The average speed in the hands-free scenario is 1.87 km/hr less than the average speed in the hand-held scenario. On the other hand, the average speed in the voice command scenario is 0.4 km/hr less than the no cellphone scenario. Furthermore, the average speed in the texting scenario is 1.06 km/hr less than the one with no cellphone. The average speed in the voice command drive is 0.66 km/hr more than the average speed during the texting scenario.

4.4.4 Road Comparison

In this section, driving performance variables are compared in each scenario for each road class, separately. These variables are average normalized speed, average brake, average throttle, and average offset from the centerline. The results of the two-way ANOVA test are described below:

The results disclosed significant differences in speed, throttle, and steering when comparing different types of cellphone distractions with no cellphone distraction.

Table 16 shows the difference of average of variables on an urban road for different types of distraction. Based on the results, the average speed in different scenarios is statistically significant on the urban road.

Table 16 Descriptive analysis of urban road

Variables		Urban Road				
		N	Mean	Std. Deviation	F	Sig.
Speed	No cellphone	36	55.9099	15.12511	6.800	0.000
	Hand-held	40	44.4321	9.10547		
	Hands-free	39	44.8390	9.42470		
	Voice command	37	45.0089	12.12334		
	Texting	36	42.4511	12.42605		
Throttle	No cellphone	36	0.1398	0.07572	0.345	0.885
	Hand-held	40	0.1351	0.07074		
	Hands-free	39	0.1428	0.07264		
	Voice command	37	0.1356	0.06436		
	Texting	36	0.1252	0.05702		
Brake	No cellphone	36	0.0544	0.04004	1.733	0.128
	Hand-held	40	0.0464	0.02731		
	Hands-free	39	0.0599	0.03182		
	Voice command	37	0.0634	0.03686		
	Texting	36	0.0711	0.05661		

Steering	No cellphone	36	0.0114	0.00681	0.762	0.578
	Hand-held	40	0.0100	0.00696		
	Hands-free	39	0.0113	0.00580		
	Voice command	37	0.0121	0.00710		
	Texting	36	0.0096	0.00478		
Offset from the centerline	No cellphone	36	0.4678	0.26415	0.564	0.727
	Hand-held	40	0.4492	0.19504		
	Hands-free	39	0.4204	0.18806		
	Voice command	37	0.4830	0.25091		
	Texting	36	0.4633	0.26304		

In general, the base scenario (no cellphone drive) has the highest average speed compared to other scenarios, and texting while driving has the lowest average speed on the urban road. There is no statistically significant difference between other variables in the different scenarios on the urban road.

Table 17 Post Hoc results of urban road

Variables			Urban Road		
			Mean Difference	Std. Error	Sig.
Speed	No cellphone	Hand-held	11.47785	2.60107	0.000
		Hands-free	11.07092	2.61682	0.000
		Voice command	10.90107	2.65055	0.001
		Texting	13.45882	2.66864	0.000
Throttle	No cellphone	Hand-held	0.00468	0.01519	1.000
		Hands-free	-0.00296	0.01528	1.000
		Voice command	0.00422	0.01547	1.000
		Texting	0.01458	0.01558	0.937
Brake	No cellphone	Hand-held	0.00803	0.00897	0.947
		Hands-free	-0.00545	0.00902	0.991
		Voice command	-0.00904	0.00914	0.921
		Texting	-0.01673	0.00920	0.457
Steering	No cellphone	Hand-held	0.00140	0.00150	0.937
		Hands-free	0.00018	0.00150	1.000
		Voice command	-0.00068	0.00152	0.998

		Texting	0.00184	0.00153	0.837
Offset from the centerline	No cellphone	Hand-held	0.01865	0.05283	0.999
		Hands-free	0.04748	0.05315	0.948
		Voice command	-0.01511	0.05384	1.000
		Texting	0.00459	0.05420	1.000

Table 17 presents the results of Post Hoc analysis. The average speed in no distraction is 11.47 km/hr more than the average speed in hand-held distraction, 11.07 km/hr more than the average speed in hand-free, 10.90 km/hr more than the average speed in voice command drive, and 13.45 km/hr more than the average speed in texting while driving.

Table 18 presents the difference between various distractions for the average value of variables on a highway road. Based on the results, average speed, throttle, and steering in different scenarios are statistically different from the urban road.

Similar to the urban road, the no cellphone distraction has the highest average speed compared to other scenarios, and texting while driving has the lowest average speed on the highway road.

Furthermore, the no cellphone distraction has the highest average steering compared to other scenarios, and texting while driving has the lowest average steering on the highway.

Table 18 Descriptive analysis of highway road

Variables		Highway Road				
		N	Mean	Std. Deviation	F	Sig.
Speed	No cellphone	72	85.8944	11.28891	28.634	0.000
	Hand-held	80	73.4873	8.90369		

	Hands-free	78	74.5100	7.69657		
	Voice command	74	74.6800	9.36189		
	Texting	72	67.8939	10.38866		
Throttle	No cellphone	72	0.3136	0.09238	2.378	0.038
	Hand-held	80	0.2837	0.08958		
	Hands-free	78	0.2911	0.08224		
	Voice command	74	0.2787	0.08806		
	Texting	72	0.2672	0.08736		
Brake	No cellphone	72	0.0046	0.00547	1.336	0.248
	Hand-held	80	0.0062	0.00709		
	Hands-free	78	0.0069	0.00842		
	Voice command	74	0.0046	0.00633		
	Texting	72	0.0057	0.00684		
Steering	No cellphone	72	0.0152	0.00954	2.463	0.032
	Hand-held	80	0.0131	0.00654		
	Hands-free	78	0.0132	0.00625		
	Voice command	74	0.0141	0.00551		
	Texting	72	0.0142	0.00932		
Offset from the centerline	No cellphone	72	0.4262	0.15970	0.494	0.781
	Hand-held	80	0.3908	0.15854		
	Hands-free	78	0.4228	0.21319		
	Voice command	74	0.4183	0.17769		
	Texting	72	0.4322	0.18367		

Table 19 is the results of Post Hoc analysis on the highway road. The average speed in the no cellphone distraction is 12.40 km/hr more than the average speed in the hand held-distraction, 11.38 km/hr more than the average speed in the hands-free drive, 11.21 km/hr more than the average speed in voice command, and 18.00 km/hr more than the average speed in texting while driving. .

The average throttle ratio in no cellphone distraction is 0.02 more than the average throttle in hand-held, .02 more than the average throttle in hands-free drive, 0.03 more than the average throttle in voice command, and0.04 more than the average throttle in texting while driving.

Table 19 Post Hoc analysis of highway road

Variables			Highway Road		
			Mean Difference	Std. Error	Sig.
Speed	No cellphone	Hand-held	12.40706	1.51196	0.000
		Hands-free	11.38439	1.52112	0.000
		Voice command	11.21442	1.54072	0.000
		Texting	18.0005	1.55124	0.000
Throttle	No cellphone	Hand-held	0.02997	0.01397	0.266
		Hands-free	0.02249	0.01405	0.599
		Voice command	0.03493	0.01423	0.140
		Texting	.04639	0.01433	0.016
Brake	No cellphone	Hand-held	-0.00167	0.00112	0.673
		Hands-free	-0.00236	0.00113	0.295
		Voice command	-0.00009	0.00115	1.000
		Texting	-0.00112	0.00115	0.927
Steering	No cellphone	Hand-held	0.00207	0.00121	0.526
		Hands-free	0.00200	0.00122	0.572
		Voice command	0.00108	0.00123	0.952
		Texting	0.00091	0.00124	0.978
Offset from the centerline	No cellphone	Hand-held	0.03538	0.02929	0.833
		Hands-free	0.00338	0.02947	1.000
		Voice command	0.00789	0.02985	1.000
		Texting	-0.00604	0.03005	1.000

Like the urban road, average speed is the only variable which is statistically significant among the different scenarios on the rural road (Table 20). The no cellphone drive has the highest average speed compared to other scenarios and voice command driving has the lowest average speed on the rural road.

Table 20 Descriptive analysis of rural road

Variables		Rural Road				
		N	Mean	Std. Deviation	F	Sig.
Speed	No cellphone	36	67.4091	17.17559	5.053	0.000
	Hand-held	40	56.1744	14.01888		
	Hands-free	40	54.5220	11.22080		
	Voice command	37	54.3640	14.13524		
	Texting	36	54.8433	12.22424		
Throttle	No cellphone	36	0.2435	0.11183	1.815	0.111
	Hand-held	40	0.2163	0.08671		
	Hands-free	40	0.1996	0.06819		
	Voice command	37	0.1922	0.07642		
	Texting	36	0.2107	0.06862		
Brake	No cellphone	36	0.0337	0.04019	0.645	0.666
	Hand-held	40	0.0328	0.02922		
	Hands-free	40	0.0380	0.03742		
	Voice command	37	0.0265	0.03324		
	Texting	36	0.0372	0.03970		
Steering	No cellphone	36	0.0117	0.00879	1.573	0.169
	Hand-held	40	0.0089	0.00619		
	Hands-free	40	0.0093	0.00575		
	Voice command	37	0.0101	0.00583		
	Texting	36	0.0106	0.00755		
Offset from the centerline	No cellphone	36	0.3223	0.13625	0.190	0.966
	Hand-held	40	0.3209	0.14217		
	Hands-free	40	0.3179	0.12932		

	Voice command	37	0.3399	0.14345		
	Texting	36	0.3333	0.13306		

Table 21 Post Hoc analysis of rural road

Variables			Rural Road		
			Mean Difference	Std. Error	Sig.
Speed	No cellphone	Hand-held	11.23470*	3.20300	0.007
		Hands-free	12.88707*	3.20300	0.001
		Voice command	13.04513*	3.26393	0.001
		Texting	12.56578*	3.28620	0.002
Throttle	No cellphone	Hand-held	0.02715	0.01894	0.707
		Hands-free	0.04388	0.01894	0.192
		Voice command	0.05129	0.01930	0.088
		Texting	0.03274	0.01943	0.543
Brake	No cellphone	Hand-held	0.00087	0.00818	1.000
		Hands-free	-0.00434	0.00818	0.995
		Voice command	0.00722	0.00833	0.954
		Texting	-0.00345	0.00839	0.998
Steering	No cellphone	Hand-held	0.00286	0.00155	0.435
		Hands-free	0.00240	0.00155	0.631
		Voice command	0.00157	0.00158	0.919
		Texting	0.00107	0.00159	0.985
Offset from the centerline	No cellphone	Hand-held	0.00140	0.03136	1.000
		Hands-free	0.00443	0.03136	1.000
		Voice command	-0.01765	0.03196	0.994
		Texting	-0.01096	0.03218	0.999

On the rural road the average speed in no cellphone distraction is 11.23 km/hr more than the average speed in hand-held, 12.88 km/hr more than the average speed in hands-free, 13.04 km/hr more than the average speed in voice command, and 12.56 km/hr more than the average speed in texting while driving (Table 21).

Furthermore, in the school zone the average speed is the only variable that is statistically significant among the different scenarios like the urban and rural road (Table 22).

Table 22 Descriptive analysis of school zone

Variables		School Zone				
		N	Mean	Std. Deviation	F	Sig.
Speed	No cellphone	31	36.6241	9.13105	11.142	0.000
	Hand-held	28	26.9076	10.66512		
	Hands-free	34	26.4056	7.09234		
	Voice command	33	21.5448	8.95761		
	Texting	31	22.1331	8.40699		
Throttle	No cellphone	31	0.1119	0.09029	1.125	0.349
	Hand-held	28	0.0837	0.06885		
	Hands-free	34	0.1078	0.09671		
	Voice command	33	0.0866	0.06339		
	Texting	31	0.0728	0.06041		
Brake	No cellphone	31	0.0846	0.06715	0.674	0.643
	Hand-held	28	0.1001	0.07850		
	Hands-free	34	0.0779	0.05530		
	Voice command	33	0.0941	0.08818		
	Texting	31	0.0768	0.07284		
Steering	No cellphone	31	0.0108	0.00551	0.150	0.980
	Hand-held	28	0.0103	0.00849		
	Hands-free	34	0.0106	0.00774		
	Voice command	33	0.0090	0.00535		
	Texting	31	0.0108	0.01203		
Offset from the centerline	No cellphone	31	0.2773	0.14041	0.547	0.741
	Hand-held	28	0.3068	0.19298		
	Hands-free	34	0.3395	0.26765		
	Voice command	33	0.3567	0.32767		
	Texting	31	0.3364	0.21304		

The no cellphone distraction (first scenario) has the highest average speed compared to other scenarios and voice command driving has the lowest average speed in the school zone.

According to the results of Post Hoc analysis in Table 23, the average speed in the no cellphone drive of 9.71 km/hr is more than the average speed in the hand-held drive. Likewise, the average speed in the no cellphone drive 10.21 Km/hr is more than the average speed in the hands-free drive. And average speed in the no cellphone drive 15.07 Km/hr is more than the average speed in voice command drive Also average speed in no cellphone drive 14.49 Km/hr is more than the average speed in texting drive in school zone.

Table 23 Post Hoc analysis of school zone

Variables			School zone		
			Mean Difference	Std. Error	Sig.
Speed	No cellphone	Hand-held	9.71650*	2.37317	0.001
		Hands-free	10.21850*	2.26047	0.000
		Voice command	15.07933*	2.27674	0.000
		Texting	14.49096*	2.31205	0.000
Throttle	No cellphone	Hand-held	0.02814	0.02062	0.748
		Hands-free	0.00409	0.01964	1.000
		Voice command	0.02529	0.01978	0.797
		Texting	0.03904	0.02009	0.379
Brake	No cellphone	Hand-held	-0.01547	0.01858	0.961
		Hands-free	0.00676	0.01770	0.999
		Voice command	-0.00946	0.01783	0.995
		Texting	0.00787	0.01811	0.998
Steering	No cellphone	Hand held	0.00055	0.00307	1.000
		Hands-free	0.00022	0.00292	1.000
		Voice command	0.00184	0.00294	0.989
		Texting	0.00006	0.00299	1.000
Offset from the centerline	No cellphone	Hand-held	-0.02951	0.06274	0.997
		Hands-free	-0.06214	0.05976	0.904
		Voice command	-0.07944	0.06019	0.774
		Texting	-0.05907	0.06112	0.928

The results reveal the significant difference of independent variables when comparing each type of scenario with the no cellphone drive. Brake and offset from the centerline did not change among different scenarios on different roads. This result shows a negative relationship between speed, steering, throttle, and distractions, probably due to focusing on the second task of cellphone usage.

Participants significantly reduced their speed on all four different road types in all four scenarios compared to the no cellphone scenario.

4.4.5 Before/During/After Analysis

The Kolmogorov-Smirnov test was applied to evaluate the distribution of these data. In Table 24, none of the variables have normal distribution.

Table 24 One-Sample Kolmogorov-Smirnov Test

		Speed before	Speed during	Speed after	Steering before	Steering during	Steering after
N		1100	1099	705	1100	1099	705
Normal Parameters	Mean	61.05	61.20	72.83	.018	.011	.008
	Std.	17.51	20.44	16.16	.013	.008	.010
Most Extreme Differences	Absolute	.040	.105	.077	.169	.135	.214
	Positive	.034	.071	.043	.169	.135	.180
	Negative	-.040	-.105	-.077	-.147	-.121	-.214
Test Statistic		.040	.105	.077	.169	.135	.214
Sig. (2-tailed)		.000[c]	.000[c]	.000[c]	.000[c]	.000[c]	.000[c]

Therefore, their description is possible with Median evaluation, and Friedman's repeated measurements will be a suitable statistical test for these analyses. Based on the results of the previous section, speed and steering as the two important independent variables have been selected to analyze the performance of participants before, during, and after distraction, in each scenario. Table 25 is the results of the Friedman test.

Table 25 Descriptive statistics of Friedman test

Scenario			SPEED BEFORE	SPEED DURING	SPEED AFTER	STEERING BEFORE	STEERING DURING	STEERING AFTER
No cellphone	N	Valid	176	175	109	176	175	109
		Missing	0	1	67	0	1	67
	Median		58.2	59.65	80.11	.016	.0103	.008
	Minimum		24.11957	15.75594	36.22626	.00542	.00347	.00016
	Maximum		119.46867	119.41451	119.39326	.08424	.07065	.08154
Hand-held	N	Valid	188	188	129	188	188	129
		Missing	0	0	59	0	0	59
	Median		59.97	60.90	74.54	.014	.009	.006
	Minimum		18.75184	16.87639	34.90387	.00362	.00101	.00054
	Maximum		103.80999	110.26746	111.26626	.10899	.04716	.02636
Hands-free	N	Valid	191	191	121	191	191	121
		Missing	0	0	70	0	0	70
	Median		61.33	60.39	74.16	.015	.010	.007
	Minimum		22.25911	23.95946	33.84141	.00402	.00143	.00053
	Maximum		106.32803	103.92717	103.59940	.09069	.05073	.21179
Voice command	N	Valid	181	181	114	181	181	114
		Missing	0	0	67	0	0	67
	Median		61.69	64.36	75.92	.015	.010	.007
	Minimum		23.15683	13.09194	21.73001	.00276	.00000	.00048
	Maximum		99.92061	100.93612	109.50474	.08303	.04117	.02772
Texting	N	Valid	175	175	111	175	175	111
		Missing	0	0	64	0	0	64
	Median		63.43	63.56	73.60	.015	.009	.007
	Minimum		25.74890	9.33066	.99474	.00489	.00046	.00042
	Maximum		107.00887	109.63113	117.47770	.09478	.05070	.05494

As shown in Table 26, an increasing trend in speed variations during the test (before, during, and after distraction) is seen in all scenarios. These changes are significant in all scenarios, except the texting scenario. In this case, the increase of speed after distraction compared with before is statistically significant, except for the texting scenario.

Table 26 Speed analysis in different scenarios

Scenarios		Mean of Speed	Chi-Square	Sig.
No cellphone	Speed before	58.2	18.128	.000
	Speed during	59.65	18.128	.000
	Speed after	80.11	18.128	.000
Hand-held	Speed before	59.97	21.411	.000
	Speed during	60.9	21.411	.000
	Speed after	74.54	21.411	.000
Hands-free	Speed before	61.33	8.198	.017
	Speed during	60.39	8.198	.017
	Speed after	74.16	8.198	.017
Voice command	Speed before	61.69	6.333	.042
	Speed during	64.36	6.333	.042
	Speed after	75.92	6.333	.042
Texting	Speed before	63.43	4.108	.128
	Speed during	63.56	4.108	.128
	Speed after	73.60	4.108	.128

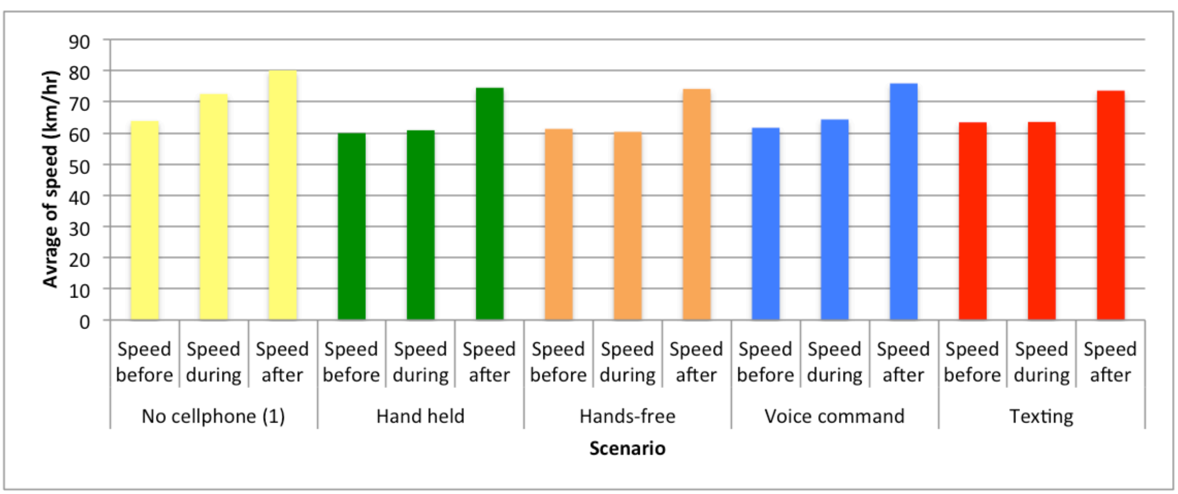

Figure 28 Mean of speed in different scenarios

Table 27 Steering analysis in different scenarios

		Mean of Steering	Chi-Square	Sig.
No cellphone	Steering before	.016	76.459	.000
	Steering during	.010	76.459	.000
	Steering after	.008	76.459	.000
Hand-held	Steering before	.014	121.736	.000
	Steering during	.009	121.736	.000
	Steering after	.006	121.736	.000
Hands-free	Steering before	.015	107.025	.000
	Steering during	.010	107.025	.000
	Steering after	.007	107.025	.000
Voice command	Steering before	.015	92.860	.000
	Steering during	.010	92.860	.000
	Steering after	.007	92.860	.000
Texting	Steering before	.015	90.649	.004
	Steering during	.009	90.649	.004
	Steering after	.007	90.649	.004

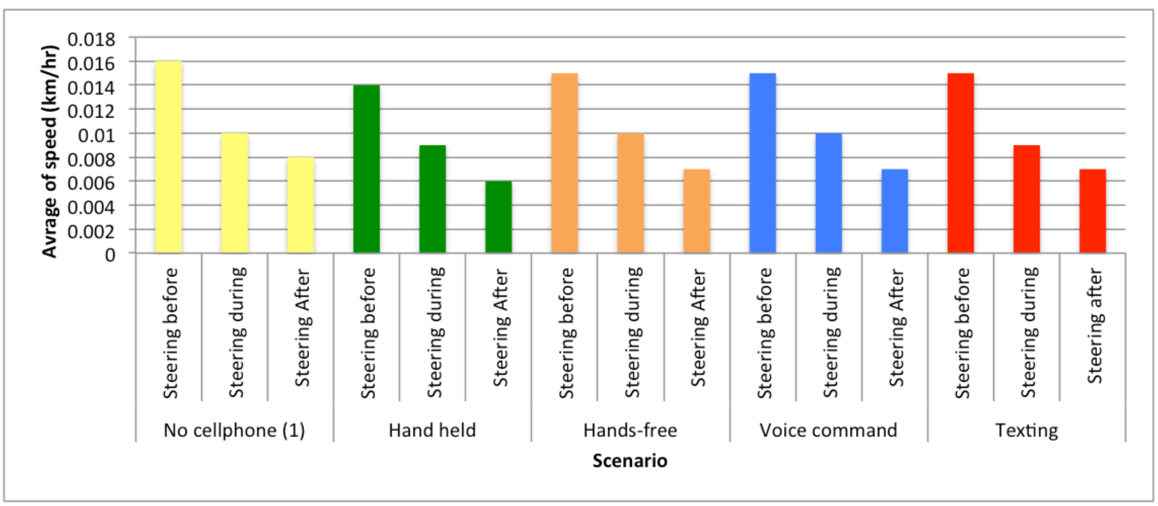

Figure 29 Mean of steering in different scenarios

On the other hand, in the case of steering (Table 27), a decreasing trend course in steering variations during the test (before, during, and after distraction) is seen in all scenarios. These changes are statistically significant in all scenarios.

Moreover, in the case of steering, its reduction after distraction is statistically significant in all scenarios rather than before distraction.

4.4.6 Distraction Statistical Model

As described in Chapter 2, there are different methods to design a statistical model. In this study a distraction statistical model was developed using binary logistics regression. The model predicts whether participants are distracted based on their driving performance. Also all four types of distraction (hands-free, hand-held, voice command, texting) have been considered in this test. The results show that sociodemographic characteristics do not significantly affect driver's distraction. The only factors affecting distractions are speed and steering.

However, pertaining to some studies the effects of cellphone usage on the performance of drivers are the same for both younger and older drivers. Younger drivers have less experience and so find it more difficult to divide their notice properly between driving and the secondary task, which is cellphone usage. Older drivers may have impaired visual and cognitive attention, which may make it more complicated for them to manage two tasks, driving and cellphone usage, together (54, 55). Also this study finds drivers of all ages have the same risk when distracted while driving (Table 28).

Furthermore, this study also finds that cellphone usage has the same impact on males and females. Comparably some studies stated cellphone usage may have a greater impact on female driving performance, but other studies found no differences (28, 56).

Moreover, the results (Table 28) show that there is a positive relationship between the steering and distraction, as distraction occurs, steering increases. On the other hand, there is a negative relationship between speed and distraction, as distraction happens speed decreases.

Table 28 Distraction statistical model

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Speed	-.010	.002	16.22	1	.000	.990
	Steering	89.81	6.627	183.68	1	.000	1.017E+39
	Gender (1)	-.094	.096	.957	1	.328	.910
	Age			.	2	.758	
	Age (1)	-.046	.162	.081	1	.776	.955
	Age (2)	.056	.099	.317	1	.574	1.057
	Constant	-.628	.175	12.88	1	.000	.534

Table 29 Model summery

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	2763.913[a]	.121	.162

CAPTER 5: Discussion

5.1 Conclusions

This study was designed to evaluate driver's performance in different conditions of cellphone usage while driving in a simulator on different road types such as urban, highway, rural, and school zone. Participants had to wear an eye tracking system, and different distractions were used to study their reactions. About 40 participants participated in this study. Each participant drove in six different scenarios with a few minutes break in between each simulated ride. The first and the last (sixth) scenarios were similar, no cellphone drive, and the other scenarios included as the distracting component a hand-held cellphone, hands-free communication, voice commanding, and texting while driving.

Accordingly, more than 960 other simulator drives were analyzed using different statistical methods such as Kolmogorov-Smirnov test (KS), one-way, and two-way ANOVA, and Friedman, in order to examine the effect of each distraction on each road on the participant's driving performance. As mentioned earlier, the first and last scenarios were designed similarly in order to consider the effects of tiredness and learning curve and minimize the error. Additionally, a separate distraction model was developed to examine the level of distraction, based on sociodemographic characteristics of the participants, and their performance variables.

Repeated scenario exposure (scenario 1, 6) during this research resulted in performance (e.g., increased speed) improvement (stabilized learning curve) for drivers using a cellphone. An explanation for this finding is that participants have learned to better regulate the primary task of driving in the simulator. Also as it turned out, the speed in scenario 6 had the highest average among all, with a significant difference from the average speed in other scenarios. It can also be interpreted that since there were no distractions and participants were familiar with the road and situations after six rounds of driving, the average speed in scenario 6 ranked on top, compared to other scenarios

The statistical analysis of the results indicated that the impaired performance of participants due to these distractions is affected by other driving parameters such as speed, steering, and throttle. Based on the results of this analysis, increasing the complexity of the distraction will result in decreased speed. In other words, participants decreased their speed in all scenarios, on all roads, in the presence of an external distraction. The average speed in the hand-held drive scenario decreased 0.45 km/hr compared to the first scenario (no cellphone); also, the average speed in the hands-free drives, voice command drives, and texting drives, respectively, decreased 2.32 km/hr, 0.4 km/hr, and 1.06 km/hr compared to the first scenario with no distractions. On the other hand, the hand-held calls showed an increased level of eyes-off road time by about 9%, while hands-free, voice command messaging, and texting, respectively, increased this time by 7%, 28%, and 46%.

It was also observed that drivers tend to reduce their speed during the talking conditions. This corresponds with the results of Kircher et al. (79) which indicated that participants tend to reduce their speed when receiving a call. Wilde (80, 81, 82) described this phenomenon as 'risk homeostasis,' whereby in response to a change in the road-vehicle-user system, behavior changes to maintain a target level of risk per unit time. While there is some debate about the exact processes involved (see Grayson, 1996), the evidence from the questionnaire supports the theory that drivers were aware that their driving was impaired to some degree while engaged with their cellphone and chose to reduce their speed in order to mitigate the risk of accidents.

On the other hand, the study shows the distraction levels on different road types also has a direct correlation to the speed limit, as well as the capacity of the road. This indicates the effect of cellphone distraction is more severe at higher speeds, and with higher traffic flow. Specifically, on the highway, the level of time the eyes are off the road is 13% higher than the school zone, while this indicator shows a 9% increase on the urban road and a 6% increase on the rural road compared to school zone designated roads.

Additionally, comparing scenario 2 with scenario 3, and scenario 4 with scenario 5, it was determined that automobile technologies such as voice command are extensively effective in reducing distractions and decrease the time drivers are looking off the road by about 18%. Cellphone hands-free accessories such as headphones are also effective and reduce this number by about 3%. However, the result of this research shows there are still risks involved in using a cellphone while driving and does not favor the decision to permit hands-free, or voice command phone use while driving. Conversely in some states, including Maryland where this study took place, the use of hands-free cellphone communication while driving is permitted. Based on the results of this study, the same conclusion can also be drawn in reference to the use of automotive technologies such as voice-command.

According to previous studies, the effects of mobile phone usage on driving performance are more extreme for both younger and older drivers. Younger drivers with less experience find it more difficult to divide their attention appropriately between driving and the secondary task of talking on the phone. Also, older drivers suffer from decreased visual and cognitive capacities, which will make it more difficult for them to conduct two tasks concurrently (28, 54, 55). On the other has, this research did not find any significant relationship between the level of distraction while driving with cellphone use and different age categories, indicating all ages are at risk of accident when in one way or another are distracted while driving.

Additionally, some studies suggest mobile phone use may have a greater impact on female driving behavior, while others show no differences (28, 56). This study also found cellphone usage had similar impacts on male and female participants' performance. Comparably, a study on the effects of text messaging while driving found that male drivers were more likely to text while driving but impairment caused by text messaging was far more significant among female drivers. Male drivers were also less likely to reduce their speed while texting and driving (57).

The effects of other factors such as race, education, and even time licensed were analyzed, but none of these variables showed any rational impact on distraction levels, which matched previous studies' findings. However, some literature stated that since many novice drivers are also young drivers, it is difficult to separate out the effects of age and experience on driving ability while using a mobile phone. However, younger inexperienced drivers appear to be more susceptible to the effects of distraction on their driving performance.

Latterly by comparing and drawing inspiration from participant's inputs, here are some methods and strategies to eliminate distraction for safer driving:

- Only 5% of participant mentioned that the cellphone distracts them while driving. Therefore, put the phone on silent and keep the vibrate function off. Drivers are generally tempted to respond to their phone when it's buzzing or vibrating; turning the volume and vibration off completely while driving might reduce cellphone use.

- Keep the phone inaccessible. According to the data from the pre-test survey, for 43% of drivers, turning the volume and vibration off does not suffice and they may still check their phones regularly out of habit, to see if someone has contacted them. Keeping the phone out of sight can help with this situation.

- According to results of the survey 78% of drivers don't stop and pull over if necessary. So in urgent situations, taking a few extra minutes to pull off the road and stop safely to send a message or answer the phone is recommended, instead of increasing the risk of an incident by using cellphones while driving. Social education will play a great role in this strategy.

- According to results of the survey 59% of drivers don't use applications and technologies to limit the distraction. Thus using certain apps and cellphone features may help eliminate the use of cellphones during driving. There have been a few attempts to come up with a technological solution; there are apps that lock the cellphone as the vehicle is moving, for example, iPhone's "Do Not Disturb While Driving" feature. This feature automatically senses when the vehicle is on the move and automatically disables most notifications; however, it still lets the driver use other applications such as navigation tools. It helps drivers avoid the temptation to use their phones while driving. On the other hand, there is no equivalent feature on Android devices yet, but Android users can benefit from applications such as “Driving Detective” to get parallel functionality. Applications like “Mojo” or “Drive Well” for both Android and iOS devices can also get a report on how safely a driver drives.

Also another immense issue has to be included when it comes to any discussion of cellphones causing distracted driving, and that is driving law. For instance, in Great Britain it’s illegal to use cellphone while driving, while it’s only applicable for 16 states in the United States. Surprisingly, while as of today it’s illegal to text and drive in 47 states, you can still legally hold your phone and drive in most states.

“Successful enforcement is one of the biggest obstacles to curbing the issue of cellphone distraction,” John Larid, former legislator, said. “Handheld bans are the most enforceable type of law as they eliminate the loopholes that tend to see with texting-only laws. With a ban only on texting, drivers can claim they were manipulating their phone to use an app or dial a call, which makes it difficult to identify texting drivers or ensure the ticket will hold up in court.”

It should also be noted, similar to other simulator-based researches, it is impossible in a simulated environment to capture all of the real-world dynamics of driving. However, the current study observed performance in a wide range of driving conditions with different scenarios. In many aspects, the city and highway driving environments used in this research portrayed situations that drivers are likely to face in routine real-world driving. Nonetheless, in order to generate reliable data, the current research incorporated a higher density of immediate-response events than is typical in real-world driving (83). In addition, 40 participants attended this study and as a result of increasing the number of participants, it could be claimed more accurate results have been reached (40).

Accident data was not collected in this study. By collecting data from a crash in similar research and using the surrogate safety analysis, it is possible to predict the crashes caused by distracted driving. It would also be possible to validate the results of this study using real-world data or naturalistic driving data.

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Appendix A: Pre-test Survey

Dear Participant,

We greatly appreciate your participation in this brief survey. This study aims to investigate drivers' behavior in a distracted driving situation. Your participation is of a great importance to this study. Please note that there are no right or wrong answers and responses will remain confidential. Individual will not consider information provided and all responses will be recorded together and analyzed as a group. The survey should take no more than 10 minutes to complete.

Please fill in the appropriate choice for each question. Thank you.

1. **What is your gender?**
   - ☐ Female
   - ☐ Male

2. **What is your age?**
   - ☐ 18 to 21
   - ☐ 21 to 25
   - ☐ More than 25 years old

3. **Please specify your ethnicity.**
   - ☐ White
   - ☐ Hispanic or Latino
   - ☐ Black or African American
   - ☐ Native American or American Indian
   - ☐ Asian / Pacific Islander
   - ☐ Other

4. **What is the highest level of education that you have achieved?**
   - ☐ High School or less
   - ☐ Associate degree
   - ☐ College student
   - ☐ College graduate
   - ☐ Post graduate

5. **Are you employed?**
   - ☐ No
   - ☐ Yes, part time
   - ☐ Yes, full time

6. **What type of driving permit do you have?**
   - ☐ Don't have
   - ☐ Learner's Permit
   - ☐ Permanent license for regular vehicles (class C)

☐ Permanent license for all types of vehicles (class A)

7. What is your household annual income?

☐ Less than $20K
☐ $20K to $30K
☐ $30K to $50K
☐ $50K to $75K
☐ $75K to $100K
☐ More than $100K

8. What is your household size (the number of persons for whom you or your parents are financially responsible)?

☐ 1
☐ 2
☐ 3
☐ 4 or more

9. How many cars does your household own?

☐ No car
☐ 1 car
☐ 2 cars
☐ 3 cars or more

10. How long have you been driving?

☐ Less than a year
☐ 1 to 3 years
☐ More than 3 years

11. What is the average annual driving mileage on your own car (in miles)?

☐ I do not own a car
☐ Less than 8,000
☐ 8,001 to 15,000
☐ 15,001 to 30,000
☐ More than 30,000

12. How many miles do you drive per week averagely?

☐ Less than 100 miles
☐ 100 to 200 miles
☐ 201 to 300 miles
☐ 301 to 400 miles
☐ More than 400 miles

13. How often do you text and drive usually?

☐ Never
☐ Rarely
☐ Sometimes

☐ Always

14. How often do you talk, using your phone, while driving usually?

☐ Never
☐ Rarely
☐ Sometimes
☐ Always

15. How often do you use any cellphone accessories such as headsets when you drive?

☐ Never
☐ Rarely
☐ Sometimes
☐ Always

16. What cell-phone-related technologies do you use while you drive?

☐ None
☐ Voice to text
☐ Text to voice
☐ Signal jammers (blocking the signal)
☐ Others (please specify ______________________________)

17. If you need to text or answer/make a call, while you are driving, how much is it likely that you pull over first and then use your cellphone?

☐ To a great extent
☐ Somewhat
☐ Very little
☐ Not at all

18. How much are you confident that you would not experience any problem using your cell phone while you drive?

☐ Very confidant
☐ Confident
☐ Neither
☐ Doubtful
☐ Very doubtful

19. How many times have you experienced a near-crash experience due to using cell phone / GPS while you were driving in the last three years.

☐ 0
☐ 1
☐ 2
☐ 3
☐ More than 3 times

20. How many times have you experienced a crash due to using cell phone / GPS while you were driving in the last three years.

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ More than 3 times

21. How many times have your friends or family members experienced an accident due to using cell phone / GPS while they were driving in the last three years.

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ More than 3 times

22. To what extent are you confident that YOU, driving in following situations, would NOT experience any driving mistakes such as deviating from the destination, going through a red light, near-crash experience, crash, etc.?

No cellphone while driving	☐Very confident	☐Confident	☐Neither	☐Doubtful
Using accessories such as headsets	☐Very confident	☐Confident	☐Neither	☐Doubtful
Technologies such as voice to text	☐Very confident	☐Confident	☐Neither	☐Doubtful
Using cellphone freely	☐Very confident	☐Confident	☐Neither	☐Doubtful

Appendix B: Post-test Survey

Dear Participant,

We greatly appreciate your participation in this brief survey. This study aims to investigate drivers' behavior in a distracted driving situation. Your participation is of a great importance to this study. Please note that there are no right or wrong answers and responses will remain confidential. Individual will not consider information provided and all responses will be recorded together and analyzed as a group. The survey should take no more than 5 minutes to complete.

Please share your experience with us. Thank you.

Appendix C: Questions while Distraction

Scenario 1: No Cellphone

Scenario 2: Hands Free
1) On Hampton: Can you give me your mom's #, it's urgent → alternative, best friend
2) On 695 (the short message): What's your major?
3) On 695 (long message): what comes to your mind when you hear the word 'America'? Describe it in a short sentence.
4) On Perring Parkway: How many of your friends have names beginning with 'L?
5) On the school zone: When is the best day/time to schedule you for the next session?

Scenario 3: Hand Held
1) On Hampton: Can you give me your dad's #, it's urgent → alternative, sibling
2) On 695 (the short message): What's your favorite sport?
3) On 695 (long message): what comes to your mind when you hear the word 'Christmas? Describe it in a short sentence.
4) On Perring Parkway: How many of your friends have names beginning with 'F?
5) On the school zone: What did you order the last time you went to a restaurant?

Scenario 4: Voice Commands
1) On Hampton: What is 8 + 11 – 5?
2) On 695 (the short message): What do you enjoy most during the summer?
3) On 695 (long message): what comes to your mind when you hear the word 'George Washington? Describe it in a short sentence.
4) On Perring Parkway: How many of your friends have names beginning with 'K?
5) On the school zone: How many Billboards did you see while driving? What was their content?

Scenario 5: Texting
1) On Hampton: What is 6 + 12 – 3?
2) On 695 (the short message): What's your number one vacation destination?
3) On 695 (long message): what comes to your mind when you hear the word 'Honest? Describe it in a short sentence.
4) On Perring Parkway: How many of your friends have names beginning with 'J?
5) On the school zone: How many and what kind of animals did you encounter while driving?

Scenario 6: No Cellphone

Appendix D: Data Labels/Definition

1. Time (Time from simulation start) (Second)
2. ID (Unique ID of the Object)
3. Speed In Meters Per Second (Speed of vehicle) (M/S)
4. Local Acceleration In Meters Per Second2 X (Acceleration of car) (Km/S2)
5. Steering (showing the steering) (-1: Max left, 0: Straight, +1: Max right)
6. Steering Velocity (Rotation rate of steering per second)
7. Throttle (Force on throttle pedal) (0: No throttle, 1 Max throttle)
8. Brake (Showing brake of pedal) (0: No brake force, 1 Max brake force)
9. Road (Name of Road)
10. Offset From Lane Center (Offset of the vehicle's position from the center of its lane) (Meter) (Left: -, Right: +)
11. Lane Number (Number of lane the car is driving)
12. Distance Along Latest Road (Distance along the road from start of each road) (Meter)