Using Driver Simulators to Measure the Impact of Distracted Driving on Commercial Motor Vehicle Operators

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

June 2015

FOREWORD

Driver distraction is at the forefront of public discussion concerning safety on America's roads and highways. Understanding the risks of distracted driving and finding ways to prevent it has been the goal of Federal, State, and private organizations for decades. The objective of this study was to address the identified gaps in the literature by conducting applied research to better quantify the dangers of distracted driving. Using state-of-the art driving simulators in realistic traffic, this project focused on commercial driver's license (CDL) operator performance while experiencing distractions in several driving scenarios combined with various attention-stealing distractions. A research design was created to account for real-world phenomena and used touchscreen devices, cell phones, and external distractions while commercial motor vehicle (CMV) drivers drove a motion-based truck-driving simulator.

NOTICE

Technical Report Documentation Page

1. Report No. **FMCSA-RRR-13-048**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Using Driver Simulators to Measure the Impact of Distracted Driving on Commercial Motor Vehicle Operators**		5. Report Date **June 2015**
		6. Performing Organization Code
7. Author(s) **Tarr, Ronald W.; Gammoh, Diala T.; Totten, Eric P.**		8. Performing Organization Report No.
9. Performing Organization Name and Address **University of Central Florida** **Institute for Simulation and Training** **Orlando, FL**		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address **U.S. Department of Transportation** **Federal Motor Carrier Safety Administration** **Office of Analysis, Research, and Technology** **1200 New Jersey Ave., SE** **Washington, DC 20590**		13. Type of Report and Period Covered **Final Report**
		14. Sponsoring Agency Code **FMCSA**
15. Supplementary Notes		

16. Abstract

Driver distraction is at the forefront of public discussion concerning safety on America's roads and highways. Understanding the risks of distracted driving and finding ways to prevent it has been the goal of Federal, State, and private organizations for decades. The objective of this study was to address the identified gaps in the literature by conducting applied research to better quantify the dangers of distracted driving. Using state-of-the-art driving simulators in realistic traffic, this project focused on the performance of commercial driver's license (CDL) operators while experiencing distractions in several driving scenarios, combined with various attention-stealing distractions. A research design was created to account for real-world phenomena, using touchscreen devices, cell phones, and external distractions while commercial motor vehicle (CMV) drivers drove a motion-based truck-driving simulator. These actions and the level of distraction inflicted were quantified by simulator, observation, and electroencephalography (EEG) and electrocardiography (ECG) data. Overall, both performance and physiological measures showed evidence of driver distraction. Performance measures suggested that the largest performance deficiencies came from actively using a touchscreen Mp3 player. Physiological measures (e.g., EEG) showed that both Mp3 players and cell phones increased workload and decreased attention. After the experiment, drivers provided testimonials that were recorded on video for use in outreach activities to communicate the extreme risks of distracted driving.

17. Key Words **CMV, commercial motor vehicle, crash avoidance, distracted driving**		18. Distribution Statement **No restrictions**	
19. Security Classification (of this report) **Unclassified**	20. Security Classification (of this page) **Unclassified**	21. No. of Pages **74**	22. Price **NA**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

TABLE OF APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Milometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME	1,000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	Milliliters	ml
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE/PRESSURE/STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

TABLE OF APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8C + 32	Fahrenheit	°F
		ILLUMINATION		
lx	Lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE/PRESSURE/STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

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ABBREVIATIONS AND ACRONYMS

Acronym	Definition
AAA	American Automobile Association
ANOVA	analysis of variance
CDL	commercial driver’s license
CMV	commercial motor vehicle
ECG	Electrocardiography
EEG	Electroencephalography
FMCSA	Federal Motor Carrier Safety Administration
HRV	heart rate variability
mi/h	miles per hour
Mp3	Motion Picture Experts Group
NHTSA	National Highway Traffic and Safety Administration
POI	points of interest
RAPTER	Research in Advanced Performance Technology and Educational Readiness
SAS	simulation adaptation syndrome
USDOT	U.S. Department of Transportation

EXECUTIVE SUMMARY

This project addressed the identified gaps in the literature on distracted driving by conducting applied research to better quantify the dangers of distracted driving. Using state-of-the-art driving simulators in realistic traffic, the project focused on commercial driver's license (CDL) operator performance while distractions were experienced in several driving scenarios. Scenarios placed drivers in situations such as congested traffic, highway driving, and driving in work zones. These situations were combined with various distractions that competed for the drivers' attention.

During this project, researchers created a research design that used touchscreen devices, cell phones, and external distractions to divert commercial motor vehicle (CMV) operators' attention while they drove a motion-based truck-driving simulator. These actions and the level of distraction inflicted were quantified by simulator, observation, and electroencephalography (EEG) and electrocardiography (ECG) data.

The data led researchers to conclude that among these distractions, manipulating hand-held touchscreen devices is the most impairing, while combinations of any devices and external events caused considerable distraction, even among professional drivers.

Lane deviation was the most frequent error type. It represented 71 percent of the total errors. Speeding violations represented 20 percent of the total violations. Only 8 percent of the distracted drivers had off-road and dangerous braking violations.

Overall, both performance and physiological measures showed evidence of driver distraction. Performance measures suggested that the largest performance deficiencies came from actively using a touchscreen Mp3 player. Physiological measures (e.g., EEG) showed that both Mp3 players and cell phones increased workload and decreased attention.

After the experiment, drivers provided testimonials that were recorded on video for use in outreach activities. Outreach efforts are focused on the following:

- Presentations by the researcher at local college campuses.
- Advertisements, news stories televised by local news stations, and video-sharing Web sites.
- Articles submitted to the Transportation Review Board, as well as several other non-academic publications.

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1. INTRODUCTION

This report describes research completed using a new approach to study driver distraction among commercial motor vehicle (CMV) operators. Instead of engaging in crash analysis or naturalistic studies, the research team chose to use a motion-based driving simulator to ensure driver immersion and the reduction of simulation adaptation syndrome (SAS), or motion sickness. To keep the study as realistic as possible, researchers conducted a thorough front-end analysis of common complaints and issues related to distracted driving with trucking companies. The study overcame the lack of real-world situations in previous studies by putting CMV operators in environments that are too dangerous for live experimentation.

The team chose two common hand-held devices that were the biggest issues for truckers today: touchscreen audio (i.e., motion picture experts group [Mp3]) players, and cell phones. The study required drivers to use these devices at different points on the simulated highway scenario. In addition, some scenarios included external distractions. This experimental design provided accurate results about the use of the two devices both alone and in a variety of combinations. The results of these interactions were measured using simulator data output, trained observers, and an electroencephalography/electrocardiography (EEG/ECG) device. Using EEG/ECGs on CMV operators, combined with motion-based simulators, is an approach that is infrequently used among distracted driving studies and can illustrate the taxing nature of using technology while driving. This approach keeps drivers safe from accidents that occur in the real world and keeps them healthy, because the motion-based simulator helps prevent SAS. Furthermore, this information suggests that if professional drivers are challenged by these distractions, then every other driver in America has similar limitations. Thus, the risks of distracted driving can only be mitigated by a combination of new training, awareness campaigns, active safety systems, and real-time feedback.

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2. LITERATURE REVIEW

Distraction was identified by the U.S. Department of Transportation (USDOT) in the late 1970s as a "contributing factor to motor vehicle crashes in reviews of accident causation."[1, 2] Since then, leading researchers have published hundreds of studies over the past 40 years detailing how a variety of technologies, from windshield wipers, to hands-free wireless cell phones, have affected drivers' performance through distraction. In 2000, the National Highway Traffic Safety Administration (NHTSA) expanded on this assertion with updated studies providing advanced statistical and technological analysis. NHTSA went as far as to say that, "Driver inattention is one of the most common causes of traffic crashes."[3] The report further asserted that it is not just technology that brings about driver distraction but a driver's "willingness to engage" in any secondary task. The task could be driving related, like adjusting mirrors or using windshield wipers. These distracting tasks can also be non-driving related, like tuning a radio, making a phone call, eating, smoking, etc., all of which divert a driver's attention.[4] Scholarly articles have attempted to place the number of police-reported crashes caused by driver distraction at around 25 percent of all crashes,[5, 6] with other works putting the number between 35 percent and 50 percent.[7, 8]

Academic studies over the past decade have found an abundance of new information about driver distraction. Scholars seeking to understand driver distraction have employed three investigatory methods to illuminate such questions—crash data studies, naturalistic studies, and simulated studies—each with its own benefits and shortfalls. This is not a complete listing or review of all the literature on distracted driving, but rather an overview of the major trends that informed this study's design.

The first investigatory theme used in-depth statistical analysis to look at data (focused on specific distracting tasks) that was collected from crash statistics over several months or years. This theme became more common as computer-based research increased due to the rise in computer efficiency and accessibility to scholars. Scholars have sought to understand how off-task glances are related to in-vehicle stimuli and out-of-vehicle events, along with environmental and vehicle peculiarities that affect drivers of different experience levels and different generations.[9, 10, 11, 12, 13, 14] One of the main challenges for this form of inquiry is that assessing old police reports and crash statistics may provide information that is biased, incomplete, and oversimplified.[15, 16, 17] J. Stutts, writing for the American Automobile Association (AAA) Foundation Study in 2001, stated:

> The data limitations are considerable and include potential underreporting of distracted driving in general as well as differential underreporting of specific distracting events. […] Additional research is needed to quantify the frequency and intensity of different driver distractions and to understand how other variables affect distractibility and willingness to engage in distracting behaviors.[18]

Naturalistic studies are conducted while drivers go about their daily work routines, requiring lengthy video recordings of real-time drivers.[19, 20, 21] Naturalistic studies took off as video recording devices and electronic storage technology became more affordable, reliable, and user friendly, thereby expanding the situations and locations in which they could be employed. These works are similar to crash report studies because they view raw data over an extended period, searching for statistical relationships between distracted actions and crashes or near-crashes. Naturalistic studies are helpful because they provide researchers with abundant recordings that can be used to illustrate how tasks substantially raise the risk of inducing a crash. However, naturalistic studies suffer from participant tampering, real-world dangers, and the expense of videotaping dozens of CMVs. Some studies placed cameras around numerous long-haul trucks, recording the vehicles for more than a year. One study found that drivers were 23 percent more likely to be involved in a safety-critical event when texting and 6.7 times more likely to be involved in a safety-critical event when reaching for or using an electronic device.[22, 23, 24]

A recent investigatory approach that became more common a decade ago uses driving simulators to place participants in realistic yet safe experiments. As with the other approaches, these studies were influenced by the progression of technology. Simulator usage increased as simulation fidelity evolved to reduce SAS or simulation sickness. This created more polished graphics and motion-based designs at an affordable cost and resulted in reduced sickness among participants. Simulator studies take place in the virtual world and use driving simulators to prompt subjects with multiple distractions in an unlimited number of environments, without exposing participants to actual dangerous situations. A major published study using this method served as a model for simulation research on distracted driving.[25] Furthermore, most works involving driver simulators have focused on the viability of using simulators as a tool to view risky behavior among participants.[26, 27, 28, 29, 30, 31]

Some experts focus largely on reproducing and proving generational and experiential differences among driving participants.[32, 33, 34, 35] Other experts focus on the workload imposed on the brain by dual task activity (i.e., cell phone use while driving) that yields interesting data about a person's ability to multi-task. [36, 37, 38, 39] Results have shown that cell phone conversations are more taxing and distracting for drivers than in-car conversations with passengers. These conclusions were tested against other methods of distraction in comparative studies, such as radios, texting, and drunk driving.[40] Overall, it is clear that simulator-based experiments led scholars to determine that cell phone-induced distracted driving caused drivers to have a less durable visual memory of objects seen on the road.

Considering all these advances in research approaches, development of technology, and repeated inquiries into driver distraction were important for this lab's decision to use simulation devices as its mode of inquiry. Admittedly, some scholarly simulation studies are confined to unrealistic experiments or factors that do not occur in the real world in the same way as they are used in laboratory experiments. Despite this, the team felt that the limitations of crash data analysis and naturalistic studies precluded their use for this study, where motion-based simulators could be cost-effectively and safely employed.[41]

3. OVERVIEW OF STUDY DESIGN

In the first stage of designing the study, the research team went to numerous trucking companies to conduct interviews, inspect trucks, and recruit drivers for the project. The interviews with safety officials helped researchers select the in-cab technologies that were causing the most trouble. These were narrowed down to Mp3 players and cell phones. However, safety officials also discussed how external factors, such as accidents, and more importantly, other drivers, compounded the problems of distraction. With this information, the team defined three distractions for the experiment: in-cab, external, and cognitive.

With the equipment selected and the types of distractions defined, the research team needed an objective way to record data for later analysis. This was accomplished using EEG/ECG data and simulator data, all of which were stored for later analysis by the team to see the full effect of the distractions. Concurrently, the research team designed eight scripted scenarios for the motion-based truck simulator, with a video capture of each run by every participant. Video cameras recorded the participant's drive from the vantage point of inside of the simulator cab and the simulation room for later analysis.

All of these measures were documented and monitored by a designated evaluator and expert peer reviewers. The following sections detail the potential risks and benefits to participants based on the experimental design.

3.1 RISKS TO PARTICIPANTS

The risks to participants were minimal. First, the experiment was conducted in the virtual world, so there was no risk of bodily injury. There is a slight risk of SAS or motion sickness from using driving simulators. However, participants could stop the experiment at any time, and if sick they were allowed to rest until it passed and then allowed to leave. Additionally, the motion-based simulator helps decrease SAS as a result of the quality of the graphics and the simulated environmental feedback. A further protection for participants was the maintenance of their anonymity due to the fact that participant data was recorded blind and remains anonymous. This means there is no risk that participants will be harmed based on performance data collected or should the video be used for outreach purposes. Participation in this study was voluntary, subjects' permission and consent were noted, and they were able to terminate their involvement at any time without consequence.

3.2 POTENTIAL BENEFITS TO PARTICIPANTS

There are several theoretical and practical implications of this research. A series of practical recommendations regarding the use of in-vehicle devices follows. CMV operators will learn about the major safety measures related to driver distraction and will gain a personal awareness of the dangers of distracted driving. Because there is a public outreach component in the study, additional benefits also include an increase in public awareness of accident potential caused by in-vehicle devices.

3.3 ACTIONS IN DEVELOPMENT OF THE EXPERIMENT

The first stage of development required the team to design and script scenarios that included a freeway database with alternating distraction and relief miles. Out of the eight scenarios, four had an external event (e.g., construction, car accident, or road repairs). All eight scenarios were designed to include:

- A freeway terrain database to facilitate the best controlled conditions.
- Posted speed limits of 45 and 65 miles per hour (mi/h).
- Daytime driving.
- An external event to extend 1 mile.
- Clear weather to prevent defining another external distraction.
- Three reliefs and two distraction segments divided by 1-mile markers, where each event takes place over the full run.
- Low traffic and congestion (12 vehicles within 400 feet of the participant's truck).

As part of the experimental design, a pilot study was conducted to test the feasibility and efficiency of the design. After the pilot, the team suggested alterations to reduce the time it took to conduct a single experiment. These alterations included:

- Shortening the length of the first and the last relief to 0.5 mile, a total of a 4-mile drive.
- Reducing the video storage.
- Reducing EEG/ECG data storage.
- Shortening total participant time from more than 3 hours to 2 hours.

The research team determined that dividing the scenarios into reliefs and distractions helped generalize the use of the distracting factors by assigning different tasks associated with them. For instance, the driver was asked to answer his/her cell phone in one distraction and return a phone call in a second distraction. This experimental design simplified the data collection, strengthened the procedures of the experiment, and focused on the critical factors of the study. Moreover, the distractions during the relief areas provided an indication that the driver was still under the influence of the distracting event after the task ended. This bleed-over of distractions and the ability to generalize the factors is a benefit of this study and offers the chance for further analysis in future work.

4. CONDUCTING THE EXPERIMENT

4.1 PARTICIPANTS

Participants had to have a CDL with a minimum of 3 years' experience driving a CMV; all drivers who participated had more than 5 years of CMV experience. The drivers were asked by their respective companies to take a part of one of their workdays to volunteer for the study. Their respective companies compensated the volunteers as if it were a regular workday. Both commercial fleets and a few independent owner-operator drivers volunteered their time to participate in the experiment. The researcher offered discount cards supplied by local businesses as added incentive for drivers to participate.

4.2 EQUIPMENT AND RESOURCES

A list of equipment and resources used in this experiment includes:

- Participants' personal cell phones.
- Touchscreen 2-gigabyte audio (Mp3) player.
- 10-channel EEG/ECG.
- Motion-based simulator.
- Light-emitting diode (LED) infrared (IR) cameras.
- Projectors.
- Two-way walkie-talkies.

This equipment was chosen to guarantee that the experiment was conducted in a controlled and safe fashion. Requiring the participants to bring their own cell phones prevented the obstacle of dealing with participants who were unfamiliar with such handheld devices. Furthermore, by providing the Mp3 player and instructing the participant on how to use it, the research team controlled the variability among touchscreen skill sets. The EEG/ECG did not affect the outcome of the experiment, but it is important in discussing data analysis, which appears later in this paper. Figure 1 is an example of the screen captures that the video recorded for later analysis.

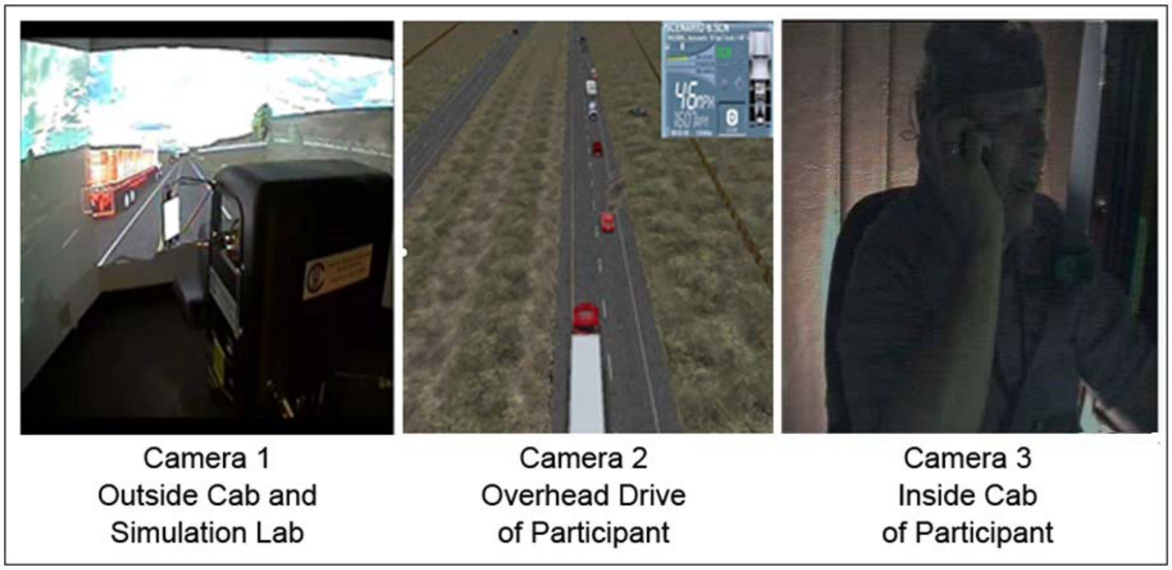

Figure 1. Photograph. Screenshots of simulator, simulated vehicle, and participant.

4.2.1 Video Recording

- Camera 1 viewed the simulator room; this allowed the team to observe the experiment and ensured that no influences affected the driver outside of the experiment.
- Camera 2 viewed the simulated drive from a helicopter view. This camera was used for data collection, coding, and counting.
- Camera 3 viewed the participant inside the CMV cab to monitor the participant, and to ensure that the driver was performing the proper tasks and was not displaying any discomfort.

4.2.2 Simulator Immersion

The simulator configuration was important because it directly affected the immersion of participants in the virtual world. By improving the simulator configuration, the team increased fidelity, which minimized the feelings of SAS. This was accomplished by:

- Updating the motions of the hydraulic pistons on the motion-based platform to provide realistic environmental responses to gravitational forces, bumps, and CMV movements felt by the driver in the simulator cab.
- Installing three projectors for the driving simulator. After local testing of the resolution, lens, and brightness, it was clear that the edge blending of the three screens presented a better quality image for the experiment.

4.3 PREPARATION OF THE PAPER WORK FOR EACH DRIVER

The team designed a strategy for producing and processing the complete set of forms for each driver. Prior to each experiment, the team prepared a folder that included all the required documentation. This ensured uniformity and safety to a controlled experiment. Each folder included the following:

- Folder cover checklist.
- Driver instructions.
- Consent form.
- Driver demographic survey.
- EEG/ECG form.
- Video disclosure form.
- Safety technician checklist.
- Distractor checklist and questions.
- Experimenter checklist.
- Operator checklist.
- Survey A (after the fourth run).
- Survey B (after the eighth run).
- Post-simulation sickness form (if required).

4.4 TEAM ROLES AND RESPONSIBILITIES

During the experiment, the research team consisted of five members: simulator operator, distractor, safety technician, experimenter, and EEG/ECG technician. Subjects/participants were scheduled two and three per day. Thus, two complete teams of experimenters were established to prevent fatigue and to accommodate student schedules. Furthermore, this design ensured uniformity when conducting the experiment. The roles were:

- Experimenter: Responsible for primary interface with participants, distributing and explaining all the paperwork to each driver, informed consent, assuring that the driver completely understood the instructions and conditions of the study, and explaining to the driver how to use all devices for the experiment. During each scenario, it was the responsibility of the experimenter to write down the beginning and ending time of each scenario and the time when each factor was interjected and ended. This helped the EEG/ECG team to synchronize the time of their data with the simulator data.

- Simulator Operator: Responsible for running the simulator and ensuring that the correct scenario was selected, instructing the distractor when to begin, ensuring that video feeds were started and stopped, and ensuring that all activities with the system were operating correctly. Also, this member ensured that the scenarios and video feeds were saved for later use by the observers.

- Distractor: Responsible for interacting with the subject, either over the phone, asking questions to engage the subject in a realistic manner, or providing instructions via walkie-talkie on when to make adjustments to the Mp3 device.

- Safety Technician: Responsible for ensuring that the driver knew how to use the simulator/operate the Mp3 player and the walkie-talkie device in the cab, and setting the appropriate playlist on the Mp3 player prior to each scenario. A major role of the safety technician was to stay inside the room in case any emergency or incident occurred while the driver was in the simulator.

- EEG/ECG Technician: Responsible for explaining the EEG/ECG device, installing it on the subject, conducting the baseline tests, and ensuring that all the leads were collecting data as they should. The EEG/ECG technician also saved and backed up all raw data to an external drive for later analysis.

A visual example of the operator and distractor is shown in Figure 2. Figure 3 shows images of the safety technician and the EEG/ECG technician.

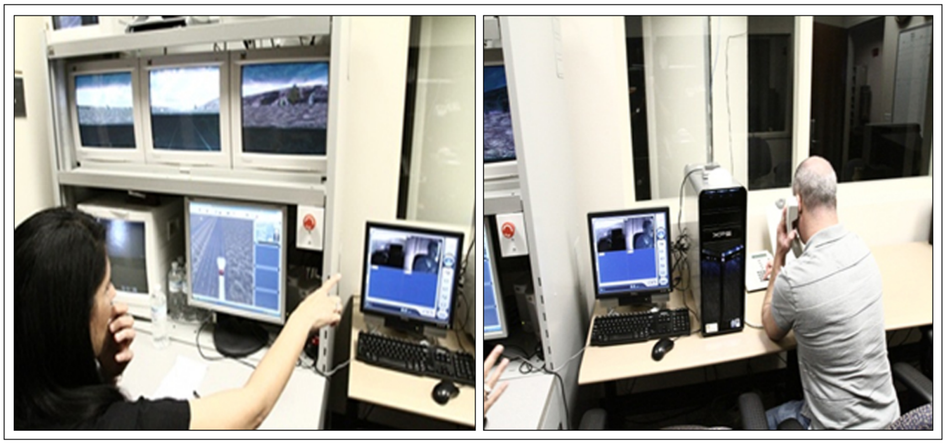

Figure 2. Photograph. Operator/Distractor.

Figure 3. Photograph. Safety technician EEG/ECG technician.

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5. DATA ANALYSIS

5.1 DATA TYPES AND COLLECTION METHODS

The team conducted the analysis on four types of data: survey data, performance data, physiological measures (EEG/ECG data), and simulator data. The study included 27 participants (drivers). Only two were excluded from the study because they were not able to complete the eight scenarios due to SAS symptoms.

5.1.1 Survey Data

Survey data included three sources of data. The first source was demographic survey information that was completed by each participant prior to each experiment. The second and third sources of data were surveys distributed in the middle (Survey A), and at the end (Survey B) of each experiment. The detailed analysis is provided in the Survey Analysis Section below.

5.1.2 Performance Data

Performance data represent the number of errors (distractions) a driver made in each scenario. Each simulation had a standard route for the driver to follow. Along this designated path, the driver experienced situations created by the research team. During these situations, the team's goal was to track the driver's performance in a consistent manner that would later allow for statistical analysis.

Records included five main driving error types: lane deviations, off road, speed limit (speeding or hazardously slow), dangerous braking, and collisions. The research team implemented situations to prompt opportunities for distraction and then recorded how the driver's performance was affected. The team counted and recorded the number of occurrences in which the driver's performance changed in each distraction and relief. Detailed counting techniques are described in Appendix A. The research team's analysis and findings are provided in detail in Section 5.4.

5.1.3 Physiological Data

EEG and ECG sensors were used to record performance and physiological measures. EEG records brain waves of the user and has been shown to provide an accurate indication of various processes in the brain while driving,[42] which serves as the basis for its inclusion in this experiment. The EEG data were used to record and measure various brain waves. The magnitude of alpha, beta, and theta waves is the measure of workload. The ECG recorded heart rate variability (HRV), where frequency and variability of heart rate were the team's measure for magnitude of simulator sickness. EEG/ECG data were measured at each scenario and for each driver.

To maintain accurate comparisons between participants, a 5-minute baseline scenario was recorded for each driver prior to the experiment. This information was stored on external hard drives for later analysis.

The team hypothesized that measurements with EEG and ECG for the participant (driver) would be different when the participant was presented with a distraction compared to driving without the distraction. The analysis results are described in the Physiological Analysis Section below.

5.1.4 Simulator Data

Simulator data included the simulator output in text files for each driver. The text file provided information about the steering, accelerator (gas pedal), brake, and speed. To ensure reliability, the team stored the virtual playback of each simulated scenario. Additionally, if Camera 2 failed, researchers could use the virtual playback to conduct an after-action review and to score the subject's observed distraction. The team saved this additional data for any contingencies during or after the experiment.

The team's analysis and findings are provided in detail in the "Simulator Analysis" section.

5.2 SURVEY ANALYSIS

Two types of surveys were given for each driver: a demographic survey given at the beginning of the experiment, and two condition assessment surveys given during the experiment.

The demographic survey gathered information about the driver's experience in driving a truck and knowledge of using touchscreen devices and cell phones. The analysis of the demographic survey showed that most participants were fairly similar despite some recorded demographic differences. However, Mp3 touch ownership was strongly correlated with a significant reduction in errors during the Mp3 player condition (Scenario 3). Despite this, exposure to the Mp3 player, as seen in Scenario 3, always caused a significant increase in driving errors when compared to Scenario 1, which had no distractions. This satisfies the team's hypothesis that exposure to the factor causes errors (distractions).

The one-way analysis of variance (ANOVA) was calculated between participants based on their familiarity with using touchscreen Mp3 players (see Figure 4). The F-value is 4.587 and the p-value is 0.04. This means that both touchscreen Mp3 owners and non-touchscreen Mp3 owners significantly differed in Scenario 3 compared to Scenario 1 (no distractions).

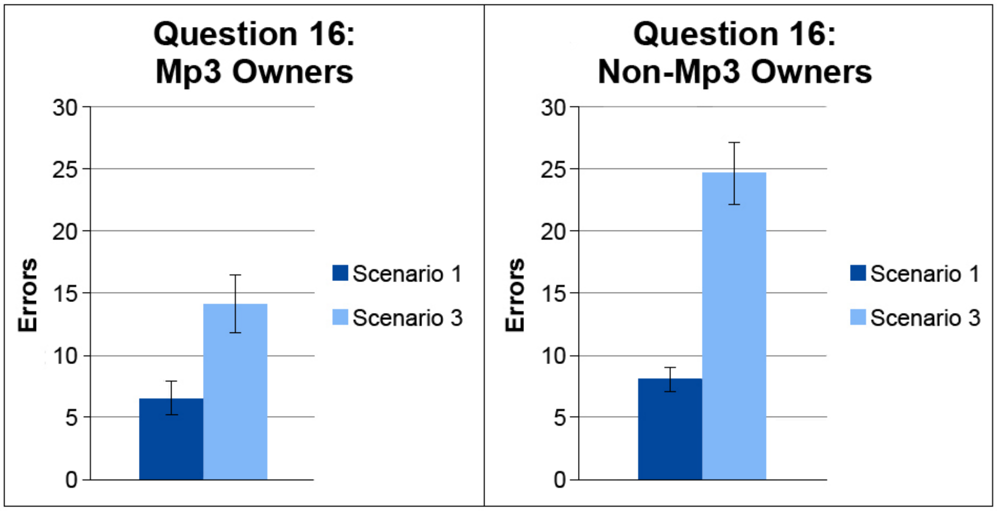

Figure 4. Bar chart. Mp3 owner vs. non-Mp3 owner Driving error comparison.

The other types of surveys were Survey A (distributed after the fourth run) and Survey B (distributed after the eighth run). The main purpose of these surveys was to evaluate the driver's condition in the middle and at the end of the experiment. Drivers who had SAS symptoms were excluded from the experiment. The questions, used on both surveys, are shown in Table 1:

Table 1. Questions appearing on both surveys.

Q1	I enjoyed this experience.
Q2	I think the break between drives needs to be longer.
Q3	The driving experience was realistic.
Q4	Using the phone and/or Mp3 player was distracting to me.
Q5	The traffic situation was a distraction.
Q6	I could tell what each traffic sign was supposed to be.
Q7	I feel I can still go in the simulator for another few runs.

The team's hypothesis about the surveys is as follows:

- Drivers will agree that they enjoyed the simulation throughout the study.
- Drivers will not agree that breaks should be longer throughout the study.
- Drivers will always agree that the simulation was realistic.
- Drivers will always agree that cell phones and touchscreen Mp3 players were distracting.
- Drivers will always agree that signs were easy to see, since the team designed the scenarios to make the road signs clear.
- Participants will experience some discomfort by the end of the experiment, and thus the number of runs they think they can complete will decrease. The mean was expected to be less than 3; that is, that participants would agree that they could do more runs. This is

because the team designed the experiment to end before drivers experienced much discomfort from simulator sickness.

Table 2 lists the options for Likert scale surveys. Figure 5 provides the average response comparison for Surveys A and B.

Table 2. Likert scale.

1	Strongly Agree
2	Agree
3	Neutral
4	Disagree
5	Strongly Disagree

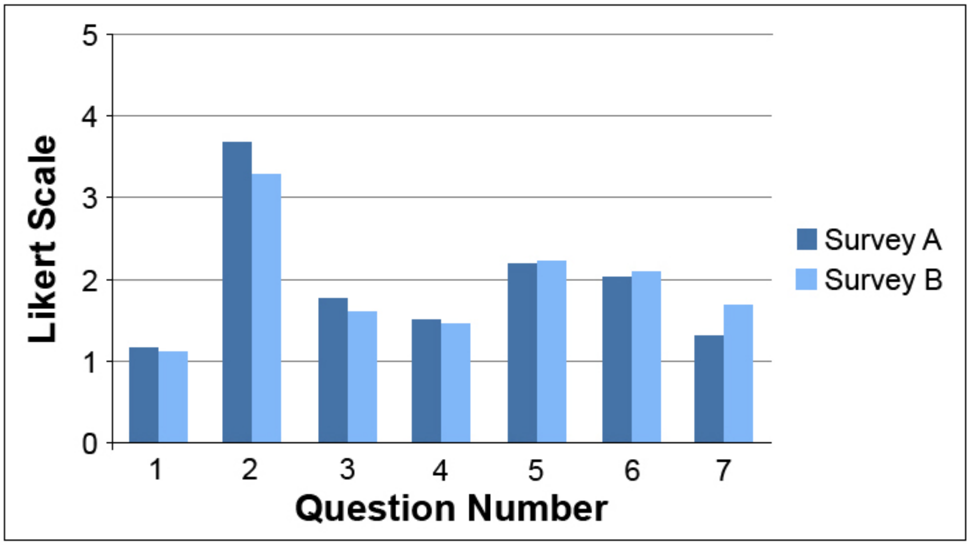

Figure 5. Bar chart. Average response number for every question in Survey A versus Survey B.

The data support the team's hypothesis for each question. Correlation analysis was used to analyze Surveys A and B, because the team was interested in seeing whether individual drivers would change their answers. This allowed the team to make insights into the scenario and run order. Strength of correlations in this paper is judged by the value of the Pearson's correlation coefficient (see Table 3). The descriptive statistics and the paired sample correlations are available in Appendix B.

Table 3. Pearson's correlation coefficient.

Correlation	Negative	Positive
None	-0.09–0.0	0.0–0.09
Weak	-0.3– 0.1	0.1–0.3
Moderate	-0.5–-0.3	0.3–0.5
Strong	-1.0–-0.5	0.5–1.0

- Q1 had a strong correlation (0.891, $p < 0.000$) with a nearly identical mean from the beginning (1.1852) to the ending (1.1154). This indicates that everyone strongly agreed that they enjoyed the experience throughout the entire study.
- Q2 had a moderate correlation (0.462, $p < 0.017$) with a beginning mean of 3.7037 and an ending mean of 3.3077. This indicates that participants tended neither to agree nor disagree that breaks needed to be longer.
- Q3 had a strong correlation (0.743, $p < 0.000$) with a beginning mean of 1.7778 and an ending mean of 1.6154. This indicates that participants agreed that the situation was realistic throughout the entire study.
- Q4 had a strong correlation (0.932, $p < 0.000$) with a beginning mean of 1.2727 and an ending mean of 1.1905 with very little variance. This indicates that participants strongly agreed that phones and touchscreen Mp3 players were distracting throughout the entire study.
- Q5 had a strong correlation (0.856, $p < 0.000$) with a beginning mean of 2.0909 and an ending mean of 2.0909. This indicates that drivers always thought that the external traffic situation was distracting throughout the entire experiment.
- Q6 had a moderate correlation (0.529, $p < 0.005$) with a beginning mean of 2.037 and an ending mean of 2.1154. This indicates that participants agreed throughout the experiment that road signs were clear and easy to understand. This is important because, for the measures of speed to be valid, the team needed participants to be able to clearly identify the posted speed limits.
- No significant correlation was found for Q7. The mean rose from 1.3333 to 1.6923. This is as expected, because the experience becomes more fatiguing and simulator sickness increases. The team predicted, based on the design, that by the end of the experiment most participants would still feel capable of more runs, and this was true. Both means are in the strongly agree to somewhat agree range for continuing.

5.3 PERFORMANCE THEORY

Previous studies showed that touchscreen Mp3 players(43) and cell phones(44) were detrimental to driver performance and attention. Decreases in driver performance were expressed through the performance data, while decreases in driver attention were seen in the physiological data. This is suggested to be caused by prolonged or repeated interruption in the visual processing of the driving task, such as looking away from the road. Such interruptions were found to be caused by Mp3 players.(45, 46) Additionally, this finding supports previous research showing that more complex Mp3 player tasks decrease driver performance when compared to less complex Mp3 player tasks.(47)

According to Klimesch, different EEG recording techniques have been used to objectively assess attention,(48) while other researchers like Lin and Muratt, respectively, focused on using an EEG to assess mental workload,(49, 50) and Patten assessed the relationship between the two.(51) The team's goal was to show that a factor was psychologically distracting, which an EEG can show through mental workload.[52, 53, 54, 55] Patten et al.[56] found that increased workload (as a result of a secondary task such as a phone conversation) is related to a decrease in attention to the primary task. This finding is synonymous with Wickens' work with resource theory, which states that fewer resources are available to be allocated as workload/task demand increases.[57] Therefore, one can expect that almost any additional tasks while driving will cause a decline in mental resources. Since visual resources are critical for driving, while auditory resources are less important, the team expected that tasks requiring a lot of visual processing would cause more of a decrease in performance than tasks that are more audio-focused. However, the team still expected a performance drop in both, because any additional task while driving will place more demands on mental workload.

5.4 PERFORMANCE ANALYSIS

The experiment included eight scenarios that were randomized in a balanced sequence. This means that none of the drivers experienced the experimental scenarios in the same order. Therefore, each driver knew that he was going to drive for the experiment eight times but did not know which scenario he would experience.

The team established a naming convention of "run number" that represents the order of the scenarios. Each successful driver started the experiment on Run 1 and ended on Run 8, although to the experimental team each run was a different scenario (condition). To keep track of which scenario was happening and in what order, the team created a table-style list for each driver. These tables listed the run numbers sequentially and aligned them with the corresponding scenarios. Table 4 is an example of the run number versus the scenario number. Table 5 lists the eight scenarios and their conditions.

Table 4. Run number versus scenario.

Run	Driver 11	Driver 12
Run 1	3	4
Run 2	2	8
Run 3	8	3
Run 4	4	2
Run 5	7	5
Run 6	6	1
Run 7	1	7
Run 8	5	6

Table 5. Scenarios and their associated distractions.

Scenario Number	Factor A (Cell Phone)	Factor B (Mp3 Touchscreen Device)	Factor C (External Event)
1	No	No	No
2	Yes	No	No
3	No	Yes	No
4	Yes	Yes	No
5	No	No	Yes
6	Yes	No	Yes
7	No	Yes	Yes
8	Yes	Yes	Yes

Figure 6 shows the average number of errors per run. To support the notion that the team's design was a balanced, randomized design and that there were no significant learning or fatigue factors, the team conducted the following tests:

- **Testing for the difference between the total average of errors in Run 1 and Run 8.** To test for a significant difference between the total average of errors in Run 1 versus Run 8, the team tested the null hypothesis that there was no difference. The test failed to reject the null hypothesis that they were equal (t = -1.17, p = 0.249). Therefore, there was insufficient evidence to reject the null hypothesis (or to conclude that the total average of errors in Run 8 was not equal to the total average of errors in Run 1).
- **Testing for the learning factor.** If there was a learning factor (drivers' performance improved because they learned the scenario after eight runs), then the team would expect the total average of errors in Run 8 to be less than the total average of errors in Run 1. The test failed to reject the null hypothesis that the average total of errors in Run 8 was greater than or equal to the average total of errors in Run 1 (t = -1.17, p = 0.124). Therefore, there was insufficient evidence to reject the null hypothesis (or to conclude that the total average of errors in Run 8 was less than the total average of errors in Run 1).
- **Testing for the fatigue factor.** If there was a fatigue factor (drivers' performance decreased as a result of fatigue through the eight runs), then the team would expect the total average of errors in Run 8 to be greater than the total average of errors in Run 1. The test failed to reject the null hypothesis that the average total of errors in Run 8 was less than or equal to the average total of errors in Run 1 (t = -1.17, p = 0.876). Therefore, there was insufficient evidence to reject the null hypothesis (or to conclude that the total average of errors in Run 8 was greater than the total average of errors in Run 1).

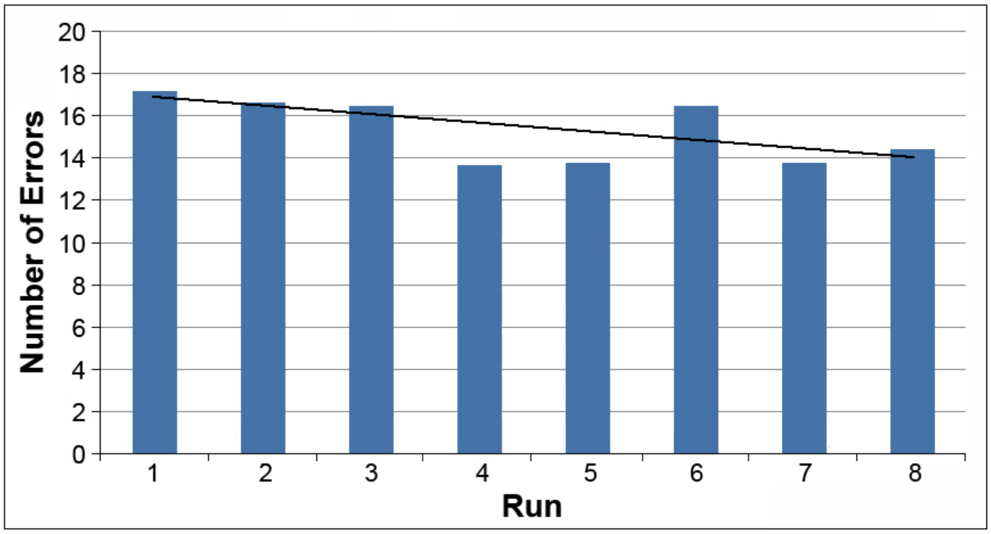

Figure 6. Bar chart. Average number of errors per run.

Scenarios 2–8 contained the three distracting factors (cell phone, touchscreen Mp3 player, and an external event) and their combinations. Figure 7 represents the average total number of errors in each scenario.

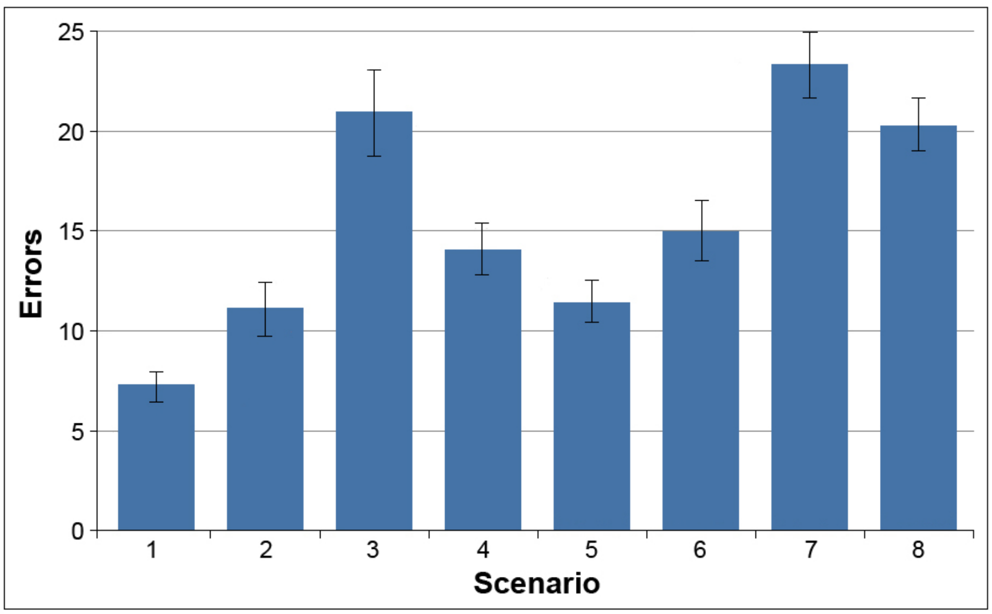

Figure 7. Bar chart. Average total errors per scenario.

Multiple *t*-test comparisons were employed to compare means of scenarios. The team's hypotheses were:

- All scenarios will cause a higher number of errors than the control scenario (Scenario 1).
- Use of a touchscreen Mp3 player (Scenario 3) will cause a higher number of errors than the use of a cell phone (Scenario 2).

- The presence of an external event, such as a construction area or a car accident (Scenario 5), will cause a higher number of errors than the use of a cell phone (Scenario 2).
- Use of a touchscreen Mp3 player (Scenario 3) will cause a higher number of errors than the presence of an external event (Scenario 5).
- Use of a touchscreen Mp3 player with an external event present (Scenario 7) will cause a higher number of errors than the use of a touchscreen MP3 player alone (Scenario 3).
- Use of a cell phone with an external event present (Scenario 6) will cause a higher number of errors than an external event alone (Scenario 5).
- Use of a touchscreen Mp3 player with an external event present (Scenario 7) will cause a higher number of errors than an external even alone (Scenario 5).
- Use of a cell phone with an external event present (Scenario 6) will cause a higher number of errors than the use of a cell phone alone (Scenario 2).
- Use of a cell phone and an Mp3 player (Scenario 4) while driving will cause a higher number of errors than the use of a cell phone alone (Scenario 2).

The *t*-test comparisons performed on the data and the outcomes of the team's hypotheses were as follows:

- The *t*-test rejected the null hypothesis that all scenarios caused equal or fewer numbers of errors than the control scenario with a *p*-value of less than 0.05 alpha. Therefore, all the scenarios caused a significantly higher number of errors than the control scenario.
- The *t*-test rejected the null hypothesis that Scenario 3 caused equal or fewer numbers of errors than Scenario 2 ($t = 4.55$, $p = 0.000$). Therefore, the use of a touchscreen Mp3 player (Scenario 3) caused a higher number of errors than the use of a cell phone (Scenario 2) with a 95-percent confidence level.
- The *t*-test failed to reject the null hypothesis that Scenario 5 caused equal or fewer numbers of errors than Scenario 2. This means that there was not sufficient evidence to reject the null hypothesis ($t = 0.74$, $p = 0.232$) with a 95-percent confidence level.
- The *t*-test rejected the null hypothesis that Scenario 3 caused equal or fewer numbers of errors than Scenario 5 ($t = 4.78$, $p = 0.000$). Therefore, the use of a touchscreen Mp3 player (Scenario 3) caused a higher number of errors than the presence of an external event (Scenario 5) with a 95-percent confidence level.
- The *t*-test failed to reject the null hypothesis that Scenario 7 caused equal or fewer numbers of errors than Scenario 3. This means that there was not sufficient evidence to reject the null hypothesis ($t = 1.17$, $p = 0.124$) with a 95-percent confidence level.
- The *t*-test rejected the null hypothesis that Scenario 6 caused fewer or equal numbers of errors than Scenario 5 ($t = 2.48$, $p = 0.008$). Therefore, the use of a cell phone caused a higher number of errors when an external event existed (Scenario 6) than not using it when an external event existed (Scenario 5) with a 95-percent confidence level.

- The *t*-test rejected the null hypothesis that Scenario 7 caused equal or fewer numbers of errors than Scenario 5 ($t = 6.96$, $p = 0.000$). Therefore, the use of a touchscreen Mp3 player when an external event existed (Scenario 7) caused a higher number of errors than not using it when an external event existed (Scenario 5) with a 95-percent confidence level.
- The *t*-test rejected the null hypothesis that Scenario 6 caused equal or fewer numbers of errors than Scenario 2 ($t = 2.66$, $p = 0.005$). Therefore, the use of a cell phone when an external event existed (Scenario 6) caused a significantly higher number of errors than using the cell phone when there was not an external event (Scenario 2) with a 95-percent confidence level.
- The *t*-test rejected the null hypothesis that Scenario 4 caused equal or fewer numbers of errors than Scenario 2 ($t = 2.39$, $p = 0.010$). Therefore, using a touchscreen device and a cell phone at the same time (Scenario 4) caused a significantly higher number of errors than using a cell phone only (Scenario 2) with a 95-percent confidence level.

The team's analysis also revealed that lane deviation was the most frequent error type. It represented 71 percent of the total errors, as shown in Figure 8.

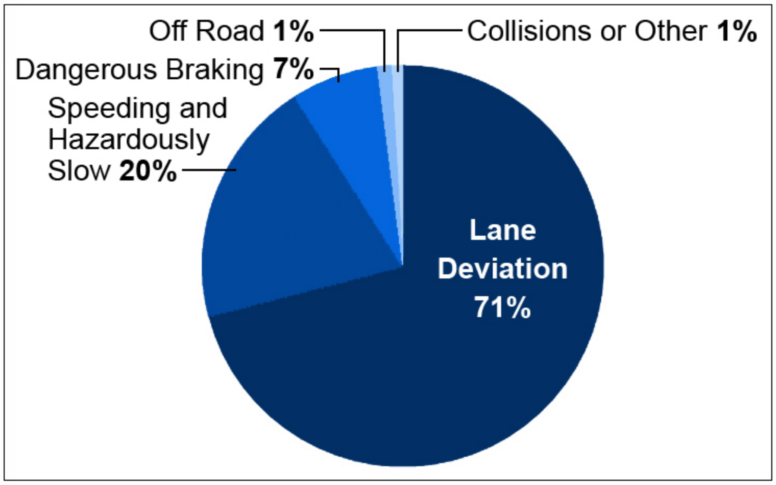

Figure 8. Pie chart. Percentage of driving errors observed by type.

It is worth mentioning that although collisions accounted for only 0.3 percent of all errors, they occurred during Scenarios 7 and 8, where the drivers were distracted by an external event and touchscreen Mp3 player (Scenario 7) or an external event, phone call, and the use of a touchscreen Mp3 player (Scenario 8). Figure 9 represents the average number of errors per error type per scenario.

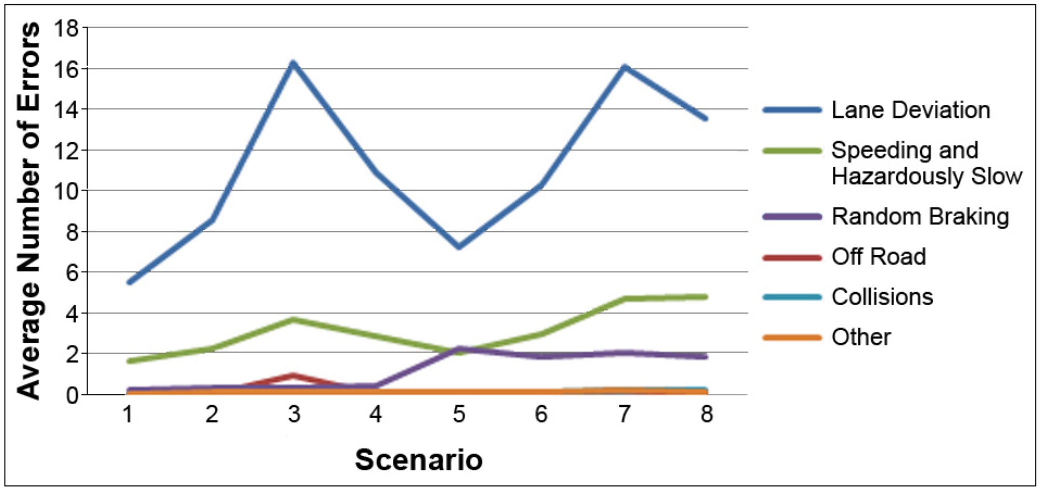

Figure 9. Line chart. Average number of errors per type for every scenario.

The second highest error type was speed violation (speeding or going hazardously slow). Speed violations are high in the scenarios where external events exist; an external event is also reported as a factor with a significant effect on the total performance of the driver. Drivers were observed driving as much as 5–30 mi/h under the posted speed limit on the highway where any external event existed (Scenarios 5, 6, 7, 8). Drivers tend to lower their speed when they are engaged in multiple tasks, yet they cause hazards to other drivers when they drive too far below the posted speed limit. Figure 10 shows the average number of speed violations (speeding and hazardously slow).

The final report of the National Motorists Association in June 1996 revealed that lowering the speed limit did not reduce the number of crashes. This means that speed reductions appeared to reflect an overreaction to the threat of punishment for being distracted.(58) Moreover, the Florida Drivers Association set the rule in chapter three of the Florida Drivers Handbook that driving too slowly—or as the team termed it "hazardously slow"—is also against the law, because it blocks other vehicles from moving at normal, safe speeds.(59)

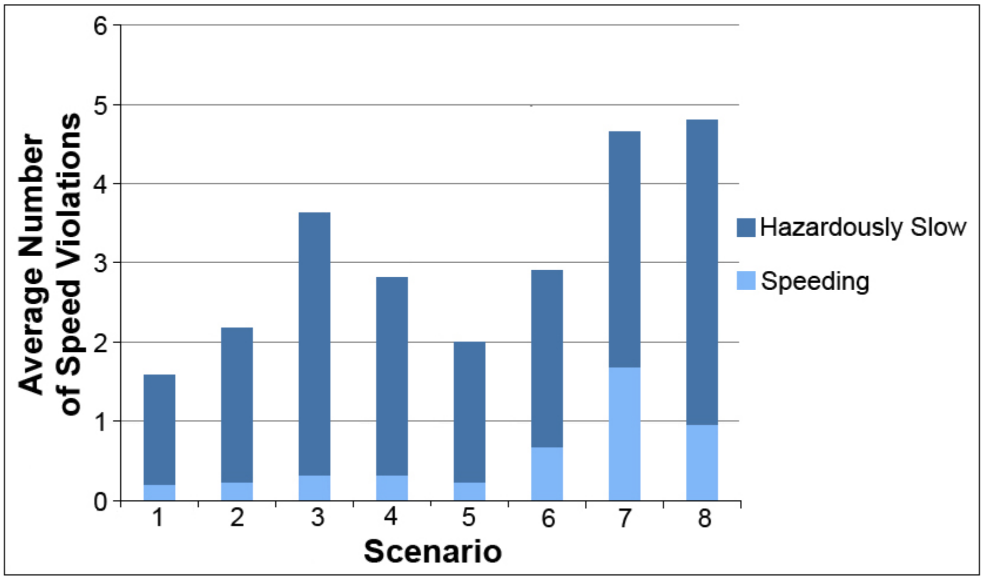

Figure 10. Bar chart. Average number of speed violations per scenario.

In an attempt to compare the effect of being distracted by the three main factors (cell phone, touchscreen Mp3 player, and an external event) and their interactions, the team observed that using a touchscreen Mp3 player device increased the number of errors by up to three times in comparison to the control scenario (Scenario 1). Moreover, being engaged in multiple tasks caused approximately twice as many errors as driving without any distracting factor (Scenario 1). Figure 11 and Figure 12 show the percent of errors by task and by multiple tasks.

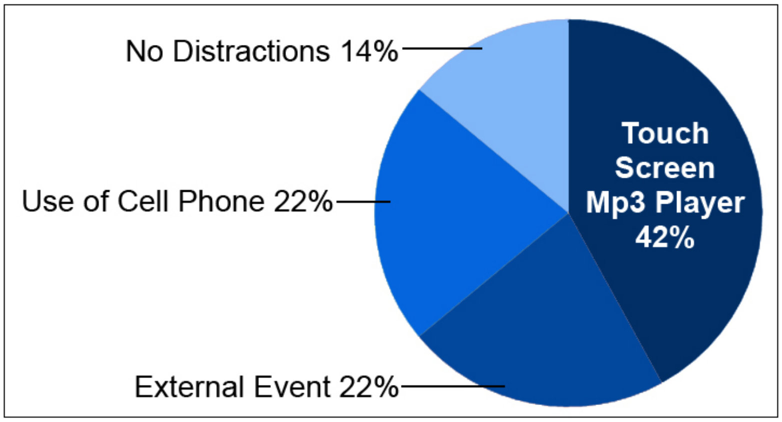

Figure 11. Pie chart. Percentage of errors, by distraction type.

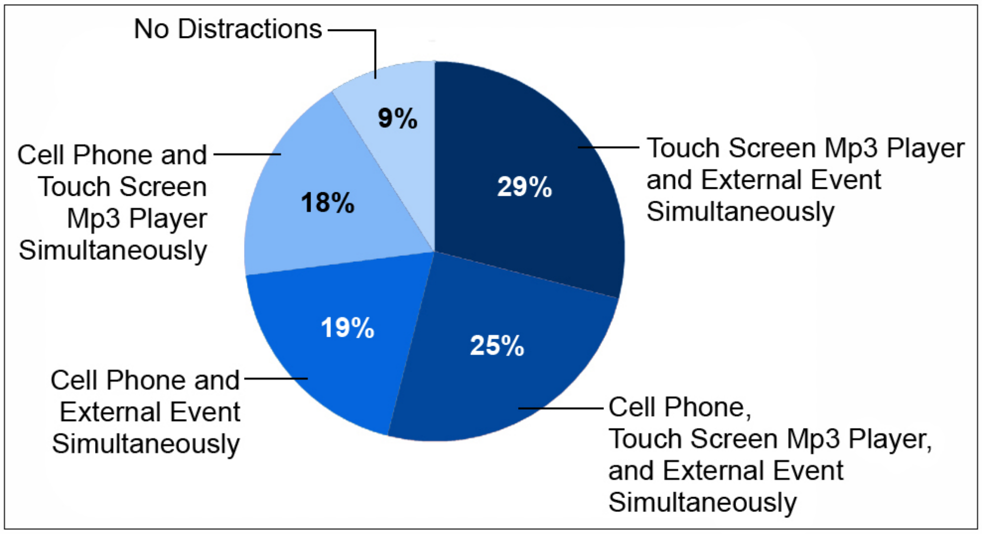

Figure 12. Pie chart. Percentage of errors, by scenario.

5.5 PHYSIOLOGICAL MEASURES ANALYSIS

5.5.1 Electroencephalography Theory

To evaluate distraction through EEG measures, changes from baseline scores were compared using a one-way (8-level) within-subject ANOVA, across total alpha, total beta, total theta, frontal theta, and alpha measures. Total alpha, beta, and theta measures were compared to investigate increase in workload,[60] which is related to distraction.[61]

Frontal theta was compared across scenarios to investigate increase in working memory load,[62] while parietal alpha was looked at to determine the participants' driving task load.[63] Driving task load refers to the amount of resources allocated to the driving task as opposed to the distractor tasks. The team hypothesized that the factors are distracting and would therefore cause total alpha, total beta, and total theta to have a significant main effect in Scenarios 2–8 when compared to Scenario 1.

5.5.2 Electroencephalography Results

Significant main effects, shown in Figure 13, Figure 14**,** Figure 15**,** Figure 16**,** and Figure 17 were found for total alpha [$F(7,119) = 3.784$, $p = 0.001$], total beta [$F(7,119) = 5.660$, $p = 0.000$], total theta [$F(7,126) = 3.509$, $p = 0.002$], frontal theta [$F(7,126) = 4.814$, $p = 0.000$], and parietal alpha [$F(7,126) = 4.768$, $p = 0.000$]. Scenarios 2, 4, and 8 showed consistent, significant increases across all EEG measures as compared to Scenario 1. In addition, Scenario 6 showed significant increases across total alpha, beta, theta, and parietal alpha measures compared to Scenario 1. Finally, Scenario 3 showed increases in total alpha and theta, while Scenario 7 showed increases only in total theta.

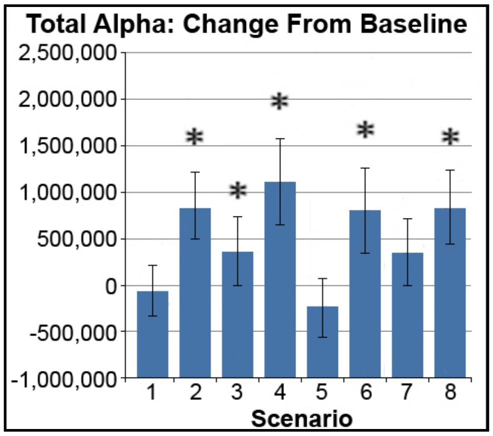

Figure 13. Bar chart. EEG results—total alpha per scenario.

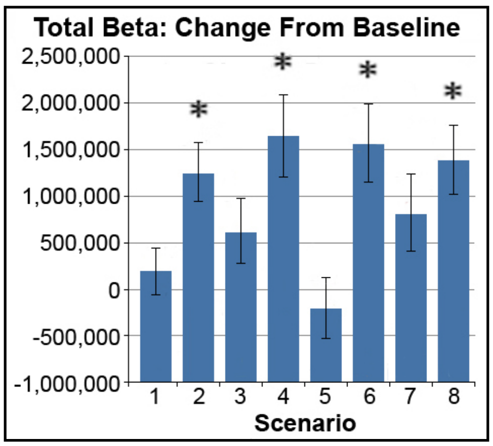

Figure 14. Bar chart. EEG results—total beta per scenario.

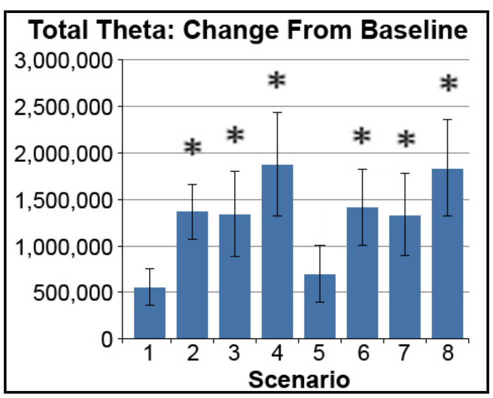

Figure 15. Bar chart. EEG results—total theta per scenario.

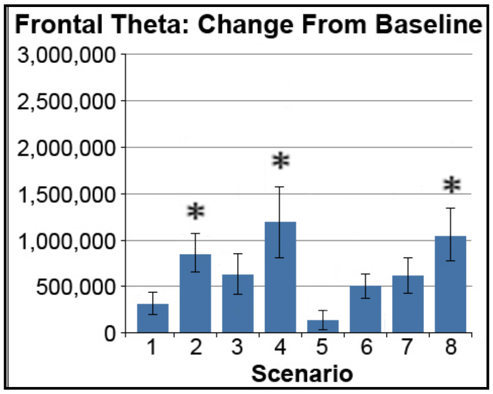

Figure 16. Bar chart. EEG results—frontal theta per scenario.

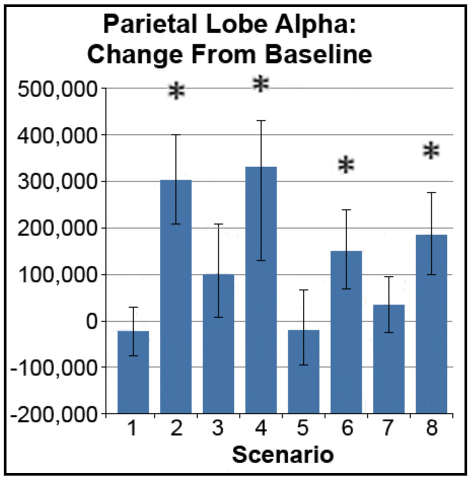

Figure 17. Bar chart. EEG results—parietal lobe alpha per scenario.

5.5.3 Electrocardiography Theory

Previous research on virtual reality studies has reported that an increase in heart rate variability (HRV) is an indicator of simulator sickness.(64) The team hypothesized that participants who reported sickness would show a significant increase in HRV.

5.5.4 Electrocardiography Results

To evaluate distraction through ECG measures, HRV was compared using a one-way (8-level) within-subject ANOVA. Both *z* scores and difference from baseline scores were evaluated. Significant main effects for HRV *z* scores [$F(7,133) = 2.499$, $p = 0.019$] and HRV difference from baseline [$F(7,140) = 2.422$, $p = 0.023$] were found. Scenarios 2, 3, 7, and 8 showed significant increases in HRV compared to Scenario 1, as shown in Figure 18 and Figure 19.

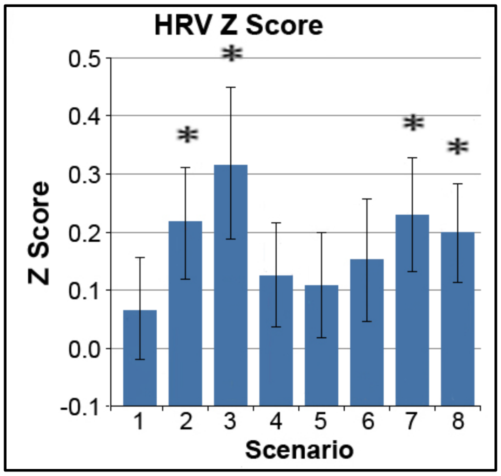

Figure 18. Bar chart. HRV *z* scores per scenario.

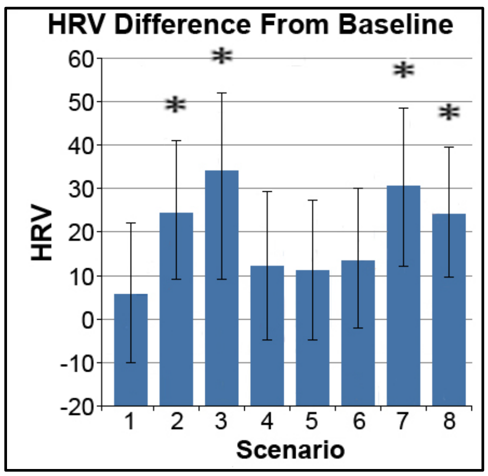

Figure 19. Bar chart. HRV difference from baseline per scenario.

To determine whether simulator sickness influenced HRV, a one-way (8-level) within-subject ANOVA was run across the HRV variables for participants who reported having or not having symptoms of simulator sickness. Significant main effects for HRV *z* score [$F(7,70) = 2.877$, $p = 0.011$] and HRV difference from baseline [$F(7,77) = 2.662$, $p = 0.017$] were found for the group that reported symptoms of simulator sickness. No significant differences were found among the group that reported having no symptoms of simulator sickness. This supports the hypothesis that HRV increases in participants who feel sick.

5.6 SIMULATOR ANALYSIS

5.6.1 Raw Data

The simulator used in this study records various data for each run a driver performs. The simulator produces records at a high rate, ranging from one record every 1/45th of a second to a record every 1/60th of a second. The data are compiled by the simulator into a report and saved as a simple text file similar to Figure 20. To assist in validating the three most frequent driving violations, the team graphed each of the following categories: steering (Steer), accelerator (Accel), braking (Brake), and speed (mi/h). The steering was graphed separately from the accelerator, brake**,** and speed. Each line has a unique sequential index in the frame category. Each line represents, in this experiment, 1/60th of a second. To synchronize the simulator data with the time clock from the videos, the frame number was transformed into a decimal that was then displayed as time by spreadsheet software. Figure 20 provides a snapshot of the simulator data output. For this experiment, it often contained more than 20,000 rows of data.

Records: 107687
DriverName: none (none)
Scenario Name: SCENARIO 3
RDB Name: FREEWAY
VDD Name: TTAUTO
Host Name: hostname: M1Mdyn IP address: 10.1.0.1.10
Mdyn 2K release build date: Tuesday, December 04, 2007 Release 5.4.0107
**

Frame	X	Y	Z	P	R	H	Steer	Accel	Brake	mi/h	D_spd	Elapsed	Gear	Clutch	RPM
1262	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.91446	10	0.00	800.04
1263	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.93126	10	0.00	800.04
1264	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.94791	10	0.00	800.04
1265	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.96395	10	0.00	800.03
1266	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.9808	10	0.00	800.03
1267	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.99774	10	0.00	800.03
1268	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	24.01404	10	0.00	800.03
1269	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.06	0.00	0.00	0.00	25.03188	10	0.00	800.06
1270	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.11	0.00	0.00	0.00	25.04862	10	0.00	800.13
1271	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.06	0.00	0.00	0.00	25.06481	10	0.00	800.15
1272	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	25.08088	10	0.00	800.14
1273	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	25.09706	10	0.00	800.13
1274	1631.46	4980.86	1000.88	0.03	0.01	1.96397	0.08	0.00	0.00	0.00	0.00	25.11378	10	0.00	800.12

Figure 20. Screenshot. Snapshot of simulator data output.

It is worth mentioning that the simulator data have been extensively analyzed to validate the observed data while watching and coding the videos of each driver and scenario. This comparison increases the validity and reliability of the team's analysis. Mostly, the simulator output showed similar results to the coded videos; however, any mismatching results triggered the need to watch and code the videos again.

5.6.2 Steering Chart

Once the data were placed into the software template, the data were then graphed onto two charts (steering and speed). The steering chart represents the direction and the magnitude the driver rotated the steering wheel (in blue). Also on this chart, anytime the driver moved the steering wheel beyond a significant threshold, it is shown as a spike in red and is called a major motion. Due to the nature of driving a vehicle, when a driver deviates outside of his lane quickly, it usually requires a major motion of the steering wheel. However, when the driver purposely changes lanes it can also show up as a major motion. Likewise, it is possible for a driver to drift gradually outside of his lane, and this type of lane deviation is not recorded as a major motion. Hence, the team is calling groups of these major motions "points of interest" (POI). The point of interest is the result of the driver moving the steering wheel in a major motion large enough to move the driver outside of his lane. However, further investigation with the recorded videos is required in order to determine whether it was in fact a lane deviation, off road, or a lane change. It has been observed that drivers with more POI have more lane deviations than a driver with fewer POI.

By watching the video of Driver 19's Scenario 4, the team recorded 12 lane deviations, and inside his POI, there were 11 major motion spikes (represented by the stars) that can be seen from the simulator data (see Figure 21). The team has randomly compared the simulator data outputs to the coded video (observed data) to validate the team's lane deviation counting technique.

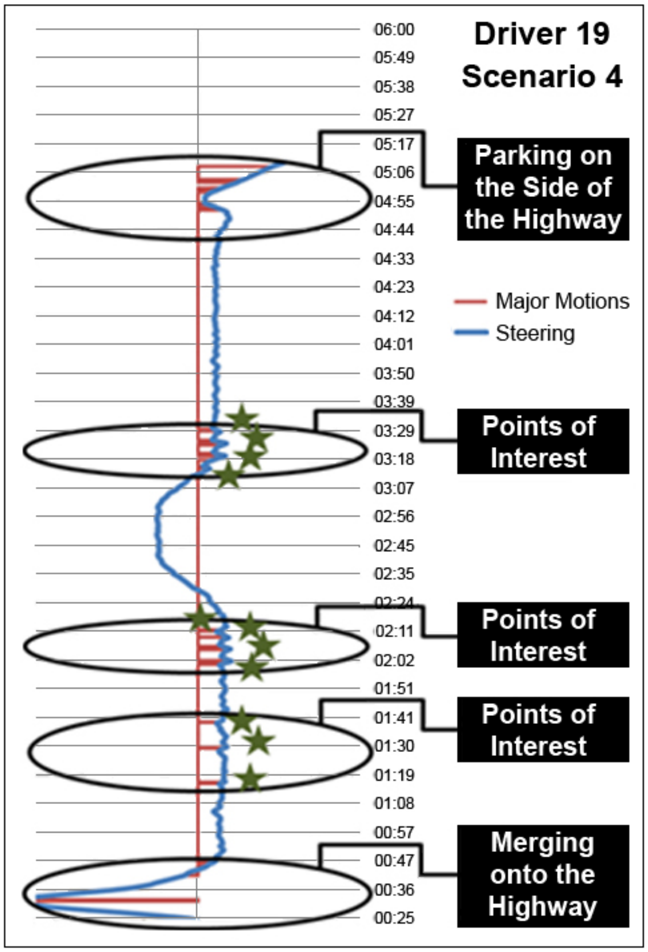

Figure 21. Chart. Example of a steering chart.

Figure 22 represents the steering charts for Drivers 4 and 16. Clearly, Driver 4 was able to stay in control of his vehicle for a longer amount of time compared to Driver 16. These two drivers represent the extremes of the best case and worst case responses to the factors in the scenario. Keep in mind that the red bars indicate only those motions on the steering wheel large enough to produce a lane deviation, but it is possible for a driver to deviate without drastically moving the steering wheel.

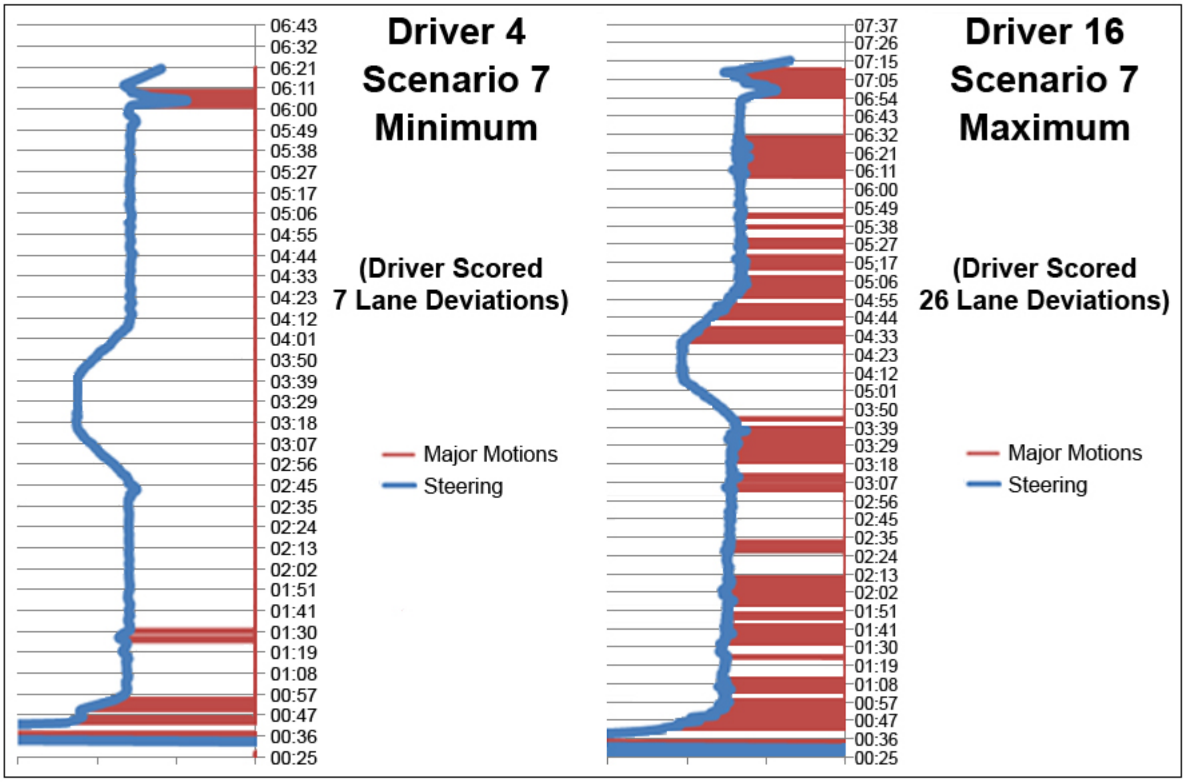

Figure 22. Chart. Scenario 7, minimum (driver 4) and maximum (driver 16) lane deviations

Comparisons between the minimum and maximum observed scores for all the scenarios are available in Appendix C.

5.6.3 Speed Chart

The second chart that is graphed from the raw simulator data—the speed chart—shows how much the accelerator and brake pedals are depressed (ranging from 0 to 100 percent), along with the speed (0–100 mi/h). On this chart, it is possible to identify when the vehicle deviates from the acceptable speed. The acceptable speed boundaries are indicated on the chart by dashed black horizontal lines. In addition, it is possible to identify the POI for potential dangerous braking. Moreover, because the drivers were not allowed to use cruise control, graphing the speed in this manner can tell researchers about the driver's ability to maintain or regulate his speed. An example of the speed chart is shown in Figure 23.

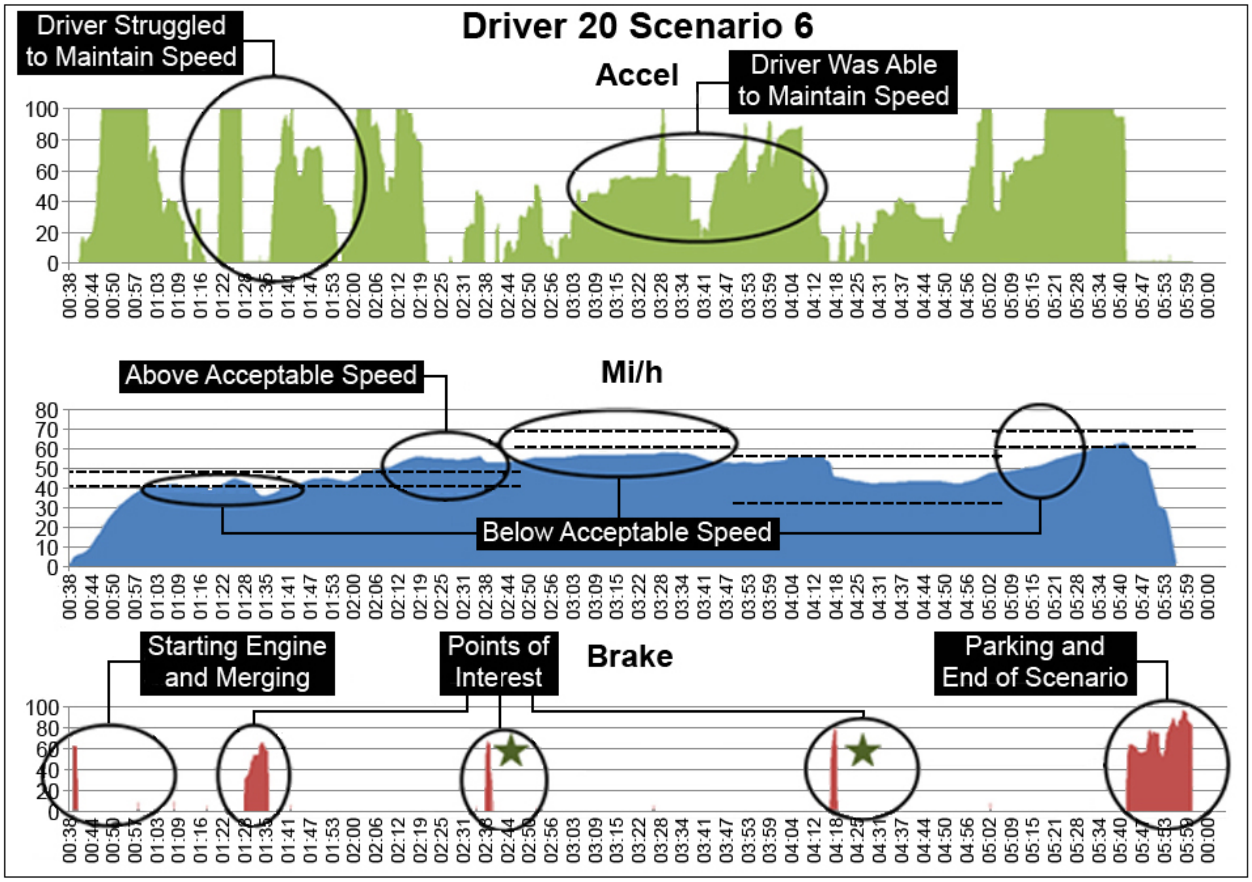

Figure 23: Chart. Example of speed chart (accelerator, miles per hour and brake spikes).

By watching the video of Driver 20's Scenario 6, the team recorded three below-speed violations and one above-speed violation at the speed checkpoints. The speed chart validates the team's speed counting techniques. The data show that out of Driver 20's three POI in this scenario, two were recorded as dangerous braking violations.

6. DISCUSSION

The primary aim of this experiment was to examine the effects of different distractions on commercial vehicle drivers' performance while driving. The results from this study are consistent with Chisholm and Horrey's works, which show that touchscreen Mp3 players(65) and cell phones(66) are detrimental to driver performance and attention. Decreases in driver performance were expressed through the performance data, while decreases in driver attention were seen in the physiological data.

Compared to Scenario 1, in which there were no distractions, all distractor scenarios (2–8) resulted in significantly more errors during the driving task. This suggests that (compared to having no distractors) driving errors increase with the addition of a cell phone, Mp3 player, external event, or any combination of the three. Moreover, scenarios in which participants had to actively interact with an Mp3 player (both with and without external distractions), as opposed to simply listening or turning the volume up and down, showed the highest error rates. Researchers have attributed these performance deficits to the prolonged glances away from the road required to operate an Mp3 player.(67, 68) Additionally, this finding supports previous research showing that more complex Mp3 player tasks decrease driver performance when compared to less complex Mp3 player tasks.(69)

As described earlier, different EEG recording techniques have been used to objectively assess attention,(70) mental workload,(71, 72) and the relationship between the two.(73) Patten et al.(74) found that increased workload (as a result of a secondary task, such as a phone conversation) is related to a decrease in attention to the primary task. This finding is synonymous with Wickens' work with resource theory, which states that as workload or task demand increases, fewer resources are available to be allocated.(75)

This study was completed with some complications and challenges. One limitation was the inability to garner a larger sample size of CMV operators. Expert drivers in the field are limited in number, and their time is expensive. Additionally, representatives from the trucking industry expressed concern over the possibility of negative consequences that the industry has associated with prior university studies. Although a few drivers in this study had only 5 years of driving experience, the average experience for all drivers was 19 years. Despite the variance, results from the baseline scenario were similar, validating that the expertise of the sample group was homogeneous.

With respect to the physiological data, the current study shows that decreases in parietal alpha power,(76) increases in total band (alpha, beta, theta) power,(77) and increases in frontal theta power(78) were indicators of increased workload and decreased attention. Lei and Roetting(79) found that a decrease in parietal alpha was related to a higher driving task load. In other words, the present study indicates that decreases in parietal alpha were indicators that participants were allocating more resources to the driving task. On the contrary, an increase in parietal alpha was an indicator that participants were allocating more resources to a secondary task. This suggests that participants were allocating their attention resources to the distractor instead of the driving task during those scenarios, which is consistent with Wickens' mental resource theory.(80)

In this investigation, Scenarios 2, 4, 6, and 8 showed significant increases in parietal alpha. In Scenarios 2, 4, 6, and 8, drivers used cell phones. In Scenario 4, drivers used a cell phone and an Mp3 player. In Scenario 6, drivers used a cell phone and there was an external event. In Scenario 8, drivers used a cell phone and an Mp3 player, and there was an external event present. Murata(81) found that as task difficulty/workload increases, total power for the frequency bands (alpha, beta, and theta) increases. Consistent and significant increases from Scenario 1 were seen across all bands during Scenarios 2, 4, 6, and 8. Finally, Lin et al.(82) showed that an increase in frontal theta power is an indicator of driver distraction through increases in working memory load. In this study, significant increases were seen in Scenarios 2, 4, and 8 as compared to Scenario 1. Overall, Scenarios 2, 4, 6, and 8 showed evidence of increased workload and decreased attention. One commonality among these scenarios was the use of the cell phone as a distractor. Previous research on cell phone use, driving, and attention(83, 84) has also found that the use of a cell phone takes attention resources away from driving.

7. CONCLUSION

The results of this investigation show that the use of a cell phone, the use of a touchscreen Mp3 player, the presence of external distraction(s), or any combination of the three causes deficits in driving performance. Overall, both performance and physiological measures showed evidence of driver distraction. Performance measures suggested that the largest performance deficiencies come from actively using a touchscreen Mp3 player. EEG measures showed that while both Mp3 player and cell phone use increased workload and decreased attention, the cell phone was the highest distracting factor.

Comparing the effect of the distracting scenario to the non-distracted scenario, the team found that manipulating a touchscreen Mp3 player device is approximately three times more distracting among professional drivers. In addition, the team found that being engaged with multiple tasks while driving is approximately two to three times more distracting than non-distracted driving among professional drivers. From the scope of this study it was not possible to quantify positively which aspect of using a touchscreen Mp3 player caused the most cognitive and visual distraction.

Another strength of this study is that it used the EEG/ECG with collected/observed information to confirm and to quantify levels of distraction, which has never been attempted before. In addition, the experiment was conducted in a safe, controlled environment, which pushed participants to the extremes of their driving abilities. Although not quantified for this study, the distractions during the relief areas of the current experiment provided an indication that the driver was still under the influence of the distracting factor even after the task ended.

It should be noted that many studies have questioned the viability of using simulators when the topic concerned driver training, distracted driving, and other topics. Chan et al., noted:

> Simulators measure driving performance, what the driver can do. However, safety is determined primarily by driver behavior of what a driver chooses to do. It is exceedingly unlikely that a driving simulator can provide useful information on a driver's tendency to speed, drive while intoxicated, run red lights, pay attention to non-driving distractions or not fasten a seat belt.[(85)]

Although the study measured the CMV operators' performance, there is a high correlation between what drivers can do versus what they choose to do.[(86)] This study focused on what professional drivers can do while behind the wheel of a motor vehicle. To influence and change drivers' behavior, the research team believes that distracted driving studies should be accompanied by awareness campaigns that include outreach to influence not just CMV operator behavior but the general public, as well. Since CMV operator behavior can be measured by the number of crashes or fatalities that are caused by the factors highlighted in this study, such results should be related to drivers so they can see for themselves that their choices directly impact their driving performance. The researchers are currently working on disseminating future results, not only to the USDOT but also to the public through public service announcements, magazines, the Internet, briefings, and newspaper articles.

This study combined aspects of previous experiments described in the literature review and focused on a key demographic. The combined aspects of the previous research were the most relevant to the demographic being studied, which ensured that the project would be as realistic and useful as possible. The challenge of distracted driving continues to be a concern for overall traffic safety.

8. OUTREACH

Per contract requirements, the research team proposed a method to disseminate the study findings in a way that would raise public awareness to partners and stakeholders. The research team began by analyzing who the relevant stakeholders (audience) would be and the best methods for disseminating the information in a way that would reach them in a cost-effective manner. The research team discovered that the general audience would include not only CDL holders but anyone who holds a valid driver's license. Additionally, stakeholders could be truck companies as well as insurance companies that could be affected financially due to the cost and litigation involved with accidents. Another community that could benefit from the outreach program would be law enforcement and other government entities that might be able to push for changes to the laws involving distracted driving.

Once the research team completed the research and analysis on the best way to implement an outreach program, the team chose the following methods of dissemination:

- Magazine article/journal.
- Brochures/pamphlets.
- Presentation software briefings.
- A Web-based informational site.
- Video (traditional and possibly social media).

8.1.1 Magazine/Journal

The research team began by developing a journal article on which the rest of the team could base its outreach portion. The magazine article was developed in a non-academic way that anyone could read and understand. However, it was soon realized that due to the varying natures of the audience, several variations of the magazine article needed to be developed. Therefore, the research team developed two shortened versions of the magazine article, one that was a project summary and another that was a one-page description. These were written in laymen's terms and were short and directly to the point.

8.1.2 Brochures/Pamphlets

One of the items the research team developed next was a brochure entitled, "The Dangers of Distracted Driving." This brochure was designed to be used for demonstrations at conferences, at briefings to truck or insurance companies, or in other settings to provide information to drivers. The brochure provided distracted driving facts and described the research conducted and unique aspects of the study. The results of the study and their implications for the driving public were also listed in the brochure, as well as contact information.

8.1.3 Presentation Software Briefings

The research team developed two levels of briefings to be used for meetings with distracted driving stakeholders or to be used at demonstrations. The longer briefing provided more detail about the project to include the following topic areas:

- Great risk posed by losing focus.
- Distracted driving facts.
- Project overview.
- Why the study was unique.
- The experiment.
- The results.
- Outreach and awareness.
- Distracted driving video.

An additional briefing was created that focused solely on the experiment itself and showed images of the steps taken during the experimental process. These briefings were presented to the researcher's students and faculty during the student government's "Put Down Ur Cell Phone" anti-distraction event on September 14, 2011.

8.1.4 Web-based Informational Site

The research team also developed a Web-based informational site that anyone with Internet access can view. Unlike the briefing, the Web site was developed so that users have the option to view only the information that is of interest to them. In addition, the Web site provides more information and expanded details of bullet points that a presenter would normally cover while briefing a software presentation. Users of the Web site can access videos, testimonials, and any content related to the distracted driving study from their home computers without physically attending a workshop or demo. Additional distracted driving resources and links are also provided.

8.1.5 Videos

Finally, the research team used videos to help reach a wide ranging audience that would be interested in the dangers of distracted driving. These videos include testimonials created in-house, as well as videos produced by outside agencies. During the actual distracted driving experiment, at the conclusion of the drive, truck drivers were asked if they would provide testimonials on their experience participating in the study as well as their thoughts on the dangers of distracted driving. Truck drivers participating in the experiment signed waivers providing the research team permission to videotape them and use their testimonials. The main purpose of the videos was to use them in the "testimonials" section of the distracted driving Web site and as a part of briefings. Furthermore, the research team composed a 3-minute video on the current distracted driving study, then placed the completed video online for anyone to view while surfing the Web.

Other departments within the University also contacted the research team to discuss and feature the current study. UCF TV (a television station at UCF) completed a 3-minute segment on the project that ran across campus for a week-long period during the spring of 2012. This video segment was placed online for wider circulation. Additionally, a local news station contacted the team, and a television reporter visited and conducted an interview, which was aired on the evening news that night (July 27, 2011).

8.1.6 Opportunities for Outreach

Finally, once all of the outreach products were completed, the research team contacted the stakeholders to actually implement the outreach program. Fortunately, many major companies were receptive to the program.

In addition to the delivering presentations at the student government event, “Put Down Ur Cell Phone,” the research team highlighted the distracted driving research at the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2012. This is a major industry conference with numerous companies, military organizations, and countries participating, making it the perfect venue for outreach and large-scale dissemination of the results of this study.

Furthermore, the principal investigator for the study (and program director for the Research in Advanced Performance Technology and Educational Readiness [RAPTER] Labs at UCF), presented the current study and results to the “UCF for Life” program. This event was sponsored by a large organization of retired professionals who provide presentations on a variety of topics of community interest during the fall and spring 2013 semesters. The presentation on the current study was attended by over 450 people and consisted of a 45-minute address and 20 minutes of questions and answers.

Finally, the current study forms a centerpiece for all briefings conducted by RAPTER Labs, reaching hundreds of visiting professionals and students per year. Videos, posters, pamphlets, and links to the Web site are provided to these visitors so that they can follow up on the information and pass it along to others after they leave the facility.

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APPENDIX A: COUNTING TECHNIQUES

COUNTING TECHNIQUES FOR THE OBSERVED PERFORMANCE MEASURES OF CMV DRIVERS

Overall Project Description

Each simulation had a standard highway route designed for the driver to follow. Along the designated path, the driver experienced situations created by the research team. During these situations, the goal was to track the driver's performance in a consistent manner that would later allow for statistical analysis.

Records included five main driving error types: lane deviation, off road, speed violation (speeding or hazardously slow), dangerous braking, and collision. The research team created situations to prompt opportunities for distraction, which were recorded to measure how the driver's performance was affected. The counts were recorded using the coding sheets in the corresponding areas in which they occurred. The method of recording counted the number of occurrences in which the driver's performance changed in each distraction and relief, as shown in Table 6.

Table 6. Free highway.

Relief 1 (0.5 mile)	Distraction 1 (1 mile)	Relief 2 (1 mile)	Distraction 2 (1 mile)	Relief 3 (0.5 mile)

LANE DEVIATION:

- Every time the vehicle's tires crossed over a lane line (left or right side).
  - Note: This represents an unintentional motion in the vehicle significant enough to cause collisions with other vehicles or objects, and it can directly result in collisions
  - Counts as +1
- Exclusion notes:
  - This rule does not apply when the driver swerves inside the lane and the truck tires do not cross over a lane line.

OFF ROAD:

Every time the vehicle's tire went beyond the shoulder of the road and over the grass.

- Note: Passing the shoulder requires crossing a lane line, which requires a +1 count on lane deviation.
- Counts as +1.

SPEED VIOLATION (SPEEDING OR HAZARDOUSLY SLOW):

- When speed was far from the speed limit and could result in receipt of a ticket:
  - Normal highway (65 mi/h): The acceptable range is 60–70 mi/h.
  - Construction zone (45 mi/h): The acceptable range is 40–50 mi/h.
  - Accident zone (below 65 mi/h): The acceptable range is 35–65 mi/h.
    - Note: If the vehicle's speed falls outside the acceptable range at the designated checkpoints (listed on second page).
  - Counts as +1.
- Exclusion notes:
  - This rule does not apply when a driver is accelerating to reach the proper speed while coming from an area of lower speed.
  - This rule does not apply when a driver enters a slower zone and drifts to the lower speed rather than immediately breaking.
  - This rule does not apply if simulated vehicles physically block and prevent the driver from going the proper speed.

DANGEROUS BRAKING:

- When a truck driver brakes suddenly in a fashion that is dangerous for the safe operation of the vehicle.
  - A driver "dangerously brakes" when the magnitude of the brake is more than 80 percent braking power within 1 second of time. This was chosen because this can cause a tractor trailer truck to become destabilized or present hazard to other vehicles. Counts as +10.
- Exclusion notes:
  - This rule does not apply when a driver attempts to avoid a collision due to an error from a simulated vehicle (if it is a defensive situation, then it is not his/her fault).
  - This rule does not apply when a driver attempts to avoid a collision that would be his/her fault, but under such a situation a +1 would likely be applied for another violation.
  - For example, this rule does not apply if the sudden brake is to avoid a collision caused by tailgating as defined in "Other." However, a point for tailgating would apply.

COLLISION:

- Every time a driver hits anything from the front, such as but not limited to mile markers, road signs, other vehicles, etc.

    - Counts as +1.
- Exclusion notes.
    - Any collision when the driver is struck from behind does not count because of Florida law.
    - Any collision that is from a simulator error is not recorded.
        - This includes invisible off-road objects.
        - This includes simulated vehicles that do not drive properly and cause an accident.

OTHER:

- Every time a driver uses turn signals in a hazardous way that could mislead nearby traffic.
    - Merging suddenly without using a signal.
    - Using a signal without merging (only counts once during the entire duration of the signal).
- Every time a driver tailgates for more than 0.2 miles—that is, behavior that could result in a ticket for reckless driving. At highway speeds a trucker must maintain a gap of at least 200 feet in front of the vehicle for room to brake.
- Every time a driver uses hazard lights improperly.
    - There is no proper time to use hazard lights in this simulation.
    - Counts as +1.
- Exclusion Notes.
    - Turn signals do not count if the reason for using the signal and not merging was because a simulated vehicle prevented the merge from being completed.
    - Hazard lights do not count if the driver was confused about what to do after a collision.

Table 7. Speed limit checking points (periodic, every 0.2 miles after the start).

Relief 1	Distraction 1	Relief 2	Distraction 2	Relief 3
0.3 mile	0.5 mile	1.1 mile	1.7 mile	2.3 mile
–	0.7 mile	1.3 mile	1.9 mile	2.5 mile
–	0.9 mile	1.5 mile	2.1 mile	–

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APPENDIX B: SURVEY A AND B ANALYSIS

QUESTIONS USED

Table 8. Questions appearing on both surveys.

Q1	I enjoyed this experience.
Q2	I think the break between drives needs to be longer.
Q3	The driving experience was realistic.
Q4	Using the phone and/or Mp3 player was distracting to me.
Q5	The traffic situation was a distraction.
Q6	I could tell what each traffic sign was supposed to be.
Q7	I feel I can still go in the simulator for another few runs.

Table 9. Survey A.

Question	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Mean Standard Error	Standard Deviation Statistic	Variance Statistic
Enjoy	27	4.00	1.00	5.00	1.1852	0.15132	0.78628	0.618
Longer Break	27	3.00	2.00	5.00	3.7037	0.19107	0.99285	0.986
Realistic	27	3.00	1.00	4.00	1.7778	0.14454	0.75107	0.564
Phone Pod Distracting	27	4.00	1.00	5.00	1.5185	0.17189	0.89315	0.798
Traffic Distracting	27	4.00	1.00	5.00	2.2222	0.23469	1.21950	1.487
Sign	27	3.00	1.00	4.00	2.0370	0.16436	0.85402	0.729
More	27	4.00	1.00	5.00	1.3333	0.16013	0.83205	0.692
Valid N (List Wise)	27	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 10. Survey B.

Question	N Statistic	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Mean Standard Error	Standard Deviation Statistic	Variance Statistic
Enjoy 2	26	2.00	1.00	3.00	1.1154	0.08462	0.43146	0.186
Longer Break 2	26	4.00	1.00	5.00	3.3077	0.20583	1.04954	1.102
Realistic 2	26	3.00	1.00	4.00	1.6154	0.14756	0.75243	0.566
Phone Pod Distracting 2	26	4.00	1.00	5.00	1.4615	0.18589	0.94787	0.898
Traffic Distracting 2	25	4.00	1.00	5.00	2.2400	0.19391	0.96954	0.940
Sign 2	26	3.00	1.00	4.00	2.1154	0.20250	1.03255	1.066
More 2	26	3.00	1.00	4.00	1.6923	0.19030	0.97033	0.942
Motion Sickness	26	4.00	1.00	5.00	3.8462	0.21974	1.12044	1.255
Valid N (List Wise) 2	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 11**. Paired sample *t*-tests (95-percent confidence interval was used [significant when p < 0.05])**

Pair	Question	Mean	N	Standard Deviation	Standard Error Mean
Pair 1	Enjoy	1.1538	26	0.78446	0.15385
Pair 1	Enjoy 2	1.1154	26	0.43146	0.08462
Pair 2	Longer break	3.7308	26	1.00231	0.19657
Pair 2	Longer break 2	3.3077	26	1.04954	0.20583
Pair 3	Realistic	1.7692	26	0.76460	0.14995
Pair 3	Realistic 2	1.6154	26	0.75243	0.14756
Pair 4	Phone pod distracting	1.5000	26	0.90554	0.17759
Pair 4	Phone pod distracting 2	1.4615	26	0.94787	0.18589
Pair 5	Traffic distracting	2.1600	25	1.10604	0.22121
Pair 5	Traffic distracting 2	2.2400	25	0.96954	0.19391
Pair 6	Sign	2.0385	26	0.87090	0.17080
Pair 6	Sign 2	2.1154	26	1.03255	0.20250
Pair 7	More	1.3077	26	0.83758	0.16426
Pair 7	More 2	1.6923	26	0.97033	0.19030

Table 12: Paired samples test.

Pair	Question	Mean	Standard Deviation	Standard Error Mean	*Lower	*Upper	t	df	Sig. (2-tailed)
Pair 1	Enjoy—enjoy2	0.03846	0.44549	0.08737	-0.14148	0.21840	0.440	25	0.664
Pair 2	Longer break—longer break2	0.42308	1.06482	0.20883	-0.00701	0.85317	2.026	25	0.054
Pair 3	Realistic—realistic2	0.15385	0.54349	0.10659	-0.06568	0.37337	1.443	25	0.161
Pair 4	Phone pod distracting—phone pod distracting2	0.03846	0.34418	0.06750	-0.10056	0.17748	0.570	25	0.574

Pair	Question	Mean	Standard Deviation	Standard Error Mean	*Lower	*Upper	t	df	Sig. (2-tailed)
Pair 5	Traffic distracting—traffic distracting2	-0.08000	0.57155	0.11431	-0.31592	0.15592	-0.700	24	0.491
Pair 6	Sign—sign2	-0.07692	0.93480	0.18333	-0.45450	0.30065	-0.420	25	0.678
Pair 7	More—more2	-0.38462	1.23538	0.24228	-0.88359	0.11436	-1.588	25	0.125

*95 percent confidence interval of the difference.

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APPENDIX C: STEERING CHARTS

The following figures represent the drivers with the minimum and maximum number of observed lane deviations in each of the eight scenarios.

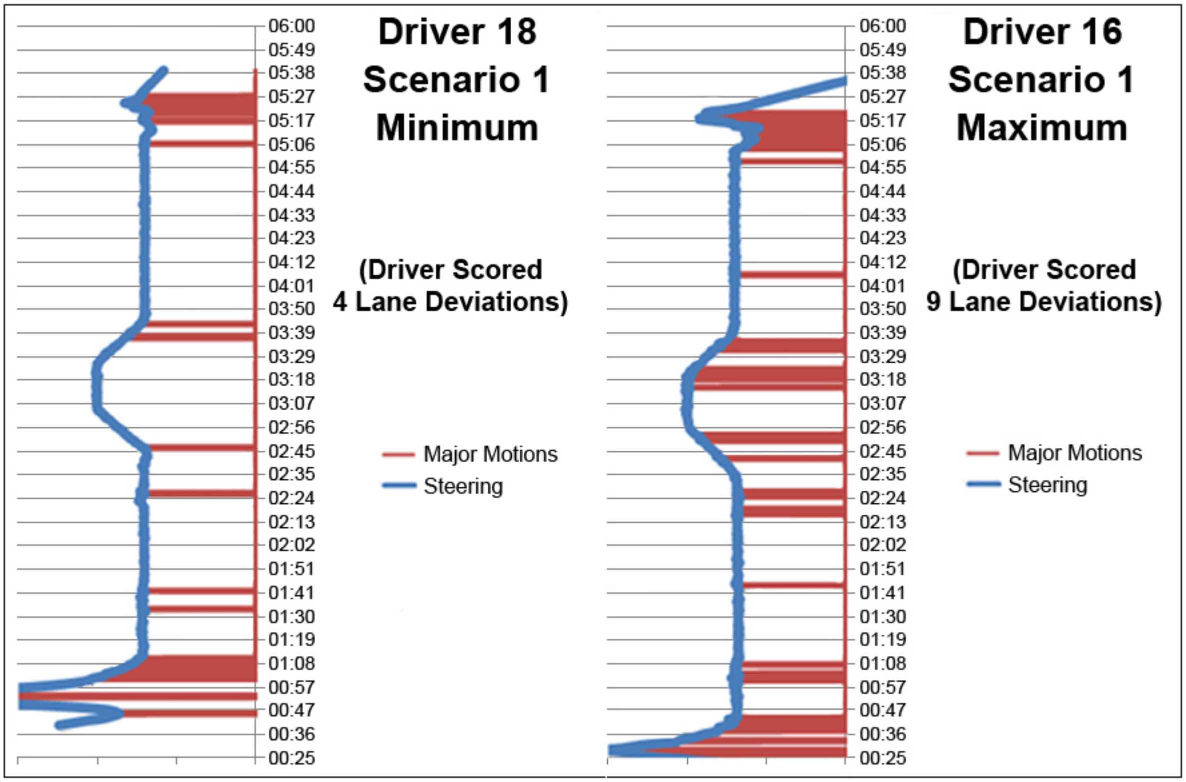


Figure 24. Chart. Scenario 1, minimum (driver 18) and maximum (driver 16) number of lane deviations

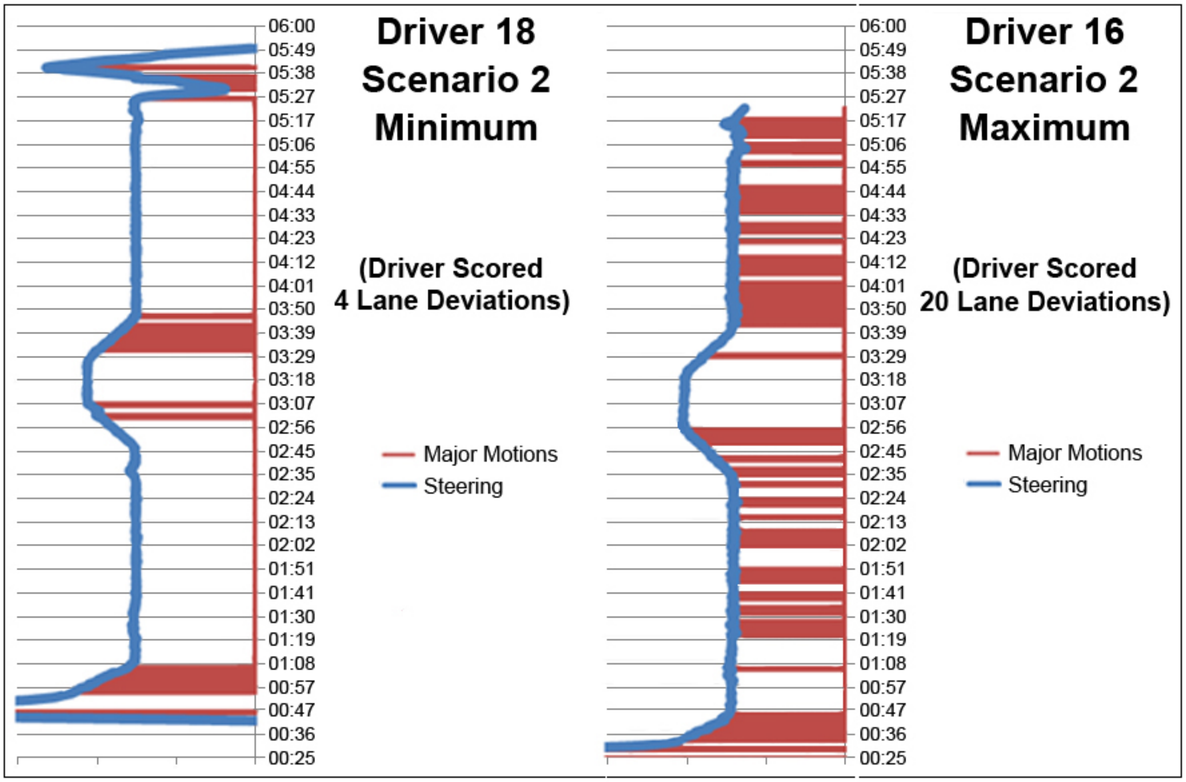
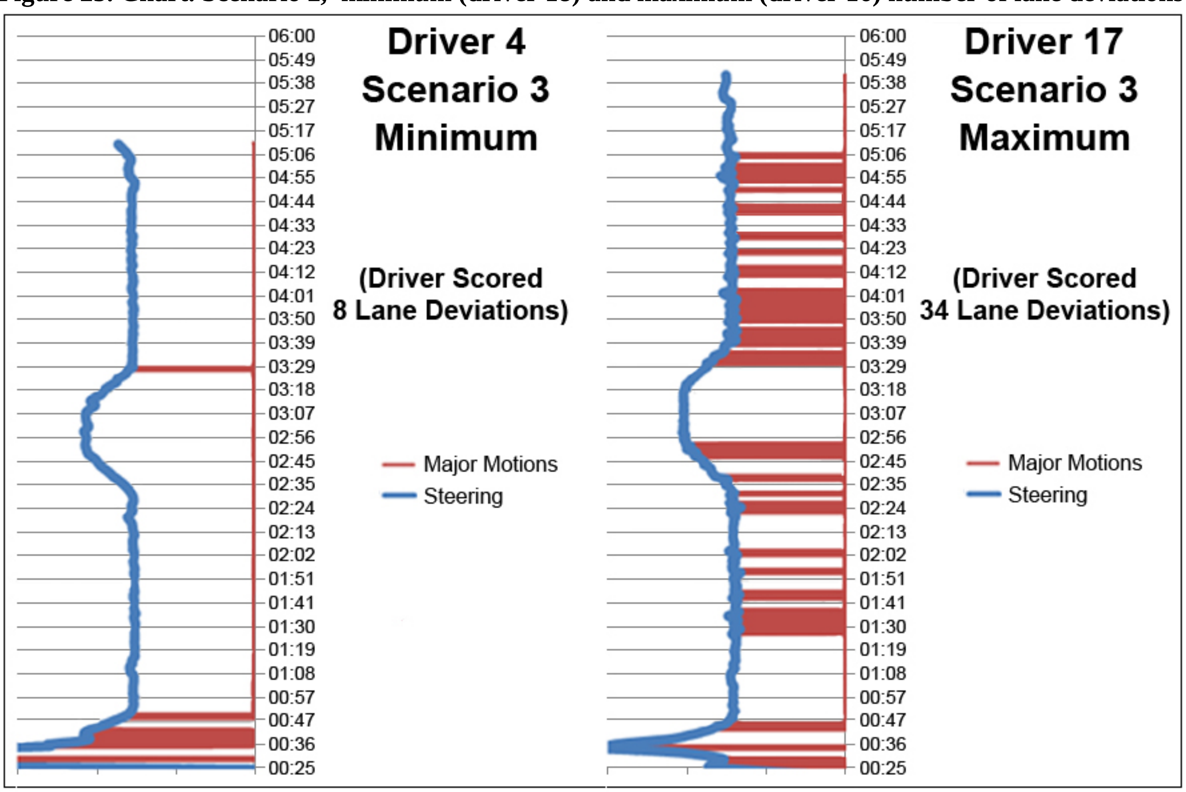


Figure 25. Chart. Scenario 2, minimum (driver 18) and maximum (driver 16) number of lane deviations



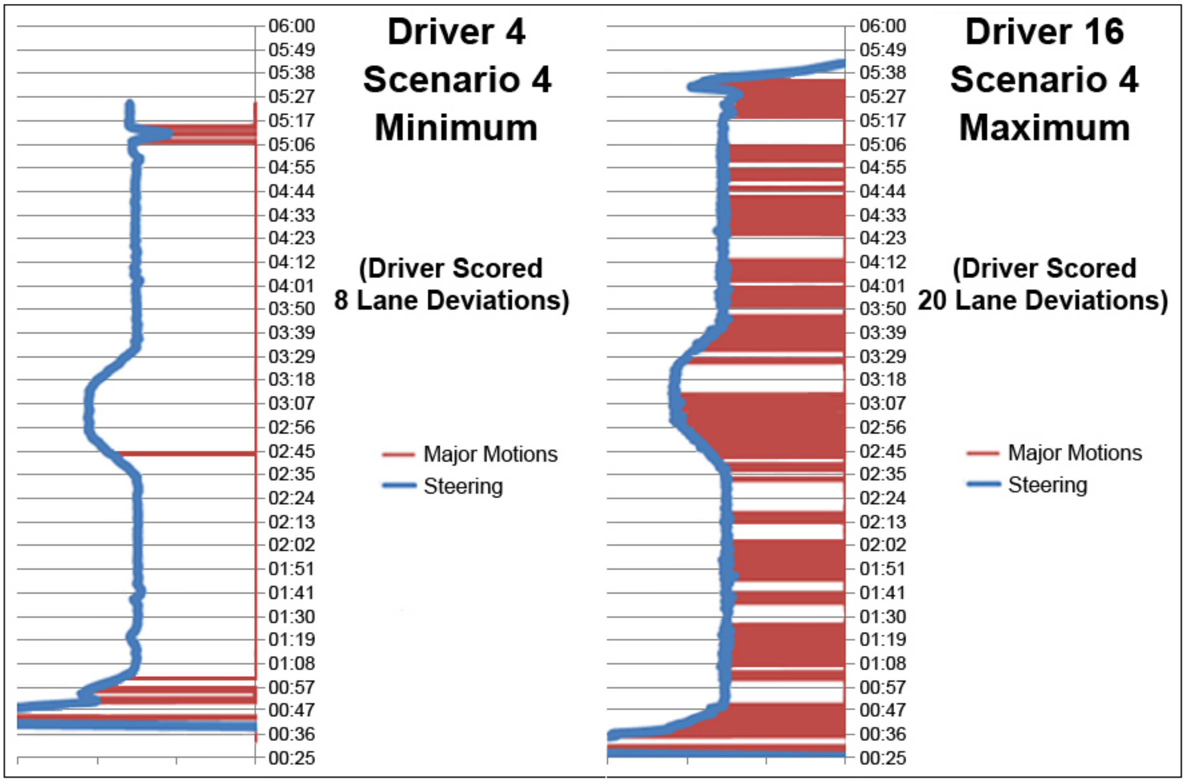


Figure 27. Chart. Scenario 4, minimum (driver 4) and maximum (driver 16) number of lane deviations

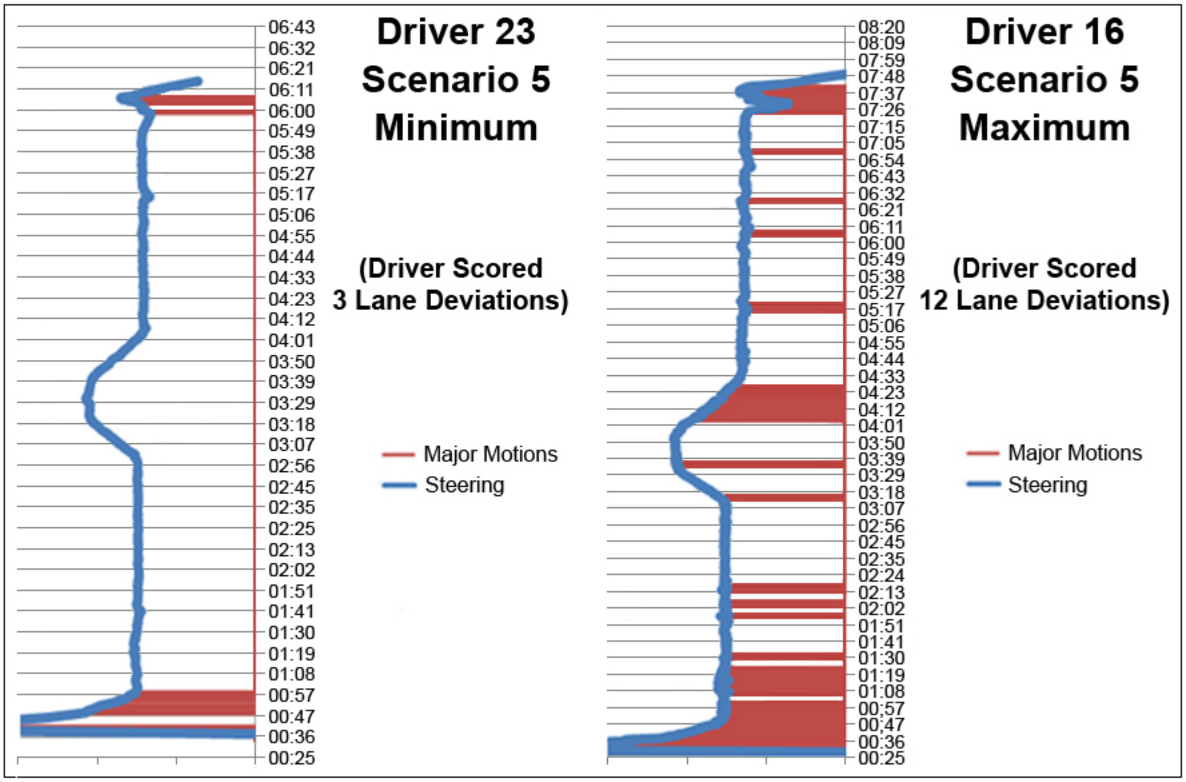


Figure 28. Chart. Scenario 5, minimum (Drivers 23) versus maximum (Driver 16) score of lane deviations.

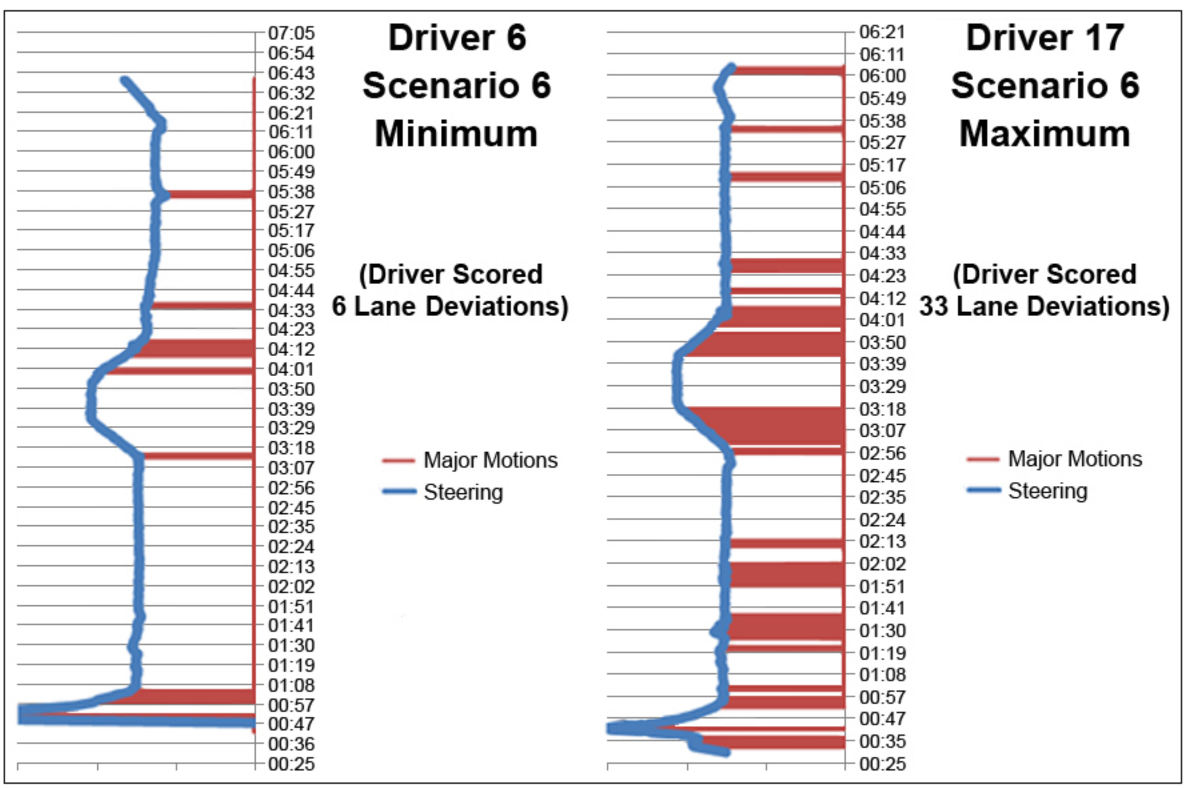


Figure 29. Chart. Scenario 6, minimum (driver 6) and maximum (driver 17) number of lane deviation.

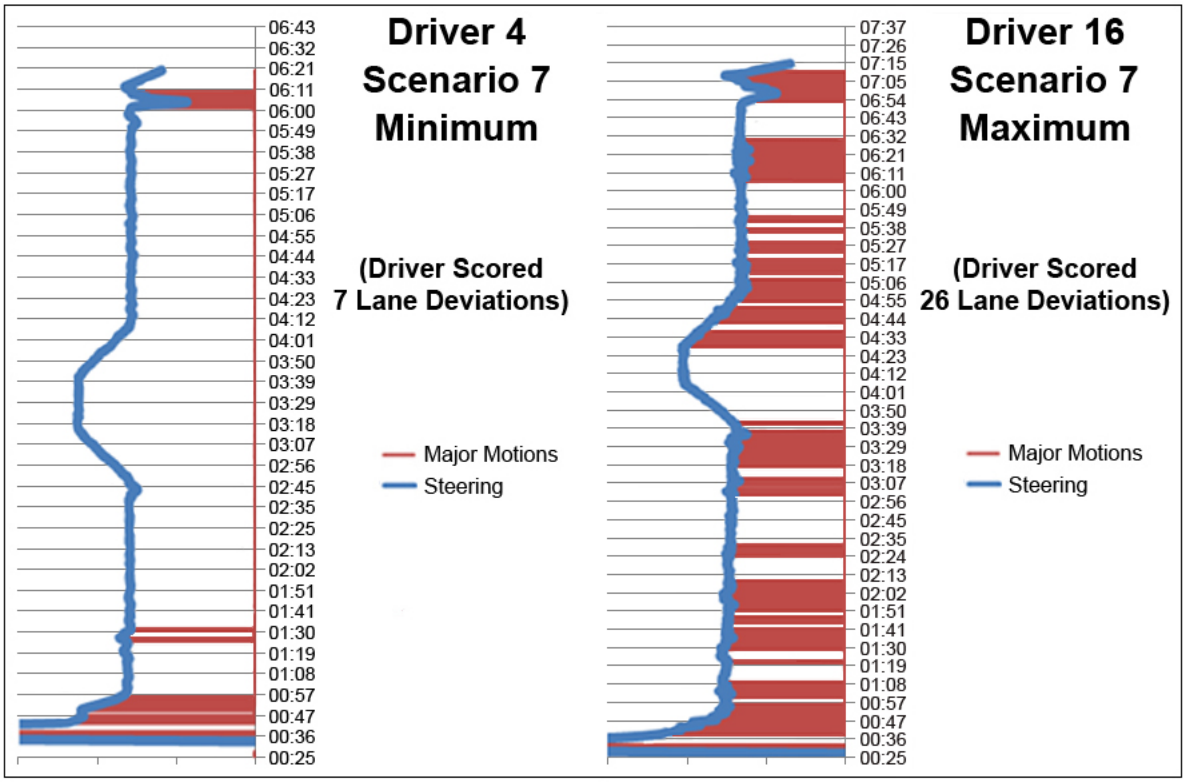


Figure 30. Chart. Scenario 7, minimum (driver 4) and maximum (driver 16) number of lane deviations.

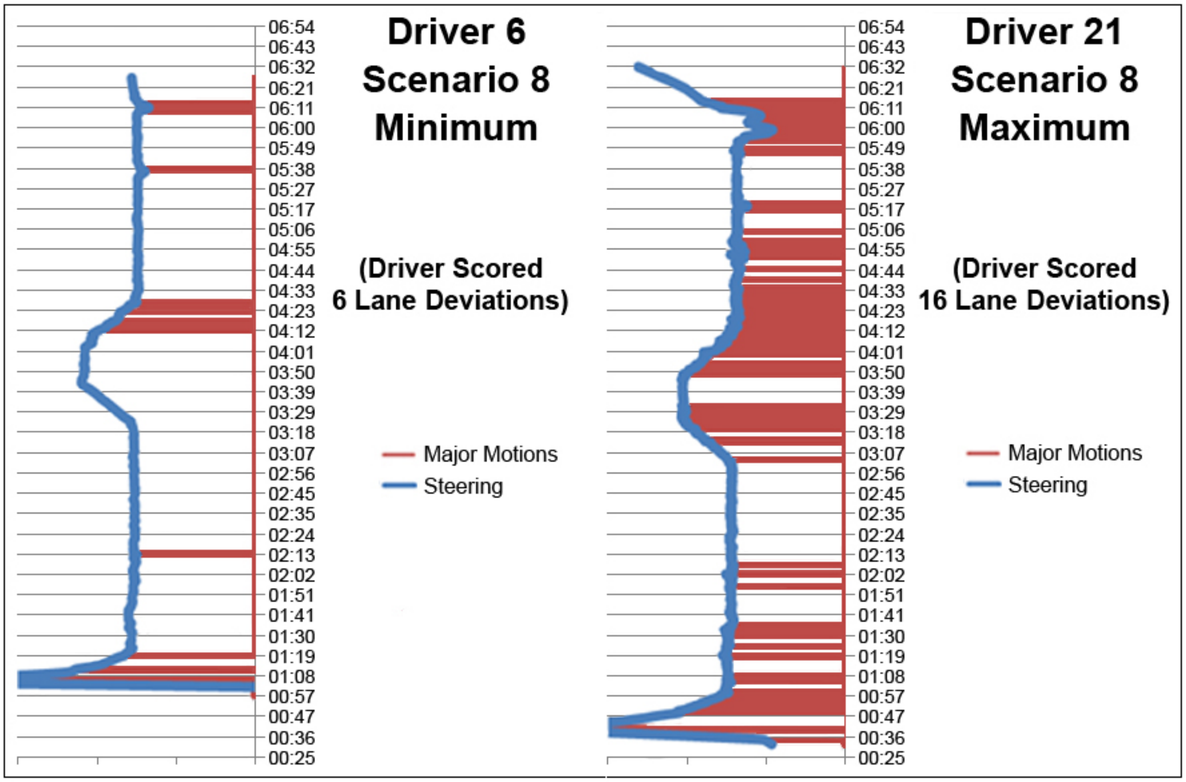


Figure 31. Chart. Scenario 8, minimum (driver 6) and maximum (driver 21) number of lane deviations.

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ACKNOWLEDGMENTS

The researchers would like to thank the sponsors of the project, the USDOT and the Florida State Division of FMCSA, for the grant that made this study possible. Besides the authors of this paper, many individuals contributed a great amount of work during this project. The authors would like to single out: James Booher, Lisa Hernandez, Jonathan Martin, Tim Forkenbrock, Scott Tanner, Erinn Scott, Jennifer Stover, Carol Jones, Rae Hanson, Simone Basilio, and Nelson Rivera for their contributions to the project.

In addition, the cooperation of the Active Lab was instrumental in accomplishing this project. Special thanks go to Dr. Lauren Reinerman, Dar-Wei Chen, Brandon Sollins, and James Tyson.

Furthermore, this project would not have been possible without the help of the many CMV companies who provided volunteers to the project. The research team would like to thank Southeastern Freight Lines, Frito-Lay, FedEx, Mid-Florida Tech, Disney, Coca-Cola, Inc., and Pepsi, Inc., for their contributions. Lastly, the team would like to thank the CMV operators who took the time to participate in this project. Without all of this assistance, this study would not have been possible.

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