Driving Simulator Transportation Safety: Proper Warm-up Testing Procedures, Distracted Rural Teens, and Gap Acceptance Intersection Sight Distance Design

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ABSTRACT

Driving Simulators have become invaluable tools for researchers through technological advancements of the twenty-first century. With increasing availability and affordability of these systems, this dissertation focuses on three research projects utilizing the University of Tennessee's high fidelity driving simulator.

Chapter I discusses how previous research efforts reveal inconsistencies in acclimating test participants to driving simulators. Through proper warm-up time periods, researchers can be confident that the test subjects are comfortable with the handling of the simulator vehicle. This will create reliable test results for the researcher's analysis. The warm-up acclimation study found that approximately 65% - 85% of the sample group acclimated to the handling of the vehicle in 6 minutes.

The rural teen driving population has been identified as a critical population in terms of high fatality rates. The second driving simulator study analyzed vehicular input controls and revealed distracted drivers significantly increase lateral vehicle velocity, thus escalating the probability of crashes. Multitasking, such as talking on the phone, reduced the teen driver's abilities to maintain their normal operating speed.

The final driving simulator study aimed to improve the current intersection sight distance design standards. Gap acceptance behavior was analyzed through multiple series of intersections. The current American Association of State Highway and Transportation Officials gap acceptance design values were found to be less than comfortably accepted in the driving simulator. Nearly 50% of the sample group accepted gaps in the traffic stream of 7.5 seconds when turning left. Only 10% of the participants accepted a

6.5 second gap when proceeding straight or turning right at the intersection. Gaps accepted throughout the testing were found to decrease as the testing progressed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In the summer of 1954 the National Society of Professional Engineers adopted the Engineers' Creed, "As a professional engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare."[1] This creed accentuates the commitment of this engineering research effort to develop safer transportation systems through improved driving simulator research methods, understanding of our transportation user population, and design standards of intersections. National, state, and local agencies realize the dangers of our current transportation systems and have recently addressed the issue by emphasizing programs and philosophies targeted at a zero traffic fatality goal[2-4]. Transportation safety engineers seek to achieve the same goal through quality, groundbreaking research as intended through this effort.

Driving Simulators have become invaluable tools for researchers through technological advancements of the twenty-first century. With increasing availability and affordability of these systems, the opportunity for flawed human behavior research methodology becomes more prevalent. Recognizing the importance of collecting quality data in a driving simulator to ensure the validity of each and every study, Chapter I discusses how previous research efforts reveal inconsistencies in acclimating test participants to driving simulators. Nearly all researchers using a simulator tool recognize the need for a practice session to allow the drivers to adjust to the vehicle handling and virtual environment. This dissertation discusses results found and recommendations regarding the establishment of guidelines for researchers to follow when warming-up subjects before collecting data in a simulator.

Understanding the user population of our transportation system is yet another important aspect of engineering to consider in safety designs. Teenage and novice drivers quickly became a population of interest to researchers given their inexperience operating an automobile and their tendencies to be easily influenced by their environment and more prone to impulsive behavior[5]. Additionally, drivers primarily traversing rural roads are of particular concern given their history of higher fatality rates[6]. Combining these populaces with the disposition of adolescents to be technologically reliant and inseparable from their cell phones, we obtain the distracted, rural, teenage driver. Chapter II discusses the driving characteristics of rural, teen drivers and presents results vital to understanding this special group.

Researchers have modest influence regarding direct impacts to transportation networks without consultants who implement innovative research to create the safest possible geometric designs. Although few if any aspects of design have been studied more than intersections, the inherent nature of at-grade intersections with multiple conflict points result in numerous crashes and traffic fatalities. Creating a safer traffic network requires iterations of updating existing infrastructure and rejuvenation of outdated, design standards for future projects. To better understand the requirements to optimize designs for safety, researchers much first recognize and integrate evolving driver behavior and modern vehicle performance into their design considerations. With safety being the top priority in all transportation projects, the acquisition of funding falls closely behind. In tough economic times and with increasing costs of construction material, it is important to make every dollar count on improvement projects[7]. Therefore, economical solutions to problematic intersections are needed to improve safety. Chapter III examines the research effort to analyze driver behavior at intersections regarding their comfortable gap acceptance behavior. The reported results will provide information to ensure the current intersection sight distance design standards meet the needs of the current driver population.

CHAPTER I

WARM-UP ANALYSIS

Abstract

Embracing recent technological advances, transportation researchers are increasingly using driving simulators as an affordable means to collect driver behavior data through driving experiments. Nearly every researcher addresses a warm-up period to allow drivers to adjust to the controls of the vehicle and minimize the possibility of subjects becoming sick or collecting erroneous data. Nevertheless, few guidelines have been established to ensure that drivers are acclimated to the vehicle controls and comfortable in the simulator environment. The purpose of this study is to identify key driving behavior indicators that would signify that subjects have adapted to the driving simulator system and determine an exposure length of warm-up to ensure subjects have acclimated to the vehicle. In this research, the driving scenario consisted of sixteen sections including right turns at stop signs, left turns at traffic signals, long curves, and short curves. Hotelling's Two-Sample T-Square test was used to compare simulator variables between sections of the experiment. The position of the steering wheel measured in degrees and lateral acceleration were found to be the variables revealing differences in driving behavior as subjects progressed through the course. The intersection turning movements revealed significant differences among numerous sections. Analyzing the individual variable data, the correction of oversteering revealed the most telling trend of acclimation among all the variables. The long curves did not prove to contribute to the acclimation of drivers, while the short curves exhibited signs of continued acclimation. Assuming researchers warm-up test subjects with a series of curves and intersections, a minimum of seven minutes is needed for subjects to

acclimate to the virtual environment and normalize their handling of the simulator vehicle.

1.1 Introduction

Although the concept of studying driving ability dates back to the 1920s [8], wide use of driving simulators in transportation research was not until last decade with the emergence of enabling technologies that made driving simulators affordable enough to own and authentic enough for research. Numerous validation studies examining various performance variables have proven driving simulators to be an appropriate research tool [9-12]. The main advantage of driving simulators is its provision of an inherently safe environment for testing driving scenarios that can be economically created, easily configured, and reliably replicated to investigate a variety of human factors research problems[13]. One of the crucial concerns when using driving simulators is Simulator Adaptation Syndrome (SAS) or Simulator Sickness (SS), which Mollenhauer claims to always be an issue when using an immersive driving simulator[14]. Although several researchers have hypothesized the cause of the syndrome[15], it is generally accepted that conflicting visual and bodily cues cause the uncomfortable feeling. Brooks describes multiple theories of motion sickness and presents a method for assessing and reacting to simulator sickness symptoms in a recent study[16]. However, no insight or suggestions are given regarding how long participants should practice to become comfortable in the virtual environment. Researchers typically combat the occurrence of simulator sickness with what is generally referred to as a warm-up or practice session in the simulator. These sessions are designed to familiarize the individuals with the feel and the controls of the vehicle and ensure that each subject is comfortable in the virtual environment.

1.2 Literature Review

Numerous studies have been conducted using a driving simulator as the data collection tool. This section will provide insight to select simulator studies and contrast the practice times provides to test participants to acclimate to the simulator vehicle. A rear-end collision simulator study adopted a “10 minute (or as long as required)” practice session with 60 minutes of experimental testing to follow[17]. It is unclear what the authors are describing in their statement, “as long as required.” Are the researchers waiting for the subjects to signal that they are comfortable with the handling of the virtual vehicle and ready on their own? Another recent study cited an introductory session, with no specified time frame, and reported 9% of participants feeling dizziness after the simulator assessment. It was not indicated whether the dizzy subjects’ data were disregarded or treated with special considerations in the study[18]. Researchers conducting a spot treatment simulator project allowed “two or three training sessions, depending on how quickly he learned the task.” They continued by adding the main subjective criterion for judging whether significant learning trends were evident was the “judgment of the experimenter that each subject had adequately learned to drive the simulator.” The training sessions were 15 to 20 minutes long, and one subject did not complete 2 of the 36 test segments due to illness[19]. The use of subjective data and reasoning is vulnerable to many fallacies and should be avoided unless independent data confirmation safeguards are performed. McGhee concluded that approximately three minutes of driving was all the time needed to become familiar with a driving simulator[20].

Table 1 summarizes diverse experimental designs for warm-up time frames and underscores the need for guidelines in the area of warming up subjects to driving simulators. One could argue that due to the reported ailment, the subject's driving performance was not natural or normal. If the driving performance of individuals who suffered discomfort were significantly different from that of individuals without discomfort, the data should be treated with special care or even disregarded. One may thus pose questions such as: "How long should the warm-up time be?" "If everyone is different, shouldn't everyone have a different warm-up time?" and "How does one decide the warm-up time for different individuals?" Review of previous driving simulator studies shows that few guidelines have been established regarding pretesting exposure lengths during the warm-up period to ensure drivers have acclimated to the system while keeping the subjects' health and comfort as the top priority. Although Table 1 reports certain studies in which individuals became sick during their research effort, the identification of population groups more susceptible of simulator sickness exceeds the objective of this research effort.

Table 1 Warm-Up Time Used In Previous Simulator Studies

Warm-Up Given	Warm-Up Time	Subject Sickness	Reference
Yes	Unspecified	No Report	[21]
Yes	User Defined[1]	No Report	[22]
Yes	User Defined[1]	No Report	[23]
Yes	2-5 minutes	No Report	[24]
Yes	7 minutes	No Report	[25]
Yes	8 minutes	No Report	[26]
Yes	10 minutes	No Sick Subjects	[27]
Yes	10 minutes	Yes – 4 subjects	[28]
Yes	10 minutes	Yes – 5 subjects[2]	[29]
Yes	10 minutes	No Report	[30]
Yes	18 minutes	No Sick Subjects	[31]
Yes	30 minutes	No Report	[32]
Yes	60 minutes	No Report	[33]
Yes	3 – 6 hours	No Report	[34]
No	-	Yes – 3 subjects[3]	[35]
No	-	No Report	[36]
No	-	No Report	[37]

[1]Subjects determined when they were comfortable with the simulator.
[2]Three subjects became ill before test completion; two reported ill after the test.
[3]Cited motion sickness / Data disregarded.

Sahami has built upon previous research to calculate cost functions utilizing accelerator and brake pedal depressions to categorize subjects as adapted, adapting, and nonadapting through a series of trials. The methodology to obtain results in this manner is labor intensive and too costly in terms of time for researchers to adopt into their testing procedures. Furthermore, Sahami provides a methodology for analyzing the concept of experience curve effect in the steering performance measure. This evaluation of adaptation is subjective and relies on the judgment of the researcher[38]. McGehee analyzed warming up test participants through a quantitative steering adaptation study on a straight roadway and determined that approximately 240 seconds (4 minutes) was all the time required for steering adaptation to occur[39]. This oversimplified approach does not represent real life driving maneuvers by excluding the more difficult task of curve and turning negotiation. Sahami created a revised steering adaptation pattern study in 2010 and found that average adaptation time was 456 seconds (7.6 minutes.) Self-reported acclimation was noted to be significantly less (122 seconds) than the calculated steering adaptation[40]. With highly sophisticated driving simulators of the 21st century, variables beyond just steering need to be tested to determine a warm-up, practice period for subject acclimation.

1.3 Purpose

The purpose of this study is to identify key driving behavior indicators that will signify the driver has become acclimated to the driving simulator system. These indicators will be tested to show variations in driving behavior and signal an approximate time in which the subject has reached their normal driving state. This would ensure the collection of quality data instead of those when the subject is still getting accustomed to the handling difference between the subject’s everyday driving vehicle and the apparatus that is the virtual driving simulator. Because of the vast difference in individuals and in the types of vehicles they usually operate, it is not readily clear how long this adjustment period may be for each subject. As such, indicators that can help determine when a test subject is ready in an objective fashion are desirable. Aiken identified that unreliability can stem from behavioral changes due to distracting or uncomfortable test conditions [41].To this end, this study seeks to determine a desired warm-up period so the test subjects can become comfortable with the driving simulator and the data collected subsequently can be of good quality. The hypothesis in this research is that: *changes in driving behavior as subjects acclimate to the handling of the simulator vehicle will be evident from statistical differences in driving characteristics. As these differences are monitored and diminish, as acclimation progresses, an established warm-up time can be calculated to ensure the test subjects have reached their normal driving state.*

1.4 Methodology

1.4.1 Apparatus

Tests for this study were conducted using the DriveSafety DS-607c, which consists of 5 extreme angle projectors wrapping around a Ford Focus cab, where the test subject is to be seated. Data collection monitored 6 variables at 10 Hz for this study. The collected variable data will be used for comparative purposes as a way to view the subject’s driving performance. Monitoring the changes in driving performance will reveal deviations from the subject’s normalized driving state. The screen projection has a resolution 1024 x 768 pixel each. A digital audio system was functional in the cab with four speakers to allow for audio commands and other sounds in the virtual environment. The interior of the vehicle is an exact replica of a Ford Focus featuring: windshield, driver and passenger seats, center console, radio/CD player, full functioning instrument panel. In addition, the driver has rear views through a LCD rear view mirror and two LCD side view mirrors.

Figure 1 DriveSafety DS-607c driving simulator cab and projection.

1.4.2 Test Participants

Participation in this study was voluntary and consisted of men and women. Subjects were recruited randomly with the only requirements being a valid driver's license holder and healthy to complete all tasks. An even gender split was found among the 30 test subjects (Age Mean = 32.4, STDV = 20.4) who completed the course. The reason for such a large standard deviation is due to 5 subjects being over the age of 67 and the remaining test subjects under the age of 35. Data was disregarded for an additional 10 subjects who stopped testing due to sickness or finished testing but indicated being uncomfortable during testing. Only data from the 30 subjects who reported feeling comfortable and normal were analyzed. Age and gender split driving performance was analyzed.

1.4.3 Virtual Scenario & Section Comparisons

Each participant was asked to drive a roadway course for the purpose of this experiment. The roadway was designed with a series of intersections and curves. Approaching an intersection the subjects were informed on which way to turn by a visual display of words on the center driving simulator screen and an audible voice indicating the direction to turn such as, “turn right” or “turn left.” The directions were given well in advance of the intersection not to interfere or distract the subjects, thus altering their driving performance. The time exposure to the warm-up course is determined by the driving speed of the individual, because the test course has a predefined distance. Every subject was tested on the exact same driving course so comparative statistical tests could be performed across the participant population. Figure 2 shows the test course and the 16 different sections that were analyzed. Sections 1 and 13 are the long curves turning in the right direction. Sections 4 and 14 are the long curves turning in the left direction. Sections 7 and 15 are the short curves right and sections 10 and 16 are the short curves left. The long and short curves were predefined by the limitations of the simulator software. During the experimental design it was determined to only give one comparison between the 4 different curve types because quick adaptation is expected on the relatively easy maneuvers. It is hypothesized that the subjects will show little to no adaptation while traversing the curve maneuvers.

The intersection sections of the experiment were given additional test sections, because an intersection maneuver is more strenuous and requires greater skill. Sections 2, 5, 8, and 11 are the intersections with stop signs and the subjects are instructed to turn right. Sections 3, 6, 9, and 12 are the intersections with traffic signals and the subjects are instructed to turn left. The traffic signals were timed in a manner to simulate a stop or “rolling stop”. When the subjects reached the stop bar of the traffic signal intersections, the traffic signal immediately changed from red to green. More intersection turning maneuvers were designed in the experiment, because the maneuver is believed to more prevalently reveal changes in driving behavior thus signifying adaptation.

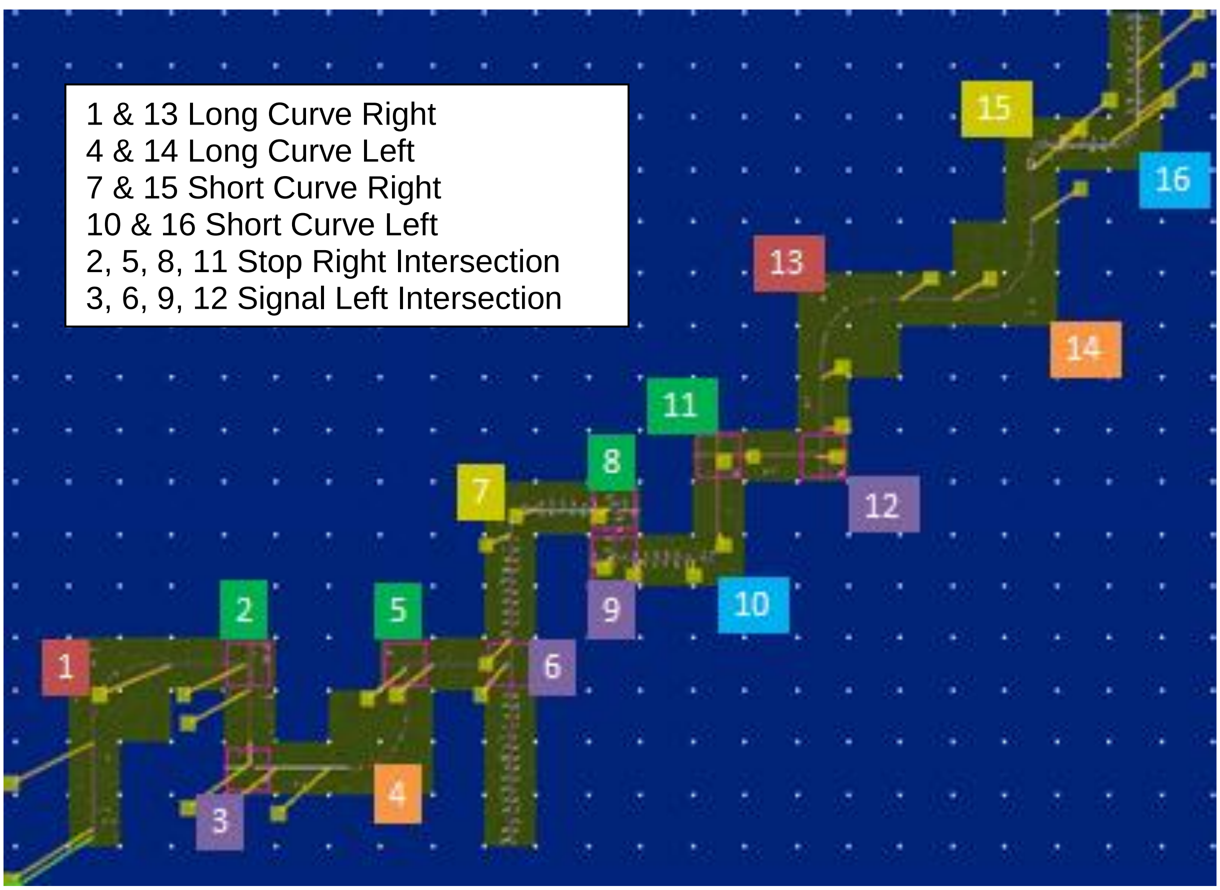


Figure 2 Warm-up map with color coordinated matching sections

1.4.4 Testing Procedure

Upon arrival to the University of Tennessee Driving Simulator Laboratory (UTDSL), each participant was greeted and asked to sit down in the consultation area to review the outline of the testing procedures. Participants were informed that this study is on a voluntary basis and if at any time they feel uncomfortable or uneasy taking part in this research effort they are free to stop immediately and all of the results from the testing will be disregarded. The subject information and the data collected are to remain confidential according to the Human Research Institutional Review Board guidelines at the University of Tennessee. Each subject was presented with an informed consent form approved by the Institutional Review Board (IRB) at the University of Tennessee. Immediately following agreement to the consent form, the subject was introduced to the simulator. Each subject was asked to sit in the driver seat of the car cab and familiarize themselves with the interior of the cab. Directions for the testing procedure were as follows: “Drive the vehicle and follow the on screen directions. Please drive in your usual driving behavior as if you were on a real roadway. Finally, if at any time you feel uncomfortable or sick; stop immediately and I will assist you out of the vehicle. Do you have any additional questions?” After all questions were answered, the scenario was loaded and the participants began testing. At the conclusion of the testing procedures, each subject was offered refreshments and thanked for their participation in the study. For this study, no warm up period or practice session was given to the subjects due to the nature of the data collection for such research. It is the goal of this research to use the initial driving behavior of each subject for data analysis. All of the voluntary subjects had no previous acquaintance to any driving simulator to ensure that the data collected from the participants was of the same nature concerning exposure to such technology. Future research may include the study of subjects with multiple tests over several days or weeks to evaluate how multiple exposures to the simulator changes their adaptation and comfort level in the simulator.

1.4.5 Independent and Dependent Variables

The variable outputs from the driving simulator to be analyzed include:

- Velocity – The speed of the subject in m/s.
- Steer – Position of the steering wheel recorded in degrees. Clockwise is positive with +/-540 degrees, or one and half turns, being the maximum values.
- Accel – The normalized accelerator position value. Zero meaning no pushing of the accelerator pedal, while 1.00 reports that the gas pedal is fully depressed.
- Brake – The normalized brake position value. Zero meaning no pushing of the brake pedal, while 1.00 reports that the brake pedal is fully depressed.
- Lateral Acceleration (Lat.Acc.) – The latitudinal component of the total acceleration of the vehicle in the simulated environment in m/s^2. This is not the actual force on the subject in the car cab.
- Longitudinal Acceleration (Long.Acc.) – The longitudinal component of the total acceleration of the vehicle in the simulated environment in m/s^2. This is not the actual force on the subject in the car cab.

Independent variables such as age, gender, etc. were coded accordingly for statistical testing. Special interest was given to the use of the lateral acceleration data and velocity data collected on the fixed based simulator. Research has shown that the load transfer of the car during a turning maneuver, represented as lateral acceleration, felt by the vestibular system has direct correlation with the speed adopted by the driver. Reymond et al. established that stable or fixed based driving simulators, not capable of producing a lateral acceleration response to the driver, generally see higher speeds than their motion based counterparts. It was also determined that the acceptable threshold for lateral acceleration felt by the driver is a function of his or her driving experience, familiarity with the vehicle, and risk level [42]. Isabelle notes that the driver's increase in the threshold of acceptable risk, indirectly affects the speed in a driving simulator [43].

1.4.6 Statistical Analysis

The Two-Sample Hotelling's T^2 multivariate test was performed to evaluate the driver performance inputs while traversing the simulator scenario. The main advantage and reason for performing the Hotelling's test to discover differences between samples is the lack of needed normality and equal-variance assumptions in order to provide probability levels based on randomization tests[44, 45]. The driving behavior of each matching section was tested using Hotelling's T^2 analysis to determine whether driving behaviors change as exposure to the driving simulator increases. The null hypothesis (H_o) is that no differences among the dependent variables can be determined between the two sections in question[46].

H_o: There are no differences between driving characteristics.

H_a: There are significant differences between driving characteristics.

If testing reveals a rejection of the null hypothesis, we accept the alternative hypothesis (H_a) and conclude that significant differences in driving behavior has been determined and additional individual variable t-test significance levels will be used when the overall T^2 value is significant to determine which dependent variables differ.

Randomization Test results will be reported when discussing the overall significance of the sectional testing. The randomization test is conducted following a Monte Carlo approach by enumerating all possible data permutations of the sample data and counting the permutated results that produce T^2 values greater than or equal to the actual T^2 values[44]. The randomized results are reported assuming equal variance-covariance matrices, unequal covariance cases, and all individual t-test. A portion of the following results failed to meet the assumption of equality of covariance matrices as a result of the Bartlett-Box Homogeneity of Variance Tests[47, 48]. Appendix A gives results for one of the Box's M Chi^2 Probabilities for Section comparison 2 versus 8. The significance of the Chi^2 Probability leads us to use the unequal variance version of the randomization test. Throughout testing the reported results were nearly identical for the equal and unequal covariance matrices. Therefore, the Hotelling's Two-Sample comparison can be viewed with confidence.

1.4.7 Controlling Error Rate for Multiple Comparisons

The experimentation of the multiple comparisons of the individual driver behaviors requires controlling the overall experiment's significance level or alpha ($\boldsymbol{\alpha_E}$). To accomplish controlling the experiment wide error the individual comparison Type 1 error rate ($\boldsymbol{\alpha_I}$) must be controlled for each comparison (**M**) of the driving sections. To determine the individual comparison significance level, $\boldsymbol{\alpha_I}$, for analysis the following equation will be used.

$$\boldsymbol{\alpha_E = 1 - (1 - \alpha_I)^M}$$

Choosing to control the experiment wide error rate at .05 significance and obtaining a total of 28 comparisons for each testing procedure of the turning data, the individual comparisons significance level is calculated.

$$\boldsymbol{\alpha_E = 1 - (1 - \alpha_I)^M}$$
$$\boldsymbol{.05 = 1 - (1 - \alpha_I)^{28}}$$
$$\boldsymbol{\sqrt[28]{.95} = \sqrt[28]{(1 - \alpha_I)^{28}}}$$
$$\boldsymbol{1 - \alpha_I = \sqrt[28]{.95}}$$
$$\boldsymbol{\alpha_I = .002}$$

Therefore, an individually controlled error rate $\boldsymbol{\alpha_I}$ =.002 will ensure that the experiment wide error rate $\boldsymbol{\alpha_E} \leq 0.05$.

1.5 Results

1.5.1 Hotelling's Results: Intersection Turn Maneuvers – Variable Averages

The Hotelling's results for the turning maneuvers were summarized into charts for analysis. The initial analysis was conducted on the averages of each variable throughout the section movement. For instance, the data collected for the right turn maneuver at the stop sign was averaged from the time the vehicle passed the stop bar to a distance 20 meters down the perpendicular roadway. Table 2 is the summary for all of the right turning maneuver comparisons at the stop signs and includes sections 2, 5, 8, and 11. A full report of one comparison of the two sections in question can be viewed in Appendix A. A similar report was produced for every section comparison reported in the summary tables embedded.

Table 2 Summary of Right Turn Section Comparison Significance

α_{I28}=0.002		Prob	Individual Variables Section Variable Omitted					
Stop	Right	Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.1565						
2	8	0.0001	0.0017	0.0008	0	0	0.063	0
2	11	0.0543						
5	8	0.0001	0.0002	0.0007	0	0	0.0674	0
5	11	0.019						
8	11	0.0001	0.0024	0	0	0	0.0037	0

The results show significant differences among one of more variables between sections 2 versus 8, 5 versus 8, and 8 versus 11. Further analyzing the individual variables that contribute to the overall differences between sections, an interesting trend can be seen with the lateral acceleration variable. For the overall significantly different sections above, in which the alternative hypothesis was accepted, the significance levels of the combined 6 variables minus the variable listed at the head of the column are reported. This shows a trend among the three statistically different sections that lateral acceleration accounts for the majority of the difference among the combined variables. For example, comparing section 2 versus 8 and removing the lateral acceleration variable from the Hotelling's comparison analysis, the combined other variables do not prove to be significantly different because the significance level omitting lateral acceleration is only 0.063. Because differences have been found between the sections compared to section 8 and lateral acceleration is the most influential variable, a further analysis of section 8 lateral acceleration was performed. Appendix B highlights the finding of an unusually high standard deviation for the section 8 lateral acceleration. Individual subject data was scanned to reveal the high standard deviation of Section 8.

Using Figure 3, the Inter Ocular Traumatic Test reveals subject ID #11 grossly deviates from the norm average lateral acceleration [49].

Removing subject ID #11 from the analysis we obtain new significant findings for sections 2, 5, 8, and 11. Although subject ID #11 was a clear outlier, Table 3 reveals the same significance findings with and without Subject ID #11.

Differences in the mean lateral acceleration between the sections were calculated without subject ID #11. Section 2, 5, and 11 produced average lateral accelerations of 1.097m/s^2, 1.104 m/s^2, and 1.168 m/s^2 respectively, while section 8 produced a larger average lateral acceleration of 1.569 m/s^2 from our sample group.

The left turning movements at the traffic signal intersections were analyzed in the same fashion as the right turning movements at the stop signs. Table 4 reveals a similar pattern of significance surrounding section 9. Comparing section 3 and 9, section 6 and 9, and section 9 and 12 results in significantly different probability levels of 0.0001, 0.0002, and 0.0001, correspondingly.

The Individual Variables Section Variable Omitted results in Table 4 do not reveal an individual variable that accounts for a majority of the identified differences. The mean differences and standard deviations for the six variables as well as the Student's Individual Randomization Test Probability Levels for each variable are shown in Appendix C. The Randomization Test Probability Level reveals the steer variable to be significantly different between the three comparisons with section 9. The section 9 average steering wheel positions is -49.70°; while sections 3, 6, and 12 are -60.77°, -60.72°, and -56.63°, respectively.

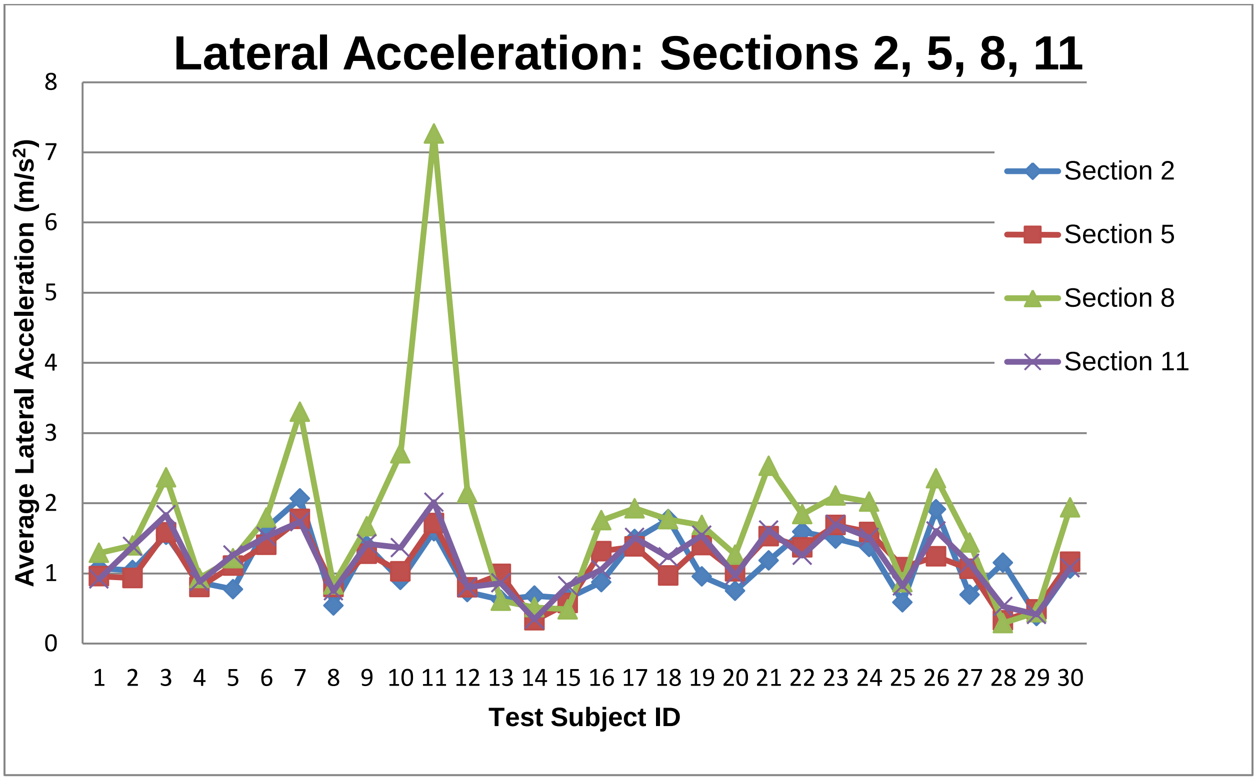


Figure 3 Average Lateral Acceleration Values for Individual Subjects

Table 3 Right Turn Section Comparison Excluding Subject ID #11

α_{I28}=0.002		Prob	Individual Variables Section Variable Omitted					
Stop	Right	Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.0897						
2	8	0.0001	0	0	0	0	0.0382	0
2	11	0.0306						
5	8	0.0001	0	0	0	0	0.0009	0
5	11	0.0227						
8	11	0.0001	0	0	0	0	0.0763	0

Table 4 Left Turn Section Comparison

α_{l28}=0.002		Prob	Individual Variables Section Variable Omitted					
Light	Left	Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
3	6	0.1582						
3	9	0.0001	0	0.0007	0	0	0	0
3	12	0.0046						
6	9	0.0002	0	0.0254	0.0001	0.0002	0.0002	0
6	12	0.0189						
9	12	0.0001	0	0	0	0	0	0

The differences surrounding sections 8 and 9 are interesting due to the fact that the roadway geometry is exactly the same for all of the intersections. However, one possible explanation for the change in behavior would be the virtual scenarios scenery. In an attempt to keep the subjects from becoming bored during the testing procedure, sections 8 and 9 were designed with houses as opposed to rural grass and fields in the other intersection sections. Consequently, noticeable behavior changes are present at sections 8 and 9. Perhaps the change in observed behavior is similar to the results found in Larue's study indicating vigilance varies as road scenery changes [50].

1.5.2 Hotelling's Results: Curve Maneuvers – Variable Averages

The analysis for the curves was conducted on the averages of each variable throughout the movement, similar to the intersection turns. The data collected for the curve maneuvers was averaged from the time the vehicle entered the point of curve until the radius ended and the roadway straightened at the point of tangent. The long and short curve variables were compared across sections to reveal differences in driving behavior to establish a trend to acclimation progression. Section 4 and 14, long left curves, proved to be significantly different with a p-value = 0.0001.Section 1 and 13, long right curves, were compared using the Hotelling's T^2 test and resulted in p-value = 0.2616. Similarly, no significance was found among the velocity, steer, accel, brake, lateral acceleration, and longitudinal acceleration when comparing short curve section 7 versus 15 (p-value = 0.2584) and section 10 versus 16 (p-value = 0.0162). The right curve sections could not be compared with the left curve section with the steer and lateral acceleration variables included in the analysis. This is due to the steering wheel turning in opposite directions resulting in positive and negative steer and lateral acceleration values.

Finding one or less significant comparisons among the curve movements was expected, thus only four comparisons from the experiment design. However, removing the obvious conflicting variables, steering wheel position and lateral acceleration, new comparisons can be made across all possible combinations of long and short curves. Table 5 summarizes the results of the comparisons without steer and lateral acceleration.

A lack of trending significant differences creates a difficult argument attempting to reveal changes in driving behavior. Comparing the short curves without the steer and lateral acceleration we can see significant differences in section 7 versus 16 and section 10 versus 15. Although no individual variable can be seen to account for most of the variability, we should understand that a small amount of adaptation may be occurring. One possible explanation for the lack of prevailing significance between the curve sections could be carry-over effects, which are reductions in the power or sensitivity on measurements from prior treatments[44]. In this case the intersection maneuvers may be reducing the sensitivity to detect significant changes in curve negotiation driving behavior.

Table 5 Curve Comparison without Steer or Lateral Acceleration

α_{l28}=0.002		Prob	Individual Variables Section Variable Omitted			
LongCurve-S-Lata		Level	X1V	X1A	X1B	X1LONGA
1	4	0.0203				
R	L					
1	13	0.1254				
R	R					
1	14	0.0003	0.0007	0.0014	0.0027	0.0347
R	L					
4	13	0.2234				
L	R					
4	14	0.6262				
L	L					
13	14	0.1158				
R	L					
ShortCurve-S-Lata						
7	10	0.0529				
R	L					
7	15	0.1443				
R	R					
7	16	0.0001	0.0008	0.006	0.0008	0.0001
R	L					
10	15	0.0014	0.0044	0.0184	0.003	0.0291
L	R					
10	16	0.0081				
L	L					
15	16	0.0106				
R	L					

It is interesting to note the change in significance between sections 4 and 14 when the steer and lateral acceleration variables where removed in Table 5. As discussed earlier, differences were found in the variables compared in sections 4 and 14. While the other long and short curve comparisons do not reveal differences. The significant finding contradicts the experimental idea that the curve sections should be easy to traverse and learn, thus revealing little differences in driving behavior. Therefore, further analysis of the section 4 versus 14 comparison revealed an interesting interaction effect among the variables.

Immediate review of the standard deviations provides no evidence of gross outliers skewing the data among the variables. The Equal and Unequal Parametric and Randomization Tests in Table 6 produce virtually the same results signifying significant driving behavior differences between section 4 and section 14. However, reviewing the individual variable Student's T-Test probability levels shows that no individual variable is significantly different from the other variable across sections. Therefore, we know an interaction effect is occurring between the variables. We proceed to reveal the interaction by performing a step-up variable selection.

Viewing the individual probability levels in the section 4 versus 14 analysis, we identify brake (X1B) prob. level = 0.1638, steer (X1S) prob. level = 0.1762, and velocity (X1V) = 0.2227 as the most significant. Therefore, we begin our step-up variable selection analyzing all other combinations with the three most significant individual variables. All combinations with brake do not reveal any significance even though the brake variable analyzed alone is the single most significant variable. Table 7 shows the combination of velocity with steer and lateral acceleration identifies the unusual interaction effect found in the significant results.

In an attempt to reduce the significance of the interaction effect among the variables, a data transformation was completed. It is believed that the steer and lateral acceleration variables that bound zero with positive and negative results may be creating the interaction. Appendix D reveals that the scaling of the steer and lateral acceleration variables produced similar results as before with an overall significant difference without any individual variables proving significantly different. The steer variable raw data was scaled by adding the absolute value of the lowest reported individuals average steering wheel position plus 0.1 to everyone's steer value. This created a steer data set with all positive values. The same theory was applied to the lateral acceleration data set to create all positive values. Yet another step-up variable analysis was completed to gauge any improvement in the interaction. Once again brake, steer, and velocity were the most significant individual variables. Table 8 summarizes the scaled data step-up results.

A final natural log transformation was performed on the data, but not changes occurred in the interaction effects between the variables. Further inquiry into data transformations exceeds the scope of this research.

Table 6 Hotelling's T^2 Test Comparing Section 4 versus 14

Covariance Assumption	T^2	DF1	DF2	Parametric Test Prob Level	Randomization Test Prob Level	
Equal	164.715	6	58	0.0000	0.0001	
Unequal	164.715	6	48	0.0000	0.0001	
Individual Variables Section						
Variable Omitted	**T^2 Others**	**Prob Level**	**T^2 Change**	**Prob Level**	**T^2 Alone**	**Prob Level**
Velocity	33.334	0.0001	131.381	0.0000	1.520	0.2227
Steer	133.726	0.0000	30.989	0.0050	1.875	0.1762
Accel	120.513	0.0000	44.203	0.0007	0.033	0.8566
Brake	139.209	0.0000	25.507	0.0115	1.989	0.1638
Lat. Acc.	153.540	0.0000	11.176	0.1002	0.962	0.3307
Long. Acc.	162.502	0.0000	2.213	0.4690	0.061	0.8051

*The randomization test results are based on 10000 Monte Carlo samples.

Table 7 Step-Wise Variable Selection - Section 4 versus 14

Variables Entered						Randomization Test Prob.
VEL			BRK			0.3144
	STR		BRK			0.0359
		ACL	BRK			0.4004
			BRK	LATA		0.0956
			BRK		LONGA	0.3925
VEL	STR					0.0001
	STR	ACL				0.0514
	STR		BRK			0.0359
	STR			LATA		0.0445
	STR				LONGA	0.1435
VEL	STR					0.0001
VEL		ACL				0.3174
VEL			BRK			0.3045
VEL				LATA		0.0001
VEL					LONGA	0.4308

Table 8 Step-Wise Variable Selection – Section 4 versus 14 Scaled Data

Variables Entered						Randomization Test Prob.
VEL			BRK			0.3017
	STR		BRK			0.0372
		ACL	BRK			0.3964
			BRK	LATA		0.1003
			BRK		LONGA	0.3906
VEL	STR					0.0001
	STR	ACL				0.0495
	STR		BRK			0.0372
	STR			LATA		0.0436
	STR				LONGA	0.1429
VEL	STR					0.0001
VEL		ACL				0.3275
VEL			BRK			0.3017
VEL				LATA		0.0001
VEL					LONGA	0.4325

1.5.3 Hotelling's Results: Age & Gender Comparisons

Gender comparisons showed no differences among males and females. Appendix E shows the 28 comparisons between testing all female subjects and testing all male subjects. Testing was also performed removing the 5 subjects over the age of 67 to comparing elderly drivers against non-elderly drivers. Appendix F shows no changes were found in the results when the older subjects were removed.

1.5.4 Hotelling's Results: Intersection Turn Maneuvers – Maximum and Minimum Variable Values

Analysis of the maximum (max) and minimum (min) values of the data collected for each variable may offer additional insight into the adapting behavior of drivers in a simulator. The means for previous comparisons may dilute the critical behavior that need to be captured to fully understand driver adaptation. The max and min values of each variable for each subject were selected rather than a set observation point in an attempt to capture the best or worst performance. For instance, when over steering during a turning maneuver, the most extreme value for lateral acceleration will identify the closest point to loss of control.

Table 9 shows a large amount of differences regarding the right turn maneuver at the intersection. Compared with the means comparison table, we cannot immediately identify an individual variable accounting for most of the differences. However, section 8 reveals itself as a focal point of significant differences.

Table 9 Hotelling's Results Intersection Right & Left - Maximum Values

Variable Maximum Value Comparisons								
αl28=0.002		Prob	Individual Variables Section Variable Omitted					
StopRight		Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.0104						
2	8	0.0001	0	0.003	0	0	0	0
2	11	0.003						
5	8	0.0001	0.0002	0	0	0	0.0004	0
5	11	0.0159						
8	11	0.0001	0.0003	0	0	0	0	0
LightLeft								
3	6	0.054						
3	9	0.0023						
3	12	0.0031						
6	9	0.5177						
6	12	0.0383						
9	12	0.0005	0.0095	0.0005	0.0004	0.0007	0.0014	0.0013

Table 10 Hotelling's Results Intersection Right & Left - Minimum Values

Variable Minimum Value Comparisons								
αl28=0.002		Prob	Individual Variables Section Variable Omitted					
StopRight		Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.1213						
2	8	0.0001	0.0003	0.0007	0	0.0001	0.0001	0.0001
2	11	0.0003	0.0057	0.0005	0.0056	0.0005	0.0036	0.0012
5	8	0.0001	0.0007	0.0305	0.0001	0.0001	0.0018	0.0001
5	11	0.001	0.1994	0.0121	0.0425	0.0014	0.0396	0.0024
8	11	0.0013	0.0092	0.3016	0.0015	0.0018	0.0431	0.0271
LightLeft								
3	6	0.6712						
3	9	0.0001	0	0.0601	0	0	0	0
3	12	0.6558						
6	9	0.0003	0.0001	0.2392	0.0001	0.0001	0.0002	0.0001
6	12	0.8179						
9	12	0.0001	0.0001	0.6764	0.0002	0.0001	0.0002	0.0001

Table 10, the turn comparisons using the minimum values, identifies a large amount of difference among the right turn maneuvers. Section 9 is found to be the center of the left turning significant differences.

Understanding the nature of the turning movements as compared to the maximum and minimum values exposes an interesting finding. Thinking of a number line, the maximum values will capture mostly positive numbers if the variable contains both positive and negative numbers. While the minimum values will capture mostly negative numbers. In the case of turning right, the theoretical values for the steer variable will be mostly positive with a maximum of approximately 200-300 degrees and the minimum around zero. While a left turning vehicle we have a maximum value near zero and a minimum value approximately -200 or -300 degrees. Therefore, combining the right turning comparisons of sections, 2, 5, 8, and 11 maximum values with the left turning, sections 3, 6, 9, and 12 we see results in Table 11 very similar to the mean variable comparisons.

The steer variable can now be identified as the variable producing the largest amount of differences. Further analyzing the steer variable, an adaptation trend is found in the direction of turn and the correction of oversteering throughout the movement. Figure 4 displays the steering behavior of the sample group. The red line shows that on average each subject's steering wheel reached a max position of 263° while performing the right turn. Throughout the same turn, the subjects needed to correct the oversteer of the vehicle with an average maximum steering wheel position of 83°. Comparing these results with the understanding that a perfect right turn maneuver should not require any steering in the opposite direction shows a clear lack of familiarity with the handling of the vehicle. The left turning movement, displayed by the green line, shows a max steering wheel position of 200° with 43° of correction. Viewing the oversteer trend lines, it is evident that subjects are reducing oversteer as exposure time increases in the simulator. Sections 8 and 9 show a slight reduction in the steering movement for the right and left turns, perhaps due the residential visuals creating the feel of a smaller roadway.

Table 11 Right Turn Maximum & Left Turn Minimum Comparisons

Variable Maximum Value Comparisons								
αl28=0.002		Prob	Individual Variables Section Variable Omitted					
StopRight		Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.0104						
2	8	0.0001	0	0.003	0	0	0	0
2	11	0.003						
5	8	0.0001	0.0002	0	0	0	0.0004	0
5	11	0.0159						
8	11	0.0001	0.0003	0	0	0	0	0
Variable Minimum Value Comparisons								
LightLeft								
3	6	0.6712						
3	9	0.0001	0	0.0601	0	0	0	0
3	12	0.6558						
6	9	0.0003	0.0001	0.2392	0.0001	0.0001	0.0002	0.0001
6	12	0.8179						
9	12	0.0001	0.0001	0.6764	0.0002	0.0001	0.0002	0.0001

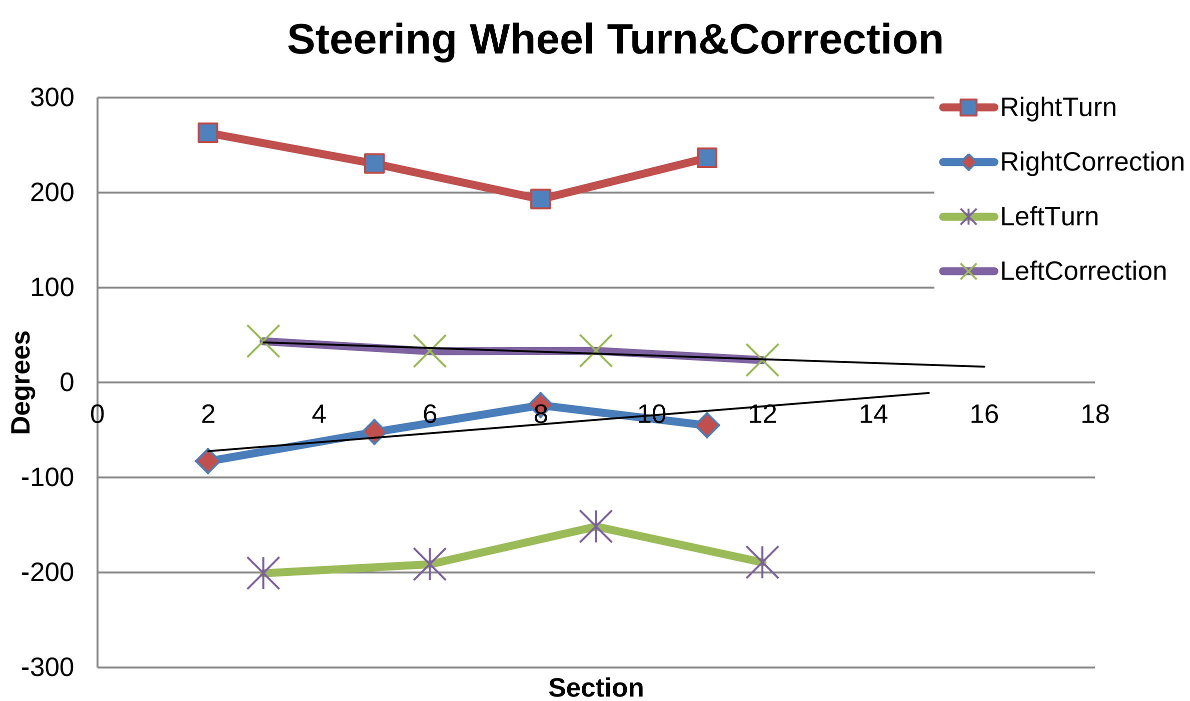


Figure 4 Steering Wheel Turn & Correction

1.5.5 Hotelling's Results: Curve Maneuvers – Maximum and Minimum Variable Values

The long and short curve comparisons were calculated using the maximum and minimum variable values. Among all of the 32 comparisons, both max and min values, only one comparison was found to be significantly different. Short right turn section 7 compared to short left turn section 16 without variables steer or lateral acceleration resulted in an overall significance of 0.0008 with no clear variable standing out as the most significant. It should be noted that the short curve comparisons nearly produced significant findings with section 7 versus 15 = 0.0035 and section 10 versus 16 = 0.0043. The lack of significant differences in both the max and min values for section 4 versus 14 further supports the argument against the previously significant findings regarding section comparison 4 versus 14 with the mean variables.

1.5.6 Cumulative Frequency Acclimation Predictor

The minimum and maximum steering wheel position data displayed in Figure 4 shows promising results of drivers acclimating to the handling of the vehicle. We further analyze this data by computing the absolute values of the oversteering performance to create eight maximum oversteering data points, regardless of direction, for each individual. Appendix G displays the multiple groups into which each individual steering performance was places. Two individuals performed exceptionally well, showing no signs of acclimation with less than 30 degrees of steering wheel correction across the combined 16 sections in Figure 7. Four subjects displayed very quick learning of the steering wheel showing no signs of adaptation after section 3 of the course in Figure 8.

Stabilizing their steering wheel behavior less than 50 degrees, Figure 8 displays four subjects that showed no additional signs of acclimation beyond section 5. Three subjects acclimated near section 8 and seven subjects approached steady steering wheel behavior at section 12 in Figure 9 and Figure 10. No adjustments to the steering wheel were displayed in Figure 11 by two individuals and were classified as not acclimated. The final eight subjects were difficult to classify in Figure 12. They showed no signs of erratic behavior and no significant changes or patterns could be observed in their steering wheel position. However, they continued to fluctuate their steering wheel behavior below 60 degrees.

The formation of a cumulative frequency chart calculated from the instance each individual displayed acclimated behavior through stabilizing oversteering corrections can be used to estimate an approximate time to adaptation. Each subject averaged approximately 30 seconds to complete each section of the test course. Therefore, the sections listed in the previous paragraph can be converted to exposure time in the simulator. The two subjects who never showed signs of acclimation must be assigned an approximated time to acclimation to complete the cumulative normal frequency. A 10 minute time penalty was given to the two subjects. It should be noted that claims regarding an approximated acclimation time frame cannot exceed the 6 minute (12 section) mark in which the normal frequency curve is based on assumed values. Assuming the seven individuals in Figure 12 were acclimated from the beginning of the test session, Figure 5 shows that 85% of the sample group tested signified acclimation through changes in their steering behavior approximately 6 minutes into the test session.

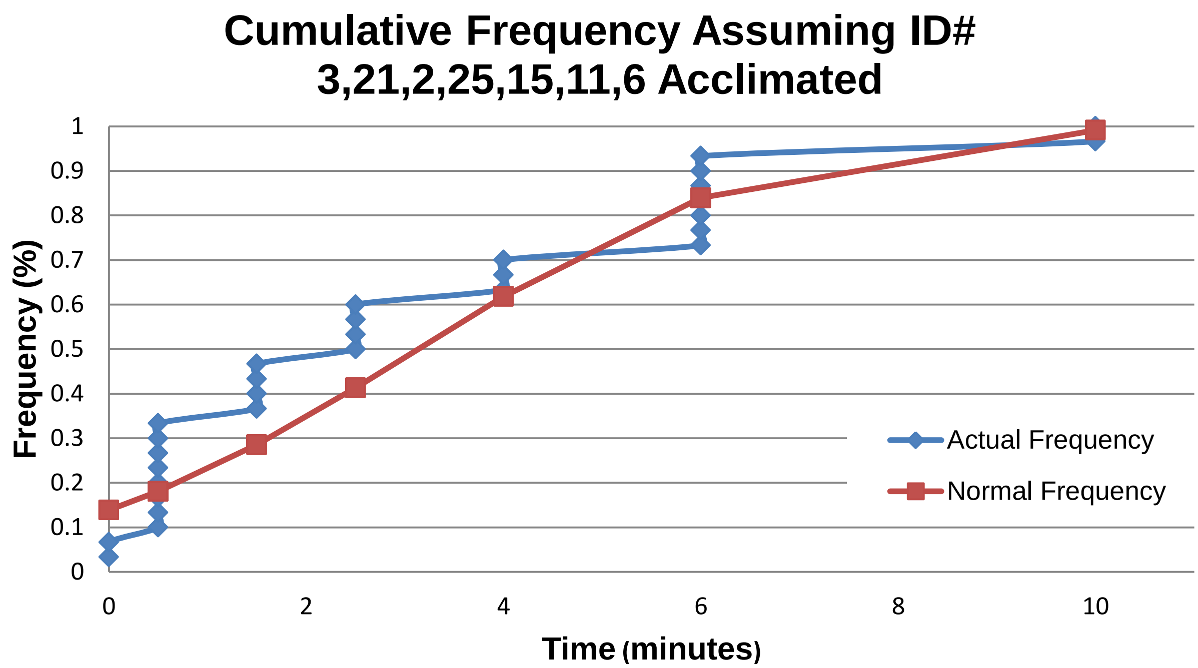


Figure 5 Cumulative Frequency of Acclimation Based on Steering Behavior Assuming Acclimation

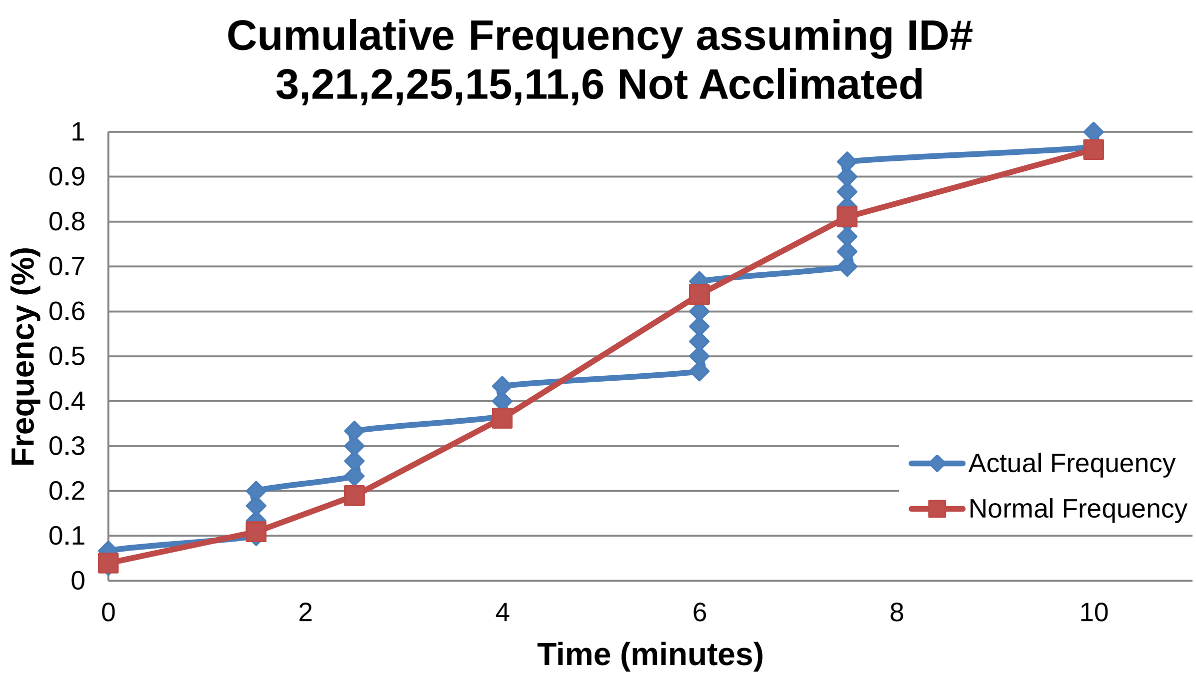


Figure 6 Cumulative Frequency of Acclimation Based on Steering Behavior Assuming Not Acclimated

Assuming the same seven individuals had not acclimated to the handling of the steering wheel, approximately 65% of the sample group was acclimated 6 minutes into the test session.

1.6 Conclusions

The right and left turns at the intersections computed using the averages of the variables and the max and min values revealed significant differences surrounding sections 8 and 9. During the experimental design, sections 8 and 9 were designed with a residential look as compared to the bare or rural look of the other compared intersections. No significance was placed on the appearance of the designed sections. The change of scenery was intended to give the driving experience a more natural feel and to reduce the probability of subjects becoming bored. The roadway sections were identical in terms of geometric design, but it was observed that the scenery of the road network may have affected the driving behavior of the subjects. Further research regarding whether changes in roadside features affect warming-up driving simulator subjects would be beneficial.

The curve section analysis revealed results on par with the anticipated results. With the exception of the unusual interaction effects in the comparison between sections 4 and 14, no significant differences were revealed using the mean, max, and min data across the long curves. The short curves revealed significant differences using the mean data and the max and min data. The significant results show that consideration should be given to short, sharp curves when analyzing adaptation.

The Figure 4 steering correction trend lines indicate that some level of adaptation to the handling of the simulator vehicle is occurring. Individual subject steering correction analysis was performed to visualize when each participant reduced the variation in their intersection overcorrection patterns. Normal frequency curves were used to estimate the level of acclimation among the sample population. Based on the steering wheel overcorrections of each individual, approximately 65%- 85% of individuals acclimated to the handling of the simulator vehicle after six minutes of exposure.

Future research may include a longer virtual scenario with increased intersections and curves. This will allow the oversteer correction progression to be further analyzed and modeled with additional data points to gain further insight into the steering and lateral acceleration of the subjects. If research efforts require additional vehicle movements beyond 90° turns and simple curves, it is advised to place these components into the warm-up session for further acclimation. Data collection from roundabouts and skewed intersections to monitor acclimation of the more difficult vehicle movements will be of interest in future research considerations.

Appendix A: Example of Two-Sample Hotelling's T2 Report

Database	E:\NCSS\Turn.S0
Filter	SECTION=2,8
Group	SECTION

Descriptive Statistics

	Means		**Standard Deviations**	
Variable	**2**	**8**	**2**	**8**
V	10.17018	10.64031	2.152361	2.204844
S	66.76871	72.34553	9.602363	30.24709
A	0.2676792	0.2379712	0.1414675	0.1516117
B	1.621674E-02	2.675449E-03	3.212682E-02	6.541225E-03
LATA	1.114124	1.759387	0.4509365	1.273837
LONGA	1.044436	1.019001	0.4875915	0.507047
Count	30	30	30	30

Hotelling's T2 Test Section

Covariance Assumption	**T2**	**DF1**	**DF2**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
Equal	43.504	6	58.0	0.0000	0.0001
Unequal	43.504	6	34.9	0.0003	0.0001

The randomization test results are based on 10000 Monte Carlo samples.

Individual Variables Section

Variable Omitted	**T2 Others**	**Prob Level**	**T2 Change**	**Prob Level**	**T2 Alone**	**Prob Level**
V	30.627	0.0003	12.878	0.0076	0.698	0.4068
S	26.570	0.0008	16.935	0.0020	0.926	0.3398
A	42.721	0.0000	0.783	0.5237	0.616	0.4358
B	43.038	0.0000	0.466	0.6229	5.118	0.0274
LATA	11.784	0.0682	31.720	0.0000	6.841	0.0113
LONGA	43.032	0.0000	0.472	0.6207	0.039	0.8437

Student's T-Test Section

Variable	**T2 or |Student's T|**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
All (T2)	43.504	0.0000	0.0001
V	0.836	0.4068	0.4106
S	0.963	0.3398	0.4019
A	0.785	0.4358	0.4457
B	2.262	0.0274	0.0126
LATA	2.615	0.0113	0.0027
LONGA	0.198	0.8437	0.8441

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

Two-Sample Hotelling's T2 Report

Database	E:\NCSS\Turn.S0
Filter	SECTION=2,8
Group	SECTION

Confidence Intervals for the Mean Differences Section

Variable	Difference	Lower 95.0% Bonferroni Conf. Limit	Upper 95.0% Bonferroni Conf. Limit	Lower 95.0% Simultaneous Conf. Limit	Upper 95.0% Simultaneous Conf. Limit
V	-0.4701286	-2.006894	1.066637	-2.644548	1.704291
S	-5.57682	-21.40451	10.25087	-27.97194	16.8183
A	0.029708	-7.371404E-02	0.13313	-0.1166272	0.1760432
B	1.354129E-02	-2.81072E-03	2.989331E-02	-9.595701E-03	3.667829E-02
LATA	-0.645263	-1.319223	2.869708E-02	-1.598871	0.3083449
LONGA	2.543525E-02	-0.3254107	0.3762812	-0.470988	0.5218585

Bartlett-Box Homogeneity of Variance Tests

Variable(s) Tested	Test Value	DF1	DF2	F Approx	F Prob	Chi2 Approx	Chi2 Prob
Box's M Test							
ALL	159.961	21	12373	6.769	0.0000	142.429	0.0000
Bartlett Individual Variable Tests							
V	0.017	1	10092	0.017	0.8977	0.017	0.8977
S	31.915	1	10092	31.469	0.0000	31.365	0.0000
A	0.139	1	10092	0.137	0.7117	0.137	0.7117
B	54.464	1	10092	53.822	0.0000	53.525	0.0000
LATA	26.876	1	10092	26.487	0.0000	26.413	0.0000
LONGA	0.044	1	10092	0.044	0.8346	0.044	0.8346

Appendix B: Section 2,5,8,11 Lateral Acceleration Differences

Filter	SECTION=2,8
Group	SECTION

Descriptive Statistics

	Means		**Standard Deviations**	
Variable	**2**	**8**	**2**	**8**
V	10.17018	10.64031	2.152361	2.204844
S	66.76871	72.34553	9.602363	30.24709
A	0.2676792	0.2379712	0.1414675	0.1516117
B	1.621674E-02	2.675449E-03	3.212682E-02	6.541225E-03
LATA	1.114124	1.759387	0.4509365	1.273837
LONGA	1.044436	1.019001	0.4875915	0.507047
Count	30	30	30	30

Student's T-Test Section

Variable	**T2 or |Student's T|**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
All (T2)	43.504	0.0000	0.0001
V	0.836	0.4068	0.4106
S	0.963	0.3398	0.4019
A	0.785	0.4358	0.4457
B	2.262	0.0274	0.0126
LATA	2.615	0.0113	0.0027
LONGA	0.198	0.8437	0.8441

Filter	SECTION=5,8
Group	SECTION

Descriptive Statistics

	Means		**Standard Deviations**	
Variable	**5**	**8**	**5**	**8**
V	10.52702	10.64031	1.972095	2.204844
S	66.60902	72.34553	8.47261	30.24709
A	0.3068768	0.2379712	0.1599834	0.1516117
B	3.163916E-03	2.675449E-03	1.067215E-02	6.541225E-03
LATA	1.124244	1.759387	0.392002	1.273837
LONGA	1.248158	1.019001	0.4110911	0.507047
Count	30	30	30	30

Student's T-Test Section

Variable	**T2 or |Student's T|**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
All (T2)	58.039	0.0000	0.0001
V	0.210	0.8346	0.8309
S	1.000	0.3213	0.3722
A	1.712	0.0922	0.0870
B	0.214	0.8315	0.8480
LATA	2.610	0.0115	0.0020
LONGA	1.923	0.0594	0.0591

Filter	SECTION=8,11
Group	SECTION

Descriptive Statistics

	Means		Standard Deviations	
Variable	**8**	**11**	**8**	**11**
V	10.64031	11.21145	2.204844	1.948658
S	72.34553	65.65321	30.24709	6.706572
A	0.2379712	0.2989304	0.1516117	0.1506472
B	2.675449E-03	2.548042E-03	6.541225E-03	1.021186E-02
LATA	1.759387	1.196112	1.273837	0.4277564
LONGA	1.019001	1.215071	0.507047	0.3896057
Count	30	30	30	30

Student's T-Test Section

Variable	T2 or |Student's T|	Parametric Test Prob Level	Randomization Test Prob Level
All (T2)	121.961	0.0000	0.0001
V	1.063	0.2921	0.2834
S	1.183	0.2416	0.2790
A	1.562	0.1237	0.1186
B	0.058	0.9543	0.9569
LATA	2.296	0.0253	0.0097
LONGA	1.679	0.0984	0.0960

Appendix C: Section 3, 6, 9, 12 Left Turn Analysis of Steer

	Means		**Standard Deviations**	
Variable	**3**	**9**	**3**	**9**
V	10.97787	11.6007	2.209262	2.413592
S	-60.76741	-49.70045	6.618906	4.596298
A	0.2765194	0.208227	0.1511936	8.855599E-02
B	8.229792E-03	8.246668E-03	1.610567E-02	1.836983E-02
LATA	-1.257738	-1.422642	0.4979192	0.4959105
LONGA	0.9528053	0.6724786	0.3857599	0.3540724
Count	30	30	30	30

Hotelling's T2 Test Section

Covariance Assumption	**T2**	**DF1**	**DF2**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
Equal	93.113	6	58.0	0.0000	0.0001
Unequal		6			1.0000

The randomization test results are based on 10000 Monte Carlo samples.

Variable	**T2 or |Student's T|**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
All (T2)	93.113	0.0000	0.0001
V	1.043	0.3015	0.3025
S	7.522	0.0000	0.0001
A	2.135	0.0370	0.0367
B	0.004	0.9970	0.9974
LATA	1.285	0.2038	0.2057
LONGA	2.932	0.0048	0.0055

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

	Means		**Standard Deviations**	
Variable	**6**	**9**	**6**	**9**
V	11.2833	11.6007	2.116888	2.413592
S	-60.72381	-49.70045	15.71853	4.596298
A	0.2504038	0.208227	0.1167288	8.855599E-02
B	0.0170659	8.246668E-03	4.622032E-02	1.836983E-02
LATA	-1.293948	-1.422642	0.4730972	0.4959105
LONGA	0.8045366	0.6724786	0.4418991	0.3540724
Count	30	30	30	30

Hotelling's T2 Test Section

Covariance Assumption	**T2**	**DF1**	**DF2**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
Equal	41.441	6	58.0	0.0000	0.0001
Unequal		6			1.0000

The randomization test results are based on 10000 Monte Carlo samples.

Student's T-Test Section

Variable	T2 or |Student's T|	Parametric Test Prob Level	Randomization Test Prob Level
All (T2)	41.441	0.0000	0.0001
V	0.542	0.5902	0.5931
S	3.687	0.0005	0.0001
A	1.577	0.1203	0.1201
B	0.971	0.3355	0.4220
LATA	1.028	0.3080	0.3058
LONGA	1.277	0.2066	0.2025

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

	Means		Standard Deviations	
Variable	**9**	**12**	**9**	**12**
V	11.6007	11.95745	2.413592	1.586658
S	-49.70045	-56.62521	4.596298	4.613665
A	0.208227	0.3300488	8.855599E-02	0.146287
B	8.246668E-03	2.724984E-03	1.836983E-02	4.411732E-03
LATA	-1.422642	-1.356111	0.4959105	0.3881786
LONGA	0.6724786	1.147025	0.3540724	0.2826653
Count	30	30	30	30

Hotelling's T2 Test Section

Covariance Assumption	T2	DF1	DF2	Parametric Test Prob Level	Randomization Test Prob Level
Equal	70.313	6	58.0	0.0000	0.0001
Unequal		6			1.0000

The randomization test results are based on 10000 Monte Carlo samples.

Student's T-Test Section

Variable	T2 or |Student's T|	Parametric Test Prob Level	Randomization Test Prob Level
All (T2)	70.313	0.0000	0.0001
V	0.676	0.5014	0.5063
S	5.824	0.0000	0.0001
A	3.902	0.0003	0.0004
B	1.601	0.1148	0.1231
LATA	0.579	0.5651	0.5696
LONGA	5.737	0.0000	0.0001

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

Appendix D: Section 4 versus 14 Scaled Transformed Comparison

Two-Sample Hotelling's T2 Report

Database E:\NCSS\TurnTransform.S0
Filter SECTION=4,14

Descriptive Statistics

	Means		**Standard Deviations**	
Variable	**4**	**14**	**4**	**14**
V	22.4667	23.99101	5.603535	3.804164
A	0.171668	0.176348	0.1067739	9.249188E-02
B	5.836442E-03	2.195708E-03	1.373084E-02	3.372263E-03
S	118.6479	120.3023	5.72372	3.320336
LATA	2.009753	2.207128	0.9102678	0.6211334
LONGA	1.000897	1.01169	0.1973854	0.1338257
Count	30	30	30	30

Hotelling's T2 Test Section

Covariance Assumption	**T2**	**DF1**	**DF2**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
Equal	164.715	6	58.0	0.0000	0.0001
Unequal	164.715	6	48.8	0.0000	0.0001

The randomization test results are based on 10000 Monte Carlo samples.

Individual Variables Section

Variable Omitted	**T2 Others**	**Prob Level**	**T2 Change**	**Prob Level**	**T2 Alone**	**Prob Level**
V	33.334	0.0001	131.381	0.0000	1.520	0.2227
A	120.513	0.0000	44.203	0.0007	0.033	0.8566
B	139.209	0.0000	25.507	0.0115	1.989	0.1638
S	133.726	0.0000	30.989	0.0050	1.875	0.1762
LATA	153.540	0.0000	11.176	0.1002	0.962	0.3307
LONGA	162.502	0.0000	2.213	0.4690	0.061	0.8051

Student's T-Test Section

Variable	**T2 or |Student's T|**	**Parametric Test Prob Level**	**Randomization Test Prob Level**
All (T2)	164.715	0.0000	0.0001
V	1.233	0.2227	0.2239
A	0.181	0.8566	0.8614
B	1.410	0.1638	0.1809
S	1.369	0.1762	0.1729
LATA	0.981	0.3307	0.3368
LONGA	0.248	0.8051	0.8085

The randomization test results are based on 10000 Monte Carlo samples.
These individual t-test significance levels should only be used when the overall T2 value is significant.

Appendix E: Male and Female Testing Results

MALE								
αl28=0.002		**Prob**	**Individual Variables Omitted**					
StopRight		**Level**	**Velocity**	**Steer**	**Accel**	**Brake**	**Lat.Acc.**	**Long.Acc.**
2	5	0.7489						
2	8	0.0002	0.0003	0.0001	0.0002	0.0001	0.1745	0.0001
2	11	0.2583						
5	8	0.0001	0	0	0	0	0.1168	0
5	11	0.126						
8	11	0.0001	0.0001	0	0	0	0.1416	0
LightLeft								
3	6	0.2962						
3	9	0.0001	0	0.0035	0	0	0	0
3	12	0.0598						
6	9	0.0045						
6	12	0.1047						
9	12	0.0001	0.0001	0	0	0	0.0002	0
LongCurve								
1	13	0.911						
R	R							
4	14	0.0001	0.0164	0	0	0	0	0
L	L							
ShortCurve								
7	15	0.4803						
R	R							
10	16	0.0163						
L	L							
LongCurve-S-Lata			**Velocity**	**Accel**	**Brake**	**Long.Acc.**		
1	4	0.1725						
R	L							
1	13	0.6744						
R	R							
1	14	0.1172						
R	L							
4	13	0.5247						
L	R							
4	14	0.7548						
L	L							
13	14	0.3426						
R	L							

ShortCurve-S-Lata								
7	10	0.1363						
R	L							
7	15	0.3095						
R	R							
7	16	0.0003	0.0069	0.0826	0.0171	0.0004		
R	L							
10	15	0.0851						
L	R							
10	16	0.0183						
L	L							
15	16	0.0294						
R	L							

FEMALE								
αl28=0.002		Prob	Individual Variables Omitted					
StopRight		Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.0139						
2	8	0.0005	0.0006	0.006	0.0042	0.0009	0.0259	0.0015
2	11	0.0777						
5	8	0.0001	0	0	0	0	0.0145	0.0004
5	11	0.4889						
8	11	0.0001	0.0002	0	0	0	0.3738	0
LightLeft								
3	6	0.8331						
3	9	0.0018	0.0018	0.4831	0.0019	0.0017	0.0018	0.0017
3	12	0.2878						
6	9	0.0033						
6	12	0.5221						
9	12	0.0058						
LongCurve								
1	13	0.5869						
R	R							
4	14	0.0001	0	0	0	0	0	0
L	L							
ShortCurve								
7	15	0.3794						
R	R							
10	16	0.2694						
L	L							

LongCurve-S-Lata			Velocity	Accel	Brake	Long.Acc.		
1	4	0.2138						
R	L							
1	13	0.3038						
R	R							
1	14	0.0088						
R	L							
4	13	0.7727						
L	R							
4	14	0.9725						
L	L							
13	14	0.5844						
R	L							
ShortCurve-S-Lata								
7	10	0.1675						
R	L							
7	15	0.5643						
R	R							
7	16	0.1076						
R	L							
10	15	0.0331						
L	R							
10	16	0.2321						
L	L							
15	16	0.1641						
R	L							

Appendix F: Results with Older Subjects Removed

α_{l28}=0.002		Prob	Individual Variables Section Variable Omitted					
StopRight		Level	Velocity	Steer	Accel	Brake	Lat.Acc.	Long.Acc.
2	5	0.1565						
2	8	0.0001	0.0017	0.0008	0	0	0.063	0
2	11	0.0543						
5	8	0.0001	0.0002	0.0007	0	0	0.0674	0
5	11	0.019						
8	11	0.0001	0.0024	0	0	0	0.0037	0
LightLeft								
3	6	0.291						
3	9	0.0001	0	0.0002	0	0	0	0
3	12	0.0091						
6	9	0.0001	0.0001	0.01	0.0003	0.0005	0.0008	0.0001
6	12	0.0691						
9	12	0.0001	0	0	0	0	0	0
LongCurve								
1	4	0.0001	0	0	0	0	0	0
R	L							
1	13	0.0669						
R	R							
1	14	0.0001	0	0	0	0	0	0
R	L							
4	13	0.0001	0	0	0	0	0	0
L	R							
4	14	0.0001	0	0	0	0	0	0
L	L							
13	14	0.0001	0	0	0	0	0	0
R	L							
ShortCurve								
7	10	0.0001	0	0	0	0	0	0
R	L							
7	15	0.0229						
R	R							
7	16	0.0001	0	0	0	0	0	0
R	L							
10	15	0.0001	0	0	0	0	0	0
L	R							
10	16	0.0678						

L	L							
15	16	0.0001	0	0	0	0	0	0
R	L							
LongCurve-S-Lata			Velocity	Accel	Brake	Long.Acc.		
1	4	0.0833						
R	L							
1	13	0.1665						
R	R							
1	14	0.0009	0.0063	0.0165	0.0911	0.0165		
R	L							
4	13	0.8955						
L	R							
4	14	0.9657						
L	L							
13	14	0.3069						
R	L							
ShortCurve-S-Lata								
7	10	0.0263						
R	L							
7	15	0.0504						
R	R							
7	16	0.0011	0.0491	0.0088	0.0012	0.0088		
R	L							
10	15	0.0001	0.0022	0.0004	0.0125	0.0004		
L	R							
10	16	0.0465						
L	L							
15	16	0.0026						
R	L							

Appendix G: Cumulative Frequency Data Plots

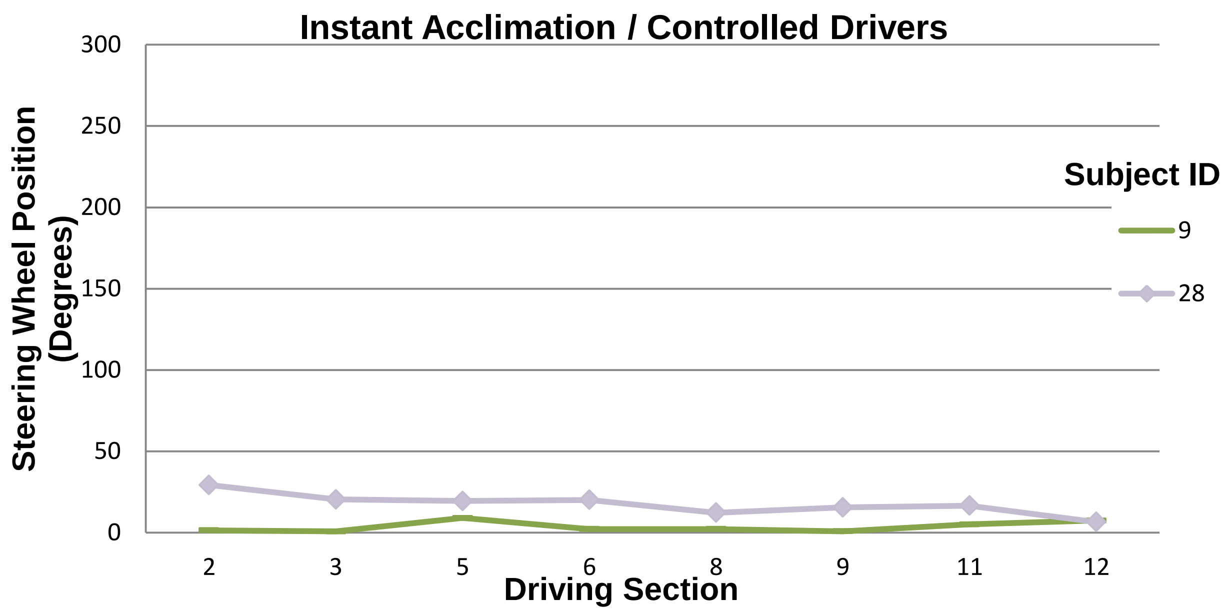


Figure 7 Instant Acclimation

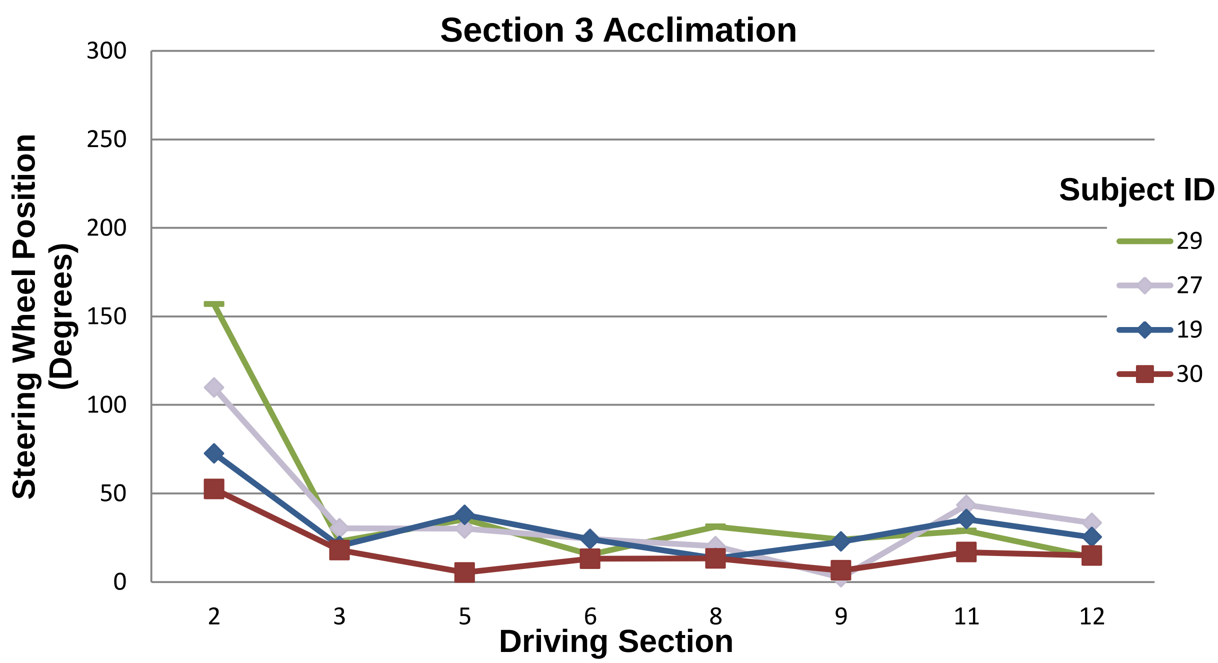


Figure 8 Section 3 Acclimation

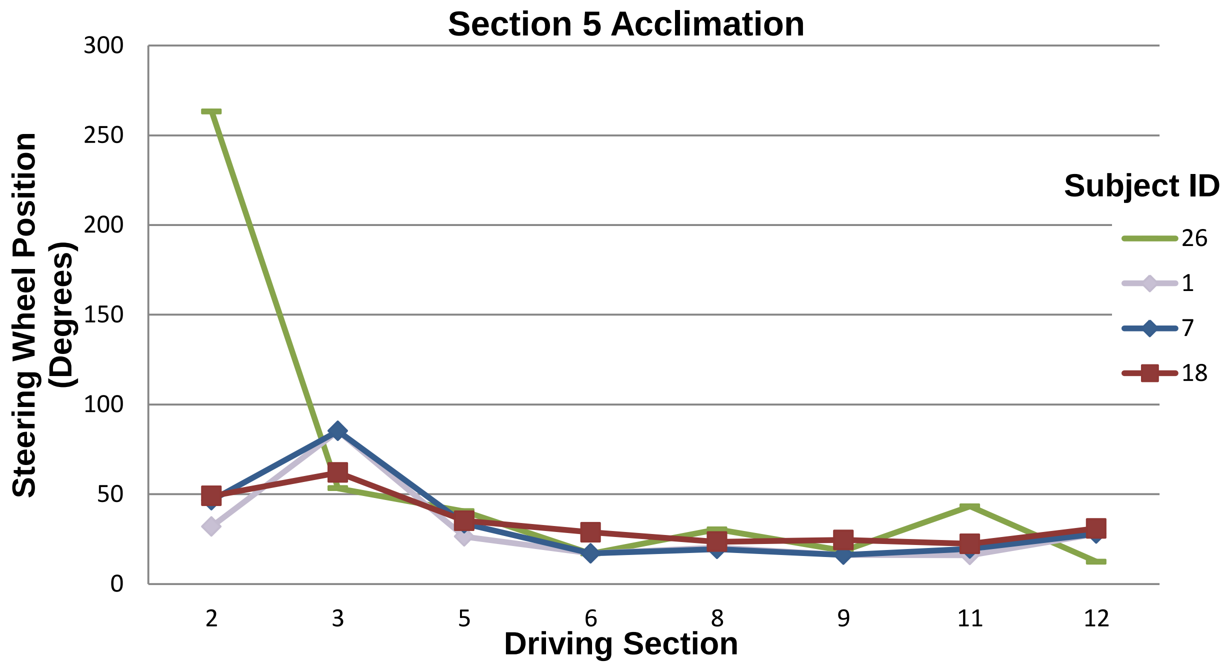


Figure 9 Section 5 Acclimation

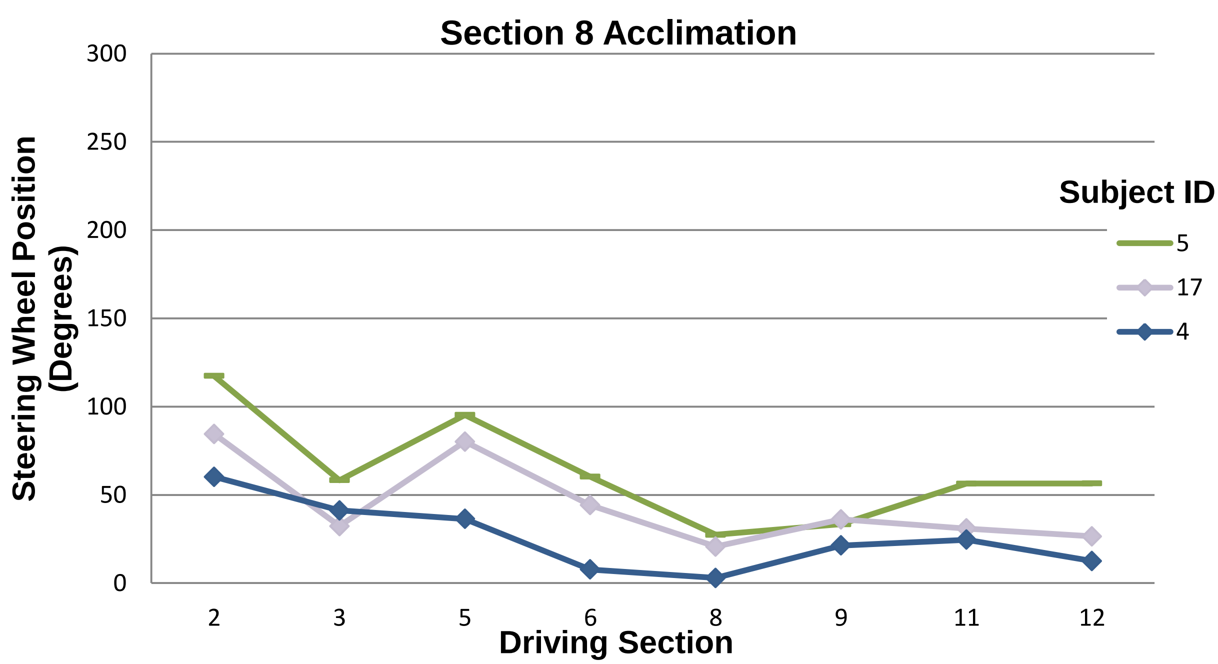


Figure 10 Section 8 Acclimation

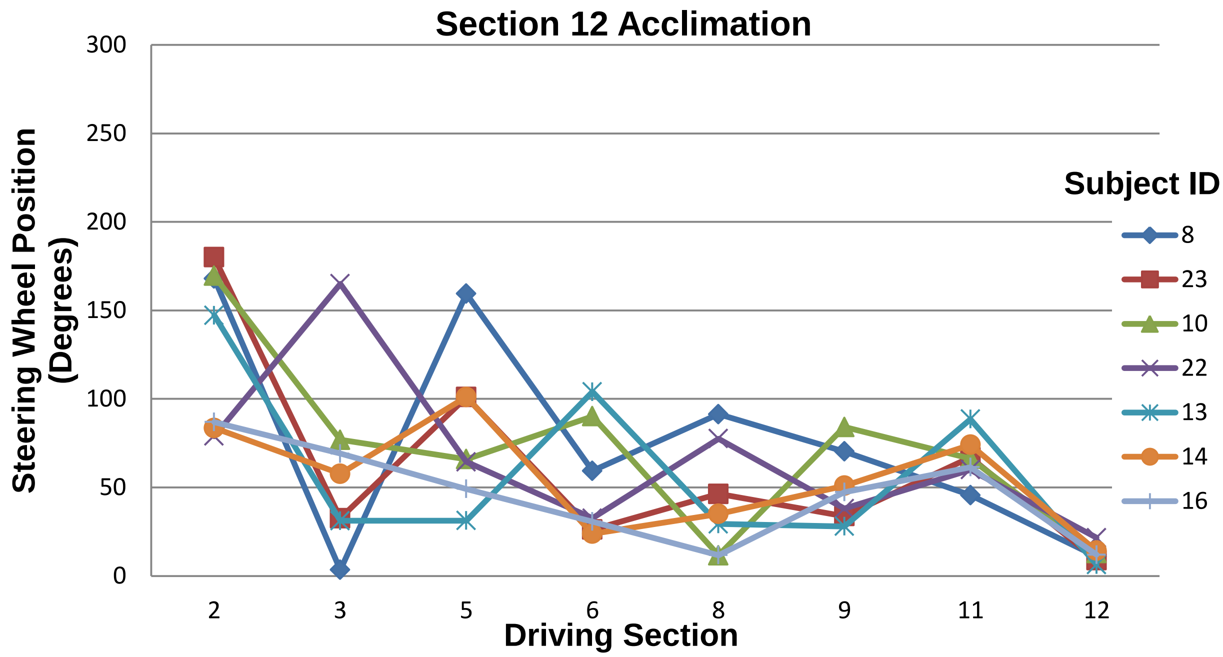


Figure 11 Section 12 Acclimation

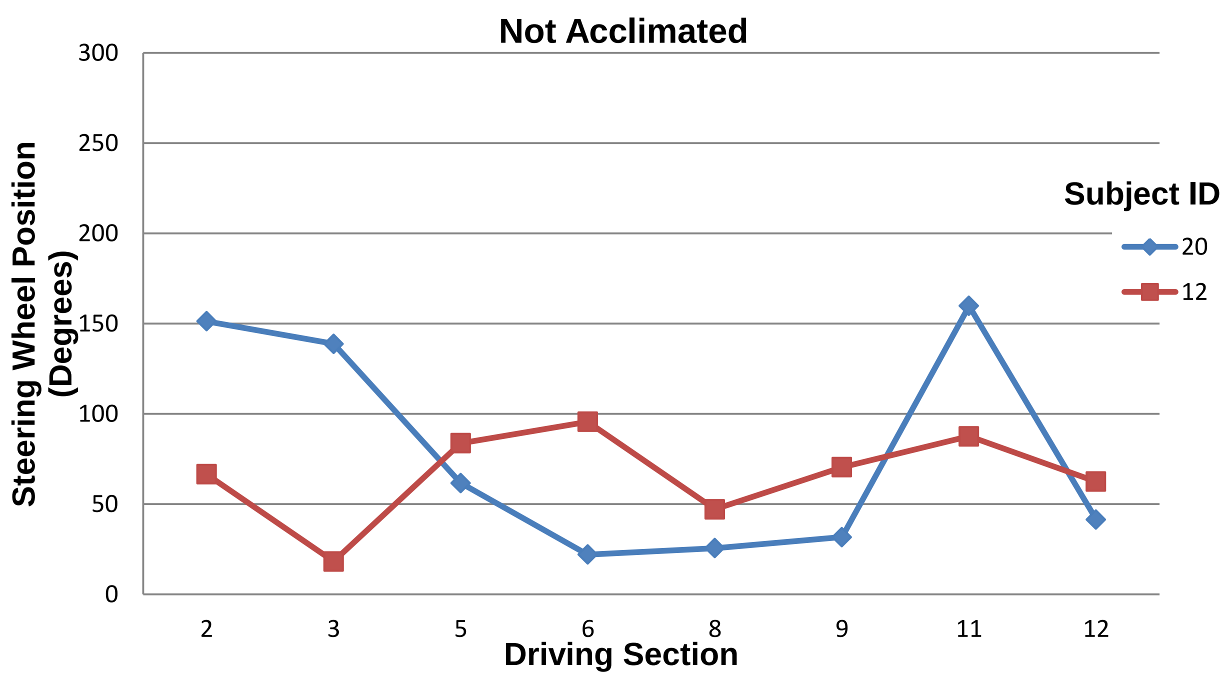


Figure 12 No Acclimation

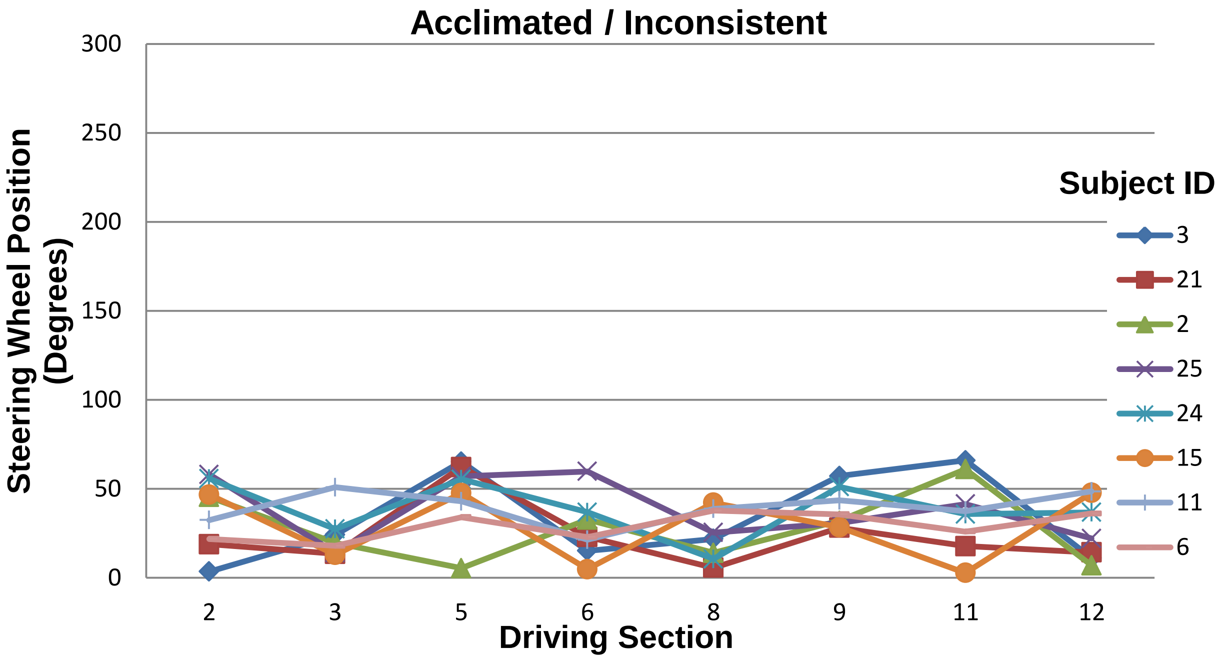


Figure 13 Acclimated Subjects / Inconsistent Steering

Appendix H: Institutional Review Board Research Consent Form

INFORMED CONSENT STATEMENT

Driving Simulator Warm-Up Analysis

As a participant, you are invited to participate in a research study. The purpose of this research is to utilize the DriveSafety DS-600 model driving simulator located in Perkins Hall room 72 to conduct tests of participants' driving performance. You will be tested to analyze the effects of different factors on your driving performance. The objective of this study is to establish a proper protocol to acclimate subjects to a driving simulator environment and ensure they have adjusted to the handling of the virtual vehicle.

INFORMATION ABOUT PARTICIPANTS' INVOLVEMENT IN THE STUDY

You will be asked to read and sign this consent form. You will then be asked your age and relevant driving experience for proper data collection. After information is collected, you will be asked to open the door of the car cab and sit down in the seat of the simulator cab. Next, you will be asked to drive a simulated network of streets totaling approximately 15-30minutes in the University's driving simulator. Each session will be comprised of a virtual driving course developed by the researchers. Breaks in the testing will be permitted at your discretion.

RISKS

The only potential risk to you during testing could be motion sickness due to the conflicting body queues of visual movement without actual body movement. You can quit the test anytime during the test without penalty if you feel uncomfortable or simply do not wish to continue.

BENEFITS

In transportation research, the use of driving simulators to conduct research is growing rapidly due to the declining costs of high quality technology. The results of the study will provide researchers with information to ensure that data collected in a simulator is an accurate representation of the individuals usual driving performance.

CONFIDENTIALITY

All information in the study records will be kept confidential. Data will be stored securely and will be made available only to persons conducting the study. No reference will be made in oral or written reports which could link participants to the study.

CONTACT INFORMATION

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study,) you may contact the researcher, Ryan Overton, at 72 Perkins Hall and (865) 585-4004. If you have questions about your rights as a participant, contact the Office of Research Compliance Officer at (865) 974-3466.

PARTICIPATION
Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed.

CONSENT
I have read the above information. I have received a copy of this form. I agree to participate in this study.

Investigator’s signature

Date

Participant’s signature

Date

CHAPTER II

DISTRACTED RURAL TEEN DRIVER ANALYSIS

Abstract

Teen drivers are among the most vulnerable populations traversing our transportation networks and have a high propensity of fatal crashes due to their inexperience behind the wheel. Integrated with the dangers of rural roadways containing undesirable clear zones and extended distances from emergency services, rural teen drivers can be classified as high risk for potential fatal crashes. Research efforts must pursue understanding rural teen driving behaviors to consequently save lives. In this study a group of 64 high school junior students were separated into four groups and analyzed across three sections of testing in a high fidelity simulator to examine driver-to-vehicle inputs and resulting lateral vehicle velocity while performing phone conversations and texting. Two-Sample Hotelling's T^2 testing found that on average non-distracted driving, phone conversation driving, and texting while driving had little effect on the driving parameters of accelerator position, brake position, and steering wheel position. However, the group performing the phone conversations drove slower than the undistracted or texting groups. The lateral vehicle velocity of the text messaging group was found to be significantly greater than the phone conversation or undistracted group of teens.

2.1 Introduction & Literature Review

Distracted driving continues to plague the transportation community after several decades of research. With early distracted driving research efforts dating back to the mid-1900s, the transportation safety professionals around the world still struggle to alleviate the pandemic. Brown, Tickner, and Simmonds (1969) were among the first to study drivers' performance on the task of engaging in a conversation over a mobile telephone while driving a car [51]. The 2009 Fatality Analysis Reporting System (FARS) and the National Automotive Sampling reported 33,808 fatalities on US roadways. It is also reported that 5,474 people killed (16% of the total fatalities) were involved in driver distraction crashes [52]. Distracted driving has been reported to interfere with judgment and recognition more than alcohol impairment [53]. The National Highway Traffic Safety Administration acknowledges yet another disturbing statistic, indicating that motor vehicle crashes are the leading cause of death for teens in the United States. Additionally, teens are 3 times more likely to be involved in a fatal traffic crash per mile driven than any other age group [54]. While distractions and inexperience on the roadways considerably compromise the safety of travel, the spatial location of vehicle miles traveled further complicates the argument for providing safe travel. 2008 FARS data indicated that while only 23 percent of the United States population lives in rural areas, rural fatalities account for 56 percent of all traffic fatalities [6]. Distractions, inexperience, and rural locations combine to identify rural teen drivers as a special population with a high vulnerability for highway fatalities. For this reason, we aim to identify key driving parameters that compromise the driving behavior among rural teen drivers utilizing a driving simulator.

Although the concept of driving simulators dates back to the 1960's, wide use in transportation research was not until last decade with the emergence of enabling technologies that made driving simulators affordable enough to own and authentic enough for research. Numerous validation studies examining various performance variables have proven driving simulators to be an appropriate research tool [9-12]. The main advantage of driving simulators is its provision of an inherently safe environment for testing driving scenarios that can be economically created, easily configured, and reliably replicated to investigate a variety of human factors research problems [13]. Paul Green emphasized that all simulator users need to be vigilant with regard to the data they collect, and need to verify that the values reported are indeed reasonable for real driving, and not just that differences between test conditions of interest are statistically significant [55].

Numerous studies have been conducted researching distracted driving in recent years. Greenberg determined that teens are more prone to be distracted and choose unsafe following distances when operating a hand-held phone compared to their adult, experienced driving counterparts [56]. Lateral position deviation was used as the main driving performance measure in a study concluding that dialing a hands-free or handheld phone creates greater lateral deviation, but conversing actually reduced lateral deviations. This reduction is believed to be a compensatory effect of increased alertness [57]. An awareness of driving performance deterioration during cell phone use study attempted to reveal the hazards of distracted driving, even though the subjects expressed confidence in his/her abilities to multi-task while driving [58]. Significant differences in driving performance and incident detection have even been found between in-car passenger conversations and remote cellular conversations [59]. Numerous research efforts have concluded that distracted driving is dangerous; therefore, state and federal legislation continue to restrict or ban the use of distracting devices.

2.2 Purpose

The goal of this study is to analyze the intra-lane lateral velocity between teen drivers with a history of driving on predominately rural roads while conversing on a phone, texting, and undistracted. The need for lateral lane deviation information across all populations involving hand-held devices has been noted in previous meta-analysis research [60]. Driver control inputs and resulting lateral velocity parameters are evaluated for significant findings. Additional analysis of teens reacting to an emergency situation will be presented to evaluate and better educate teen drivers in the future. The results may provide researchers important information regarding driving behavior and ultimately, assist teens in learning lifesaving, experienced driving techniques. The hypothesis in this research is that: *teen drivers partaking in distracted behavior behind the wheel pose a threat to all users of the roadway. Better understanding of distracted, rural, teen drivers will allow engineers to design safer roadways to accommodate risky behavior and governing bodies to formulate educational material targeted at increasing driver awareness and enhancing safe driving performance.*

2.3 Methodology

2.3.1 Participants

Participation in this study was voluntary and consisted of 64 high school juniors. Subjects tested held a valid Tennessee driver's license and reported healthy to complete all tasks. Gender differences were not reported in this effort, but an approximately even distribution was observed. All participants reported having corrected or normal vision, as well as normal hearing in both ears. Utilizing a cell phone device in this study, every subject reported being very familiar with operating a cell phone for conversation and texting.

2.3.2 Apparatus / Equipment

Tests for this study were conducted using the DriveSafety DS-607c, which consists of 5 aspheric mirror technology projectors wrapping 300° around a Ford Focus cab, where the test subject is to be seated. The screen projection has a resolution 1024 x 768 pixel each. A digital audio system is functional in the cab with four speakers to allow for audio commands and other sounds in the virtual environment. The interior of the vehicle is an exact replica of a Ford Focus featuring: windshield, driver and passenger seats, center console, radio/CD player, full functioning instrument panel. In addition, the driver has rear views through a LCD rear view mirror and two LCD side view mirrors.

2.3.3 Design and Experimental Procedure

A two lane rural driving course was specifically designed for testing four groups of teen subjects. The first test section consists of a sweeping right hand curve and a simple straight segment of roadway. The scenario is designed with continuously flowing oncoming ambient traffic with no vehicles in the subject's lane to impede on the driver's speed. The subsequent sections were straight segments of two lane roadway with the continuous oncoming ambient traffic. No access points or intersections were designed into the simulation to avoid external influence on the driving performance. The weather conditions were programmed as clear and daytime driving.

Arriving at the laboratory, each participant received a brief introduction to the lab and was given the opportunity to review and sign the informed consent form. While the participant familiarized himself/herself with the apparatus in the driver's seat, instructions for the experiment were given. The instructions did not include any information about the purpose of the experiment, which could potentially influence driving behavior. The subjects were instructed to drive in their normal driving behavior. In order to acclimate the participants to the simulated driving environment to ensure accurate data collection, each participant was asked to drive a short practice session and drive until they felt comfortable operating the vehicle. On average the warm-up session lasted a couple of minutes for the teen drivers. McGhee concluded that approximately three minutes of driving was all the time needed to become familiar with a driving simulator [20]. If the participant did not exhibit any discomfort after the short session, the testing commenced after another set of instructions. In order to eliminate the potential effect of the order in which various tasks were presented to the subject, the sequence of the requested tasks were randomized for each participant. The participant’s comfort level was assessed during the testing to ensure data quality.

The experimental design required the 64 subjects to be separated into four groups for randomized testing. Table 12 shows the progression of tasks each group of subjects was exposed: no distraction (normal driving), receive a phone call and conversing, or sending a text message. Each subject was given the cell phone before the study to familiarize themselves with the device. The cell phone was placed on the passenger seat at the onset of each test. Immediately before the testing procedure every subject was asked to drive normally, answer the phone if it rang and converse until the other party ended the conversation, or send a text message stating “I Love the University of Tennessee” as a reply to the only message in the phones inbox. The phone conversation consisted of simple questions such as name, school, hometown, etc. to avoid excess mental workload, as the intent of the phone conversation was to serve as a physical distraction and hindrance.

Three sections of data collection occurred during the two lane road driving scenario in which each participant drove through the progression of sections in order: A, B, and C. Section A consisted of a long sweeping curve and a 400 meter straight section of roadway. Sections B & C were straight roadways 600 meters in length. The virtual scenario was designed to simulate rural driving and the two-lane roadway contained eight foot shoulders.

Table 12 Subject's Driving Task Progression

Group Code	Section A	Section B	Section C
1 (n=16)	No Distractant	No Distractant	Text
2 (n=16)	No Distractant	No Distractant	Phone
3 (n=16)	Phone	Phone	No Distractant
4 (n=16)	Text	Text	No Distractant

2.3.4 Data Analysis

The variable outputs from the driving simulator performance that were analyzed in the Two-Sample Hotelling's T^2 test of driver inputs include:

- Velocity – The speed of the subject in m/s.
- Steer – Position of the steering wheel recorded in degrees. Clockwise is positive with +/- 540 degrees, or one and half turns, being the maximum values.
- Accel – The normalized accelerator position value. Zero meaning no pushing of the accelerator pedal, while 1.00 reports that the gas pedal is fully depressed.
- Brake – The normalized brake position value. Zero meaning no pushing of the brake pedal, while 1.00 reports that the brake pedal is fully depressed.

Statistical testing of the collected data for this study was completed using the NCSS and SPSS statistical software package. The data collection parameter, lane position, was also obtained to calculate the lateral velocity of each subject's vehicle movements. The lane position output is measured in meters and it is calculated from the center of the lane to the center of the subject's vehicle with an accuracy of one millimeter. The data was sampled at a rate of 10 HZ for this experiment. The derivative of the lane position data was computed to obtain the lateral velocity of each subject's vehicle throughout the testing procedure. This lateral velocity data was then compared across groups to analyze the swerving speed between the four groups.

The Two-Sample Hotelling's T^2 multivariate test was performed to evaluate the driver performance inputs while traversing the simulator scenario. The main advantage and reason for performing the Hotelling's test to discover differences between groups is the lack of needed normality and equal-variance assumptions in order to provide probability levels based on randomization tests. The Hotelling's T^2 is a straightforward generalization of the Student's t to the multivariate case[45]. For each section of the driven course we test the null hypothesis that the group means for all the response variables are equal[44].

The different Sections were evaluated testing the performance variables: Velocity, Steer, Accel, and Brake. The Bartlett Individual Variable Tests was performed to satisfy equal variances across samples and outliers were identified and removed. The Hotelling's T^2 Randomization Test Probability Level is reported assuming unequal covariance and the randomization test results are based on 1000 Monte Carlo samples. The individual variable t-test significance levels should only be viewed with confidence when the overall T^2 value is significant.

The Analysis of Variance for the lateral velocity of the groups was analyzed to determine how the different treatments of phone conversation and texting affect performance. This analysis assumes a random sample and normally distributed data of each variable.

2.5 Results

2.5.1 Multiple Variable Hotelling's Analysis

The collected driving parameters for Section A were evaluated and the results are summarized in Table 13. During this curve maneuver and straight driving section, the velocity of the texting group was slightly higher than the two control groups. However, no statistically significant differences could be deducted from the velocity results. The position of the steering wheel (steer), accelerator (accel), and brake pedal (brake) were not found to be different between groups and no trends could be established through the relationships.

The second data collection portion of the testing resulted in similar results of Section A. Although no multivariate between group distinctions could be classified as significant, it is interesting to note that the participants talking on the phone on average drove slower than the control groups in both Sections A and B. The Section B summarized results are presented in Table 14.

The final test section Hotelling's Comparisons once again did not result in significant multivariate differences between velocity, steer, accel, and brake. The velocity means regarding texting were still inconclusive, but the decreased velocity among the group carrying on a phone conversation is still trending true. It should be noted that the implication of rejecting the null hypothesis of equal means across variables is growing in significance in comparing the non-distracted and phone drivers against the texting group. Although our testing never reached an alpha=0.05. The trend of the Two-Sample Hotelling's comparison seems to be approaching significant results the longer the subjects drove the simulator. Summarizing the driving performance with a smaller selection of data may provide mores significant results as the large portion of data computed into the means for each variable may be diluting the critical data needed to prove differences among groups.

Table 13 Section A: Curve & Straight Section Hotelling's Comparison

	Group Mean			Individual Variable		Two-Sample Hotelling's	
	1	**2**	**Δ Means**	**T^2**	**P-Value**	**T^2**	**P-Value**
Velocity	25.02	24.71	0.31	0.12	0.73	2.05	0.77
Steer	15.42	14.86	0.56	0.61	0.44		
Accel	0.19	0.16	0.03	1.26	0.27		
Brake	0.01	0.01	0.00	0.00	0.98		
	1	**3(phone)**					
Velocity	25.02	24.45	0.57	0.33	0.57	1.14	0.94
Steer	15.42	15.04	0.38	0.10	0.75		
Accel	0.19	0.18	0.01	0.04	0.85		
Brake	0.01	0.01	0.00	0.09	0.77		
	1	**4(text)**					
Velocity	25.02	25.31	-0.29	0.13	0.72	2.49	0.74
Steer	15.42	15.61	-0.19	0.08	0.78		
Accel	0.19	0.21	-0.02	0.20	0.66		
Brake	0.01	0.02	0.00	0.41	0.53		
	2	**3(phone)**					
Velocity	24.71	23.86	0.85	1.02	0.32	2.17	0.77
Steer	14.86	14.08	0.78	1.53	0.23		
Accel	0.16	0.14	0.02	0.98	0.33		
Brake	0.01	0.01	0.00	0.08	0.79		
	2	**4(text)**					
Velocity	24.71	25.31	-1.05	1.60	0.22	2.36	0.68
Steer	14.86	15.61	-0.85	1.51	0.23		
Accel	0.16	0.21	-0.02	0.66	0.42		
Brake	0.01	0.01	0.00	0.00	0.98		

[1]Group 1 in Section A: No Distractions
[2]Group 2 in Section A: No Distractions
[3]Group 3 in Section A: Phone Conversation
[4]Group 4 in Section A: Texting

Table 14 Section B: Straight Section Hotelling's Comparison

	Group Mean			Individual Variable		Two-Sample Hotelling's	
	1	**2**	**Δ Means**	**T^2**	**P-Value**	**T^2**	**P-Value**
Velocity	27.08	25.90	1.18	1.46	0.24	4.14	0.48
Steer	0.20	0.23	0.00	0.05	0.82		
Accel	0.27	0.21	0.06	2.43	0.13		
Brake	0.01	0.01	0.00	0.95	0.34		
	1	**3(phone)**					
Velocity	27.08	25.56	1.50	2.10	0.16	3.01	0.67
Steer	0.20	0.16	0.04	0.11	0.75		
Accel	0.27	0.25	0.02	0.16	0.70		
Brake	0.01	0.01	0.00	0.05	0.05		
	1	**4(text)**					
Velocity	27.08	25.94	1.13	1.01	0.32	3.51	0.56
Steer	0.20	0.24	-0.04	0.06	0.81		
Accel	0.27	0.23	0.04	0.56	0.46		
Brake	0.01	0.01	0.00	1.91	0.18		
	2	**3(phone)**					
Velocity	25.59	25.57	0.01	0.00	0.99	8.24	0.16
Steer	0.17	0.16	0.01	0.01	0.92		
Accel	0.21	0.25	-0.05	4.48	0.04		
Brake	0.01	0.01	0.00	0.60	0.45		
	2	**4(text)**					
Velocity	25.90	25.94	-0.05	0.00	0.96	1.29	0.92
Steer	0.23	0.24	-0.01	0.00	0.96		
Accel	0.21	0.23	-0.02	0.29	0.60		
Brake	0.01	0.01	0.00	0.82	0.37		

[1]Group 1 in Section B: No Distractions
[2]Group 2 in Section B: No Distractions
[3]Group 3 in Section B: Phone Conversation
[4]Group 4 in Section B: Texting

Table 15 Section C: Straight Section Hotelling's Comparison

	Group Mean			Individual Variable		Two-Sample Hotelling's	
	1	**2**	**Δ Means**	**T^2**	**P-Value**	**T^2**	**P-Value**
Velocity	21.48	20.72	0.76	0.16	0.69	7.52	0.18
Steer	0.24	0.16	0.09	0.18	0.68		
Accel	0.38	0.27	0.10	6.32	0.02		
Brake	0.11	0.01	0.02	0.53	0.47		
	1	**3(phone)**					
Velocity	21.48	20.90	0.58	0.08	0.78	7.16	0.22
Steer	0.24	-0.20	0.44	2.89	0.10		
Accel	0.38	0.30	0.08	2.90	0.10		
Brake	0.11	0.11	0.00	0.02	0.90		
	1	**4(text)**					
Velocity	20.96	22.12	-1.16	0.29	0.60	6.46	0.23
Steer	0.60	-0.04	0.65	2.24	0.15		
Accel	0.37	0.33	0.05	1.58	0.22		
Brake	0.11	0.08	0.03	2.83	0.10		
	2	**3(phone)**					
Velocity	20.73	20.95	-0.22	0.02	0.89	1.87	0.80
Steer	0.16	-0.03	0.19	1.47	0.24		
Accel	0.27	0.27	0.01	0.02	0.89		
Brake	0.10	0.09	0.00	0.01	0.92		
	2	**4(text)**					
Velocity	20.72	21.12	-0.40	0.08	0.79	3.69	0.51
Steer	0.16	-0.02	0.18	0.95	0.34		
Accel	0.27	0.32	-0.04	1.33	0.26		
Brake	0.10	0.09	0.01	0.07	0.80		

[1]Group 1 in Section C: Texting
[2]Group 2 in Section C: Phone Conversation
[3]Group 3 in Section C: No Distractions
[4]Group 4 in Section C: No Distractions

2.5.2 Subject's Lateral Velocity Analysis of Variance

The second analysis of this study involves the lateral position of the vehicle with respect to the center of the traveled lane. Using the lane position data and differentiating the data with respect to time, we obtained the lateral velocity of the simulated automobile to capture swerving movement intensity during the groups individual driving performances. The group lateral velocity mean values reported in the descriptives tables of each section was computed as the absolute value summation of the incremental lateral velocity. It should be noted that the non-random sampling and lack of common dispersion do not meet the assumptions for Analysis of Variance testing. A randomization test would be more appropriate to fit the given data. Table 16 displays the results of the Section A calculated lateral velocity mean differences between the control group, phone group, and texting group. We report significant differences between the groups with an F-test value = 7.918 (p-value=0.000). The Bonferroni Post-Hoc Test was used to determine which groups differed in average lateral velocity. The text messaging participants exhibited the most erratic lateral velocities averaging nearly 2.5 meters per second higher velocities compared to the non-distracted and phone groups.

Table 16 Section A : Lateral Velocity Analysis of Variance

Section A : Descriptives			
	N	Mean (m/s)	Std. Deviation
1.00 (No Distraction)	16	1.585	0.868
2.00 (No Distraction)	16	1.372	0.578
3.00 (Phone Conversation)	16	1.817	1.189
4.00 (Text Messaging)	16	4.083	3.210
Total	64	2.214	2.063
Model Fixed Effects			1.789

Section A : ANOVA				
	Sum of Squares	df	F	Sig.
Between Groups	76.068	3	7.918	0.000
Within Groups	192.13	60		
Total	268.198	63		

Section A : Dependent Variable Bonferroni Multiple Comparisons					
(I) V1	(J) V1	Mean Difference (I-J)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
1	2	0.213	1.000	-1.514	1.939
	3	-0.232	1.000	-1.958	1.495
	4*	-2.497*	0.001	-4.224	-0.771
2	1	-0.213	1.000	-1.939	1.514
	3	-0.444	1.000	-2.171	1.282
	4*	-2.710*	0.000	-4.437	-0.984
3	1	0.232	1.000	-1.495	1.958
	2	0.444	1.000	-1.282	2.171
	4*	-2.266*	0.004	-3.992	-0.540
4	1*	2.497*	0.001	0.771	4.224
	2*	2.711*	0.000	0.984	4.437
	3*	2.266*	0.004	0.54	3.992

*The mean difference is significant at the 0.05 level.

Table 17 displays Section B analysis of variance that nearly proved significant difference between the groups' lateral velocities (F-Test = 4.062, p-value = 0.011). The results of the Bonferroni test prove that the text messaging group of drivers shows evidence of abnormal swerving behavior when traversing the straight stretch of roadway with the 95% confidence interval not bounding zero. Texting participants averaged a lateral velocity approximately 1 m/sec greater than their study counterparts.

The final section of the testing procedure, Table 18, produced comparable results with the previous sections, with significant results. The analysis of variance proved differences among the lateral velocities between groups, however, the Bonferroni multiple comparisons only revealed one pair of differences. The text messaging subjects' lateral velocity proved significantly higher than one of the undistracted, baseline groups. It should be noted that on average the text messaging subjects' lateral velocity was calculated higher than the other non-distracted or phone groups insignificantly.

Table 17 Section B : Lateral Velocity Analysis of Variance

Section B : Descriptives	N	Mean (m/s)	Std. Deviation
1.00 (No Distraction)	16	0.883	0.668
2.00 (No Distraction)	16	0.884	0.845
3.00 (Phone Conversation)	16	0.795	0.505
4.00 (Text Messaging)	16	1.898	1.704
Total	64	1.115	1.113
Model Fixed Effects			1.039

Section B : ANOVA	Sum of Squares	df	F	Sig.
Between Groups	13.167	3	4.062	0.011
Within Groups	64.826	60		
Total	77.993	63		

Section B : Dependent Variable Bonferroni Multiple Comparisons

(I) V1	(J) V1	Mean Difference (I-J)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
1	2	-0.001	1.000	-1.003	1.002
	3	0.088	1.000	-0.914	1.091
	4*	-1.014*	0.046	-2.018	-0.012
2	1	0.001	1.000	-1.002	1.003
	3	0.089	1.000	-0.914	1.092
	4*	-1.014*	0.046	-2.017	-0.012
3	1	-0.088	1.000	-1.091	0.914
	2	-0.089	1.000	-1.092	0.914
	4*	-1.103*	0.023	-2.106	-0.101
4	1*	1.014*	0.046	0.012	2.018
	2*	1.014*	0.046	0.012	2.017
	3*	1.103*	0.023	0.101	2.105

*The mean difference is significant at the 0.05 level.

Table 18 Section C : Lateral Velocity Analysis of Variance

Section C : Descriptives			
	N	Mean (m/s)	Std. Deviation
1.00 (No Distraction)	16	2.012	1.208
2.00 (No Distraction)	16	1.164	0.776
3.00 (Phone Conversation)	16	1.234	0.963
4.00 (Text Messaging)	16	0.749	0.752
Total	64	1.290	1.029
Model Fixed Effects			0.943

Section C : ANOVA				
	Sum of Squares	df	F	Sig.
Between Groups	13.344	3	5.006	0.004
Within Groups	53.316	60		
Total	66.66	63		

Section C : Dependent Variable Bonferroni Multiple Comparisons					
(I) V1	(J) V1	Mean Difference (I-J)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
1	2	0.848	0.081	-0.061	1.758
	3	0.779	0.137	-0.131	1.688
	4*	1.263*	0.002	0.354	2.173
2	1	-0.848	0.081	-1.758	0.061
	3	-0.070	1.000	-0.979	0.839
	4	0.415	1.000	-0.494	1.325
3	1	-0.779	0.137	-1.688	0.131
	2	0.070	1.000	-0.839	0.979
	4	0.485	0.903	-0.424	1.395
4	1*	-1.263*	0.002	-2.173	-0.354
	2	-0.415	1.000	-1.325	0.494
	3	-0.485	0.903	-1.394	0.424

*The mean difference is significant at the 0.05 level.

2.6 Conclusions

The mean comparisons among the independent variables: velocity, steer, accel, and brake across three separate test sections did not reveal significant differences between any of the four groups. Although it was reported that the driving task was more difficult when texting than talking on the phone or driving undistracted, no representative distinctions could be established among the groups when analyzing these inputs. When viewing the trends of the velocity data, it can be seen that the group tasked with talking on the phone while navigating the course drove slightly slower than the other groups: non distracted and texting. This finding coincides with other research claiming phone conversations have been linked with reduced driving speeds from excess mental workload [61, 62]. It is believed that the amount of data collected was inconsequential to capture larger speed variations for extended phone conversations or texting. The lack of determining differences in driver inputs could also be resultant of insufficient warm-up exposure. Increasing the driver mental workload would have been beneficial in this study. Besides using the phone, the subject's driving task consisting of navigation, guidance, and control was minimal[63]. Asking the subjects to memorize a map to increase the navigation driving task and creating more interaction with other vehicles to increase the guidance task would increase the overall driving load further deteriorating the control performance. It is recommended for future research to ensure all subjects have fully acclimated to the simulator and that data collection sections are generous enough to capture substantial differences among populations of interest. It was observed that poor driving performance among the non-distracted teen population could also be a factor in the lack of significant differences. This hypothesis agrees with previous research comparing driving tasks between novice teens and experienced adults[64, 65].

The results of the lateral velocity group comparisons agree with intuition when evaluating the texting drivers and conclude that the lateral velocity increases when attempting to send text messages. These results concur with other research claiming that dialing a phone, similar to sending a text message, biomechanically interferes with steering and affects lateral vehicle control[66, 67]. The apparent reduction in lateral velocity by the phone conversation group during Section B has also been observed in a similar study[57]. A randomization test is more appropriate for this testing, because the lack of a random sample and common dispersion do not meet the Analysis of Variance assumptions. Through this research effort it is hoped that the scientific community can better understand and expound on the driver behavior knowledge needed to improve safety for the rural teen driver population.

Appendix A: Institutional Review Board Research Consent Form

INFORMED CONSENT STATEMENT

Investigation of driving behaviors on rural highways with driving simulator

As a participant, you are invited to participate in a research study. The purpose of this research is to utilize the DriveSafety DS-600 model driving simulator located in Perkins Hall room 72 to conduct tests of participants' driving performance. You will be tested to analyze the effects of different factors to your driving performance. The objective of this study is to explore the effects of driving behaviors such as speed selection and lane position control on rural/suburban highways while distracted with an ordinary portable electronic device such as a cellular telephone. The results of the study will provide useful information for transportation engineers as distracted driving evolves into a greater nationwide issue.

INFORMATION ABOUT PARTICIPANTS' INVOLVEMENT IN THE STUDY

You will be asked to read and sign this consent form. You will then be asked your age and relevant driving experience for proper data collection. After information is collected, you will be asked to open the door of the car cab and sit down in the seat of the simulator cab. Next, you will be asked to drive a 3 minute practice session in order to familiarize yourself with the simulated driving environment. Then, you will be asked to complete one 3 minute session in the University's driving simulator. Each session will be comprised of a virtual driving course developed by the researchers. The total amount of time required of you as a participant is 6 minutes.

RISKS

The only potential risk to you during testing could be motion sickness due to the conflicting body queues of visual movement without actual body movement. You can quit the test anytime during the test without penalty if you feel uncomfortable or simply do not wish to continue.

BENEFITS

In transportation research, the use of driving simulators to conduct research is growing rapidly due to the declining costs of high quality technology. The results of the study will provide useful references for highway engineers as distracted driving issues are deliberated nationwide.

CONFIDENTIALITY

All information in the study records will be kept confidential. Data will be stored securely and will be made available only to persons conducting the study. No reference will be made in oral or written reports which could link participants to the study.

CONTACT INFORMATION

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study,) you may contact the researcher, Ryan Overton, at 72 Perkins Hall and (865) 585-4004. If you have questions about your rights as a participant, contact the Office of Research Compliance Officer at (865) 974-3466.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read the above information. I have received a copy of this form. I agree to participate in this study.

Investigator's signature

Date

Participant's signature

Date

CHAPTER III

GAP ACCEPTANCE INTERSECTION SIGHT DISTANCE DESIGN

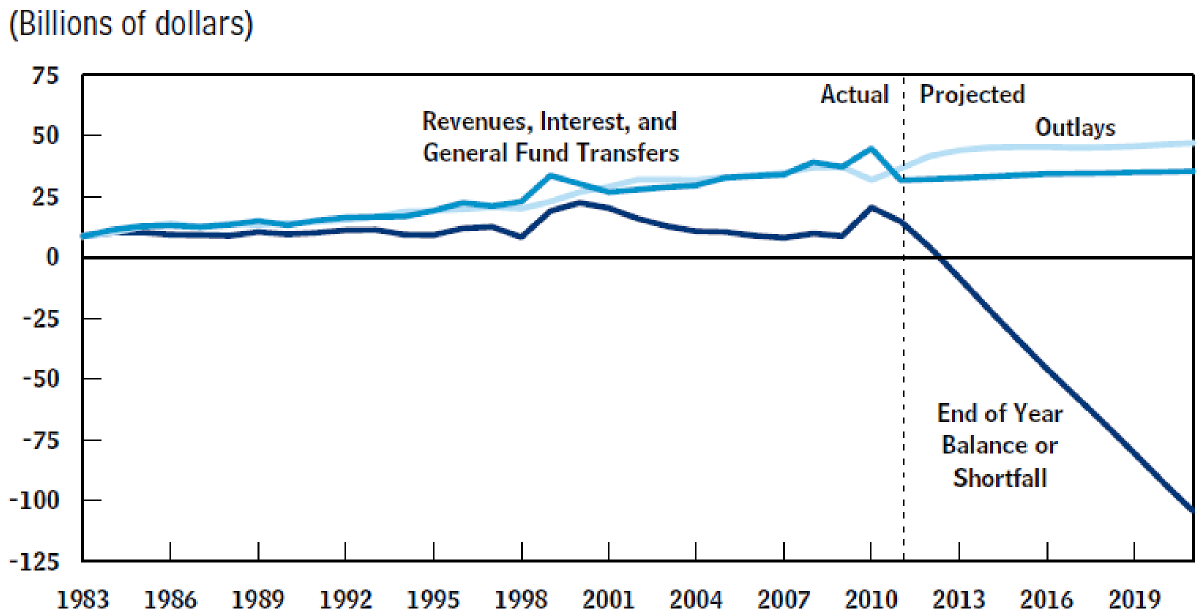
Abstract

Intersection Sight Distance remains a topic of interest as intersections continue to experience millions of crashes and thousands of fatalities each year. With cash strapped budgets, the desired level of safety at intersections is difficult to fund based on traditional AASHTO design standards. This research effort utilized a high-fidelity driving simulator to monitor gap acceptance behavior of our evolving motorist population in hopes of developing new gap acceptance values for context sensitive intersection sight distance design. However, the results contradict the hypothesis and found drivers are accepting larger gaps in traffic than current standards recommend. The gap acceptance results validate the AASHTO design standards acceptance of using the same gap in traffic for both the straight and right turn movements. The gap acceptance interval for left turning vehicles was found to be 7.7 seconds. While the straight and right turning movement gap acceptance was 8.2 seconds and 8.3 seconds, respectively. These results are slightly higher than the current AASHTO 7.5 second left movement gap acceptance and 6.5 seconds straight and right turn gap acceptance. Drivers over the age of 55 exceeded the current standards gap acceptance by 48% by comfortably accepting gaps in traffic greater than 9.5 seconds. Analysis was performed on changing gap acceptance behavior during the test procedure and revealed no significant differences could be found. Finally, comparisons of the calculated gap acceptance percentiles were performed with the current AASHTO recommended values. Nearly 50% of the sample group accepted the recommended 7.5 second gap turning left. Approximately 10% of the participants proceeding straight or turning right at the intersections accepted the recommended 6.5 second gaps

3.1 Introduction

The United States Department of Transportation recently reported a decrease of fatal crashes by 9.9 percent from 2008 to 2009. However, great efforts are still needed to further reduce the amount of crashes on our road networks. A point of interest that accounts for as much as 54 percent of all crashes is intersections. Intersection safety is recognized as a high-priority research area by multiple national research institutes and organizations including: AASHTO, FHWA, TRB, ITE, AAA, STC and many state DOTs. NHTSA's Traffic Safety Facts 2009 compiles motor vehicle crash data from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) and reported nearly 6,800 intersection traffic fatalities. It was also found that a staggering 2.2 million crashes occurred at intersections in the United States[68]. Numerous intersection safety factors contribute to the operation and safety of intersections, including the provision of intersection sight distance (ISD) that plays an integral part in ensuring users safe, yet efficient intersection operation. Adequate ISD should be provided at all intersections to minimize potential conflicts and reduce the likelihood of a crash occurring between vehicles vying to traverse the same facility. The problem with insufficient sight distance is it does not afford the driver ample time for reacting to potential conflicts or hazards. As a result, the likelihood of a crash at such an intersection can be elevated, sometimes significantly.

Improving the safety of our roadways require extensive funding from the design phase until construction is complete. With a sharp downturn in the national economy and failed policies to ensure future funding for transportation projects, each federally funded organization is financially impoverished and only provides funding for the highest priority projects. Figure 14 highlights projections shown that the Highway Trust Fund, the major source of income for transportation funding, will be nearly $100 billion in the red by 2021 [69] . Predicting less available funding for future projects due to increased national debt and unpredictable political agendas, research should be focused on providing innovative solutions at economic prices while maintaining the betterment of human welfare. Previous design standards are full of safe-guards and factors of safety to ensure the highest possible protection for transportation users, however, stronger degrees of safety require higher price tags. With advancements in technology and changes in driving behavior, a reevaluation of the current standards is imperative to sustain sufficient infrastructure at the most economical price. Technology will allow researchers to accurately condense the standards on engineering factors of safety to economically optimize outdated intersection standards.



Source: Congressional Budget Office.

Note: Under current law, the Highway Trust Fund cannot incur negative balances. The negative balances shown above illustrate the projected inability of the fund to pay obligations as they are incurred by the states. If the Highway Trust Fund was unable to meet its obligations in a timely manner, spending on programs financed by the fund could continue more slowly, to keep pace with tax collections. The Department of Transportation has stated that if the fund faced a shortfall, it would ration the amounts it reimburses to states in order to maintain a positive balance in the fund.

Figure 14 Status of the Highway Account of the Highway Trust Fund[69].

3.2 Literature Review

AASHTO's monolith on *A Policy of Geometric Design of Highways and Streets*, often referred to as "AASHTO Green Book," has long recognized the safety concerns of restricted intersection sight distance. It identified six scenarios; see below, corresponding to various intersection controls and maneuvers that may have ISD issues.

- Case A - Intersections with no control;
- Case B - Intersections with Stop control on the minor road;
  - B1 - Left turns from the minor road;
  - B2 - Right turns from the minor road;
  - B3 - Crossing maneuver from the minor road;
- Case C - Intersections with Yield control on the minor road;
  - C1 - Crossing maneuver from the minor road;
  - C2 - Left or right turns from the minor road;
- Case D - Intersections with traffic signal control;
- Case E - Intersections with all-way Stop control;
- Case F - Left turns from a major road.

Green Book's procedures for determining required ISD are based on the time gap acceptances methodology; we will only consider passenger cars in this study[70].

$$\textbf{ISD} = \mathbf{1.47}\ \mathbf{V_{major}}\ \mathbf{t_g}$$

ISD = Intersection Sight Distance
V_{major} = Design Speed (mph) – posted speed limit + 10 mph
t_g = time gap for major road

t_g = 7.5 passenger car (utilize for all cases except where substantial volumes of heavy vehicles enter the major road)

For this study, consideration of Case B – Intersections with Stop control on the minor road will be considered. The procedure used to formulate this equation is simplistic in comparison with the actual operation situations in the real world and have the following shortcomings:

1. The gap acceptance data used for determining critical gaps assumes the stream of traffic will, in the most extreme condition, reduce their operating speed 15% to accommodate the vehicle entering the roadway. This assumption is based on early driving behavior and has not been updated to capture changes in driving behavior.
2. The critical gap procedure per Green Book only reflects the behavior of 50% of the drivers. The other 50%, who do not consider the established critical gap acceptable, are likely to be conservative and/or older drivers. The population of the latter has been on the rise, which exasperates the ISD problem.
3. The required ISD procedure is based on road design speed, which is generally correlated with the 85th percentile operation speed. Thus, the minimum ISD standard is unlikely to meet the actual required sight distance of 15% of the drivers. Furthermore, it is commonly observed that a significant portion of motorists tends to exceed the posted speed limits, which makes the ISD problem more serious.

In reality, it is not unusual to find intersections with inadequate sight distances due to complex geometric conditions or even overgrowth of vegetation. State and local governments continue to trim budgets and this reduces available funding for maintenance, mowing, and cleaning the clear zones of roadways. Therefore, there is a research need to assess the adequacy of AASHTO ISD design standards through comprehensive and thorough analyses of changes in driving behaviors. AASHTO recognized the needs to allow engineers to exercise “engineering judgment” in regards to intersection sight distance with their publication of, “A Guide for Achieving Flexibility in Highway Design.” This allows designers flexibility in adjusting key parameters for context sensitive solutions in the ISD design, including approach design speed which has already been argued to be flawed[71].

With numerous safety shortfalls looming at nearly every intersection, intersection safety has been a heavily studied topic in the past. Gap Acceptance Models have been formulated using observed traffic flows and driver behaviors at intersections that are subjectively considered safe to calculate accepted gaps by vehicles. Harwood concluded that observed subjects required a gap of 6 seconds to enter the mainstream traffic flow[72].

Gattis reviewed several methods for modeling critical gap acceptance for atypical intersections and found 7.8 second gap for the predominant traffic stream approaching from the right[73]. Moussa utilized an Augmented Reality Vehicle System to determine that most drivers will accept a gap in traffic between 4 and 9 seconds for left-turn maneuver at two-way stop-controlled “TWSC” intersection[74]. Yan et al. performed a left turn gap acceptance simulator study and found that older drivers and female drivers are more conservative in accepting gaps in traffic streams than their counterparts[75]. Harwood arguably produced the most influential article of research regarding gap acceptance with his work that produced the currently accepted AASHTO intersection sight distance policy[76]. This research was considered exceptional following its publication in 1999; however, technological advancements have improved the capacity in which we can analyze driving behaviors over traditional observation studies such as Harwood's. With the use of highly precise driving simulators, in depth analyze of driving characteristics can give researchers invaluable information regarding attitudes towards risky driving behavior. It is also of interest to investigate how improved performance of everyday vehicles has transformed driving behavior.

3.3 Purpose

The purpose of this research is to expound on the current ISD guidelines using driver behavior analysis as opposed to traditional design speed standards. Results will be reported from drivers' gap acceptance behavior to better understand risk perception and safety threshold. Understanding driving perception and judgment through quantitative analysis will allow for scientific revisions or validation to the current ISD standards. Special emphasis will be placed on maintaining safety, but formulating standards that are economically advantageous in context sensitive situations is ideal. These standards will be developed with the understanding that tradeoffs are required to balance the thin line of safety and frugality. The hypothesis in this research is that: *current ISD standards are outdated and do not consider evolving driving behavior and technological advances that may result in increased driver confidence and riskier behavior by accepting smaller* *gaps in traffic. New gap acceptance values will be determined to gauge evolving risk thresholds and avoid fallacies of traditional design. It is desired that the new, economically optimized ISD recommendations be beneficial in providing pragmatic, context sensitive ISD solutions.*

3.4 Methodology

3.4.1 Apparatus

Tests for this study were conducted using the DriveSafety DS-607c, which consists of 5 aspheric mirror technology projectors wrapping 300° around a Ford Focus cab, where the test subject is seated. The screen projection has a resolution 1024 x 768 pixel each. Real-time data collection will be sampled at a rate of 20 Hz. A digital audio system is functional in the cab with four speakers to allow for audio commands and other sounds in the virtual environment. The interior of the vehicle is an exact replica of a Ford Focus featuring: windshield, driver and passenger seats, center console, radio/CD player, full functioning instrument panel. In addition, the driver has rear views through a LCD rear view mirror and two LCD side view mirrors.

3.4.2 Participants

50 volunteers participated in this effort and every subject held a valid driver’s license with at least 2 years of driving experience. The gender split consisted of 31 females and 19 male subjects with an average age of 40 years old (STD = 24.6). Every participant was required to read, agree, and adhere to the consent form approved by the University of Tennessee’s Institutional Review Board.

3.4.3 Scenario Design & Research Approach

A series of intersections were designed in a street network for subjects to drive during simulation. Ambient traffic was provided on the streets, but selected intersections for gap accepted analysis contained specifically designed traffic for monitoring. The test intersections were randomly chosen to obtain an independent sample. Two driving tests were given that lasted approximately 5 to 7 minutes each. Approaching the select test sights, a series of cars approached the intersection on the perpendicular street with predefined gaps between each vehicle and unlimited sight distance. The gaps in the traffic gradually increased from 1 second up to 12 seconds with the vehicles traveling 45 miles per hour. At some point the participant chose to accept a gap in the traffic stream and proceeded left, right, or straight depending on the learned map provided before driving. Each turning movement was analyzed separately, due to the perceived risk of crossing traffic. With the numerous types of intersections and available combinations of conflicting vehicles, this study only analyzed vehicles approaching the subject from the left side of the perpendicular street.

Through the gap acceptance procedure valuable information was gained testing assumptions regarding risk taking behavior among certain groups, including: young drivers, elderly drivers, and male/female drivers. New gap acceptance values are reported to revise the t_g value in the ISD equation. The short leg of the sight triangle, measurement *a* in Figure 16, is currently recommended to be 14 feet from the edge of traveled way. Future research will analyze the stopping location of drivers relative to the travel way.

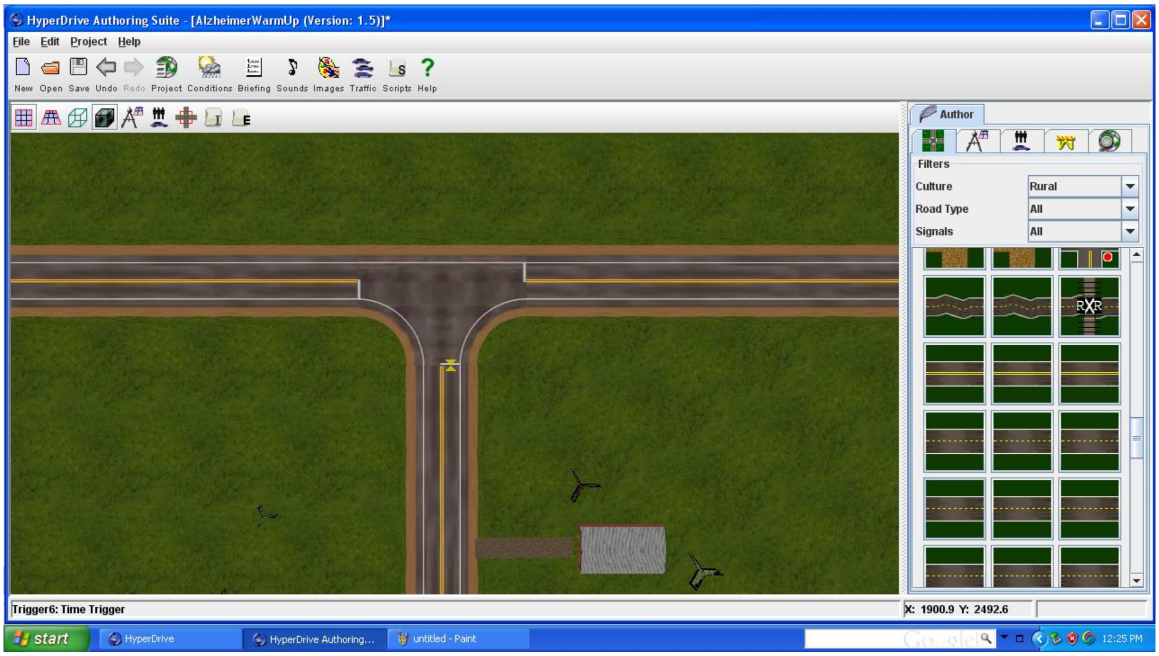


Figure 15 Plan View of Intersection in Virtual Scenario

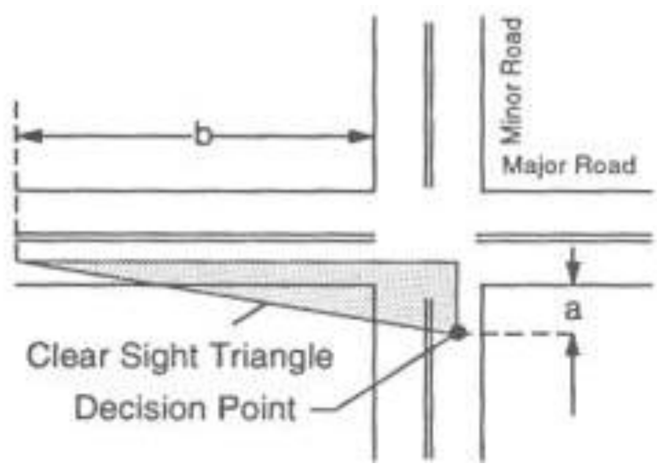


Figure 16 Departure Sight Triangle for Traffic Approaching from the Left

The variables analyzed in this research include the gap accepted by the subjects performing a straight movement, right turn movement, and left turn movement at an intersection. Differences between the gaps accepted for each individual are also used to avoid statistical fallacies. D1 refers to the difference between the gap accepted performing the straight movement versus the right movement. D2 is the calculated difference between the straight movement gap accepted and the left movement gap accepted. D3 is the right turn movement minus the left turn movement while accepting a gap.

3.4.4 Data Analysis

The paired t-test as a randomization test was performed on the paired differences between the gaps accepted among the movements. The paired differences must be used instead of the actual gap accepted value, because pairing the individual subject's data removes the level of dependence within the observation. A bootstrap t-test was also performed to help estimate the errors that result from using a sample in place of the population and to visualize the differences between our gap acceptance behavior. In a similar manner, regression analysis is shown to assist in visualizing the effects of age and sex on the gap behavior. The bootstrap and regression model should be viewed with caution as the data does not meet all of the requirements to fully support the use of these tests.

A Hotelling's One-Sample t-test randomization test was performed to evaluate if gaps accepted by the sample group change between the first series of test intersections and the last series of test intersections. The main advantage and reason for performing the

Hotelling's test to discover differences between samples is the lack of needed normality, the lack of a truly random sample, and equal-variance assumptions in order to provide probability levels based on randomization tests[44, 45]. The accepted gaps of each population were hypothesis tested to determine whether risk perception change as exposure time increases and according to independent variables. The null hypothesis (H_o) is that no differences among the gaps accepted can be determined between the two groups in question[46].

H_o: There are no differences between accepted gaps

H_a: There are significant differences between accepted gaps

Only one response variable is chosen on the comparison between movements, therefore the analysis results come from the reported Student's t distribution. Due to the non-normality of the individual variable movement data, a Modified Levene Equal-Variance Test shows no difference in variance between any pair of the groups. The Randomization Test Probability Level based on 10000 Monte Carlo samples will be used due to the data closely following a few sets of unique values. The data is not binary; however we desire to avoid conflicts that may arise from reporting the parametric test significance levels.

The experiment wide error rate was set at .05 significance level and obtaining a total of 3 comparisons for each testing procedure of the gap accept data, the individual comparisons significance level is calculated.

$$\boldsymbol{\alpha_E = 1 - (1 - \alpha_I)^M}$$
$$\boldsymbol{.05 = 1 - (1 - \alpha_I)^3}$$
$$\boldsymbol{\sqrt[3]{.95} = \sqrt[3]{(1 - \alpha_I)^3}}$$
$$\boldsymbol{1 - \alpha_I = \sqrt[3]{.95}}$$
$$\boldsymbol{\alpha_I = .017}$$

Therefore, an individually controlled error rate $\boldsymbol{\alpha_I}$ =.017 will ensure that the experiment wide error rate $\boldsymbol{\alpha_E} \leq 0.05$.

3.5 Results

3.5.1 Gap Acceptance Paired Movement Comparison

On average the test subjects accepted an 8.17 second gap in the traffic flow proceeding straight through the intersection. When turning right an 8.29 second gap was accepted and a 7.68 second gap turning left on average. Testing to determine if significant differences exist between these behaviors, a Hotelling’s one pair t-test was performed on the differences between the gaps. As discussed in the statistical analysis section prior, the paired differences are needed for comparison to remove dependence identified by a Person Correlation Matrix Analysis. In essence the subjects will be tested against their own behavior. The subjects accepting small gaps in traffic will not create discrepancies in the results when compared with individuals who on average comfortably accept larger gaps in traffic.

Overviewing our difference variables: d1 = Straight gap – Right gap, d2 = Straight gap – Left gap, and d3 = Right gap – Left gap. Table 19 summarizes the results of the one-sample T^2 randomization tests.

Table 19 Gap Acceptance Differences between Movements

Variable	p-value*	Mean	St.Dev.	5^{th} Percentile	95^{th} Percentile
d1	0.5996	-0.123	1.672	-2	2
d2	0.0148	0.492	1.602	-1	3
d3	0.0006	0.615	1.377	-1	3

*Based on 10000 Monte Carlo Simulation Randomization Test

The straight minus right(d1) gap acceptance comparison did not prove to be significantly different with a p-value = 0.5996. Therefore, we conclude that drivers accept the same gaps in traffic when proceeding straight and turning right. However, we reject the null hypothesis comparing straight minus left(d2) and right minus left(d3) gap acceptance and conclude significant differences exist with p-value = 0.0148 and p-value = 0.0006, respectively. Confidence limits were not reported because we reject normality across all three difference variables and the data is a non-random sample. However, the 5^{th} and 95^{th} percentiles are reported. Bootstrap Confidence Limits were calculated with 3000 samples to estimate and visualize results for a larger group sample. The bootstrap will not reproduce all the relevant characteristics of a population and cannot be used to estimate extreme data points. The data set tested does not meet all of the bootstrap assumptions and should be used as a visual aid to better understand the Hotelling's one-pair randomization t-test results. Figure 17 shows the estimation of finding differences between straight gap acceptance and right gap acceptance behavior. Clearly bounding zero, the estimation agrees with the previous results that no differences can be determined.

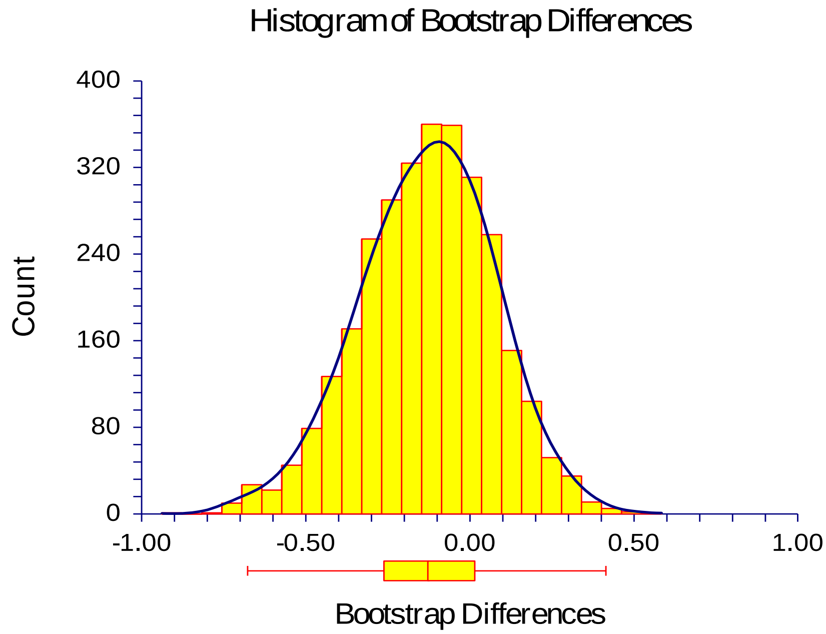


Figure 17 D1 / Straight - Right Gap Bootstrap Estimation

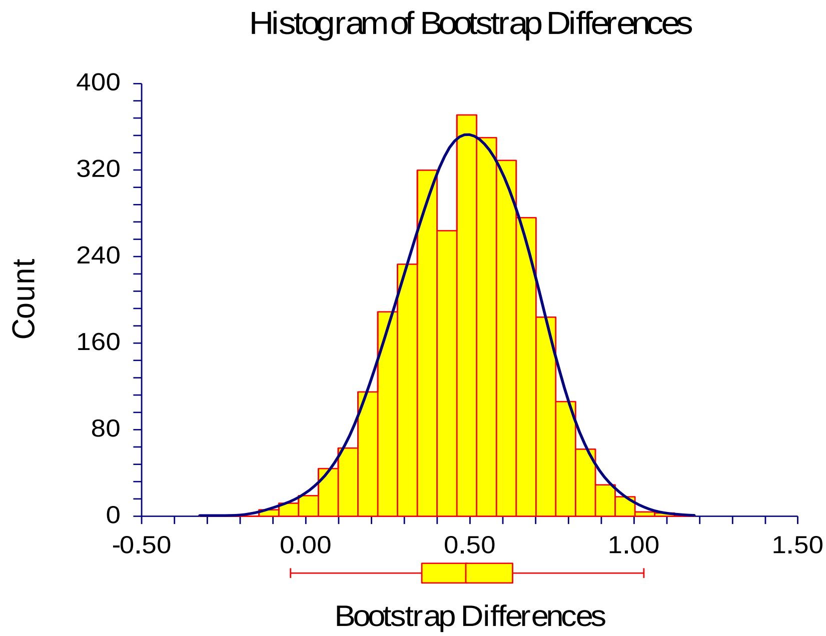


Figure 18 D2 / Straight - Left Gap Bootstrap Estimation

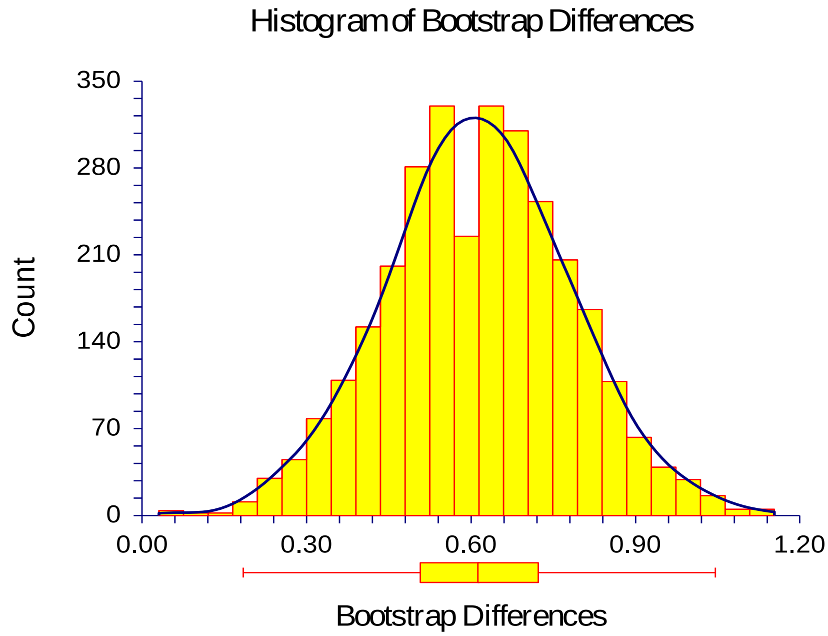


Figure 19 D3 / Right - Left Gap Bootstrap Estimation

Figure 18 shows the estimate that straight gaps accepted will typically be between 0 and 1 second larger than gaps accepted turning left. Similarly, Figure 19 shows that right gaps will be approximately 0.2 seconds to 1.0 second larger than the gaps accepted turning left.

A Randomization T-Test was performed comparing the average gaps accepted between the movements. Table 20 displays the results of the drivers performing the straight, right, and left turning movements and confirms the previous findings that significant differences exist between the straight versus left movement and right versus left movement accepted gaps. The reported average gap accepted is slightly different from the paired gap acceptance results, because additional data points were included in this data series from the participants that did not complete all of the turning movements. These data points were not used in the previous paired analysis.

Table 20 Gap Acceptance Comparison between Movements

		Avg. Accepted Gap			
Age	**Sex**	**Comparison**		**Prob Level**	**Difference**
All	**All**	**Straight**	**Right**	**0.6240**	
		8.43	**8.29**		
All	**All**	**Straight**	**Left**	**0.0040**	**0.75**
		8.43	**7.68**		
All	**All**	**Right**	**Left**	**0.0070**	**0.62**
		8.29	**7.68**		

Woman and men were analyzed in an attempt to reveal a specific population accounting for a majority of the difference between the movements. No significant probability levels are revealed in the male and female movement comparisons, but it is interesting to note that the female straight versus left movement (p=0.027) and right versus left movement (p=0.028) comparisons near the significant alpha. This indicates that the female subjects account for a large portion of the overall significant differences between the straight versus left and right versus left movements.

The effects of age on the gap acceptance behavior were analyzed. The initial comparison divided the population into age groups, 19-34 and over the age of 55. This was concluded after a brief scan of the ages revealed a gap in our sample group between 34 and 56 years of age. When comparing the straight movement gap acceptance, the older drivers on average accepted a straight gap of 9.6 seconds. The 19-34 age group accepted a significantly different (p-value=0.004) straight gap of 8.0 seconds.

3.5.2 Gap Acceptance Regression Analysis

A regression model can be used to show the relationship between a variable introduced into the analysis with the predictor variable. For this research, a model was desired to predict gap acceptance based on the subject's age and sex. Multiple regression analysis models were formed predicting the straight, right, and left gap acceptance behavior. However, the dependent structure of the non-random sample proved not to be a good predictor of performance. Regression models were formulated for the differences between the gap movements. This was performed to pair the data and remove the level of dependence within the observations. Once again, no models produced a R^2 greater than 0.024. Finally, a robust multiple regressions using Tukey's biweight was performed to down weight the outliers within the data set which were influencing the previous models. Analyzing the d3 variable, right gap accepted minus left gap accepted, a model was produced with a R^2 value equal to 0.14 and the coefficients are significant at the 0.01 level. Because there were only two predictor variables, age and sex, one interaction independent variable was included in the model. The difference between the right and left movement gap accepted = -0.711 + 0.0399*age + 1.50*sex + -0.0423*age*sex. The sex independent variable was dichotomously coded as male equal to zero and female equal to one. From this regression model we can see that female drivers and older drivers are more likely to accept larger gaps in traffic turning right than turning left.

3.5.3 Gap Acceptance Comparing 1st Intersections and 2nd Intersections

Comparisons were made to determine if gap acceptances differ as exposure time increases in the simulator. New variables Ds, Dr, and Dl were created for comparing the individual's paired data. Ds was formed by subtracting the initial straight movement gap accepted from the latter straight movement gap accepted. In a similar manner, Dr was created using the right turn gap accepted and Dl for the left turn gap accepted. A Hotelling's One-Sample T^2 revealed no significant differences between the first intersections and the last intersection gap behavior (p-value=0.445). A paired t-test as a randomization test calculated the individual significance of each variable. Ds was the closest variable approaching significance with a p-value = 0.103. Dr and Dl produced significance values of 0.473 and 0.9533.

A robust regression analysis was performed to remove outliers potentially affecting the results. No valid models were produced, because we fail to reject the null hypothesis and determine no differences between the coefficients.

Although no differences were found attempting to determine gap acceptance learning. More paired data is necessary to validate this finding, especially to look at age and gender categories.

3.5.4 Gap Acceptance Percentiles

For comparison with the current AASHTO recommended gap acceptance intersection sight distance design values, percentiles were computed to estimate what percentage of our sample group meets these criteria. The percentiles are computed to analyze the data without visualizing outliers. Figure 20 displays the percentage of individuals that accept a particular gap in the traffic. With the current standard gaps displayed on the figure, estimations can be conceived as to what percentage of the group comfortably accepts these gaps in traffic. Nearly 50% of the sample group accepted the left turning gap on par with the current AASHTO recommendation of 7.5 seconds. However, approximately 10% of the group accepted the 6.5 second straight and right turn design gap.

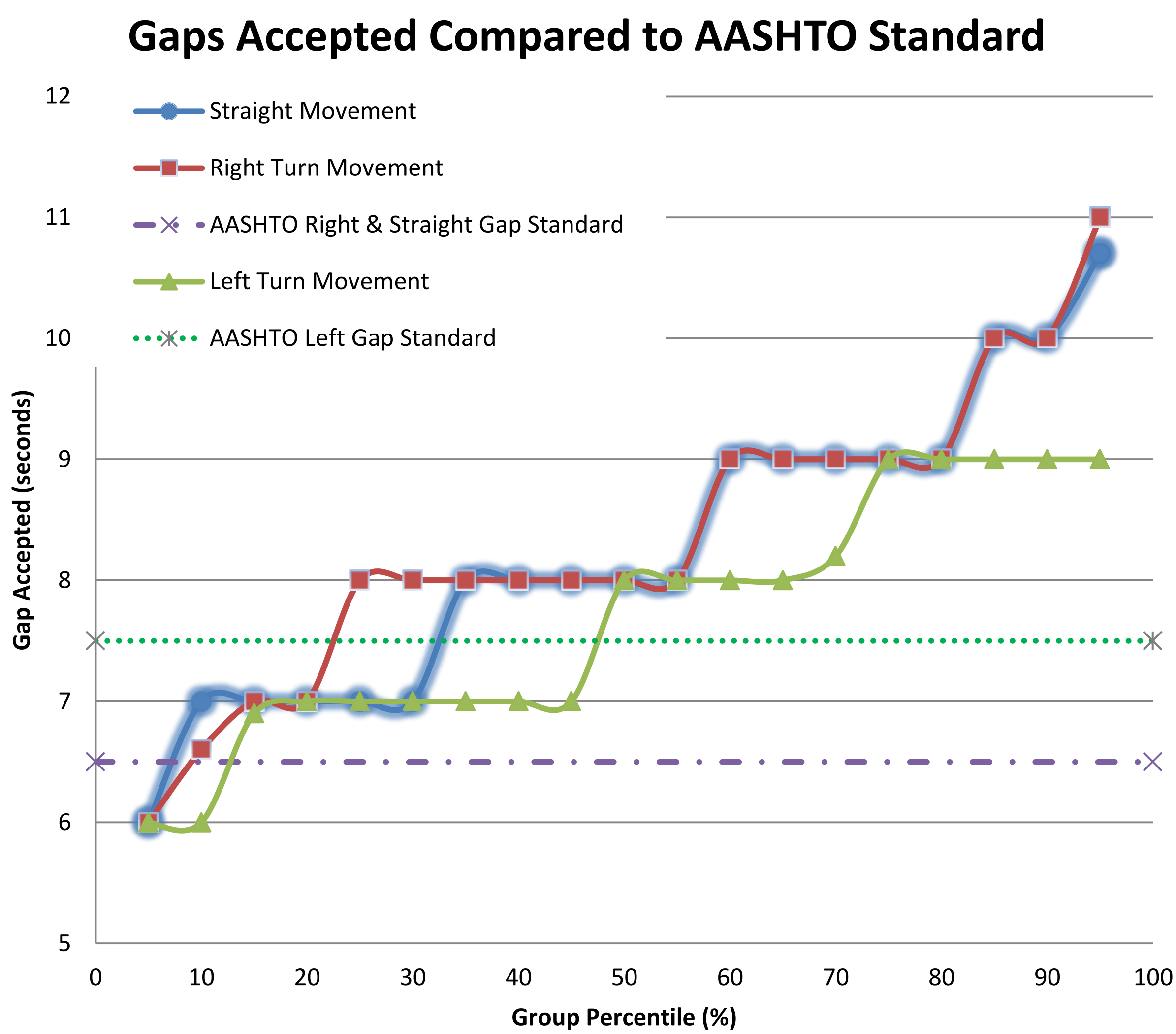


Figure 20 Gap Acceptance Comparison with AASHTO Recommendation

3.6 Conclusions

The gap acceptance results validate the AASHTO design standards acceptance of using the same gap in traffic for both the straight and right turn movements. Table 19 and Table 20 identified significant differences between straight versus left and right versus left movement. Figure 9-54 in the AASHTO green book shows the gap used for calculating intersection sight distance for left turning vehicles as 7.5 seconds[70]. Using paired gap acceptance data, we calculate a 7.7 second gap acceptance for left turning vehicles. The straight movement gap accepted was 8.2 seconds and the right turn movement gap acceptance was 8.3 seconds. The right and straight gaps exceed the AASHTO recommendation according to Figure 9-57 for cases B2 and B3 of 6.5 second gap[70]. These results contradict the original hypothesis that motorists are negatively evolving into hazardous drivers. Perhaps an alternative hypothesis claiming increased knowledge and emphasis on driver safety are positively impacting drivers; resulting in less risky driving behavior. The analogous results between the gaps accepted in this fixed-base high fidelity driving simulator and the current standards based on observed traffic operations is a strong testament to the validity of simulator use as an accurate and useful research tool. Population breakdowns reveal that women account for a large portion of the differences between the straight versus left and right versus left comparison. For intersection design with a high population of older drivers, this study revealed that drivers over the age of 55 comfortably accept gaps in traffic larger than 9.6 seconds. Particular emphasis should be placed on the 48% gap accepted increase over the current AASHTO design gap acceptance standard with an expected 80 million baby boomers traversing the roads by 2030[77].

Attempting to determine if a learning behavior of gap acceptance was present between the first three intersections and the latter three intersections, no significant differences were found. However, more paired data would be beneficial for further analysis into the study of whether individuals change the gaps they choose as simulator exposure time increases.

Finally, a percentile plot was produced to compare the gap acceptance with the AASHTO recommended value. Nearly 50% of the sample group accepted the recommended 7.5 second gap turning left, while approximately 10% of the participants proceeding straight or turning right at the intersections accepted the recommended 6.5 second gaps. Although this research effort failed to produce newly discovered gap acceptance behavior results for context sensitive intersection sight distance design, the results can be used to uphold the validity of our current AASHTO standards. Future research includes increasing the older driver test population for different movement comparisons and additional gap acceptance test intersections with a variety of speeds. Further data collection will validate the claim that drivers are reducing risky driving behavior by comfortably accepting larger gaps in the traffic stream.

Appendix A: Institutional Review Board Research Consent Form

INFORMED CONSENT STATEMENT

Effects of Intersection Sight Distance on Gap Acceptance

As a participant, you are invited to participate in a research study. The purpose of this research is to utilize the DriveSafety DS-600 model driving simulator located in Perkins Hall room 72 to conduct tests of participants' driving performance. You will be tested to analyze the effects of different factors on your driving performance. The objective of this study is explore gap acceptance behavior at intersections designed according to AASHTO design standards and intersections that do not meet the standards.

INFORMATION ABOUT PARTICIPANTS' INVOLVEMENT IN THE STUDY

You will be asked to read and sign this consent form. You will then be asked your age and relevant driving experience for proper data collection. After information is collected, you will be asked to open the door of the car cab and sit down in the seat of the simulator cab. Next, you will be asked to drive an 8 minute practice session in order to familiarize yourself with the simulated driving environment. Then, you will be asked to complete a series of intersection scenarios totaling 30-45 minutes in the University's driving simulator. Each session will be comprised of a virtual driving course developed by the researchers. The total amount of time required of you as a participant is approximately an hour. Breaks in the testing will be permitted at your discretion.

RISKS

The only potential risk to you during testing could be motion sickness due to the conflicting body queues of visual movement without actual body movement. You can quit the test anytime during the test without penalty if you feel uncomfortable or simply do not wish to continue.

BENEFITS

In transportation research, the use of driving simulators to conduct research is growing rapidly due to the declining costs of high quality technology. The results of the study will provide useful guidance in regards to intersection design standards.

CONFIDENTIALITY

All information in the study records will be kept confidential. Data will be stored securely and will be made available only to persons conducting the study. No reference will be made in oral or written reports which could link participants to the study.

CONTACT INFORMATION

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study,) you may contact the researcher, Ryan Overton, at 72 Perkins Hall and (865) 585-4004. If you have questions about your rights as a participant, contact the Office of Research Compliance Officer at (865) 974-3466.

PARTICIPATION
Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed.

CONSENT
I have read the above information. I have received a copy of this form. I agree to participate in this study.

Investigator's signature

Date

Participant's signature

Date

CONCLUSION

The aforementioned research efforts were completed with the upmost diligence and respect to all parties involved. Extensive care was taken in each study to ensure all participating test subjects in the driving simulator were comfortable and in optimal condition to perform their tests naturally. Following all Institutional Review Board mandates and guidelines, quality data was extracted and tested to obtain valid and useful information.

Complying with the creed of all professional engineers to dedicate knowledge and skill to the betterment and preservation of human welfare, the following results are intended to improve transportation engineering research and design. With regards to the warm-up analysis study, approximately 65% - 85% of the sample group acclimated to the handling of the vehicle in 6 minutes. These acclimation results will allow researchers to be confident in accurate data collection and subjects to become comfortable testing in a driving simulator. The rural teen driving population has been identified as a critical population in terms of high fatality rates. Driving simulator input analysis revealed distracted driving significantly increases lateral vehicle velocity thus escalating the probability of crashes. Multitasking, such as talking on the phone, reduced the teen driver's abilities to maintain their normal operating speed. Finally, gap acceptance behavior was thoroughly analyzed to formulate new values for improved intersection sight distance design. The current AASHTO gap acceptance design values were found to be less than comfortably accepted in the driving simulator. Nearly 50% of the sample group accepted gaps in the traffic stream of 7.5 seconds when turning left, while only

10% of the participants accepted a 6.5 second gap when proceeding straight or turning right at the intersection.

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VITA

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