THE EFFECT OF SIMULATION ATTRIBUTES ON DRIVER PERCEPTION AND BEHAVIOR

by

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APPROVAL

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ABSTRACT

Transportation systems in today’s world are complex, diverse, and dangerous. Drivers execute many tasks in order to safely and efficiently maneuver their vehicles in these systems. Evaluation of vehicle speed (ego motion) and inter-vehicle distance (egocentric distance) are crucial skills and constant demands while operating a motor vehicle. Common maneuvers such as braking, obstacle avoidance, and overtaking rely heavily on such skills. Driving skills and transportation safety concerns in general have been studied over the years by many research methodologies. One such methodology, the driving simulator, has emerged as a leading research tool to help understand driver behavior and mitigate traffic safety concerns. The overall effectiveness of driving simulation as a research tool is linked to how accurately modern technology can model reality. Therefore determining how valid simulators are in representing reality is a chief concern among researchers, as validity ensures accuracy and credibility of research efforts. Simulation validity is established both physically and behaviorally. The objective of this project was to conduct a driving simulator experiment to examine the perceptual and behavioral effects of various parameters of the simulation deemed relevant from theories of ego motion. Twenty drivers completed speed and following distance perception tasks (absolute production, fixed-increase production, and ratio production) while driving through rural road scenarios that varied in the presentation of motion, field of view, and optic flow. Tasks and dependent variables assessed driver perception of speeds (25-65 MPH) and following distances (150-300 ft) common in everyday driving. The study concluded that field of view (FOV) and optic flow simulation parameters were significant to the perception of absolute speed, with high levels of each parameter (large FOV, high optic flow) resulting in more accurate perception than low levels (small FOV, low optic flow). Also, participants perceived a high level of field of view as significantly more natural than a low level of field of view. The results of this study will add to the existing simulator body of knowledge and will also allow the researchers to quantify the relative importance of simulation parameters as a basis for future behavioral validation of the driving simulator.

CHAPTER 1

INTRODUCTION

The skilled and complex task of driving a vehicle is undertaken by millions of people world-wide every day. In the United States alone, over 200 million drivers traveled nearly three trillion miles in 2006 [1]. During this one-year period, 43,300 people lost their lives in traffic crashes [1]. Traffic safety is not a problem unique to the United States, as more than a million people are killed worldwide every year due to traffic crashes [2]. With a problem of such "staggering magnitude", there is a definite need for "increased systematic understanding and more effective countermeasures" [2].

Many research tools have been developed to help understand and mitigate traffic safety concerns. Simulation has emerged as a leading research tool for exploring human driving behavior. Simulation can take many forms, from simulation software platforms used for modeling traffic flow to driving simulators that are useful both as research and training tools. Driving simulators are typically comprised of a physical vehicle representation and screens or monitors that portray a driving environment. Driving simulators have become increasingly advanced as a result of advances in technology (software, visual resolution and graphics, motion components, sound, etc.). The overall effectiveness of driving simulation as a research tool is linked to how accurately modern technology can model reality. A heightened sense of modeling accuracy in terms of vehicle dynamics, visuals, sound, etc. is generally desired by researchers. As simulation characteristics increase in fidelity (realism), it is expected that driver behavior and response to simulation will also approach real-world behavior.

Determining how valid simulators are in representing reality is a chief concern among simulator researchers, as validity ensures accuracy and credibility of research efforts. One of the main concerns of designers and users of driving simulators is to understand to what extent the control strategies and the decision-making rules used by the drivers in real world situations are transposed with fidelity in simulation conditions. Simulator validation is established both physically (matching simulator dynamics to reality) and behaviorally (driver behavior corresponds in simulator and reality). Once a simulator has been established as "validated", it may be properly used in exploring human factors problems in traffic safety and designing future roadway systems.

This study presents a discussion and literature review of:

- role of driving simulators in human factors research
- importance of simulator validation
- psychological models of perception and ego motion

The purpose of the study is to gain a better understanding of simulator attributes and their affect on driver behavior.

Research Objectives

The objective of this project was to conduct an experiment to examine the perceptual and behavioral effects of various parameters of the simulation (motion, field of view, and level of optic flow) deemed relevant from theories of ego motion. Data will be compared with data from existing research on driver perception and behavior from simulated and real world environments to infer behavioral validation. Upon completion of the study, researchers will have greater understanding of the relevance of various simulation parameters on the fidelity of driver perception and driving behavior. This knowledge will support the cost-effective utilization of the driving simulators (including the suite of driving simulators at WTI) for human factors research or in assisting the community with driving training.

CHAPTER 2

LITERATURE REVIEW

Role of Driving Simulators in Human Factors Research

Simulation was initially developed prior to World War II as a tool for training pilots. Flight simulators were introduced as a method to reduce the operational costs of using actual aircraft in training. Two main approaches were used in developing flight simulators: designing a high-fidelity system that models the real-world as accurately as possible, and designing a simulator as cost-effectively as possible without compromising training effectiveness [3].

Highway research simulators were first developed in the 1950's, with the first highway simulator being operational in the 1960's [3]. Growth in the field of simulation was slow until the late 1960's when advances were made in computers and visual displays [4]. Technology developed by the National Aeronautics and Space Administration (NASA) renewed interest in highway simulation. By 1975 at least sixteen driving simulators were operational in the United States and two driving simulators were operational in Europe [5].

Over the last twenty years driving simulators have become much more common in human factors research due to increases in technological capabilities and decreasing simulation costs. Therefore it is important to better understand simulation usages, capabilities, and the validity of research that is conducted using them.

Automotive simulation research seeks to better understand the relationships (Figure 1) between man, vehicles, and road systems [6].

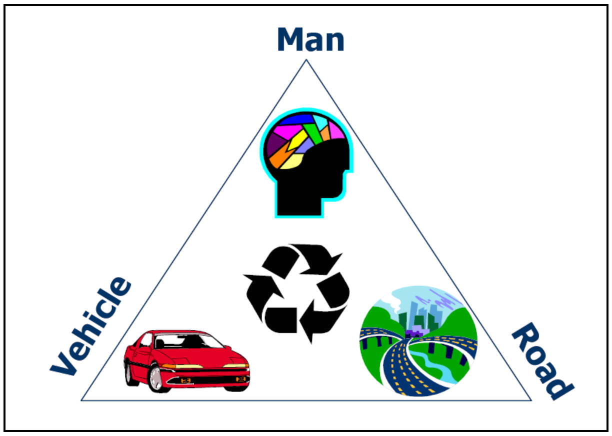

Figure 1. The interactions between the driver, the vehicle, and the road [6]

There are four primary reasons to use driving simulators as a research methodology instead of real world testing:

1. Safety. Some research is too hazardous to be conducted using real vehicles on actual road systems. Examples include studies of collision avoidance systems and studies involving the effects of alcohol on driver behavior. While the use of test tracks can reduce the likelihood of research risk, many scenarios are studied more safely in a simulation environment [7].

2. Equipment Cost. Simulators allow researchers to study driver responses to changes in the vehicle configuration without having to construct a vehicle with those features or characteristics. Advanced parameters can be studied potentially cheaper and faster than through constructing roadworthy systems [7].

3. Experimental Control. A large range of test conditions can be prescribed and applied in a consistent manner through the use of simulation. In the real world the influence of weather on driving conditions is unpredictable and can make testing difficult [7].

4. Exposure. Simulation allows researchers to create and exposure subjects to scenarios at a timing and frequency that is not possible in real world. For example, driver/animal interaction research is hard to conduct in the real world as driver/animal interactions are typically rare. In the simulator however, multiple interaction scenarios can be scripted, thus increasing the exposure of the driver to the desired scenario(s).

Driving simulators can be used for a multitude of applications. Applications related to studying driver behavior include [6]:

- Introduction of new technology and in-car IT-based services
- New road design
- New roads and traffic regulations
- New traffic equipment
- New safety features in vehicles
- Safety effects of drowsiness
- Safety effects of drugs and alcohol

Driving simulators can vary a great deal in their design, cost, and usage. They are typically classified according to their fidelity. Simulation fidelity as defined by the Department of Defense Modeling and Simulation Office is the “accuracy of the simulation representation compared to the real world” [8]. Therefore the higher the simulation fidelity (and associated cost), the more accurately the simulator represents the “real world”. A specific defining criterion for simulator classification does not exist. However, driving simulators are often divided into three basic fidelity categories (Figure 2): low level, mid level, and high level [9]. Low level driving simulators typically use one PC for graphics, traffic, and all simulator controls. They have little or no motion simulation and may contain extra devices such as a steering wheel, brake, and accelerator. As a result, low level simulators are typically cheap to develop and implement, with a purchasing price generally around $20,000 [10]. Mid-level simulators are generally much more expensive ($100,000 to $250,000) than low level simulators [10]. They vary greatly in their design and setup but most mid-level simulators lack a full motion base and extensive field of view. High level driving simulators have full motion base platforms with six degrees of freedom and a large field of view (generally greater than 180 degrees). These simulators are typically found at research facilities and can be expensive to design and implement, with a purchasing price generally starting at around $750,000 [10].

Figure 2. Low [11], Medium [12], and High Fidelity [13] Simulators (left to right)

Importance of Simulator Validation

Modern advanced driving simulators as a tool for human factors research have many advantages over real-world driving research. As discussed above, advantages include safety, equipment cost, experimental control, and exposure. However, possible disadvantages exist, including simulator sickness, accurate replication of physical sensations, and most important, validity [14]. In order to be useful as tools for human factors research, simulators must have adequate validity across multiple parameters and appropriate validity specific to simulator type and intended usage. Two perspectives on validation are typically used for simulation: physical validation and behavioral validation [15].

Physical validation is the physical correspondence of the simulator's components, layout, and dynamics with its real world counterpart. Advanced driving simulators must include a detailed, highly accurate vehicle dynamics simulation to predict the movements of the simulated vehicle in response to both control (driver) and disturbance (environmental) inputs. To show accuracy, the simulator must be thoroughly validated by comparing simulation outputs (vehicle handling, dynamics, etc.) with results obtained from experimental field testing [16].

The process by which the simulation dynamics are coordinated to actual vehicle dynamics is often referred to as "tuning". Methodologies for tuning of simulators can vary in design. Generally speaking, methodology consists of three main phases: (1) experimental data collection, (2) vehicle parameter measurement, and (3) comparisons of simulation predictions with experimental data [16]. During experimental data collection, the actual vehicle is road tested across a wide variety of inputs including steering, braking, and acceleration. Other test factors such as vehicle engine noise and road noise may be measured as well. Once the defining validation criterion has been measured, simulation outputs are compared to experimental outputs. Simulation parameters are then tuned to match real world performance as closely as possible (e.g. steering wheel angle of 15 degrees in real vehicle and corresponding wheel rotation matches that of simulator).

Measurement of actual physical responses (acceleration, braking, steering, etc) is not an error-free exercise due to the inability of the researcher in controlling the systematic error and random errors within the system [16]. Measurement systematic errors can be caused by improper equipment calibration or environmental conditions while random errors are often the result of inherently unpredictable fluctuations in the readings of a measurement or the experimenter's interpretation of the instrumental reading. Validation confidence can be improved by validating more than one vehicle, although multi-vehicle validation is both time consuming and costly to implement.

In accounting for physical validity, researchers often describe their driving simulator, citing its many aspects that reproduce actual real-world driving [14]. As a simulator approaches real driving in terms of vehicle dynamics and the sensory field, the fidelity of the simulator increases [17]. Thus a high-fidelity simulator with a full motion base and multiple visual channels is assumed to have greater fidelity than a mid-level simulator with limited motion and visualization. Although driving simulator fidelity is an attractive validation measure, its importance is often overestimated. No level of physical validity is useful to human factors research if behavioral validity cannot also be established [14].

Behavioral validity may be established for a simulator if behavioral correspondence exists between the performance of the driver in the simulator and in the corresponding actual vehicle [14]. Blaauw [18] describes four methods of assessing the behavioral validity of driving simulators, the first of which will be used in this study:

1. comparison of simulation output (e.g. lane position) or driver response (e.g. steering-wheel angle) to real world vehicle output or response;

2. comparison of simulation and real-world physical and/or mental loading by analysis of physiological variables;

3. use of subjective criteria, e.g. task difficulty ratings; and

4. transfer of training.

Blaauw argues that the most comprehensive method of undertaking behavioral validation is a comparison between the simulator and a real car, using tasks that are as similar as possible in each environment [15]. If completion of the task results in numerical values between the two systems that are equivalent or nearly so, then absolute validity can be established for the simulator for that task. More likely, performance differences between the simulator and the real car can be compared. Relative validity can be claimed for the simulator when differences found between experimental conditions in the simulator and the real world are in the same direction and have a similar or identical magnitude on both systems [15].

As most advanced driving simulators are developed independently of each other, validity information and testing is required for each individual simulator [14]. This is a result of the fact that different simulators have distinct individual parameters such as the time delay between driver action and simulator response, the amount of physical movement available, and the size and quality of the visual display [19]. Different tasks using the same simulator may have different levels of validity. Therefore validation of an individual simulator using only a single task or group of similar tasks is not adequate in arguing overall simulation validation. A more comprehensive validation effort may be achieved through the use of a broad range of task types (i.e. speed related tasks, following distance related tasks, and tasks assessing reaction time).

Drivers execute many tasks in order to safely and efficiently maneuver their vehicles. Evaluation of vehicle speed and inter-vehicle distance are crucial skills and constant demands while operating a motor vehicle. Common maneuvers such as braking, obstacle avoidance, and overtaking rely heavily on such skills. These skills rely on the representation of (1) self-motion in the 3-D environment and (2) the egocentric distances (distances between vehicles) [20]. However, humans vary greatly in their ability to comprehend situational complexity and execute proper responses in a safe manner.

Regarding human ability to estimate speed, Evans found that “errors in subjectively estimating speed are sufficiently great that drivers should consult speedometers”, and that “drivers are poor judges of speeds of oncoming cars, as required in overtaking maneuvers” [21]. However, studies conducted in which drivers just after negotiating a bend are stopped by concealed police forces, and asked whether or not they looked at their speedometers show that 90% of drivers had failed to do so [22]. Based on this evidence it is expected that the vast majority of drivers rely on environmental information to gather perception of speed [23]. As a result, simulation studies often prescribe tasks that seek to better understand human perception of speed and distance. These tasks are not only fundamental to understanding driving behavior, but can also be useful in behavioral simulator validation.

Driving perception tasks are typically categorized as either estimation tasks or production tasks. These types of tasks are commonly used in psychophysics to study the relations between observed stimuli (light, tones, etc.) and responses. When considered in the driving domain, estimation tasks require participants to estimate a speed or following distance which is pre-determined by the researcher. Driving production tasks require participants to adjust the vehicle's speed or following distance to the required value by using the brake and accelerator. Estimation and production tasks require participants to either estimate or produce absolute (fixed) values or increases and decreases in speed and following distance. Participants can increase or decrease their speed or following distance in two manners: (1) increase/decrease by a fixed amount (e.g. decrease speed by 10 MPH), or (2) increase/decrease by a relative or ratio amount (e.g. decrease speed by one half). Recarte and Nunes found that the high reliability of task behavior, either in its numerical estimation format or in its adjustment or production version, makes it possible to consider both estimation and production as consistent measures of driver aptitude [24]. Prescribing tasks that specifically address participant's ability to perceive fixed speeds as well as increases and decreases in speed allows for a more complete investigation into driver behavior and perception.

Before tasks can be prescribed by a study, an understanding of human perception and ego motion is needed to give insight as to what simulation parameters are important to achieve proper simulation behavioral validation and perform subsequent human-factors research. By understanding how humans process cues from their environment, simulation methodology and research can both be improved.

Psychological Models of Perception and Ego Motion

Proper behavioral validation of advanced simulation research equipment is vital to human factors research. Prior to implementation of behavioral validation, an understanding of the psychological models of human perception and ego motion is needed. Ego motion is defined as movement of the whole body in space [25]. By understanding these parameters, researchers can validate simulators using the proper criteria and motives.

Humans exist in a complex world that is full of visual information. We are constantly moving around our environment and interacting with objects and organisms. Thus, our view is constantly changing as we move relative to our environment. This means the ecological stimulus for vision is a globally changing optic array. Vision and subsequent guidance of motion require that spatio-temporal (time and space) information be obtained through the perceptual systems [26].

The significance of visual information in controlling locomotion is well documented. Over 60 years ago Bernstein proposed insight into how body movements are coordinated and regulated [27]. He argued that there must exist in the central nervous system exact ‘formulae of movement’ which contain a person’s whole course of movement over time. Lashley proposed a similar idea and argued that all skilled human activity involves the problem of serial ordering of units of action, and henceforth there must exist schemata to direct the sequencing of these units [28]. Unfortunately, many researchers in this era were mainly concerned with the control of movements involving minimal interaction with the environment [26].

A comprehensive theory of perceptuo-motor coordination must address the following question: What types of information are required in controlling movement relative to the environment [26]? Gibson hypothesized that there are two types of information needed: *exterospecific* information about the layout of surfaces in the environment and about external objects and events, and *propriospecific* information about bodily movements [29]. This viewpoint neglects the fact that humans are in interaction with their environment. In order to control this interaction, the organism needs information concerning position, orientation, and movement of its body as a whole or part of its body relative to the environment [26]. In the absence of visual information, it is impossible for organisms to make anticipatory modifications of their locomotion [30]. Necessary visual information can be gathered from many different sources in a variety of manners.

Of the many visual cues available during locomotion, optic flow has been the most widely investigated [20]. Optic flow (Figure 3), or the visual motion that humans experience as a result of walking, running, or driving, is a powerful signal to control the parameters of movement [31]. The importance of optic flow to visual perception becomes apparent when optic flow is not matched to true motion. For example, toddlers that have just learned to walk fall over when the walls of a surrounding room are set in motion, and adults modify their walking speed depending on optic flow [26][30].

Figure 3. Visual representation of optic flow [32]

Optic flow does not give information about absolute distance to an object and travel speed. Rather, it is used to compare spatial intervals and for time measurements relative to the object and observer [33]. Optic flow has been shown to be a reliable cue for estimating distance of travel under certain conditions [31][34]. In simulation, optic flow resulting from the continuous movement of the textured images of all objects in the scene is present. However, motion parallax due to the observer's head movement, as well as binocular cues, are often absent in simulators [20]. Therefore optic flow can be modified in a simulator as a function of scenario visual complexity (scenario texture, complexity of landscape topography, presence or absence of vegetation, etc.). Road curvature may also be used to provide additional optic flow cues that are not present in a straight roadway.

While quality of visual cues (optic flow) plays a role in driver behavior, the presentation and location of these cues in the driver's visual field of view is also important. A decrease in driver field of view reduces the amount of temporal and spatial depth cues presented to drivers [35], and can induce poor perception of speed by the driver [36]. Drivers use temporal and spatial cues for estimating speed by comparing spatial intervals and time measurements for objects passing through their view. A larger field of view provides these cues not only to the forward view of the driver, but also to the lateral, peripheral view. Jamson noted that for correct speed perception, a horizontal field of view of at least 120 degrees is needed [36]. Other work concerning field of view and driving simulators found that presence, enjoyment, and simulator sickness varied as a function of display field of view, with presence and simulator increasing with an increase in field of view [37]. It is therefore apparent that simulators should be investigated individually in order to determine if expected benefits of increased field of view (more realistic speed behavior, increased presence, etc.) outweigh the expected costs (increased monetary cost, simulator sickness, etc.).

Driving an automobile has been often regarded as a visually guided task. However, drivers take other factors into account to steer and drive their vehicle [38]. Significant evidence exists that the vestibular and proprioceptive sensory channels are significantly involved in basic driving skills. As a result, modern advanced driving simulators use motion cueing devices for increased fidelity by rendering physical accelerations together with visually simulated motion. This allows drivers to control their vehicles in a more realistic manner [39]. However, it is difficult to define the role of a motion platform in a driving simulator because the role of real or simulated accelerations as useful sensory inputs when steering a vehicle is not fully established [39]. Existing models of driving behavior are based mainly on visual cues. Therefore they cannot predict the improvement in driving fidelity which is expected when using a motion system [39].

Past research concerning the effect of motion parameters on simulation fidelity and human behavior has been conducted in both surface transportation [39][40] and aviation domains [41][42]. In these studies, motion is typically investigated independent of simulation visual characteristics. In the rare event that a simulator is tuned across all motion and dynamics parameters, behavioral research should be conducted to better understand the simulator's motion capabilities and subsequent effects on driver perception and behavior. This study proposes to extend past research by simultaneously investigating the main effects and interaction effects of three simulation factors (motion, field of view, and optic flow) on driver perception of both speed and following distance using different types of production tasks (absolute and increase/decrease). This study was conducted immediately following tuning work of the WTI simulator completed in the summer of 2009 (articles concerned with these tuning efforts are forthcoming). Therefore this study is not only important as an extension of past research, but is also vital in establishing the groundwork for extensive behavioral validation of the WTI high-fidelity simulator, allowing for its use as a realistic tool for future studies and driver training.

CHAPTER 3

METHODS

Following are a description of the perceptual performance experiment including descriptions of participants, equipment, experimental design, experimental factors and levels, task selection and implementation, dependent variables, experimental procedures, pilot study, and statistical analysis. Note that all experimental procedures were approved by the Institutional Review Board (IRB). The study's Human Subjects Committee Application to the IRB is presented in Appendix A.

Participants

Twenty participants (10 males and 10 females) were recruited from the greater Montana State University (MSU) area by the researcher. Verbal and email solicitation were employed by the researcher to gather possible participants from local businesses and the MSU campus. Solicitation continued until a sufficient participant sample size was reached. All participants were fully licensed to operate a motor vehicle. Participants were screened based on their susceptibility to motion sickness (see Appendix B for simulator sickness screening forms). Participants with medical conditions or histories (e.g., headaches and vertigo) that indicated increased levels of risk in the simulation environment were disqualified from the study. Participants who were experiencing a high level of discomfort (e.g., eye strain and increased temperature) at the time of the screening process were asked to not participate that day. Two female participants (ages 22 and 52) who experienced discomfort during the experiment were released from the study and replaced with additional female participants of similar ages.

A vision test (see Appendix C for vision testing form) was also given to all participants. All participants were tested across five vision parameters using the Optec® 5000 Vision Screening Unit: (1) peripheral vision, (2) visual acuity at 20 feet (far acuity), (3) visual acuity at 18 inches (near acuity), (4) color perception, and (5) depth perception. In order to be considered for participation in the experiment, participants had to meet minimum scores (minimums determined by the researcher) for peripheral vision (140 degrees), far acuity (20/40), and near acuity (20/40). All participants met or exceeded testing thresholds. Minimum test thresholds represent typical minimum state driving requirements for peripheral vision and acuity [43]. Most states do not have color perception and depth perception requirements for obtaining a driver's license. As a result, color and depth perception tests were administered in order to gather vision information but were not used as pass/fail criteria. Sixty-five percent of participants had corrected vision (glasses, contacts, or both). A summary of participant vision testing results is presented in Appendix D.

The average age of participants was 35.8 years of age (standard deviation ± 13.6, maximum age of 55, minimum age of 18). Participants averaged 19.7 years of driving experience (standard deviation ± 13.6 years, maximum of 40 years, minimum of 4 years), and approximate miles driven per year of 13,050 miles (standard deviation ± 9,543 miles/year, maximum of 50,000 miles/year, minimum of 5,000 miles/year). There were no differences between male (n = 10) and female (n = 10) participants in terms of age and years driving experience (all p-values > 0.55). However, male participants drove significantly more (p - value = 0.003) miles per year (M = 17,300 miles/year) when compared to female drivers (M = 8,800 miles/year). This difference is expected, as males drive more miles than females on average [44]. The experiment was configured so that all treatments and factor levels were administered to all participants equally (all 10 male participants received identical treatments as 10 female participants). All participants were compensated USD $10 for their participation.

Equipment

Western Transportation Institute's (WTI) high-fidelity simulator was used for the study (Appendix E). This simulator consists of a Chevy Impala sedan mounted on a Moog 200E motion platform with six degrees of freedom (roll, pitch, yaw, heave, surge, and sway). Motion displacement for the six degrees of freedom ranges from +/- 0.18 m to +/- 0.25 m. Motion base velocities for the six axes of surge, sway, heave, roll, pitch, and yaw were ± 0.50 m/s, ± 0.50 m/s, ± 0.30 m/s, ± 30°/s, ± 30°/s, and ± 40°/s respectively. Simulation scenarios were projected forward in front of driver by five projectors onto a curved screen (240 degree FOV) and behind the driver by one projector onto a flat screen (60 degree FOV). Side-view mirrors with digital screens also portrayed the scenarios for a total of eight visual channels. Images were projected at a resolution of 1400x1050. Audio for the simulations was delivered through a Logitech Z-5500 505 Watt 5.1 surround sound system located outside the vehicle. Levels of sound (engine sounds and traffic sounds) were adjusted by the researchers during the tuning phase of the study to ensure that level of simulation sound correspond to real-life driving sound levels. Note that many elements of the simulation including motion, field of view, resolution, etc., can easily manipulated by the researcher to represent a range of values manipulated in the conditions compared in the experiment design. Simulation scenarios for the study were designed by the researcher using the advanced software design tools available to WTI (Sim Creator, Internet Scene Assembler, and Multi-Gen 3D modeling software). Scenarios differed by experimental condition (level of motion, field of view, and optic flow). The basic component of each scenario was a four-lane highway approximately 10 miles in length.

Independent Variable Selection

The choice of independent variable selection is pivotal to the behavioral validation of the simulator and to the understanding of driver behavior as a whole. Variable selection was made based on two factors: (1) what parameters can actually be changed in the simulator, and (2) what variables are important to driver behavior based on locomotion and perception theory. Many parameters can be varied in the WTI simulator including: resolution, field of view, motion, and scenario design. Scenarios can be designed to include or neglect such elements as optic flow, urban and rural landscapes, weather, lighting, and level of traction (ice and snow conditions). All of these variables play a role in driver behavior to some extent.

Given that driving is generally regarded as a visually dominated task [20], two of the variables chosen represent visual manipulation of the simulator: field of view and optic flow. Both of these variables have been investigated in the past [45][46], with optic flow being perhaps the most extensively researched visual cue available to drivers [31]. The third variable chosen, motion, represents a non-visual sensory channel which influences driver behavior and performance. Motion has been studied by few investigators [47][48] and has been shown to be significantly involved in the execution of basic driving skills [39].

The three variables of motion, field of view, and optic flow are not only instrumental in gaining a better understanding of driver behavior and perception; they are also useful in conducting behavioral validation of the simulator. Experimental findings can be compared to past studies utilizing these variables to ensure that the WTI simulator is as robust as possible in facilitating future research and training.

Independent Variable Treatment Levels

High and low levels (Table 1) of each factor were chosen. Two levels of each factor were chosen, as investigating more than two levels of each factor would greatly increase the amount of trials and time necessary to run the experiment. Therefore, the two levels chosen signify opposing levels (high and low) of each factor.

Table 1. Factor Level Description

Factor	Level	Description
Motion	Low	Motion base turned completely off.
	High	Motion base active on all six axes.
Field of View	Low	One of five forward projectors active.
	High	Five of five forward projectors active.
Optic Flow	Low	Straight roadway with few motion cues (minimal vegetation and sand landscape texture).
	High	Dynamic, curved roadway with many motion cues (dense vegetation and cue-rich landscape texture).

Motion

In order to better understand the effects of motion on driver behavior and perception, two levels of motion were studied: low (no motion) and high (full motion). Input files written by the researcher were applied to the simulation models to deactivate and active the motion base as dictated by the study. The levels chosen indicate the maximum and minimum amounts of motion afforded by the simulator motion platform.

Field of View

Five visual channels are available for a total forward view of 240 degrees to the driver. The two levels of field of view chosen to be studied were: low (55 degrees forward field of view) and high (240 degrees forward field of view). These levels represent the maximum and minimum field of view configurations possible for the WTI simulator. Low field of view was implemented by simply deactivating four of the five overhead projectors leaving only the center channel active immediately in the center of the visual field of the driver. The high-level field of view was implemented by turning on all of the five projectors giving the driver the maximum 240 degrees of forward viewing capability.

Optic Flow

Two different roadway environments (Figure 4) were designed by the researcher to represent low and high levels of optic flow in the visual field. Optic flow was facilitated with respect to (1) number and proximity of objects; (2) granularity of surface textures; and (3) necessity of lateral (and longitudinal) motion defined by the road geometry and speed limits. A summary of optic flow characteristics is shown in Table 2 for both low and high optic flow levels.

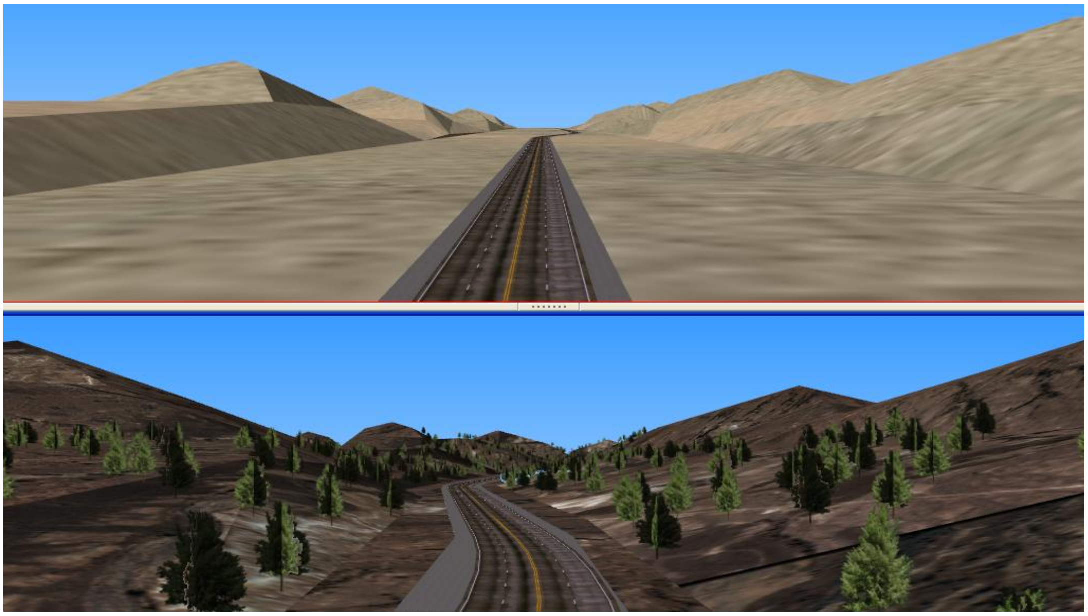

Figure 4. Low (top) and High (bottom) Optic Flow Scenarios

Table 2. Scenario Optic Flow Characteristics

	Optic Flow Level	
Characteristic	Low	High
Curvature	1 curve per 1,000 m	2 curves per 1,000 m
Signs	1 sign per 4,000 m	5 signs per 4,000 m
Barriers	None	2 per 4,000 m
Texture Image Analysis	19 objects per 1,000 m^2	243 objects per 1,000 m^2
Hill Proximity to Roadbed	Minimum 50 m from roadbed	Minimum 5 m from roadbed
Tree Density	None	17 per 1,000 m^2
Landscape Polygon Density[1]	1.15 polygons per 10,000 m^2	1.95 polygons per 10,000 m^2

[1] Landscape Polygon Density was determined using ImageJ software. Sections of landscape texture (both low and high optic flow levels) 1,000 m^2 in size were converted to binary image type. Numbers of objects indicated in table are the number of dark objects found in the binary image that were between 0.25 m^2 and 625 m^2 in size (roughly 0.5 m to 25 m in diameter). These sizes represent minimum and maximum area thresholds determined by the researcher for dark areas in the texture which may have added to perception of optic flow.

The low optic flow scenario consisted of a highway with minimum curvature (1 curve per 1,000 m). Speed limit signs were present in limited quantities (1 per 4,000 m), while common road fixtures such as dividers and barriers were not present. Sand texture with very few defining characteristics was modeled onto the surrounding terrain. Texture image analysis (texture image converted to binary) conducted using ImageJ software revealed 19 dark objects between 0.25 m^2 and 625 m^2 in size (roughly 0.5 m to 25 m in diameter) per 1,000 m^2 of texture. Hills were present in the scenario but they were placed away from the roadbed (minimum distance of 50 m from the roadbed) giving minimal visual cues. No trees were present in the scenario. Average landscape polygon density (ground polygons only) was 1.15 polygons per 10,000 m^2.

In contrast, the high optic flow level scenario had twice as many curves (2 curves per 1000 m) as did the low optic flow scenario. Turn signs were present immediately preceding each turn. Speed signs (5 per 4,000 m) and barriers (2 per 4,000 m) were present throughout the scenario. The texture applied to the surrounding terrain provided visual cues to the driver. Texture image analysis (texture image converted to binary) conducted using ImageJ software revealed 243 dark objects between 0.25 m^2 and 625 m^2 in size (roughly 0.5 m to 25 m in diameter) per 1,000 m^2 of texture. Roadside terrain including hills followed the roadbed closely (minimum distance of 5 m from the roadbed) and had large amounts of vegetation (average density of 17 trees per 1,000 m^2), thus providing a large amount of visual cues to the driver. Average landscape polygon density (ground polygons only) was 1.95 polygons per 10,000 m^2.

Experimental Design

A 2^3 factorial design was used for this study (Table 3). The simulation factors of motion, field of view, and level of optic flow were tested at two levels (low and high) each for a total of eight different combinations. Each participant drove through eight scenarios (treatments), each approximately fifteen minutes in length, resulting in approximately two hours of total driving time per participant.

Table 3. 2^3 Factorial Design

	Factor Level[1]		
Drive Reference #	M	FOV	OF
1	L	L	L
2	L	L	H
3	L	H	L
4	L	H	H
5	H	L	L
6	H	L	H
7	H	H	L
8	H	H	H

[1] M = Motion, FOV = Field of View, OF = Optic Flow, L = Low Level, H = High Level

Randomization

A variety of methods are available for allocation of treatments to participants including complete counterbalancing and partial counterbalancing. Complete counterbalancing involves randomly assigning participants to a treatment sequence and utilizes each treatment sequence the same number of times. This method is unfeasible for a 2^3 factorial design, as it requires 40,320 (8!) different treatment sequences. Many design strategies exist for partial counterbalancing including Latin square, balanced Latin square, and randomized partial counterbalancing. Latin square counterbalancing ensures that each condition appears only once in a given ordinal position of the sequence and requires an equal number of participants assigned to each sequence. However, this methodology does not account for carryover effects. Balanced Latin square methodology controls for order effects and carryover effects, but similarly requires that equal number of subjects be assigned to each sequence. Statistical calculations are also problematic for Latin square designs with missing data or lost data.

Randomized partial counterbalancing involves randomly selecting as many sequences of treatment conditions as there are subjects for the experiment. For example, an experiment with two factors at two levels each would have 24 (4!) different possible treatment sequences. If the study was utilizing 15 participants, 15 of the possible 24 treatment sequences would be randomly allocated to study participants. This design allows for simple statistical calculations even in the presence of missing or lost data. It is also the most flexible design in terms of number of required participants. Any number of participants can be chosen. Randomized partial counterbalancing was chosen for this study due to the simplicity and flexibility it regarded in terms of statistical analysis and number of required participants. This method of randomization has been used in a number of simulator studies [49][50].

Treatments were allocated to participants using the random number generator in Excel (treatment order and frequency of treatments in ordinal positions 1-8 are presented in Appendix F). The researcher administered the desired random treatment by manipulating levels of motion, field of view, and optic flow. Motion was controlled through the use of java scripts to enable (high level) or disable (low level) the motion base. Field of view was manipulated by manually turning on/off necessary projectors to achieved desired level. All five forward projectors were turned on to allow for a high level of field of view, while using only the center forward projector resulted in a low level of field of view. Optic flow was manipulated by loading the desired optic flow scenario (low or high) into the control PC. Methodology for determining number of study participants is included in the Pilot Study section.

Task Selection and Implementation

Common maneuvers such as braking, obstacle avoidance, and overtaking rely heavily on driver perception of vehicle speed and inter-vehicle distance. As a result, tasks prescribed by this study emphasize the ability of drivers to perceive speed (SP) and following distance (FDP). Each participant was asked to complete eleven separate tasks (

Table 4) for each of the eight individual drives. While each of the eight drives differed in levels of motion, field of view, and optic flow, prescribed driving tasks for each drive were identical. Speed and following distance production tasks (absolute, fixed increase, and relative change) are utilized by this study. Tasks are summarized in Table 4 according to perception type (speed or following distance).

Table 4. Description of Participant Driving Tasks

Task #	Drive Section[1]	Task	Start Point (meters)
1	SP	Drive at the 65 MPH posted speed limit.	100
2	SP	Drive at what you believe to be 50 MPH.	5900
3	SP	Decrease current speed by half.	6900
4	SP	Increase current speed by 10 MPH.	7900
5	SP	Drive at what you believe to be 25 MPH.	8900
6	SP	Double current speed.	9900
7	FDP	Follow lead car at 300 foot following distance.	12900
8	FDP	Decrease current following distance by half.	14150
9	FDP	Increase current following time by 100 feet.	15400
10	FDP	Follow lead car at 150 foot following distance.	16650
11	FDP	Double current following distance.	17900

[1] SP = Speed Perception, FDP = Following Distance Perception

Speed Perception Tasks

Speed perception tasks for the purpose of this study are broken into three categories by skill type: (1) absolute speed perception, (2) fixed speed change, and (3) relative speed change. These three categories investigate speed perception in different manners. All three skill categories are necessary for safe vehicle conduct. Absolute speed perception indicates how well drivers can replicate a defined speed (e.g. drive at 40 MPH) without speedometer feedback from the vehicle. Fixed speed change indicates how well drivers increase their speed by a defined amount (e.g. speed up or slow down by 10 MPH when changing speed limit zones). Relative speed change is defined as decreasing one's speed by a fraction amount (e.g. halve speed) or increasing speed by a relative amount (e.g. double speed). These types of tasks are used by drivers in real life when they are changing speed zones or overtaking other vehicles. All three task categories are useful in understanding driver behaviour as well as in establishing simulator behaviour validity. A variety of tasks were prescribed by this study in order to gain a more complete picture of driver perception of speed. Speed perception tasks are summarized individually in terms of description and task intent.

Average Speed: Participants were asked to begin each of the eight drives by driving at the speed limit (65 MPH) until instructed otherwise. Data was collected over a two minute period beginning one minute into the drive to assess how well drivers maintained the 65 MPH speed limit. This driving task (asking participants to drive at a set speed for a finite duration of time in order to measure their average speed) is similar to those implemented by Panerai et al. [35]. Speed data collected during this task is useful in making conclusions about general effects of simulator factors on perception of speed.

50 MPH Production: Participants were asked to drive at what they believed to be 50 MPH. This task sought to assess how well participants could replicate an absolute speed. Absolute driving speed perception tasks have been used in several past studies [24][35]. This task is useful in understanding driver perception of a speed common to rural and urban driving environments.

Halve Speed: This task required participants to decrease their current speed by half. Although speed replication tasks give valuable insight into driver perception of speed, other tasks involving drivers changing (increasing/decreasing or halve/double) their speed can help researchers gain further insight into driver perception of speed. Such tasks were performed and recommended by Groger et al. [23] as a way to compare driver behaviour across different simulation platforms. Skills utilized in this task are useful in real life driving when changing speed zones or when slowing down for changing road conditions.

Increase Speed by 10 MPH: Participants were asked to increase their speed by 10 MPH. This task sought to assess how well participants could increase their speed by a defined amount (10 MPH). Such a task is common in everyday driving; drivers routinely increase speeds by 10 MPH when changing speed zones in urban areas.

25 MPH Production: Participants were asked to drive at what they believed to be 25 MPH. This task sought to assess how well participants could replicate an absolute speed. As mentioned previously, absolute speed perception tasks have been used in several past studies [24][35]. This task is useful in understanding driver perception of a speed common to urban driving environments.

Double Speed: Participants were asked to double their current speed. As mentioned, tasks involving the halving and doubling of speed were performed by Groger et al. [23]. This task is useful in assessing skills utilized in real life driving when changing speed zones, merging with traffic, or when overtaking other vehicles.

Following Distance Perception Tasks

A total of five tasks were given during the following distance perception section of each drive. Following distance tasks were similar to those prescribed during the speed perception section, and involved participants following a lead vehicle at various following distances measured in feet. As with speed perception tasks, following distance tasks are broken into three categories: (1) absolute following distance perception, (2) fixed following distance change, and (3) relative following distance change. Absolute following distance perception indicates how well drivers can replicate a defined following distance (e.g. drive at 150 ft following distance) without speedometer feedback from the vehicle. Fixed following distance change indicates how well drivers increase their following distance by a defined amount (e.g. increase following distance to maintain proper safety margin while accelerating). Relative speed change is defined as decreasing one's speed by a fraction amount (e.g. halve following distance) or increasing following distance by a relative amount (e.g. double following distance). These types of tasks are used by drivers in real life when they are changing following distance due to road conditions, visibility, etc. All three task categories are useful in understanding driver behaviour as well as in establishing simulator behaviour validity

A variety of tasks were prescribed in order to gain a more complete picture of driver perception of following distance. A lead vehicle was introduced into each scenario immediately following the speed perception portion of the drive. The lead vehicle traveled at a static 55 MPH for the remainder of the experiment. Following distance perception tasks are summarized individually in terms of description and intent.

300 ft. Following Distance Production: Participants were asked to follow the lead vehicle at a following distance of 300 ft. Such a following distance is relatively common in everyday driving, and integral to safe driving. Studies have shown that braking response times for an alert driver in an experimental situation are about 1 s (80.7 ft traveled at 55 MPH). This response time can lengthen to over 2 s (161.3 ft traveled at 55 MPH) if the lead vehicle is without brake lights, as the driver must first register that they are closing in on the lead vehicle [51]. Therefore drivers must be able to maintain following distances in excess of 1 s, and preferably over 2 s in order to give themselves ample time to respond to speed changes in cars they are following. This task sought to evaluate how well participants perceived a distance in excess of this “safe” following distance.

Halve Following Distance: Participants were asked to decrease their current following distance by half. Procedures for this task were implemented similar to those conducted by Groger et al. [23]. Such tasks were performed and recommended by Groger et al. as a way to compare driver behaviour across different simulation platforms [23]. This task is also useful in assessing real-life driving skills. When drivers decrease speed, they may also decrease their following distance. Smaller safety stopping margins are needed at lower speeds than at high speeds. This task sought to evaluate how well participants perceived changes in following distance.

Increase Following Distance by 100 ft: Participants were asked to increase their current following distance by 100 ft. This task was chosen as a result of the fact drivers routinely increase following distance for a variety of reasons including poor road conditions, poor visibility, and driving at night. Although driver perception of static following distance is an important safety concern worthy of investigation, drivers also must be able to alter their following distance. Drivers must constantly assess their following distance and alter it as the situation demands.

150 ft. Following Distance Production: Participants were asked to follow the lead vehicle at a following distance of 150 ft. As mentioned previously, drivers must be able to maintain following distances in excess of 1 s, and preferably over 2 s in order to give themselves ample time to respond to speed changes in cars they are following. This task sought to evaluate how well participants could perceive a following distance that corresponded with a 2 second following distance at 55 MPH (161.3 ft).

Double Following Distance: Participants were asked to double their current following distance. As mentioned, tasks involving the halving and doubling of following distance were performed by Groger et al. [23]. When drivers increase speed, an increase in following distance is also needed in order to maintain proper safety stopping margins. This task sought to evaluate how well participants perceived changes in following distance.

Task Instruction and Implementation

During each experimental segment voice commands were given to the driver indicating how they were to navigate each scenario. Voice commands were recorded in the form of .wav files. Proximity sensors embedded in each scenario along with proper java scripting played the recorded .wav files through internal vehicle speakers when the driver passed through the proximity sensor. With voice commands embedded into the design of the scenario in this manner, each participant received the exact same commands at the same place in each scenario. This auditory command regime helped to eliminate the introduction of unnecessary bias into the experiment. Also note that the simulation speedometer was disabled for the duration of the experiment.

Once the initial task of driving at 65 MPH was completed, drivers were asked to drive at five different speeds and five different following distances. Once drivers have attained what they perceive to be the correct following distance or speed, they were asked to press a cruise control button located on the steering column. This action did not active the cruise control, but rather recorded the desired perception data value (speed or following distance) in the data stream. This procedure was followed by participants for the majority of the study. Occasionally participants neglected to press the cruise control button. Treatment of these missing data points is discussed in the results section of this study.

Dependent Variables

Simulation data collection is an involved process which utilizes many different computer programs. An overview of the entire simulation process including design and data collection illustrates how the many different computer programs are structured and how they relate to each other (Figure 5). Software tools including Multi-Gen, Internet Scene Assembler, and Sim Creator were used to design and implement the simulation scenarios. Data collection was done through the use of Sim-Creator, Sim Observer, and Data Distillery. Data fields identified in Sim Creator were synchronized with video data by using Sim Observer. This data was in turn fed into Data Distillery where it was later reviewed and analyzed.

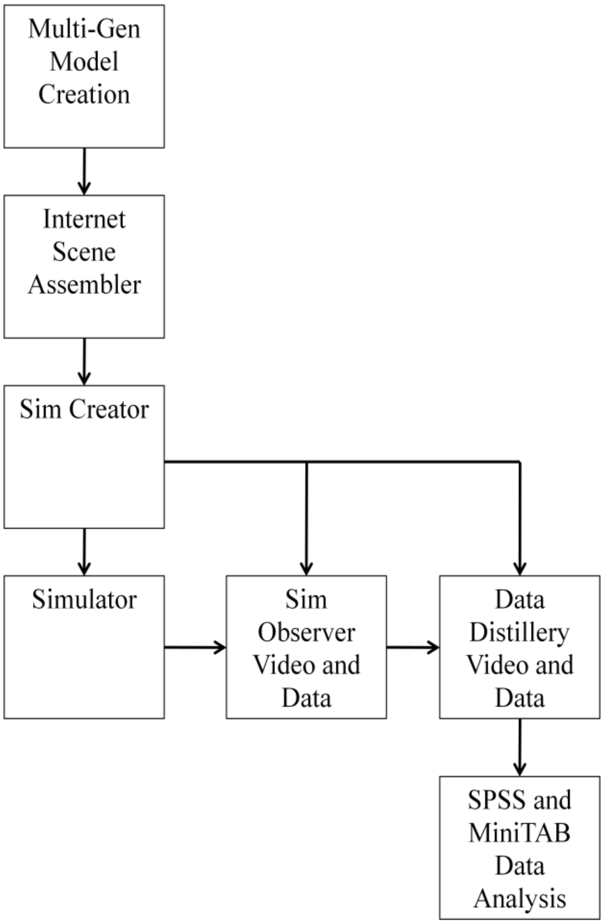

Figure 5. Overview of Simulation Programs and Interactions

One dependent variable was taken for each of the 11 driving tasks embedded within the eight individual drives taken by participants (Table 5). A summary of each dependent variable is provided for both speed perception and following distance perception categories.

Table 5. Dependent Variables

Task	Drive Section[1]	Performance Metric Computed[2]	Units	Type[3]
Average speed (65 MPH production)	SP	average speed over 2 minute duration	miles/hr	C
50 MPH production	SP	speed at time of production	miles/hr	D
Decrease current speed by half	SP	estimated halved speed / initial speed	miles/hr	D
Increase speed by 10 MPH	SP	increased speed - initial speed	miles/hr	D
25 MPH production	SP	speed at time of production	miles/hr	D
Double current speed	SP	estimated doubled speed / initial speed	miles/hr	D
300 foot following distance production	FDP	FD at time of production	ft	D
Decrease current following distance by half	FDP	estimated halved FD / initial FD	ft	D
Increase current following distance by 100 feet	FDP	increased FD – initial FD	ft	D
150 foot following distance production	FDP	FD at time of production	ft	D
Double current following distance	FDP	estimated doubled FD / initial FD	ft	D

[1] SP = Speed Perception, FDP = Following Distance Perception
[2] FD =Following Distance
[3] C = Continuous, D = Discrete

Driver Behavior Variables

One dependent variable was taken for each of the eleven tasks. Speed and following distance perception dependent variables are summarized by task in terms of how variables were measured and calculated.

Average Speed: At the beginning of each drive, participants were asked to drive at what they believed to be 65 MPH. Average speed was calculated by taking the average vehicle speed in MPH for a two minute duration beginning one minute into the drive. The first minute of the drive was neglected, as this is the time period used by participants to accelerate from a standstill to the desired speed.

50 MPH Production: Participants pressed the cruise control button once they were driving at what they perceived to be 50 MPH. The speed value recorded when the participant pressed the cruise control button was used as the 50 MPH production value.

Halve Speed: Halving speed was calculated by determining the ratio between two speed values: (1) speed value recorded when voice command (halve speed) was instigated, and (2) speed value corresponding to the instant the participant pressed the cruise control button to indicate they were at the desired speed (half of original speed). The ratio value was calculated by dividing speed value 1 by speed value 2.

Increase Speed by 10 MPH: Increase speed by 10 MPH was calculated by determining the difference between two speed values: (1) speed value recorded when voice command (increase speed by 10 MPH) was instigated, and (2) speed value corresponding to the instant the participant pressed the cruise control button to indicate they had increased their speed by 10 MPH. The value was calculated by subtracting speed value 1 from speed value 2.

25 MPH Production: Participants pressed the cruise control button once they were driving at what they perceived to be 25 MPH. The speed value recorded when the participant pressed the cruise control button was used as the 25 MPH production value.

Double Speed: Double speed was calculated by determining the ratio between two speed values: (1) speed value recorded when voice command (double speed) was instigated, and (2) speed value corresponding to the instant the participant pressed the cruise control button to indicate they were at the desired speed (double original speed). The ratio value was calculated by dividing speed value 1 by speed value 2.

300 ft. Following Distance Production: Participants pressed the cruise control button once they were driving at what they perceived to be a 300 ft. following distance. The following distance value recorded when the participant pressed the cruise control button was used as the 300 ft. following distance production value.

Halve Following Distance: Halve following distance was calculated by determining the ratio between two following distance values: (1) following distance value recorded when voice command (halve following distance) was instigated, and (2) following distance value corresponding to the instant the participant pressed the cruise control button to indicate they were at the desired following distance (half of original following distance). The ratio value was calculated by dividing following distance value 1 by following distance value 2.

Increase Following Distance by 100 ft: Increase following distance by 100 ft. was calculated by determining the difference between two following distance values: (1) following distance value recorded when voice command (increase following distance by 100 ft.) was instigated, and (2) following distance value corresponding to the instant the participant pressed the cruise control button to indicate they had increased their following distance by 100 ft. The value was calculated by subtracting following distance value 1 from following distance value 2.

150 ft. Following Distance Production: Participants pressed the cruise control button once they were driving at what they perceived to be a 150 ft. following distance. The following distance value recorded when the participant pressed the cruise control button was used as the 150 ft. following distance production value.

Double Following Distance: Double following distance was calculated by determining the ratio between two following distance values: (1) following distance value recorded when voice command (double following distance) was instigated, and (2) following distance value corresponding to the instant the participant pressed the cruise control button to indicate they were at the desired following distance (double of original following distance). The ratio value was calculated by dividing following distance value 1 by following distance value 2.

Subjective Variables

In addition to quantitative data, qualitative questionnaire data was also collected. After participants completed each of the eight driving scenarios they were asked to complete a questionnaire (Appendix G). This questionnaire sought to assess how “real” the participant perceived the scenario to be in relation to the real world in terms of motion, sound quality, field of view, and image quality. Format and general guidelines of this questionnaire follow those implemented by Witmer and Singer in studying driver presence in simulated environments [52]. As in the Witmer study, all questions use a seven-point scale format with endpoints being opposite descriptors. The scale also includes a mid-point anchor. An example of this format is shown in Figure 6.

How much did your visual experience of this virtual
environment resemble your real-world driving experiences?

Not Consistent			Moderately Consistent			Very Consistent

Figure 6. Example Questionnaire Question

Experimental Procedures

All participants followed the same process upon arriving at WTI. Participants went through each of the following steps: consent and pre-screening, experiment, and post-experiment processes. Note that due to the long nature of the study, the study was broken into two sessions; each session occurring on a different day. Session I lasted approximately 1.5 hours and Session II lasted approximately 1.25 hours. The first session was comprised of the consent and pre-screening processes as well as one half of the experimental portion of the study (four drives), and the second session completed the experimental portion of the study (four drives) and the concluded with post-experiment processes. In order to control for circadian effects, both sessions were scheduled as nearly as possible to each other in terms of time of day (i.e. both sessions occurring at 1 p.m. on separate days).

Consent and Pre-Screening

Before participants began the experiment they were asked to review and sign a consent form (Appendix H). This form reviewed the general purpose of the experiment, experimental procedures, potential risks, benefits, and participant compensation. Participant's signature of the consent form indicated they were adequately informed of the experiment and that they wished to participate.

After completing the consent form, participants were given a Pre-Screening Simulation Sickness Questionnaire (Appendix B). This questionnaire was designed to identify people who may be prone to the condition of simulation sickness, and is used by WTI for all simulation experiments. If participants were found to be susceptible to simulation sickness they were advised of their potential risk of participation. Participants with a high degree of risk were asked to not participate. Participants were asked to next fill out a brief form to gather data concerning driver demographics and driving background (Appendix I).

Next, all participants completed a vision test. Testing was conducted by the researcher using an Optec® 5000 vision screening unit produced by Stereo Optical, Inc. All participants completed testing of peripheral vision, far and near visual acuity (20 ft. and 18 inches respectively), color perception, and depth perception (Appendix C). Test standards used met the standards set by the American National Standards Institute (ANSI). Those participants with adequate testing results were allowed to continue to the experimental phase of the study.

Lastly, drivers were given a brief overview of the experimental procedure as well as the task procedures. Task procedures included following speed and following distance commands and pressing the cruise control button when indicated. Visual representations of experimental definitions of speed and following distance (Appendix J) were shown to participants at this time.

Perceptual Performance Experiment

During the perceptual performance experiment portion of this study, participants were first introduced to the simulator and vocally instructed by the researcher as to how they should physically operate the vehicle. When using a driving simulator, new drivers are likely introduced both to a new vehicle and to a virtual reality. As a result, time is needed to for the driver to adjust to both of these new situations. In order to allow participants this "adjustment time", each participant initially drove in a "pre-experiment" scenario to acclimate themselves with the vehicle and corresponding virtual reality.

The "pre-experiment" scenario was configured at a medium level of all three experimental factors as to not introduce any unnecessary bias on the participants. The motion base was limited to one–half of its normal motion range through the use of coding in the simulation model. Field of view was limited so that three of the five available projectors were operating, thus limiting forward field of view to 145 degrees. Lastly, the pre-experiment visual scenario developed had moderate optical flow. Participants drove in this scenario for two minutes. Note that no data collection occurred during this phase. After two minutes had passed, the researcher stopped the simulator and was available to answer any additional questions the participants may have had. If the participant was comfortable in the simulation environment and wished to proceed, the experimental phase of the study began.

The experimental phase of the project involved each participant driving through eight separate drives. Each drive was a different combination of the three factors at two levels. The order in which each participant completed the eight drives was be randomly assigned. Each drive was approximately 11-15 minutes in duration. Each individual drive contained two different sections: speed production and following distance production. A total of 12 separate quantitative data measures were gathered for each drive. After each drive the participant was asked to complete a questionnaire (Appendix G) to collect qualitative data in order to assess how “real” the driver felt the scenario to be, as well as how distracting each scenario was to task completion. Note that drives 1-4 were completed during Session I of the study, and drives 5-8 were completed Session II.

Post Experiment

Once the participant had completed all eight driving scenarios, they were given a post-experiment simulation sickness form (Appendix B) to gather information about how participants felt after driving in a simulated environment. Next, they were given a debriefing form (Appendix K) which detailed the experiment in depth and indicated how participants could access the findings of the study once results were published. Lastly, participants were reimbursed for assisting in the study (see Appendix L for participant compensation form).

Pilot Study

A pilot study was conducted with six participants (5 males and 1 female, average age of 23.8) in order to receive feedback on experimental procedure, instructions to participants, and questionnaire materials, as well as to estimate a necessary sample size for the experiment. Pilot study participants went through the experiment in its entirety. Pilot study participant feedback was also used to clarify unclear task command wording. Task order and placement were also changed in order to place tasks in such a manner that participants would have enough time to complete them in a logical sequence. Data collection techniques were also refined during the pilot study. While conducting the pilot study it also became apparent that a single participant would need to be processed in two sessions instead of a single session due to the length of each of the eight drives. Therefore two sessions were configured in the final study design with each session lasting approximately 1.5 hours. The final study design sessions contained four drives in each session, with treatment sequence for all eight drives randomized for each participant using the Excel random number generator as mentioned previously. Two-tailed analysis (two-tailed t-tests or Mann-Whitney tests) were conducted upon conclusion of the final study to determine what, if any, effect session had on participant behavior. Upon review of results, no dependent variables were found to be statistically different between sessions 1 and 2 when evaluated for drives 1 and 8 (drives 1 and 8 represent two states of factors, all high or all low, which were drastically different from each other). Therefore it was assumed that the structure of the experiment did not create a confounding order effect for session.

Sample Size Estimation

Sample size for the final study design was estimated by reviewing past literature of similar simulation studies. Sample size estimation for this study was not a straightforward a-priori exercise due the fact the study prescribed a number of diverse dependent variables which were expected to change in response to three within-subject factors. It was expected that different levels of participants would be needed to find and verify effects for each dependent variable. Therefore estimation was conducted by reviewing past literature.

Literature review indicated that studies investigating driver perception of speed and/or following distance generally had sample sizes between 15 and 25 participants. Behavioral validation (using mean speed) of a simulator for its use in evaluating speeding countermeasures was performed by Godley et al. using 20 participants [14]. Perception of speed and following distance estimation was investigated by Groeger et al. using 18 participants [23]. For the studies reviewed, simulator sample sizes ranged from as little as 12 participants [53] to as many as 30 participants [54]. Based on literature review, as well as time and monetary constraints, a sample size of 20 participants was selected for this study.

Statistical Analysis

All data was managed and analyzed using Microsoft Excel, SPSS 18, and MiniTAB 15. Analysis was conducted on results of the perceptual performance experiment, as well as on questionnaire data collected during the experiment.

Driver Behavior Variables

Statistical analysis of the driver behavior dependent variables that followed repeated measures analysis of variance assumptions (normality, homogeneity of covariance matrices, and sphericity) was performed using repeated measures analysis of variance (ANOVA). Shapiro-Wilk tests were used to verify the assumption of normality. Levene’s tests were conducted on all treatments of each dependent variable to verify the assumption of homogeneity of covariance matrices. As all of the factors were configured at two levels each, the condition of sphericity was met for all analyses. Data found to violate the repeated measures analysis of variance assumptions was transformed (using Box-Cox or Johnson Transform in MiniTAB 15) in order to meet repeated measures test assumptions. Non-parametric tests were conducted to verify significant ANOVA effects based on data that could not be transformed to meet parametric assumptions. Note that repeated measures ANOVA is robust concerning violations of multivariate normality and homogeneity of covariance matrices [55].

All repeated measures ANOVA analyses were conducted using a 2 (two levels of motion) x 2 (2 levels of field of view) x 2 (2 levels of optic flow) factorial repeated measures ANOVA with one between-subjects factor (2 levels of gender). Gender was included as a between-subject factor as male participants drove significantly more per year than female participants. This model was used to determine the main effects and combination effects of factors (motion, field of view, and optic flow) on dependent variables. This model also allowed for the analysis of the effect of gender on dependent variables. An alpha level of 0.05 was used to reject the null hypothesis for all cases.

The following two-tailed hypotheses were tested during the perceptual performance experiment portion of the study:

1. Level of simulator motion (low or high) affects driver behavior variables (speed perception and distance perception):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Where i = presentation of motion (1 = motion off, 2 = motion active).

2. Level of simulator field of view (low or high) affects driver behavior variables (speed perception and distance perception):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

   Where i = field of view (1 = low field of view, 2 = high field of view).

3. Level of simulator scenario optic flow (low or high) affects driver behavior variables (speed perception and distance perception):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

   Where i = presentation of optic flow (1 = low optic flow, 2 = high optic flow).

4. Gender type (male or female) affects driver behavior variables (speed perception and distance perception):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

   Where i = gender (1 = female, 2 = male).

After transformation of the data, the datasets were checked for outliers. For the purposes of all analyses, outliers were defined as those data points point which fall more than 3 times the interquartile range above the third quartile or below the first quartile. These data points are known as “extreme outliers” and can have dramatic influence on statistical analyses. Outliers were analyzed for each drive of each dependent variable. Using this definition, a total of three outliers were removed from the entire data set of eleven dependent variables. Outliers were not replaced.

A total of 20 data points were “missing” from the behavioral data set for all dependent variables (1760 total data points), indicating that participants failed to press the cruise control button as a result of (1) misunderstanding of the task, (2) forgetting to execute task due to distraction, boredom, etc., or (3) failing to complete the task in the allotted time. After the elimination of outliers, the 20 missing data points were replaced with the mean treatment level value.

Subjective Variables

Qualitative analysis was used on the participant questionnaires to determine differences in how users perceived the “realness” of the various fidelity levels. Questions were grouped into two categories (Realism and Interaction) according to question type (summary provided in Appendix G). Responses for each question category were averaged for each drive of each participant, with higher responses indicating that participants perceived a particular drive as more natural in terms of realism or interaction. All data was found to violate repeated measures ANOVA assumption of normality (analyzed using Shapiro-Wilk test). Data was transformed in a variety of manners (Box-Cox, Johnson, Square Root, and Log Transform) in order to maintain parametric assumptions. None of the transformations yielded data that followed parametric assumptions. Within-subject factors (motion, field of view, and optic flow) were analyzed using non parametric testing (Friedman’s Test), and gender effect was analyzed for each individual drive using 2 tailed t-tests and Mann-Whitney tests where appropriate. Assumptions for 2 tailed t-tests were verified using Shapiro-Wilk test (normality) and Levene's test (homogeneity of variance). The following two-tailed hypotheses were tested in relation to the driving perception questionnaire:

1. Levels of simulation motion (low or high) affect driver perception of driving experience (realism and interaction):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Where i = presentation of motion (1 = low motion, 2 = high motion).

2. Level of simulator scenario field of view (low or high) affects driver perception of driving experience (realism and interaction):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Where i = presentation of motion (1 = low field of view, 2 = high field of view).

3. Level of simulator scenario optic flow (low or high) affects driver perception of driving experience (realism and interaction):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Where i = presentation of motion (1 = low optic flow, 2 = high optic flow).

4. Gender type (male or female) affects driver perception of driving experience (realism and interaction):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Where i = gender (1 = female, 2 = male).

CHAPTER 4

RESULTS

Statistical analysis was conducted on both driver behavioral variables and subjective variables. Analysis methodology and findings are summarized for each variable.

Driver Behavior Variables

A summary of all statistical significance for within-subject factors (motion, field of view, and optic flow) and between-subject factors (gender) are presented for each dependent variable in Table 6. Interaction effects are summarized in text only.

Table 6. Statistical Significance Summary

	Factor[1]			
	Within-Subject[2]			Between-Subject
Dependent Variable	M	FOV	OF	Gender[3]
Average speed (65 MPH production)	-	H (3.9 MPH)	H (6.8 MPH)	-
50 MPH production	-	H (4.1 MPH)	H (6.0 MPH)	-
Decrease current speed by half	H (3%)	-	-	-
Increase speed by 10 MPH	-	-	-	-
25 MPH production	-	H (3.4 MPH)	-	-
Double current speed	-	-	-	-
300 foot following distance production	-	-	-	M (291.3 ft)
Decrease current following distance by half	-	-	-	-
Increase current following distance by 100 feet	-	-	-	-
150 foot following distance production	-	-	-	M (262.9 ft)
Double current following distance	-	-	-	-

[1] The significantly more accurate factor level (and difference from other level) is shown in the table, for example “H (5.0 MPH)” indicates that the high level was significantly closer to the target value and the other level (low) was less accurate by 5 MPH

[2] M = Motion, FOV = Field of View, OF = Optic Flow, L = Low Level, H = High Level

[3] M = Male, F = Female

Average Speed

The accuracy of average speed was defined by how close participants drove to the target speed of 65 MPH. Average speed was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Box plots of all eight drives revealed no outliers. The data contained one missing data point which was replaced with the treatment level mean. A variety of transformations (Box-Cox, Johnson, square root, and Log transform) were applied to the data. None of the transformations resulted in data that met the repeated measures ANOVA assumption of normality. As repeated measures ANOVA is robust concerning violations of normality, repeated measures ANOVA was still conducted. There was a main effect of field of view [F(1,17) = 6.555 , p = 0.020] on 50 MPH speed production. The larger field of view resulted in significantly better accuracy (M = 78.61 MPH) than the smaller field of view (M = 82.51 MPH). There was also an optic flow main effect [F(1,17) = 15.914, p = 0.001]. The higher level of optic flow resulted in significantly better accuracy (M = 77.18 MPH) than the low level of optic flow (M = 83.94 MPH).

As data violated repeated measures ANOVA assumption of normality, further testing was conducted to verify ANOVA analysis. Within-subject factors were verified using non parametric testing (Friedman's Test), and gender was verified using 2 tailed t-tests for drives that followed parametric assumptions (normality and homogeneity of variance), and Mann-Whitney tests when parametric assumptions were violated. Assumptions were verified using Shapiro-Wilk test (normality) and Levene's test (homogeneity of variance). Field of view and optic flow were found to be significant (N = 76, Chi-square = 8.895, significance = 0.003, and N = 76, Chi-square = 11.842, significance = 0.001 respectively), verifying previous parametric test results.

Gender was found to be significant [t (17) = 2.202, significance = .041] for one drive (high level of motion, low level of field of view and optic flow), with males significantly more accurate (M = 80.09 MPH) than females (M = 94.36 MPH).

50 MPH Production

The accuracy of 50 MPH production was defined by how close participants drove to the target speed of 50 MPH. Fifty MPH speed production was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation (all data reported as non-transformed). Box plots of all eight drives revealed no outliers. The data contained no missing data points. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. There was a main effect of field of view [F(1,17) = 11.550, p = 0.003] on 50 MPH speed production. The larger field of view resulting in significantly better accuracy (M = 66.07 MPH) than the smaller field of view (M = 70.17 MPH). There was also an optic flow main effect [F(1,17) = 11.003, p = 0.004]. The higher level of optic flow resulted in significantly better accuracy (M = 65.14 MPH) than the low level of optic flow (M = 71.10 MPH).

Halve Speed

The accuracy of halving speed production was defined by how close participants modified their speed to half (0.50) of their original speed. Halving of speed was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation (all data reported as non-transformed). Box plots of all eight drives revealed one outlier, which was removed from the data set. The data contained no missing data points. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. There was a main effect of motion [F(1,16) = 10.958, p = 0.004] on halving of speed with full motion resulting in significantly better accuracy (M = 0.65) than no motion (M = 0.68).

Increase Speed by 10 MPH

The accuracy of Increasing Speed by 10 MPH was defined by how close participants were to increasing their speed by the target amount (10 MPH). The dependent variable of Increase Speed by 10 MPH was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation. Box plots of all eight drives revealed no outliers. The data contained no missing data points. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects or interaction effects were found.

25 MPH Production

The accuracy of 25 MPH production was defined by how close participants drove to the target speed of 25 MPH. Twenty-five MPH speed production was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation (all data reported as non-transformed). Box plots of all eight drives revealed no outliers. The data contained no missing data points. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. There was a main effect of field of view [F(1,17) = 14.668, p = 0.001] on 25 MPH speed production with the larger field of view resulting in significantly better accuracy (M = 37.93 MPH) than the smaller field of view (M = 41.32 MPH).

Double Speed

The accuracy of Doubling Speed was defined by how close participants modified their speed to double (2.0) of their original speed. Double speed was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation. Box plots of all eight drives revealed two outliers which were removed from the data set. The data contained no missing data points. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects or interaction effects were found.

300 ft Following Distance Production

The accuracy 300 ft Following Distance production was defined by how close participants drove to the target following distance (300 ft). Three hundred ft following distance was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Box plots of all eight drives revealed no outliers. The data contained one missing data point which was replaced with the treatment mean. A variety of transformations (Box-Cox, Johnson, square root, and Log transform) were applied to the data. None of the transformations resulted in data that met the repeated measures ANOVA assumptions (normality assumption violated). As repeated measures ANOVA is robust concerning violations of normality, testing of data was conducted using repeated measures ANOVA. Gender was found to be significant [F(1,16) = 4.910, p = 0.042] with males performing with significantly better accuracy (M = 595.47 ft) than females (M = 886.72 ft).

As data violated repeated measures ANOVA assumption of normality, further testing was conducted to verify ANOVA analysis. Within-subject factors were verified using non parametric testing (Friedman's Test), and gender was verified using 2 tailed t-tests for drives that followed parametric assumptions (normality and homogeneity of variance), and Mann-Whitney tests when parametric assumptions were violated. Assumptions were verified using Shapiro-Wilk test (normality) and Levene's test (homogeneity of variance). No significance was found for with-in subject factors, verifying parametric results. Gender was found to be significant for three of eight drives, indicating the prior ANOVA analysis was correct.

Halve Following Distance

The accuracy of Halving Following Distance was defined by how close participants modified their following distance to half (0.50) of their original following distance. Halving of following distance was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation. Box plots of all eight drives revealed no outliers. The data contained five missing data points which were replaced with the treatment mean. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects or interaction effects were found.

Increase Following Distance by 100 ft

The accuracy of Increase Following Distance by 100 ft production was defined by how close participants were to increasing their following distance by the target amount (100 ft). Increasing Following Distance was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation. Box plots of all eight drives revealed no outliers. The data contained five missing data points which were replaced with the treatment mean. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects or interaction effects were found.

150 ft Following Distance Production

The accuracy 150 ft Following Distance production was defined by how close participants drove to the target following distance (150 ft). One hundred fifty ft Following Distance production was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation (all data reported as non-transformed). Box plots of all eight drives revealed no outliers. The data contained one missing data point which was replaced with the treatment mean. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects or interaction effects were found. Gender was found to be significant [$F(1,16) = 5.531$, $p = 0.032$] with males exhibiting significantly better accuracy ($M = 376.60$ ft) than females ($M = 638.52$ ft). No interaction effects were found.

Double Following Distance

The accuracy of Halving Following Distance was defined by how close participants modified their following distance to double (2.0) of their original following distance. Doubling of following distance was analyzed using a 2 x 2 x 2 factorial repeated measures ANOVA with one between-subjects factor (gender). Data was transformed to achieve formality using a Johnson Transformation. Box plots of all eight drives revealed no outliers. The data contained one missing data point which was replaced with the treatment mean. Testing (Shapiro-Wilk and Levene's test) indicated that the data satisfied the assumptions of normality and homogeneity of covariance matrices. No main effects were found. An interaction effect was found for the factors of motion, optic flow, and gender [F(1,16) = 6.607, p = 0.021].

Subjective Variables

A total of eight questions (see complete questionnaire in Appendix G) were given to each participant after each experimental drive. For analysis, questions were grouped into two categories (Realism and Interaction) according to question type. Responses for each question category were averaged for each drive of each participant, with higher responses indicating that participants perceived a particular drive as more natural in terms of realism or interaction. Analysis was conducted on both question categories (Realism and Interaction). A summary of all statistical significance for within-subject factors (motion, field of view, and optic flow) and between-subject factors (gender) are presented for each question category in Table 7.

Table 7. Subjective Variable Statistical Significance Summary

	Factor[1]			
	Within-Subject[2]			Between-Subject
Question Category	M	FOV	OF	Gender[3]
Realism	-	H	-	-
Interaction	-	H	-	-

[1] The significantly more accurate factor level is shown in the table, for example "H" indicates that the high level was significantly more accurate than the low level
[2] M = Motion, FOV = Field of View, OF = Optic Flow, L = Low Level, H = High Level
[3] M = Male, F = Female

Realism

A variety of transformations (Box-Cox, Johnson, square root, and Log transform) were applied to Realism data. None of the transformations resulted in data that met the repeated measures ANOVA assumption of normality. Therefore within-subject factors were analyzed using non parametric testing (Friedman's Test), and gender was analyzed using 2 tailed t-tests for all eight drives as individual drive data followed parametric assumptions (normality and homogeneity of variance). Assumptions were verified using Shapiro-Wilk test (normality) and Levene's test (homogeneity of variance). The data contained no missing data points. Box plots of all eight drives revealed no outliers. Field of view was found to be significant (N = 80, Chi-square = 4.945, significance = 0.026), with the larger field of view resulting in significantly higher realism scores (M = 4.91) than the smaller field of view (M = 4.61). Gender was found to be significant [t (18) = -2.538, significance = .021] for one drive (high level of motion, low level of field of view and optic flow), with males (M = 5.15) indicating higher realism scores than females (M = 4.13).

Interaction

A variety of transformations (Box-Cox, Johnson, square root, and Log transform) were applied to Realism data. None of the transformations resulted in data that met the repeated measures ANOVA assumption of normality. Therefore within-subject factors were analyzed using non parametric testing (Friedman's Test), and gender was analyzed using 2 tailed t-tests for all eight drives as individual drive data followed parametric assumptions (normality and homogeneity of variance). Assumptions were verified using Shapiro-Wilk test (normality) and Levene's test (homogeneity of variance). The data contained no missing data points. Box plots of all eight drives revealed no outliers. Field of view was found to be significant (N = 80, Chi-square = 3.879, significance = 0.049), with the larger field of view resulting in significantly higher interaction scores (M = 5.74) than the smaller field of view (M = 5.39). Gender was found to be significant [t (18) = -2.117, significance = .048] for one drive (high levels of motion, field of view, and optic flow), with males (M = 6.13) indicating higher interaction scores than females (M = 5.35).

CHAPTER 5

DISCUSSION

The purpose of this study was to conduct an experiment to examine the perceptual and behavioral effects of various parameters of a simulated driving environment (motion, field of view, and optic flow) deemed relevant to theories of ego motion. In this simulator study, twenty participants estimated speed and following distance while driving through eight scenarios that varied in presentation of motion, field of view, and optic flow. Participants completed eleven perception tasks for each driving scenario. Tasks measured participant's ability to perceive fixed speed and following distance, as well as their ability to increase, halve, and double their speed and following distance. Subjective questionnaires were distributed to participants after each drive in order to gather information about differences in how users perceived the "realness" of the various simulation fidelity levels. Discussions of results are summarized for both speed and following distance perception, as well as for subjective questionnaires. Delimitation and limitations of this study as well as recommendations for future work are also discussed.

Speed Perception

Participants were first asked to drive at what they thought was 65 MPH for an extended period of time. Their speed was measured and averaged over a two minute period. Participants responded by driving at an average of 124% of the target value (65 MPH) for the two minute duration. Participants were also asked to drive at target speeds of 25 and 50 MPH (fixed speed production). Participants indicated they were at the target speed (25 or 50 MPH) by pressing the cruise control button to record their estimated speed value. In general, fixed speeds produced were higher than target speeds. When asked to drive at target speeds of 25 and 50 MPH, drivers responded by driving at an average of 158% and 136% of the target speed respectively. Many past studies indicate that drivers tend to underestimate speed and overproduce speed when driving in both real and virtual environments [24][56], and that overproduction tends to decrease at higher speeds [24]. Recarte and Nunes found that drivers on real roads overproduced fixed speeds of 60 KPH (37 MPH) and 100 KPH (62 MPH) by 120% and 105% respectively [24]. There is general agreement among researchers about the tendency to underestimate and overproduce speed in real and simulated environments. However, experimental demonstration of the equivalence of simulated conditions and reality is scarce and unconfirmed [56].

A larger field of view produced significantly more accurate production of average speed (121%) than a smaller field of view (127%). A larger field of view also produced significantly more accurate production of fixed speeds (25 MPH, 152%; 50 MPH, 132%) than a smaller field of view (25 MPH, 165%; 50 MPH, 140%). These results were expected, as a smaller field of view reduces the amount of temporal and spatial depth cues presented to drivers [35]. Drivers use these cues for estimating speed by comparing spatial intervals and time measurements for objects passing through their view. A larger field of view provides these cues not only to the forward view of the driver, but also to the lateral, peripheral view. Study results suggest that visual cues in peripheral regions are vital to maintaining accurate perception and maintenance of speed. Past literature has indicated similar results, where Jamson found that a limited field of view induces poor perception of speed by the driver [36]. Jamson noted that for correct speed perception, a horizontal field of view of at least 120 degrees is needed [36].

Optic flow also affected speed perception, with a high level of optic flow producing significantly more accurate production of average speed (65 MPH) and fixed speed (50 MPH) than a low level of optic flow. These results are also expected, as past literature indicates that optic flow is one of the most important types of visual information used for driving and for everyday locomotion [31]. Optic flow spatial and temporal cues are generated as drivers pass through road environments. Vegetation, roadside textures, buildings, roadway markers, and road curvature all contribute to the overall optic flow pattern. Because the driver's and environmental object's speeds determine velocities in the optic flow pattern, knowledge of road markings or other scale factors can help the driver make good estimates of speed from optic flow [35]. Therefore it is intuitive that drivers will make more accurate speed estimations when given a higher quality (increased texture, contrast, curvature, etc.) of optic flow cues. Past psychophysical studies regarding speed perception show that observers can underestimate speed or overproduce speed when image contrast [57] or texture [58] are reduced.

The perceptual ability of drivers to halve and double their speed was also investigated. Unlike fixed speed perception tasks, halving and doubling tasks investigated drivers' ability to estimate their speed while increasing/decreasing their speed by a relative amount (half or double). Skills utilized by halving and doubling tasks are used by drivers every day when changing speed zones, merging with traffic, overtaking vehicles, etc. Therefore, the ability to execute accurate vehicle accelerations and decelerations is a vital safety concern for all drivers.

Halving speed findings from this study indicate an average reduction of speed to 66% of initial speed. Groeger et al. [23] found that ability to halve speed accurately depended on the initial speed, with reductions in speed varying from 58% to 63% of initial speed (initial speeds ranging from 20-80 MPH). The authors noted that consistent failure by participants to reduce their speed sufficiently to approximate the true 50% level can be interpreted in three ways: (1) drivers are overestimating speed to begin with, and then halving the overestimated speed correctly, with a higher final speed resulting, (2) drivers are estimating the speed correctly, and failing to reduce it sufficiently, or they are (3) both overestimating speeds and manipulating speeds inaccurately [23].

Motion was found to significantly affect halving of speed, with a high level of motion producing significantly more accurate production of halving of speed (65% of initial speed) than a low level of motion (68% of initial speed). This result is not unusual as previous studies have indicated that motion cues (vestibular and proprioceptive) play a role in the driver control strategies [59][60]. Models proposed in past studies suggest that these cues are used by the driver to control steering and regulate speed [60][61]. Results of this study indicate that the motion base offered vital cues to the perception of deceleration and therefore significantly affected driver behavior. It is apparent that a realistic motion base contributes to a realistic driving experience. However, the precise role of vestibular and other haptic and kinaesthetic cues in steering and speed control are not fully understood, and therefore must be investigated further in motion-based driving simulation experiments [35].

Double speed findings of this study also coincide with past research, for example Groeger et al. [23] found that at speeds beyond 25 KPH (15.5 MPH) participants do not increase their initial speed sufficiently to reach the actual doubling point. Similarly, the current study found that when participants were asked to increase their speed by a fixed amount (10 MPH), they did not increase their speed sufficiently (63% of target value). This finding may be linked to how drivers perceive slower speeds as opposed to faster speeds. Participants overproduced slower speeds by a greater amount than faster speeds. Therefore with a greatly overproduced initial speed (lower speed), it is expected that little acceleration would be needed to attain a higher (less overproduced) perceived speed.

Lastly, gender was not found to be a significant factor for any of the speed perception dependent variables. Lack of statistical evidence is supported by past literature, where studies indicated that males and females do not differ significantly in their ability to perceive speed [24][62].

There were some inconsistencies in the current study results for speed production in relation to past research. For example Denton found that participants are much less accurate in reducing speed by half than when required to double their speed [63]. The current study indicated the inverse, with halving values (M = 67%) more accurate than doubling values (M = 153%). Decreased accuracy of both halving and doubling values (both speed and distance perception) may have been a result of drivers overproducing initial fixed speeds and distances, which they were then required to halve or double. By driving initially at an inflated speed or following distance, participants would need to rapidly respond to the halving/doubling command in order to complete the task in the allotted time. As a result of task structure and task timing, participants may have executed halving and doubling tasks less accurately than other perception tasks.

Following Distance Perception

Participants were asked to drive at target following distances of 150 and 300 ft (fixed following distance production). In general, fixed following distances produced were higher than target following distances. When asked to drive at target following distances of 150 and 300 ft, drivers responded by driving at an average of 328% and 242% of the target following distance respectively. Many past studies indicate that people underestimate distance in real and virtual environments [64][65][66][67]. Mourant and Rockwell found that absolute judgments of distance while driving on real roadways tend to be in error up to 100%, even for experienced drivers [67]. Panerai et al. found that truck drivers maintained a safety distance in simulation which was about 210% of the safety distance measured in real-road conditions [35]. According to the authors, their results suggest that “the visual information provided to the driver in simulation, although sufficiently rich to perform the control of speed, might be poor in terms of geometric contents when considering the three dimensional layout of the road environment” [35]. They mention that increased amount of safety distance in simulation could be the result of drivers experiencing visual information which is an impoverished version of the one experienced in the real-world. In particular, Panerai et al. mentioned that some of the visual cues for used for effective depth perception are absent in simulation [35]. For example, binocular cues and motion parallax cues due to the observer movement in vehicle were not provided or rendered in their experiment. Both of these cues are important for perception of three dimensional layouts [35].

Participants were also asked to increase their following distance by relative (half and double) amounts. These types of tasks are used by drivers in real life when they are changing following distance due to changes in road conditions, visibility, etc. Halving of distance findings coincide with past research, where Groeger et al. indicated that participants underestimated bisecting distances [23]. The Groeger et al. study indicated that participants bisected further distances (300m) with more accuracy (~65% of original value) than near distances (150m, ~85% of original value). The current study found that participants bisected and doubled their initial distance (initial distance varied for each estimation) by moving to 62% and 171% of the initial distance respectively. Therefore participants underestimated both halving and doubling of following distance. Doubling of distance comparisons between the current study and the

Groeger et al. study cannot be made as Groeger et al. did not prescribe doubling distance tasks. Underestimation of fractional increases and decreases in following distance may have safety implications. Drivers that habitually underestimate increases and decreases in distance may find themselves not speeding up enough to safely pass a vehicle or not slowing down enough for changing road conditions.

Participants were also asked to increase their following distance by a fixed amount (100 ft). Participants responded by increasing their following distance to 155 ft (155% of the target value). Unlike double following distance results where drivers did not sufficiently double their following distance, this result indicates that drivers overproduced the intended increase in distance. This result is not unlikely, as participants greatly overproduced fixed speeds by two to three and a half times (242%-328%). These results indicate that drivers have less understanding of distance parameters than speed parameters. Inconsistencies in following distance results indicate the need for further research.

Gender was found to be significant for fixed following distance production (300 ft and 150 ft productions), with males performing with significantly more accuracy than females. Little work has been done concerning gender differences and following distance perception. Cavallo et al. found that gender was not significant to the distance perception of rear lights in fog [68]. Shinar and Schechtman likewise found that the likelihood of maintaining a safe headway was not affected by the driver's gender [69]. Creem-Regehr et al. conducted three experiments to examine the influence of field of view and binocular viewing restrictions on absolute distance perception in the real world [70]. None of their findings indicated gender differences for following distance perception.

There are many possible explanations for the effect of gender on perception of fixed following distance. Male participants may have been more “engaged” in the experiment than were females due to the analytical tasks prescribed and the technical nature of the simulator and the experiment. A higher engagement level may have led to more accurate production of fixed following distance. Additionally, risk perception may have played a role in distance perception. It has been shown consistently that males report more risky driving than do females, as demonstrated by Wilson [71] for safety-belt use and Arnett [72] for speeding, illegal passes and driving while intoxicated. Elander et al. reported that males consistently expressed a greater willingness to commit driving violations than females [73]. As a result of the fact females are generally more risk-adverse than males, female participants may have driven a further distances than males.

In addition to differences that exist between males and females genders as a whole, there may have been additional differences between the individual males and females selected for this study. No attempt was made to recruit males and females with similar backgrounds or driving histories. While male and female participants in the study were of similar age, males drove significantly more miles per year (M = 17,300 miles/year) than females (M = 8,800 miles/year). As a result of increased exposure, male drivers may have developed a greater understanding of following distance than their female counterparts. In addition to driving exposure, other factors such as individual intelligence and analytical capability may have contributed to the gender effect as well. It is possible that the participants chosen were not entirely representative of their respective gender. Additionally, males were likely more comfortable interacting with the male researcher than were female participants. An enhanced level of comfort may have altered driver behavior. Given the fact that individual differences were not controlled for in this study it is very difficult to discern whether the gender effects found for absolute following distance perception are truly gender effects or rather the confounding effects of differences found among the specific individuals chosen for this study.

Subjective Variables

Major findings concerning subjective variables (questionnaires) indicate that participants perceived a high level of field of view as significantly more realistic and offered significantly more natural interaction than a low level of field of view. This is expected, as a 55 degree forward field of view is hardly representative of reality, especially when coupled with an actual vehicle mounted on a full motion base. Interestingly, participants overall did not perceive the full motion base state as more natural than the state where motion was turned completely off. While debriefing participants, some participants mentioned that they could not discern between the two states of motion. Lack of significance could possibly be explained by the following:

1. The simulation motion was natural and intuitive; therefore participants didn’t notice when motion base was turned on.
2. Visual motion cues (screen visuals moving to represent swerving, acceleration, and deceleration) led participants to believe motion was activated.
3. The tasks prescribed did not involve rapid accelerations/decelerations that would have made motion base movements more noticeable.

Based on study findings, it is apparent that visual cues (field of view) played a greater role in driver perception of simulation realism than did vestibular (motion) cues.

Delimitations and Limitations

This study contained two delimitations. First, this study was comprised of drivers that reside in Bozeman, Montana. Secondly, the study was conducted entirely in a simulated environment. Participants may have behaved differently in the simulated environment than they would in reality. Therefore, simulator studies should be field tested where appropriate to validate simulation findings and conclusions.

Limitations of this study are as follows. Driving simulators and designed driving scenarios are meant to be realistic, but perfect imitation of real road conditions and vehicle behavior can be difficult if not impossible to implement. This study attempted as best as possible for all drivers to complete a large amount of tasks during each of the eight experimental drives. Tasks were given to each driver at set points in each drive. Therefore a faster driver would encounter each task in less time than a slower driver would. While task implementation done in this manner ensured that each participant received the exact same task at the exact same distance into the drive, the task implementation strategy gave slower drivers more time to complete each task. This ultimately resulted in slower drivers spending more time in the simulator than faster drivers. Increased exposure to simulation, while not entirely negative in all circumstances, may have led to increased fatigue in slower drivers. Increased fatigue may in turn have affected driver perception of speed and distance. Additionally, task order was identical in every simulation scenario. As a result of this rigid, repeated task order, participants may have come to anticipate tasks. Driver anticipation may have altered driving behavior.

Additionally, simulation tasks were limited in their application. This study did as best as possible to prescribe simulation tasks that allowed drivers to use real driving perceptual skills.

However, it is impossible to prescribe simulation tasks that perfectly emulate real driving conditions and task demands. With the low amount of significance found for following distance perception, it is possible that the tasks prescribed did not adequately replicate real driving tasks. Additional tasks types should be used by future studies in order to gain further insight into the perceptual function of drivers. It may also be beneficial to prescribe a larger (>2) number of tasks within each task type.

Another limitation was the large study scope. This study investigated the effects of not one but three diverse simulation parameters on both speed and distance perception. None of the simulation parameters investigated (motion, field of view, and optic flow) significantly affected driver perception of following distance. Lack of statistical evidence may be the result of (1) small effect size or (2) inadequate sample size. The prescribed sample size of the study (20) was large enough to find many effects with adequate statistical power (>0.80), but other effects may have remained undetected. However, if too many observations are used (or if a test is too powerful with a large sample size), even a trivial effect will be mistakenly detected as a significant one. Therefore virtually anything can be proved regardless of actual effects [74]. Additional research is recommended in order to further quantify the effects of simulation attributes on the perception of driver speed and following distance.

Recommendations

Based upon the findings of this study, a summary of recommendations and future research questions are provided:

(1) This study showed that none of the simulator factor (motion, field of view, and optic flow) levels (low or high) were significantly different from each other for all following distance variables. Therefore, further research is needed in order to better quantify driver perception of following distance as a function of these simulator parameters. Further research may indicate that simulation parameters are in fact more significant to the perception of distance than was determined in this study.

(2) Studying the potential effects of gender on driver behavior was not a primary objective of this study. During analysis of study results, it became apparent that male and female driving behavior was significantly different for fixed distance perception. Further research may include a better understanding of the role of gender in driver perception of speed and following distance as a function of simulation variables.

(3) Further studies may chose to study a fewer number of simulation factors. By studying fewer factors, more levels of each factor may be included. Further investigation may indicate significance where this study failed to do so. Due to time constraints, only two levels of each factor were chosen for this study.

(4) While it is understood that results from the WTI are fairly good representations of reality, further real-world testing would be useful to further validate the findings of this study. While this study provides a basis for behavioral validation of the WTI simulator, real world comparisons using a comparable vehicle (Chevy Impala) are needed to expand and substantiate behavioral validation claims.

(5) Concerning the need to prove the equivalence of experimental conditions and the real world, Conchillo, Recarte, Nunes, and Ruiz [56] noted that speed estimation can be affected by the presence of other vehicles. Therefore they suggest the issue of traffic and speed

perception must be addressed in order to determine the extent to which simulation results obtained can be generalized to real traffic conditions. All research conducted in this study was done in the presence of minimal traffic. Therefore further study is recommended to study driver behavior in the presence of traffic.

CHAPTER 6

CONCLUSIONS

The objective of this study was to conduct an experiment to examine the perceptual and behavioral effects of various parameters of the simulation (motion, field of view, and optic flow) deemed relevant from theories of ego motion. The data collected from this experiment allowed the researchers to quantify the relative importance of these parameters as a basis for future behavioral validation of the simulator. This study concluded that field of view and optic flow simulation parameters were significant to the perception of absolute speed. Large field of view and high level of optic flow resulted in significantly more accurate absolute speed perception. These findings were found to correlate with past research. This study also found that gender was significant to the perception of fixed following distance production, with males performing significantly better than females. It is unclear however whether this effect is truly the effect of gender or the effect of individual differences among study participants. Lastly, participants perceived a large field of view as significantly more natural than a small field of view.

This study found that drivers tended to underestimate and overproduce both speed and following distance. These findings are important for establishing behavioral validity of not only the WTI simulator, but driving simulators in general. It is expected that a simulator with a realistic motion base and large field of view (high-fidelity simulator) will elicit more realistic driver behavior than a low fidelity simulator. Study findings and comparison to previous literature indicate that relative validity for speed and distance perception can be established for the WTI simulator as opposed to absolute validity. Overproduction of speed in this study decreased at higher speeds when compared to lower speeds. Similarly, overproduction of following distance decreased at longer distances when compared to shorter distances. These findings correlate with past research, and indicate the limitations of simulation as compared to real driving conditions. Simulation does not fully render or provide all of the visual and motion cues used by drivers to adequately perceive speed and following distance when compared to reality. Therefore it is paramount to understand and quantify the behavioral relationships (both absolute and relative) that exist between simulation and reality so individual simulators can be validated and used as an accurate and adequate research methodology.

The implications of this report are important for researchers at Western Transportation Institute. In 2009 the WTI simulator was tuned in order to establish physical validation. Upon completion of this study, efforts will be made to conduct further physical and behavioral validation studies to better understand how the WTI simulator represents a real-world driving experience. This study provides a basis to understanding what simulator attributes are important and appropriate for further behavioral validation of the WTI simulator. The implications of this report are also important to the field of simulation research in general. The WTI simulator is one of the most advanced high-fidelity simulators in the world. Initial findings of this study and subsequent validation efforts of the WTI simulator will provide insight into driver behavior and validation techniques that may be useful for future validation efforts of new and existing simulators. Future research must build upon existing research, and this report provides an addition to the existing body of knowledge concerning driver behavior and driving simulator validation.

This study has shown that simulation attributes are indeed important to both driver behavior and subsequent behavioral validation of simulation. Through experimentation, WTI has learned better how to use its new high-fidelity simulator as a tool for research and training. WTI has also learned how to collect data from the simulator, as well as learn what types of data it can collect. Much has been learned about the three factors of motion, field of view, and optic flow and how they affect driver behavior and perception. Feedback from this report will be given to WTI and the greater simulation community as a contribution to overall simulation knowledge. The report will also be used as a tool to guide future studies. With this study complete as the first large-scale study done with WTI's high fidelity simulator, WTI can move on to conducting additional physical and behavioral simulator validation studies, conducting advanced human factors research, as well as assisting with training for the community.

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APPENDICES

APPENDIX A

HUMAN SUBJECTS COMMITTEE APPLICATION

MONTANA STATE UNIVERSITY
Institutional Review Board Application for Review
(revised 11/17/08)

[Include copies of PI's and Co-PI's "Completion Certificate(s)" as proof that all have received the education and instructions for researchers using human subjects. The preferred instruction and education is that from the National Cancer Institute: http:/Cancer.gov - Human Participant Protections Education for Research Teams/cme.cancer.gov/clinicaltrials/learning/ humanparticipant-protections.asp]

Beginning January 1, 2006, University policy requires that all protocols submitted from individuals NOT employeed by or students of Montana State University be charged a $500 review fee per application. Renewals for those proposals will be at no charge.

THIS AREA IS FOR INSTITUTIONAL REVIEW BOARD USE ONLY. DO NOT WRITE IN THIS AREA.

Application Number:	Approval Date:
Disapproved:	IRB Chair's Signature:

Submit 14 copies of application (including the signature copy), along with 14 copies of the subject consent form and 14 copies of all other relevant materials, to Institutional Review Board, 960 Technology Blvd., Room 127, Montana State University, Bozeman, MT 59717-3610. (Please staple, bind or clip together the application form, surveys, etc. as **14 individual packets**; one complete packet for each board member.) Submit one copy of grant contract proposal for the office file. For assistance, call 994-6783 or contact the Institutional Review Board Chair, Mark Quinn at 994-4707.

PLEASE TYPE YOUR RESPONSES IN BOLD

Date: 07/01/09

I. Investigators and Associates (list all investigators involved; application will be filed under name of first person listed)

NAME (SUPERVISOR): **Nic Ward** TITLE: **Professor**
DEPT: **WTI Safety and Operations** PHONE #: **(406) 994-5942**
ADDRESS: **PO Box 174250, Bozeman, MT 59717-4250**
E-MAIL ADDRESS: **nward@ie.montana.edu**
DATE TRAINING COMPLETED:

STUDENT NAME (THESIS): **Shaun Durkee** TITLE: **Research Assistant**
DEPT: **WTI Safety and Operations** PHONE #: **(406) 600-6430**
ADDRESS: **PO Box 174250, Bozeman, MT 59717-4250**
E-MAIL ADDRESS: **shaun.durkee@coe.montana.edu**
DATE TRAINING COMPLETED: **10/23/08**

(repeat if needed)

Do you as PI, any family member or any of the involved researchers or their family members have consulting agreements, management responsibilities or substantial equity (greater than $10,000 in value or greater than 5% total equity) in the sponsor, subcontractor or in the technology, or serve on the Board of the Sponsor? _____ YES __X_ NO

If you answered Yes, you will need to contact the Director of the Technology Transfer Office, Dr. Rebecca Mahurin at 406-994-7868.

II. Title of Proposal: [please try to fit/keep title on front page]

The effect of simulation attributes on driver perception and behavior

III. Beginning Date for Use of Human Subjects:

08/01/09

IV. Type of Grant and/or Project (if applicable)
Research Grant:
Contract:
Training Grant:
Classroom Experiments/Projects:
Thesis Project:
Other (Specify):

V. Name of Funding Agency to which Proposal is Being Submitted (if applicable):

Non-Funded student thesis

VI. Signatures

Submitted by Investigator
Typed Name: **Nic Ward**
Signature:
Date: **07/01/09**

Faculty sponsor (for student)
Typed Name: **Nic Ward**
Signature:
Date: **07/01/09**

VII. Summary of Activity. Provide answers to each section and add space as needed. Do not refer to an accompanying grant or contract proposal.

A. RATIONALE AND PURPOSE OF RESEARCH (What question is being asked?)

What are the effects of the simulation attributes of motion, field of view, and level

of optic flow on driver behavior and perception of speed and following distance.

B. RESEARCH PROCEDURES INVOLVED. Provide a short description of sequence and methods of procedures that will be performed with human subjects. Include details of painful or uncomfortable procedures, frequency of procedures, time involved, names of psychological tests, questionnaires, restrictions on usual life patterns, and follow up procedures.

Participants will first be asked for their consent. Initially they will complete a pre-screening questionnaire to ensure they are not susceptible to motion sickness. Next they will complete a vision and distance perception test.

Participants will then be brought into the simulation room where they will receive brief instructions of how to operate the driving simulator. They will be allowed to drive in a "pre-drive" scenario for two minutes to become acclimated to the simulation vehicle and the virtual reality.

Participants will then engage in the actual experiment where they will drive a series of eight individual drives. Each drive will be approximately 7-8 minutes in length. Each drive will have varying amounts of car motion, visible forward field of view, and amount of optic flow. Optic flow is the amount of visual cues present to the driver (trees, hills, road signs, etc.). After each of the eight drives, participants will answer a simple questionnaire to gather data on how real each driver thought the experience was.

Following the experiment drivers will be given a debriefing form and paid for their time.

C. DECEPTION - If any deception (withholding of complete information) is required for the validity of this activity, explain why this is necessary and attach debriefing statement.

D. SUBJECTS

1. Approximate number and ages
   How Many Subjects: **20**
   Age Range of Subjects: **18-60**
   How Many Normal/Control: **0**
   Age Range of Normal/Control: **N/A**

2. Criteria for selection:

   Valid driver's license, pass vision and depth perception test, not susceptible to motion sickness.

3. Criteria for exclusion:

Subjects will be excluded if they fail to meet any of the criteria in above question.

4. Source of Subjects (including patients):

   Subjects will be recruited from the greater Montana State University area. Both students and community members will be recruited.

5. Who will approach subjects and how? Explain steps taken to avoid coercion.

   Researcher (Shaun Durkee) will verbally recruit participants from the Montana State University area. Participants will be told about the general nature of the study and made to understand they are under no obligation to participate. Only willing subjects will be recruited.

6. Will subjects receive payments, service without charge, or extra course credit?
   Yes
   (If yes, what amount and how? Are there other ways to receive similar benefits?)

   Subjects will receive payment amounts of $10 for completing the experiment. If participants withdraw from the study for any reason they will still receive the full $10 compensation amount. Testing is expected to take two hours per subject.

7. Location(s) where procedures will be carried out.

   Western Transportation Institute Simulation Lab
   2310 University Way Building 2, Suite 2
   Bozeman, MT 59715

E. RISKS AND BENEFITS (ADVERSE EFFECTS)

1. Describe nature and amount of risk and/or adverse effects (including side effects), substantial stress, discomfort, or invasion of privacy involved.

   The study may induce a discomfort know as simulator sickness. Participants will be pre-screened to eliminate those that may be susceptible to motion sickness. Experimental exposure and other factors such as room temperature will be modulated to ensure participants are at a low risk for simulator sickness.

2. Will this study preclude standard procedures (e.g., medical or psychological care, school attendance, etc.)? If yes, explain.

3. Describe the expected benefits for individual subjects and/or society.

Through experimentation, WTI will learn how to use its new high-fidelity simulator as a tool for research and training. WTI will also learn how to collect data from the simulator, as well as learn what types of data it can collect. Much will be learned about the three factors of motion, field of view, and scenario complexity and how they affect driver behavior and perception. Feedback from this report will be given to WTI and the greater simulation community as a contribution to overall simulation knowledge. The report will also be used as a tool to guide future studies.

F. ADVERSE EFFECTS

1. How will possible adverse effects be handled?

   By investigator(s): **Shaun Durkee**
   Referred by investigator(s) to appropriate care:
   Other (explain):

2. Are facilities/equipment adequate to handle possible adverse effects? **Yes**
   (If no, explain.)

3. Describe arrangements for financial responsibility for any possible adverse effects.

   MSU compensation (explain):
   Sponsoring agency insurance:
   Subject is responsible:
   Other (explain):

G. CONFIDENTIALITY OF RESEARCH DATA

1. Will data be coded? **Yes** or No

2. Will master code be kept separate from data? **Yes** or No

3. Will any other agency have access to identifiable data? Yes or **No**
   (If yes, explain.)

4. How will documents, data be stored and protected?
   Locked file: **Locked office**
   Computer with restricted password: **YES**
   Other (explain):

VIII. Checklist to be completed by Investigator(s)

A. Will any group, agency, or organization be involved? **No**
(If yes, please confirm that appropriate permissions have been obtained.)

B. Will materials with potential radiation risk be used (e.g. x-rays, radioisotopes)? **No**

1. Status of annual review by MSU Radiation Sources Committee (RSC). Pending or Approved
   (If approved, attach one copy of approval notice.)

2. Title of application submitted to MSU RSC (if different).

C. Will human blood be utilized in your proposal? **No**
(If yes, please answer the following)

1. Will blood be drawn? **No**
(If yes, who will draw the blood and how is the individual qualified to draw blood? What procedure will be utilized?)

2. Will the blood be tested for HIV? **N/A**

3. What disposition will be made of unused blood? **N/A**

4. Has the MSU Occupational Health Officer been contacted? **No**

D. Will non-investigational drugs or other substances be used for purposes of the research? **No**

Name:
Dose:
Source:
How Administered:
Side effects:

E. Will any investigational new drug or other investigational substance be used? **No**

[*If yes, provide information requested below and one copy of: 1) available toxicity data; 2) reports of animal studies; 3) description of studies done in humans; 4) concise review of the literature prepared by the investigator(s); and 5) the drug protocol.]*

Name:
Dose:
Source:
How Administered:
IND Number:
Phase of Testing:

F. Will an investigational device be used? Yes or **No**
(If yes, provide name, source description of purpose, how used, and status with the U.S. Food and Drug Administration FDA). Include a statement as to whether or not device poses a significant risk. Attach any relevant material.)

G. Will academic records be used? **No**

H. Will this research involve the use of:
Medical, psychiatric and/or psychological records **No**
Health insurance records **No**
Any other records containing information regarding personal health and illness **No**

If you answered "Yes" to any of the items under "H.", you must complete the **HIPAA worksheet**.

I. Will audio-visual or tape recordings or photographs be made? Yes or **No**

J. Will written consent form(s) be used? Yes or **No**
(If no, explain.)

APPENDIX B

SIMULATOR SICKNESS QUESTIONNAIRES

SIMULATOR SICKNESS PRE-SCREENING QUESTIONNAIRE

A. This study will require you to drive in a simulator. In the past, some participants have felt uneasy after participating in studies using the simulator. To help identify people who might be prone to this feeling, we would like to ask the following questions.

- Do you or have you had a history of migraine headaches? ☐ yes ☐ no
  If yes, please describe: ____
- Do you or have you had a history of claustrophobia? ☐ yes ☐ no
  If yes, please describe: ____
- Do you or have you had a history of frequent or severe motion sickness? ☐ yes ☐ no
  If yes, please describe: ____
- Do you or have you had a history of any health problems (e.g., seizures, diabetes, heart problems, vertigo) that affect your ability to drive? ☐ yes ☐ no
  If yes, please describe: ____
- If you are a female, are you or is there a possibility that you might be pregnant?
  ☐ yes ☐ no

The investigator has explained to me that I may be at a higher risk for problems related to simulator exposure.

---------------------------------- --------------------- -------------------------------------
Subject Initials Date Investigator Initials

B. Please tell us how you feel right now. Are you experiencing any of the following?

Eye Strain:		☐ none	☐ slight	☐ moderate	☐ severe
Temperature increase:		☐ none	☐ slight	☐ moderate	☐ severe
Dizziness:	☐ none	☐ unsteady	☐ slight	☐ moderate	☐ severe
Headache:	☐ none	☐ lightheaded	☐ slight	☐ moderate	☐ severe
Nausea:	☐ none	☐ uneasy	☐ slight	☐ moderate	☐ severe

Part A. If a participant answered Yes to any of the questions above, indicate to them they may be at a higher risk for problems resulting from simulator exposure (may trigger migraines for migraine sufferers, the confined space may be a challenge for claustrophobics, and motion sickness may be exacerbated.) ***If a subject answered <u>Yes to two or more questions</u>, they will not be eligible to participate.*** *Ask subject to initial and date this form. Attach to signed consent form.*

Part B. If participant answers **<u>slight or higher to two or more questions</u>, they should not participate today.**

POST-EXPERIMENT SIMULATOR INDUCED DISCOMFORT QUESTIONNAIRE

There is a small risk associated with driving in the driving environment simulator. The driver may experience feelings of dizziness and increased body temperature, which are symptoms of a temporary condition called 'Simulator Induced Discomfort' (SID).

To verify the extent of SID occurrence, we are tracking the severity of any discomfort felt by those who drive in the driving environment simulator.

Sex:
☐ male
☐ female

Age: ______

Are you wearing prescription glasses or contact lenses?
☐ no
☐ glasses
☐ contact lenses

What is your exposure to the driving environment simulator?
☐ first time
☐ second time
☐ more than two times

During this most recent experience in the driving environment simulator did you experience any feelings of discomfort?

Eye Strain:		☐ none	☐ slight	☐ moderate	☐ severe
Temperature increase:		☐ none	☐ slight	☐ moderate	☐ severe
Dizziness:	☐ none	☐ unsteady	☐ slight	☐ moderate	☐ severe
Headache:	☐ none	☐ lightheaded	☐ slight	☐ moderate	☐ severe
Nausea:	☐ none	☐ uneasy	☐ slight	☐ moderate	☐ severe

APPENDIX C

VISTION TESTING FORM

01-Peripheral Test Far								
	L	**L**	**L**	**Nasal**	**R**	**R**	**R**	
	85	70	55	45	55	70	85	
01- Visual Acuity Far								
	Line	**Left**	**Both**	**Right**	**Left**	**Both**	**Right**	
	1	Z N	R O	H K	20/200	20/200	20/200	
	2	R K S	H N C	Z O D	20/100	20/100	20/100	
	3	H C D V	S K Z O	R N D S	20/70	20/70	20/70	
	4	Z R O D	N S C H	V Z K N	20/50	20/50	20/50	
	5	K H S C	O Z N R	D N V C	20/40	20/40	20/40	
	6	O N R Z V	D K H C S	K D S O N	20/30	20/30	20/30	
	7	S D C H N	V R Z K O	H S N R D	20/20	20/20	20/20	
03- Visual Acuity Near								
	Line	**Left**	**Both**	**Right**	**Left**	**Both**	**Right**	
	1	S V C	N R K	H Z O	20/100	20/100	20/100	
	2	R N Z H	D O K V	C S Z N	20/70	20/70	20/70	
	3	C K V D	S N Z R	D O H C	20/50	20/50	20/50	
	4	V H R N	O D S K	N Z C S	20/40	20/40	20/40	
	5	H S K R C	N Z D O V	Z S H N K	20/30	20/30	20/30	
	6	Z O N V R	H C S K D	V K C D S	20/20	20/20	20/20	
02-Color Perception Far								
	A	**B**	**C**	**D**	**E**	**F**		
	12	5	26	6	16	Blank	**PASS**	**FAIL**
07-Depth Perception Far								
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
B	L	B	T	T	L	R	L	R
Sherpard-Fry Percentage, 85% is average								
15	30	50	60	70	75	82	90	95

<u>APPENDIX D</u>

VISTION TESTING RESULTS

Summary of Participant Vision Testing Results:

Participant ID	Sex	Peripheral Vision (R/L)	Acuity Far (20 ft.)	Acuity Near (18 inches)	Color Perception	Depth Perception
2	F	85/85	20/40	20/20	PASS	15%
3	F	85/85	20/20	20/20	PASS	95%
4	F	85/85	20/20	20/20	PASS	90%
5	F	85/85	20/20	20/20	PASS	95%
6	F	85/85	20/20	20/20	PASS	30%
7	F	85/85	20/20	20/20	PASS	50%
8	F	85/85	20/20	20/20	FAIL	95%
10	F	85/85	20/20	20/20	PASS	70%
11	M	85/85	20/20	20/20	PASS	70%
12	M	85/85	20/20	20/20	PASS	75%
13	M	85/85	20/20	20/20	PASS	30%
14	M	85/85	20/20	20/20	PASS	60%
15	M	85/85	20/20	20/20	PASS	70%
16	M	85/85	20/20	20/20	PASS	90%
17	M	85/85	20/20	20/20	PASS	60%
18	M	85/85	20/20	20/20	PASS	50%
19	M	85/85	20/20	20/20	PASS	95%
20	M	85/85	20/20	20/20	PASS	75%
21	F	85/85	20/20	20/20	PASS	70%
22	F	85/85	20/20	20/30	PASS	50%

APPENDIX E

SIMULATOR BROCHURE

Western Transportation Institute | Safety and Operations

WTI Human Factors Research Facilities

The Western Transportation Institute (WTI) is dedicated to understanding the driver role in fatal rural traffic crashes and developing driver support system to improve traffic safety. This research requires a range of research methodologies and facilities to accommodate the diversity of interdisciplinary research questions implicit in the goal to improve traffic safety. As shown below, WTI has a comprehensive range of facilities to support traffic safety research. The rational progression of research projects through these facilities insures that research conclusions are scientifically robust, valid and generalizable.

Naturalistic Fleet

Western Transportation Institute recently received a $535,000 grant awarded by the M.J. Murdock Charitable Trust, that will allow the institute to purchase five different types of vehicles and one motorcycle. Each vehicle will be outfitted with onboard instruments that gather data about driver behavior, the vehicle's position and road conditions. This facility will support naturalistic driving studies and evaluations of system deployment.

Test Track

The TRANSCEND research test track center in Lewistown Montana is currently being expanded by WTI to support a broad range of vehicle and infrastructure based rural transportation research. The new expansion includes vehicle garages, laboratory space, weather generation equipment, and a communication backbone to support VII and VIV application research. This facility will support field research and quasi-controlled experiments including the assessment of system concepts.

- Controlled braking areas
- 360' x 64' Wet skid pad
- 150' x 700' Parking/staging area
- Classroom, office, storage
- Serpentine slalom area
- Evasive steering area
- 200' by 600' Monster pad
- Off-road recovery area
- Variable radius corner

Simulation Suite

WTI currently operates a suite of three driving simulators covering a wide range of fidelity. This suite represents the largest range and most advanced driving simulation capability of any research universities in North America. This range of capability provides for the appropriate matching of simulation fidelity to research question complexity to provide cost effective research programs, ethical exposure to risk factors, visualization of system concepts prior to real world implementation, realistic interaction with near-crash events, and the reliable control of relevant scenario conditions. Controlled test-track studies and naturalistic on-road studies are then used to validate and extend research conclusions with deployable systems.

Contact: Nicholas Ward, PhD
Western Transportation Institute; College of Engineering, Montana State University
Ph: (406) 994-5942 Email: nward@coe.montana.edu

Western Transportation Institute | Safety and Operations
www.westerntransportationinstitute.org • 406.994.6114

	Desktop	**Fixed Base**	**Motion Base**
			
Channels, projection / screen type	1 Channel - 22" Widescreen LCD Monitor	5 Channel - faceted screen consisting of 5 40" Rear Projection Screens	8 channel - 240 degree seamless cylindrical screen forward projection. Canon SX7 Projector (4000 Ansi-lumens/1000:1 contrast ratio).
FOV	22" Widescreen LCD Monitor	150 degree FOV	240 degree horizontal x 42 degree vertical; sideview is direct view LCD in side view mirror housing; rear view is actual mirror reflecting a rear mounted screen projection (60 degree FOV)
Resolution		Each monitor is 1024 x 768 resolution	< 2.6 arc minutes/pixel 1400 X 1050
Refresh Rate	60Hz	60 Hz	60 Hz graphics update
Anti-aliasing	8x FSAA (Full Scene Anti-Aliasing)	8x FSAA (Full Scene Anti-Aliasing)	8x FSAA (Full Scene Anti-Aliasing)
Transport Delay	Total transport delay from driver input to last display pixel drawn < 80 ms	Total transport delay from driver input to last display pixel drawn < 80 ms	Total transport delay from driver input to last display pixel drawn < 80 ms
Sounds	5.1 Sound System. Engine sounds and wind sounds are scaled by vehicle speed. Autonomous traffic sounds are scaled by distance and speed.	5.1 Sound System. Engine sounds and wind sounds are scaled by vehicle speed. Autonomous traffic sounds are scaled by distance and speed.	Logitech Z-5500 505 Watts, 5.1 system. Engine sounds and wind sounds are scaled by vehicle speed. Autonomous traffic sounds are scaled by distance and speed.
Motion	Fixed	Fixed	Moog 200E 6 dof Pitch, roll, yaw, heave, surge, sway
Displacement	Fixed	Fixed	DOF Max° Excursion = Surge Single: ± 0.25 m Max.: ± 0.27 m, Sway Single: ± 0.25 m Max.: ± 0.26 m, Heave Single: ± 0.18 m Max.: ± 0.18 m, Roll Single: ± 21° Max.: ± 22°, Pitch Single: ± 22° Max.: + 25°/-23°, Yaw Single: ± 22° Max.: ± 23°
Acceleration (long, lat, vert)	NA	NA	Surge ± 6 m/s2 Sway ± 6 m/s2 Heave ± 5 m/s2 Roll ± 500°/s Pitch ± 500°/s Yaw ± 400°/s
Speed (Roll, Pitch, Yaw)	NA	NA	Surge ± 0.50 m/s Sway ± 0.50 m/s Heave ± 0.30 m/s Roll ± 30°/s Pitch ± 30°/s Yaw ± 40°/s
Cab(s)	None	1/4 cab Saturn sedan	Impala Sedan Silverado
Dash Board	None	Standard dashboard	Virtual Dashboards (licenses for Altia Faceplate and Altia Designer to develop custom gauges and dashboard configurations)
Steering	Logitech MOMO pedal set	Steering uses pre-existing cab.	Steering uses the factory steering system. Tuning of the steering model is based on vehicle type.
Brake Pedal	Logitech MOMO pedal set	Factory brake pedal.	The factory brake by RTI. Custom spring and damper mechanical system has replaced the hydraulic booster in the cabs. The spring rates of the RTI system is adjustable based on specific vehicles.
Gas Pedal	Logitech MOMO pedal set	Factory gas pedal.	Factory gas pedals
Driver Interfaces	Altia Faceplate and Altia Design software has been provided by RTI and Altia for custom gauge and Instrument panel interface design.	Altia Faceplate and Altia Design software for custom gauge and Instrument panel interface design; a haptic seat cushion is available.	Altia Faceplate and Altia Design software for custom gauge and Instrument panel interface design; center Stack Display in Impala is touch screen. Altia can be used to create custom touchscreen interfaces.
Other systems		Seeing Machine Eye tracking system.	Seeing Machine eyetracking systems integrated with real time object detection.

APPENDIX F

RANDOMIZATION

Randomized Run Order:

Participant	Drive	Sequence
1	1	1
1	6	2
1	3	3
1	4	4
1	8	5
1	2	6
1	5	7
1	7	8
2	7	1
2	1	2
2	4	3
2	6	4
2	2	5
2	3	6
2	5	7
2	8	8
3	3	1
3	8	2
3	1	3
3	6	4
3	7	5
3	5	6
3	2	7
3	4	8
4	1	1
4	6	2
4	3	3
4	8	4
4	5	5
4	2	6
4	7	7
4	4	8

Randomized Run Order Continued:

Participant	Drive	Sequence
5	6	1
5	3	2
5	8	3
5	2	4
5	4	5
5	7	6
5	5	7
5	1	8
6	1	1
6	4	2
6	7	3
6	2	4
6	8	5
6	5	6
6	3	7
6	6	8
7	3	1
7	4	2
7	5	3
7	1	4
7	8	5
7	7	6
7	6	7
7	2	8
8	6	1
8	5	2
8	4	3
8	8	4
8	3	5
8	2	6
8	7	7
8	1	8

Randomized Run Order Continued:

Participant	Drive	Sequence
9	4	1
9	1	2
9	3	3
9	2	4
9	5	5
9	6	6
9	7	7
9	8	8
10	3	1
10	8	2
10	1	3
10	7	4
10	4	5
10	5	6
10	2	7
10	6	8
11	5	1
11	4	2
11	1	3
11	2	4
11	3	5
11	6	6
11	8	7
11	7	8
12	1	1
12	4	2
12	7	3
12	2	4
12	8	5
12	5	6
12	3	7
12	6	8

Randomized Run Order Continued:

Participant	Drive	Sequence
13	2	1
13	7	2
13	1	3
13	8	4
13	3	5
13	5	6
13	6	7
13	4	8
14	2	1
14	8	2
14	6	3
14	1	4
14	5	5
14	4	6
14	3	7
14	7	8
15	6	1
15	7	2
15	4	3
15	1	4
15	3	5
15	8	6
15	5	7
15	2	8
16	5	1
16	8	2
16	7	3
16	2	4
16	3	5
16	6	6
16	4	7
16	1	8

Randomized Run Order Continued:

Participant	Drive	Sequence
17	6	1
17	3	2
17	8	3
17	1	4
17	2	5
17	5	6
17	7	7
17	4	8
18	2	1
18	4	2
18	7	3
18	5	4
18	8	5
18	6	6
18	3	7
18	1	8
19	1	1
19	2	2
19	8	3
19	3	4
19	5	5
19	4	6
19	6	7
19	7	8
20	7	1
20	5	2
20	4	3
20	2	4
20	3	5
20	1	6
20	8	7
20	6	8

Randomized Run Order Continued:

Participant	Drive	Sequence
21	7	1
21	6	2
21	3	3
21	4	4
21	8	5
21	1	6
21	5	7
21	2	8
22	7	1
22	2	2
22	5	3
22	4	4
22	3	5
22	1	6
22	6	7
22	8	8

Frequency of Drive Numbers 1-8 in Ordinal Positions 1-8:

	Drive Number							
Ordinal Position	1	2	3	4	5	6	7	8
1	░ 5	▓ 2	░ 4	░ 4	▓ 0	░ 3	▓ 0	░ 4
2	░ 3	▓ 2	▓ 0	░ 7	▓ 2	░ 3	▓ 2	░ 3
3	░ 3	▓ 2	░ 4	▓ 1	░ 7	▓ 1	░ 4	▓ 0
4	▓ 1	░ 5	░ 4	░ 3	▓ 2	▓ 2	▓ 1	░ 4
5	▓ 2	▓ 2	▓ 2	▓ 1	░ 4	░ 6	░ 5	▓ 0
6	░ 4	░ 3	▓ 1	▓ 2	▓ 0	░ 4	░ 4	░ 4
7	░ 4	▓ 2	░ 4	▓ 1	▓ 1	▓ 2	░ 4	░ 4
8	▓ 0	░ 4	░ 3	░ 3	░ 6	▓ 1	▓ 2	░ 3

░ Above Average Frequency

▓ Below Average Frequency

APPENDIX G

POST-DRIVE QUESTIONNAIRE

Post-Drive Questionnaire[1] **Date____________ Participant ID________________ Drive ID_______________**

For each question, please answer by placing an "X" in the appropriate box:

	Not Consistent			Moderately Consistent			Very Consistent
How much did your visual experience of this virtual environment resemble your real-world driving experiences?							
	Not Natural			Moderately Natural			Very Natural
How natural did your interactions with the virtual environment seem compared to the real environment?							
	Not Realistic			Moderately Realistic			Very Realistic
How realistic was your sense of motion inside the virtual environment compared to the real world?							
How realistic was your sense of sound inside the virtual environment compared to the real world?							
How realistic did the vehicle feel inside the virtual environment compared to the real world?							
	Not Distracting			Moderately Distracting			Very Distracting
Did any aspect of the quality of the visual scene interfere or distract you from performing assigned tasks or required activities?							
Did any aspect of the quality of the field of view interfere or distract you from performing assigned tasks or required activities?							
Did any aspect of the quality of the motion system interfere or distract you from performing assigned tasks or required activities?							

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[1] Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240.

Questionnaire Question Classification:

Number	Question	Category
1	How much did your visual experience of this virtual environment resemble your real-world driving experiences?	Realism
2	How natural did your interactions with the virtual environment seem compared to the real environment?	Interaction
3	How realistic was your sense of motion inside the virtual environment compared to the real world?	Realism
4	How realistic was your sense of sound inside the virtual environment compared to the real world?	Realism
5	How realistic did the vehicle feel inside the virtual environment compared to the real world?	Realism
6	Did any aspect of the quality of the visual scene interfere or distract you from performing assigned tasks or required activities?	Interaction
7	Did any aspect of the quality of the field of view interfere or distract you from performing assigned tasks or required activities?	Interaction
8	Did any aspect of the quality of the motion system interfere or distract you from performing assigned tasks or required activities?	Interaction

APPENDIX H

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN SUBJECT RESEARCH AT MONTANA STATE UNIVERSITY

The effect of simulation attributes on driver perception and behavior

As a licensed driver, you are being invited to take part in a study of driver behavior and perception. The research is being conducted by the Western Transportation Institute at Montana State University.

The purpose of the study is to explore how drivers respond to virtual driving environments.

Procedures: If you agree to take part in the study, you will take part in two experimental sessions. The first session occurring today will last approximately one and a half hours. The second session will occur on a date agreed upon by the participant and researcher and will last approximately one hour.

You will the first experimental session by practicing driving a high-fidelity driving simulator on rural roads. The training session will last approximately 2 minutes and will be followed by the test session lasting approximately 1.0 hour that is comprised of 4 drives in different virtual reality scenarios in the simulator. You will be given a break after the training session and will be asked to complete a questionnaire before continuing to the experimental session. At the end of each of the drives you will be given a short break and will complete a questionnaire about your experience. The second experimental session will last approximately one hour and will be comprised of 4 drives in different virtual reality scenarios in the simulator. These drives will be conducted in a similar manner as in the first experimental session. During the drives, we will collect driving behavior data which is automatically collected by the simulator. We will also record video of your face; this will only be used for research purposes.

Risks: There are no significant risks associated with this study other than you might experience some temporary motion discomfort (sweating, dizziness, abdominal discomfort) while driving in the simulator.

In the event your participation in this research results in injury to you, medical treatment consisting of calling emergency personnel will be available. No funds are available for such treatment. Further information about this treatment may be obtained by calling Suzy Lassacher at 406-994-6010.

Benefits: There may be no immediate benefits to you. Future benefits of the research may include better understanding of the use of simulation as a research and training tool.

Compensation: You will receive $10.00 for completing the study. If you choose to withdraw from the study you will still receive full compensation.

Participation is voluntary. You do not have to take part in this research and you may withdraw your consent and leave the study at any time without penalty.

Confidentiality: Your confidentiality will be fully protected. You will be assigned a code number and all measures will be recorded under that number. No data collected from you will be identified with you directly in any public venue. Your driving performance scores will only be reported as group averages. However, excerpts of individual data may be used in conference settings as examples of this study within the academic community. In such cases, you personal identify will not be included.

Questions:

Questions or complaints about the research should be directed to Shaun Durkee, Western Transportation Institute, Montana State University – Bozeman, MT 59717-4250. Phone: 406-600-6430.

You have certain rights as a participant in this research. Questions about these rights should be directed to Dr. Mark Quinn, Chair of the Human Subjects Committee, Montana State University – Bozeman, MT. Phone: 406-994-5721.

Please feel free to ask the researchers any questions that you may have before signing this consent form.

AUTHORIZATION: I have read the above consent form and it has been explained to me. A copy of this consent form has been given to me. All of my questions have been answered to my satisfaction. I agree to participate in this study. I understand that I am free to withdraw at any time without penalty.

Name (Print): ___________________________________ Date: ___________

Signature: ___________________________________

Investigator: ____________________________________

Time of arrival: ________________ Total hours completed: ________

Time of completion: ____________ Payment: _______

APPENDIX I

SUBJECT DATA SHEET

Subject Data Sheet

ID #…….……………………____________________

Date of Birth………………. ____________________

Age………………………… ____________________

Years Driving Experience...____________________

Miles Driven per Year…….____________________

Contacts or Glasses………____________________

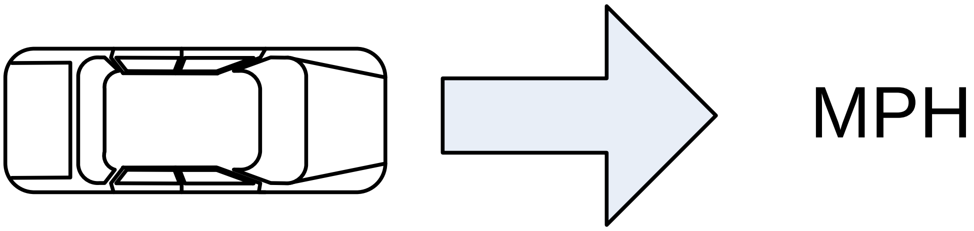
Sex:
☐ male
☐ female

APPENDIX J

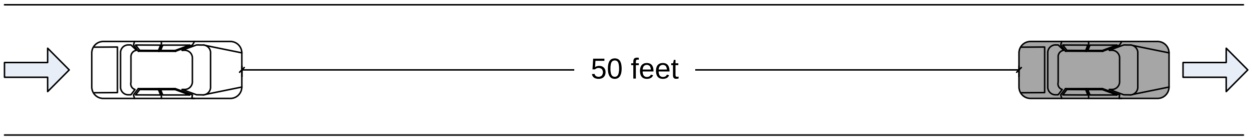
EXPLANATION OF SPEED AND FOLLOWING DISTANCE

Explanation of speed and following distance:

For speed please use miles per hour (MPH).



For following distance please use feet (ft).



APPENDIX K

DEBRIEFING STATEMENT

Debriefing Statement

Title: The effect of simulation attributes on driver perception and behavior
Principal Investigators: Shaun Durkee, Nic Ward, PhD

Dear Participant:

Thank you for your participation in our study. The purpose of this study is to explore our new high-fidelity driving simulator in depth to learn how changes in fidelity influence driver behavior and perception. We measured your driving behavior in response to changes in simulator motion, field of view, and scene complexity. This allows for collection of data that includes accuracy of speed and following distance perception.

All collected information and data will remain confidential. If you have any questions concerning your participation, please feel free to contact Dr. Nic Ward at nward@coe.montana.edu or at 406-994-5942. Researcher, Shaun Durkee, is also available for additional information and can be contacted at shaun.durkee@coe.montana.edu.

If you are interested in the final report of this research, available by spring 2010, please contact either Dr. Nic Ward or Shaun Durkee expressing your interest in our results. Thank you again for your participation.

Sincerely,

Dr. Nic Ward and Shaun Durkee

APPENDIX L

PARTICIPANT COMPENSATION FORM

RESEARCH PARTICIPANT COMPENSATION

Project: Shaun Durkee Thesis: Simulation Study

Investigator: ____

Investigator Signature: ____________________________________

Sum paid: ____

Payment to:

PLEASE PRINT LEGIBLY!!!

Name: ____

Signature: ____

Address: ____

____