A BASELINE EXPERIMENT AND INITIAL INVESTIGATION OF THE EFFECTS OF VIRTUAL IMMERSION ON VEHICLE PASSENGER RISK PERCEPTION

A Thesis in
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by
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Abstract

This thesis describes an experiment to determine a baseline for vehicle passenger risk perception. This experiment was part of a larger study aimed at understanding the effect of virtual and mixed-reality environments on risk perception in man-machine systems. Virtual environments are increasingly being used to understand system performance in preliminary stages of the design of man-machine systems. Virtual immersion, however, introduces a layer of abstraction and safety between the participant and the designed artifact, which includes an associated risk compensation. Quantifying and modeling the relationship between this risk compensation and levels of virtual immersion is the greater goal of this project. This thesis focuses on the first step, which is to determine the level of risk perception for a purely real environment for a specific man-machine system - a ground vehicle. In addition, a preliminary investigation was made in the effect of one form of virtual immersion – video pass-through – on risk perception.

The experiment was split into two parts: the first was designed to assess the subjects’ latent response, and the second was designed to assess their learned response. The latent response protocol applied to the first exposure of an experimental condition to the subject. It consisted of having the participants in the passenger seat assess comfort or discomfort within a vehicle that was driven around a curve at a randomly-chosen value among a selection of test speeds; participants were asked to indicate when they felt uncomfortable by pressing a brake pedal that was instrumented to alert the driver. Next, the learned response protocol assessed the participants for repeated exposures but allowing subjects to use brake and throttle pedals to indicate if they wanted to go faster or slower; the goal was to allow participants to iterate toward their maximum comfortable speed. These pedals were instrumented to alert the driver who responded accordingly. Both protocols were repeated for a second curve with a different radius.

The results showed that the participants’ uncomfortable speeds were independent of the direction of travel and of the approach speed. No evidence was found of a learning effect by which participants became more comfortable at higher speeds with successive exposures to a curve. A follow-up experiment was conducted that investigated the effect of wearing a headset with video pass-through capability on the participants perception of risk. The results of this experiment were mixed – some participants selected significantly different speeds when wearing the headset, while others did not. Overall, the headset did not significantly affect the average speed selection. However, the headset did significantly increase the participants’ perception of difficulty and risk while traversing the curves.
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1.1 Motivation

The studies presented in this thesis are motivated by a particular confluence of technologies including: drive-by-wire systems, portable computing, and high-fidelity gaming and simulation tools. Drive-by-wire refers to the use of electrical or electro-mechanical systems to replace mechanical systems. This technology makes it easier to record and remotely operate automotive systems such as the throttle, brake, and steering. Recent advances in computing have made portable simulators possible. Specifically, head mounted displays (HMD) have the potential to replace the monitors and projector screens that have previously formed all driving simulators. Furthermore, the computational power necessary to run a high-fidelity simulations can be handled by a single computer. Lastly, the tools used to create driving simulations have become more accessible and advanced than ever before [1–4].

These capabilities enable a unique comparison between simulator driving and real driving scenarios. For example, a HMD could be worn while travelling in a real vehicle, providing simulated visuals but real vestibular motion to the user. Another example could be a user in a stationary driving simulator that is teleoperating a real vehicle located elsewhere. These examples serve to highlight the complexity of the spectrum between real and simulated driving. Modern technology allows the possibility to manipulate the levels of this spectrum in terms of modalities (visual, auditory, vestibular motion, etc.) and in terms risk factors.

The relevance of understanding the differences between simulated and real driving behaviors is evident by the usage and need of driving simulators for engineering new vehicle technologies. For example, the design of driver alert systems have been heavily informed by studies conducted with driving simulators. These studies span from the timing of imminent rear-end collision warnings [5], to the comparison of information presented by Head-Up Displays [6], to the effectiveness of imperfect collision avoidance systems [7]. These studies are critical for development of driver alert systems, and many are only possible with the use of driving simulators due to the inherent risks of alert inducing scenarios. A more complete review of driving simulators is presented in later chapters.

The perception of risk may significantly affect behavior, and this interaction is poorly under-
stood. While details of this are also presented in later chapters, the primary theories of driver risk perception include: the Risk Homeostasis Theory [8], Risk Threshold Model [9,10], and Risk Avoidance Model [11]. Risk Homeostasis Theory is the idea that drivers make adjustments to maintain a level of acceptable subjective risk. The Risk Threshold Model, also known as the Zero-risk model, differs from Risk Homeostasis Theory in that it assumes that drivers only make risk compensating adjustments if their perceived risk is greater than some threshold. Otherwise the driver’s perceived risk is zero. Lastly, the Risk Avoidance Model suggests that drivers seek to maintain a perceived level of difficulty, rather than a perceived level of risk.

Given the available recently-developed capability at the Penn State Intelligent Vehicles and Systems Group to answer these questions, it is important and pressing to define methods to assess driver risk. The overriding motivation of this thesis is to improve understanding of driver risk behavior by developing and analyzing experiments that quantify drivers’ risk-perception inputs.

1.2 Research Goals

This thesis seeks to provide the groundwork necessary to evaluate the relationship between risk compensation behaviors and levels of immersion in virtual and mixed-reality environments. This includes designing an experiment by which risk perception can be measured and compared across different levels of virtual immersion. This experiment was conducted for the real-world scenario, providing a baseline by which to compare with risk compensation behaviors in virtual and mixed-reality scenarios. A second experiment was conducted to investigate the effect of one mixed-reality scenario, wearing a headset with video pass-through.

Specifically, this thesis seeks to quantify perception of risk in speed-keeping within high-speed cornering of passenger vehicles, from a passenger’s perspective. The experiment was split into two parts: the first was designed to assess the participants’ latent response, and the second was designed to assess their learned response. The latent response experiment consisted of having the participants in the passenger seat of a vehicle that was driven around a curve at a random speed. Participants were asked to indicate when they felt uncomfortable by pressing the brake pedal that was instrumented to alert the driver. This test was only performed once per participant. The learned response experiment was included because of the expectation that participants would become more comfortable with successive trials of the experiment. This part of the experiment was similar to the first, except that the participants used brake and throttle pedals to indicate if they wanted to go faster or slower. These pedals emitted sounds to which the driver would respond. The obtained result was the maximum speed at which the participant was comfortable for a given radius curve. Both experiments were repeated for a second curve with a different radius.

These experiments were inspired by the experiments done by Carol H. Tan in her thesis, “An Investigation of the Comfortable Lateral Acceleration on Horizontal Curves” [12]. In her experiment, 117 participants were driven around three curves at various speeds, and were asked to indicate when they felt uncomfortable. The results of this study were used to inform the safe friction limits in the design of curved roads. The experiment was conducted at the Larson
Institute Test Track, the same location used for the experiments in this thesis. The common location and use of risk assessment made Tan’s thesis an ideal template and means of comparison for the experiments of this thesis.

Although the results of this work are intended to generalize across virtual or mixed-reality environments, the experiments are focused on ground vehicles. The reasons for this are two-fold: 1) driving is a common yet licensed activity in the population and thus risk is more clearly understood within the context of requiring training for the driving task, and 2) driver decisions are mediated through a small set of easily measurable inputs (steering, braking, and throttle). The experiment is further simplified by limiting subject inputs to using only the throttle and brake. Furthermore, these inputs were mediated through a driver who interpreted the inputs as an auditory signal.

1.3 Outline of Following Chapters

The remaining chapters of this thesis are organized as follows: Chapter 2 presents the current research related to driving simulators, their validity, and risk perception. Chapter 3 details the experimental design and protocol used in this thesis. Chapters 4 and 5 present an analysis of the results gained from the latent and learned response protocols, respectively. Chapter 6 describes the protocol and data analysis of the second experiment that investigates the effect of wearing a video pass-through headset on risk perception. Lastly, Chapter 7 concludes this thesis and proposes future work.
Chapter 2  |  Literature Review

Virtual Reality (VR) and simulation technologies have rapidly improved over the last three decades to where, today, they are widely used and more heavily relied upon than before, particularly in the areas of training, research, and design. The resulting utilization of these capabilities has proven simulation technologies to be a versatile and powerful tool. Because driving simulators are fundamentally different than naturalistic driving, the validity of simulations to make conclusions about true driver behavior must be carefully considered.

For the purposes of this thesis, a more careful definition of “virtual reality” versus a “simulation” is needed. The term “virtual reality” is, in the context of this thesis, meant to denote the presentation of artificial information to a human, which can include visual, auditory, or tactile information. The term “simulation” is meant to denote the construction or instance of a situation intentionally created to study the behaviors of a system or systems interacting in time; the systems can include humans, devices, algorithms, and of course any combinations of these. In the context of these definitions, VR can be a means to interact with simulations, but VR technology is not assumed to be necessary for a simulation to be used with validity. Similarly, VR can be used outside of simulations, for example to view a static world scene in 3D rather than as a 2D image.

This thesis is motivated by the trend where real driving technologies are being deployed that are increasingly using virtual reality as interfaces for simulated environments. Some examples that have recently been employed in modern vehicles are parking assistance technologies (e.g. rear-view video camera systems) [13], augmented reality Head Up Displays (HUDs) [6], automatic collision avoidance systems [14], and adaptive cruise control [14]. These technologies introduce layers of abstraction between the driver and the driving task, which may result in an associated risk compensation. While the impact of these technologies on driver psychology has been broadly studied [15], there are opportunities remaining for further research.

2.1 Introduction

The earliest meaningful use of VR technology was in flight simulators for training pilots [16]. These were motivated because the risks and costs inherent in real-world flying make live training
exercises very dangerous and/or limited [17]. Flight simulators are the obvious solution to these limitations, and have thus become very common. In fact, the majority of commercial pilot training is now done in simulators [16], and more recently, training requirements for military pilots have emphasized a mix of live and simulator training [18]. In addition, simulators have enabled engineers to reveal design flaws early in the aircraft design process [17].

The success of flight simulators has led other fields that also have inherent usage or training risks to adopt training simulators as well. The medical field, in particular, has seen a rapid growth of simulation-based training for experiential learning [19]. Like flying an aircraft, the stakes involved in many medical procedures are life-or-death, stressing the need for effective yet safe training tools. The potential for simulation as a training tool has prompted the development of simulators for a wide variety of medical procedures [20–26]. The American Association of Medical Colleges’ and Society for Academic Continuing Medical Education’s Harrison survey reported that nearly 60% of the participating medical schools, teaching hospitals, and clinical academic societies reported at least occasional use of simulators in their education activities [19]. Other fields that have seen a similar increase in the use of simulators for training purposes are space travel [27], search and rescue teams [28], paramedics [29], and war games for the military [16], to name a few.

VR technology has also had significant impact in design. Virtual prototypes can be more easily evaluated and reconfigured, potentially reducing time and error rates in product development [30]. They also enable better integration of human factors during the design process [31]. A specific example is the design of machine tools, where VR is an effective platform for visualization and communication [32]. Another example is in the use of anthropometric data for design, where VR allows “accurate visualization of the relationships among human landmark data and workstation geometry” [33]. While the use of VR tools for design is increasing, it is not a key focus of this thesis.

In research, VR has become valuable for its contributions to studying psychology and man-machine systems. Driving simulators, in particular, are a common research tool to study human decision making specifically isolated from vehicle design or performance improvement/training of specific operators. For example, driving simulators have been used to address topics such as the factors that affect mental workload [34] or situation awareness [35], collision warning timing [5, 7, 36, 37], takeover time for highly automated vehicles [38, 39], fog conditions [40–43], and the effects of different distractions [44, 45]. The inclusion of simulators in research has provided the opportunity to study a wide range of problems, which were difficult or infeasible to study otherwise.

VR technology is likely to be an increasingly core component of simulator studies due to the inherent advantages of simulator-based testing, training, and interaction. VR simulators provide the opportunity to study rare or dangerous situations; they provide strict control and recording of a scenario; they enable reproducible situations; and they have the potential to save time and money [46, 47]. The examples provided in this section attest to the value that VR simulators can provide.

The advantages of VR usage in simulations are not without a cost, however. The widespread
use and reliance on VR simulators has prompted questions about their validity. Specific questions arise such as: how well do VR simulators create a perception of realism? How is the perception of realism related to the perception of risk? Does the absence of risk in simulators necessarily cause risk compensation behaviors? These questions have significant ramifications on the use of VR simulators, and they have not yet been satisfactorily answered.

In the sections that follow, the state-of-art is examined via a literature review focusing primarily on three areas: 1) risk theory and risk assessment; 2) historical and novel uses of driving simulators to assess driver risk and to assess fidelity of simulator-based decision-making; and 3) the specific studies and methods of driver risk measurement that motivate the experiments of this thesis.

2.2 Risk Theory and Risk Assessment

2.2.1 Risk Theory

There are several competing theories regarding the relationship between human behavior and risk. These theories generally agree that risk is a determining factor in human behavior, but differ in their ideas about how humans perceive and respond to risk. Although these theories apply broadly to psychology, they are presented in the specific context of driver behavior. This is because the potential societal impact of improving traffic safety is considerable [48], and because driver inputs to a vehicle are limited in number and relatively easy to measure. The following is not intended to be a comprehensive review of traffic psychology, but is instead meant to provide a context by which driver risk can be understood.

Wilde presented the theory of Risk Homeostasis in 1982, which suggests that drivers seek to maintain a target level of perceived risk [8, 49]. Wilde argues that drivers weigh the costs and benefits of alternative actions to find a target level of risk. Then at any moment in time, drivers compare their perceived level of risk with their target level of risk, and adjust their behavior to minimize the error between the two. The likelihood of injury for any actions taken over a period of time and in a jurisdiction ultimately yields the accident rate for that period and jurisdiction.

The implication of Risk Homeostasis Theory is that safety measures such as seat belts, airbags, and anti-lock brakes might not reduce the per-capita death rate even if widely used. Instead, drivers would perceive their level of risk as lower, thus driving more aggressively to compensate. The increase in aggressive driving would offset the safety benefits that were originally intended. Wilde suggests that a better method for improving traffic safety is to provide safety incentives. This would lower drivers' target level of risk, rather than their perceived level risk for which they would compensate. The validity of the Risk Homeostasis Theory have been extensively debated, but definitive conclusions have not yet been reached. The major factors hindering this debate are the absence of scientific rigor in the application of safety measures which would provide potentially relevant evidence and the methodological limitations of laboratory and simulator studies to evaluate naturalistic behavior [50]. A consequence of these limitations are that different researchers can draw conflicting conclusions regarding the same phenomena (see [51–54] for
examples of evidence presented against Risk Homeostasis Theory, and see [50,55] for examples of evidence supporting the theory).

The Zero-Risk Theory introduced by Näätänen and Summala says that drivers perceive no risk during day-to-day driving [10,48]. This is because driving “becomes a habitual, largely automated activity in which risk control is based on maintaining safety margins”. In this way, drivers do not account for traffic risks in a way that would be rational as they do in Risk Homeostasis Theory. Instead, only when drivers’ safety-margin thresholds of subjective risk are violated do drivers adjust their behavior. The implication of this theory is that improvements in traffic safety should be achieved by reducing the variance in the system resulting in fewer violations of a driver’s safety-margin thresholds. An example application of this concept is the use of strict speed limits which reduce speed variance and block motivational tendencies to increase speed in response to safety improvements. Summala provides evidence of the beneficial effects of speed limits and argues that this evidence supports the Zero-Risk Theory [10].

A more recent theory of risk has been presented by Fuller, called Risk Allostasis Theory (also known as Task-Difficulty Homeostasis Theory) [56,57]. This theory argues that drivers seek to maintain a range of task difficulty. The determination of task difficulty is made in the framework of the Task-Capability Interface (TCI) model which is a dynamic interface between the demands of the driving task and the capabilities of the driver. In this model, task difficulty is “inversely proportional to the difference between task demand and driver capability”. Risk Allostasis Theory is similar to Risk Homeostasis Theory in that drivers are constantly monitoring a variable and comparing it to a preferred level. The key difference is that in Risk Allostasis Theory drivers use feelings of risk as measures of task difficulty. It is also similar to Zero-Risk Theory in that it assumes that drivers typically operate with zero risk, but will make adjustments when the margins of their preferred task difficulty range are exceeded. Evidence to support this theory has been found by means of simulator experiments where the participants’ subjective measures of task difficulty, statistical risk, and feelings of risk are compared [57,58]. Further research is required to support or refute this theory.

2.2.2 Risk Assessment

To support or refute the theories of risk behavior, it is necessary to have means for measuring risk. Many different measures for assessing risk have been developed, with varying levels of effectiveness depending on the scenario and the goals of the researcher. One of the earliest and most famous risk assessment studies was conducted by Taylor in 1964, where Taylor found a relationship between participants’ galvanic skin response (GSR) and the accident rate for a section of a road [59]. Taylor associated the GSR with the participants’ level of emotional tension or anxiety, which Wilde later associated with their perceived level of risk, and Fuller associated with the task difficulty [8,56]. This example serves to demonstrate the difficulty of relating different measures (e.g. GSR) with their underlying causes (e.g. anxiety or perceived risk or task difficulty). There is no single perfect measure of risk, so often multiple measures must be considered together.

Several methods for measuring risk have been developed, and these methods generally fall into
the categories of subjective or objective measures. Subjective measures of risk include a variety of questionnaires and rating systems intended to evaluate a person’s feeling of risk. Objective measures include measures of performance such as longitudinal speed, lateral position, and error rates; and physiological measures such as heart rate and GSR.

There are many examples of subjective risk measurements in the literature, and these can be categorized more specifically by their means of assessment. For example, Likert-type scales are commonly used to provide a rating between two extremes (e.g. “no risk” and “maximum risk”). These scales are used to rate a variety of risk-related responses such as task difficulty, estimate of statistical risk, fear, and comfort [57,58,60]. Another example is questionnaires that ask about factors such as personality traits and demographics to provide an estimate of a driver’s risk taking behavior [61]. These subjective measures of risk are generally found to be correlated to objective measures of risk, but without enough predictability to be considered reliable on their own.

The examples in the literature of objective measures of risk are generally classified by the physiological measurements being collected, or the surrogates for physiological measures (naturalistic driving studies and performance measures). Commonly used physiological indicators are heart rate and GSR. As discussed previously, Taylor used measures of GSR to associated accident rate with feelings of emotional tension or anxiety [59]. Another example is from Mühlberger et al., who associated heart rate and GSR with phobic fear of tunnels in VR tunnel driving [60]. Physiological indicators are more commonly used to assess driver mental workload [62,63]. However, the limitations of physiological indicators for measuring mental workload are also applicable for measuring risk perception, and they include: lack or repeatability, difficulty discriminating signal from noise, lack of sensitivity, and confounding variables such as physical exertion, emotional state, and ambient lighting [62].

In driving, it is recognized that the situations to assess risk might inform the test-subject in a way that changes driver behavior, and thus naturalistic driving studies are increasingly used to assess driving risk. Naturalistic driving studies may collect data about individuals’ demographics and personality, as well as driving characteristics (e.g. speed, braking/acceleration behavior, accident type and rate). Examples of these studies show how they can be effective at identifying which factors most influence driver risk levels [64] and how these factors can predict high-risk drivers [65].

In driving studies, one of the most common objective methods of measuring risk is to examine a driver’s performance. Of the different measures of driver performance, the one most commonly used to assess risk compensation behavior is speed. This is related to the risk theories discussed previously, which consider speed adjustment to be the primary method by which drivers maintain their target level of perceived risk or difficulty [66]. Other performance measures of risk include standard deviation of lane position, time to collision, error rates, and gaze point. An example of the use of performance measures to assess risk is from Hiraoka et al., who measured the change in driver imposed vehicle velocity when exposed to a Night Vision Enhancement System [67]. Another example is from Itoh et al., who measured the accident rates for different levels of automation in a driving-like microworld [68]. These are only two of many experiments that have
used performance measures to evaluate compensation behaviors. It is important to distinguish that these studies measure compensation behaviors and not risk perception. The coupled relationship between compensation behaviors and risk perception is at the core of the ongoing debate between the risk theories discussed previously.

The range of objective measures of risk described above primarily focus on measurements relative to scenarios, but an equally important topic is the assessment of perceived risk relative to the display of information to the driver. In a driving simulator, the level of actual risk is always zero, yet researchers find that test-subjects exhibit risk compensation behaviors in response to changes in a scenario. This begs the question: what cues in a VR simulator influence a person’s perception of risk? And how similar are these cues to real-world situations?

2.3 Driving Simulators and Risk

2.3.1 Taxonomy

To have an effective discussion about VR mediated simulators it is first necessary to establish a taxonomy for ambiguous terms such as “virtual immersion”, “mixed reality”, or “simulator fidelity”. There are many different forms of VR ranging from cartoons to photo-realistic representations of the real world, and VR technologies that include head mounted displays, projector screens, and 6 degree of freedom motion bases. The wide variety and rapid growth of VR technology has made it difficult to classify its’ forms. Further complication is added when considering the validity of VR simulators, which raises questions such as: what makes an environment seem real?

There is ongoing debate and definition development surrounding levels of virtual immersion. The term “virtuality continuum” has been proposed by Milgram and Kishino to represent the entire spectrum between real and virtual environments [69]. Every level of reality within this continuum is considered Mixed Reality (MR). MR can be further divided into Augmented Reality (AR) and Augmented Virtuality (AV). AR refers to a real environment that includes virtual (computer-generated) objects. Conversely, AV refers to a virtual environment that includes real (e.g. video) elements. As technology improves, the distinction between AR and AV can become blurred when considering if an environment is predominantly real or virtual. Further complexity arises when considering the degree to which the environment naturally responds to a user’s inputs and the user’s point of view in the environment. Milgram and Colquhoun named these dimensions congruence and centricity, respectively [70]. The taxonomy for elements within the virtuality continuum may continue to evolve as technology enables new interfaces with virtual environments.

When discussing the quality or effectiveness of a simulator, words such as “validity”, “fidelity”, and “realism” are commonly interchanged in the literature. For the term “fidelity” alone, Lane and Alluisi (1992) found at least 22 definitions in the literature referring to the different forms of fidelity [71], and still more have been developed since then [46,72–74]. A general definition for fidelity is “the degree to which the virtual environment is indistinguishable from the real
environment” [74]. Within this definition, the many specific forms of fidelity include experiential fidelity (also known as presence), equipment fidelity, environmental fidelity, psychological fidelity, physical fidelity, etc. [75]. Several different taxonomies exist in the literature to categorize the many forms of fidelity [73, 75–77].

The taxonomy for fidelity most useful for this thesis was established by the Advisory Group for Aerospace Research and Development, and uses the categories of objective fidelity and perceptual fidelity [77]. Objective fidelity is “the degree to which a simulator would be observed to reproduce its real-life counterpart...if its form, substance, and behavior were sensed and recorded by a nonphysiological instrumentation system onboard the simulator”. The effects of objective fidelity on simulator assessment and performance has been well studied in the literature [75, 78–80]. Perceptual fidelity is “the degree to which the [user] subjectively perceives the simulator to reproduce its real-life counterpart...in the operational task situation”. This might include subcategories such as psychological fidelity, ethological fidelity, and experiential fidelity.

As this thesis is concerned with risk perception, the relevant form of fidelity is perceptual fidelity, and its subcategory, psychological fidelity. Elliot, Schlefft, and Coover define psychological fidelity with regards to training simulators as “the extent to which the training environment prompts the essential underlying psychological processes relevant to key performance characteristics in the real-world setting.” [81]. However, as discussed in Section 2.2.2, assessing risk perception is impossible to do directly. Instead, the experiment put forth by this thesis assesses risk perception by measuring compensation behavior in the form of vehicle speed control. A comparison of performance measures between levels of virtual immersion is categorized as ethological fidelity, not psychological fidelity. Ethological fidelity (also called action fidelity [73]), is the extent to which the observed behavior in a simulator resembles the observed behavior in the simulated systems [46].

Although the term “validity” is often interchangeable with “fidelity”, in this thesis “validity” will refer specifically to the type of comparison made between real and VR environments, which can be absolute or relative. Relative validity is when the performance differences between experimental conditions in a simulator are of the same order and direction as performance differences between similar conditions in the real environment [82]. Absolute validity is an additional criteria that stipulates that the numerical values for the performance differences between experimental conditions in the simulated environment are statistically equal to those in the real environment [82].

### 2.3.2 Limitations of Simulators

The technological limitations of VR simulators can be categorized by the sensory modalities that the technologies are intended for: visual, auditory, and motion. The VR technologies available for presenting visual information include computer screens, projections on flat or curved screens, and head-mounted displays. The important features of these technologies include the field of view, pixel resolution, brightness, contrast, and the capability for blending the images from multiple screens/projectors [83]. Some VR simulators include motion bases to provide the appropriate inertial, proprioceptive, and tactilo-kinesthetic cues [46]. The most advanced motion
bases include 6 degrees of freedom and linear rails for lateral and longitudinal motion. However, even the most advanced motion base cannot completely reproduce real-world accelerations [46]. The presentation of virtual auditory information can vary in the number, quality, and location of speakers, as well as the diversity of the sounds produced [46]. Unfortunately, there are relatively few studies in the literature about the effect of auditory cues in VR simulators.

VR technology is also limited by the software required to render virtual environments. A few of the ways virtual environments can vary are the quality of the graphics (textured surfaces vs. flat-shaded), the lighting algorithms, and the physics models. For example, in driving simulators the physics model for the vehicle can be as simple as the “kinematic model”, or as complex as to simulate the vehicle’s powertrain, steering, suspension, and the tire-road interface [83,84]. In addition, a limitation relevant to both the software and hardware of VR technology is extent of time lag between user inputs and the response in the virtual environment [46,83]. Further details about the limitations of VR technology can be found in the literature [46,72,77,83,85,86].

Simulator sickness (also called cybersickness) is a visually-induced form of motion sickness that causes physiological reactions in the form of clinical symptoms (headaches, nausea, etc.) [46]. Although it is relatively common in the use of VR simulators, the variation in symptoms and intensity, as well as the variation in the conditions that cause simulator sickness make the underlying processes difficult to identify and understand. There are, however, several theories to explain simulator sickness in the literature. One theory with great explanatory power is sensory conflict theory [87]. This theory suggests that a discrepancy between the sensory information that is received and the sensory information that is expected leads to a feeling of sickness. By this theory, it is the failure of a VR simulator to produce the sensory cues that an individual expects in the real scenario which causes simulator sickness. Another theory is the rest frame hypothesis, which suggests that instead of a physical conflict between contradictory sensory signals, it is a mental conflict between contradictory rest frames which cause a feeling a sickness [88]. It is a subtle, yet important distinction that simulator sickness may be caused by a cognitive conflict versus a sensory conflict. One other theory is the postural instability theory [89], which suggests that simulator sickness is caused by a “lack of adequate strategies for maintaining a stable posture in the new situation” [46]. These theories of simulator sickness serve to highlight the limitations of VR simulators, and the need to better understand the way VR simulators influence our perception of reality.

Although it may be considered both an advantage and a limitation, the absence of risk in VR simulators has significant consequences. Stoffregen et al. describe how even in a hypothetically perfect simulator, where the virtual environment is entirely indistinguishable from reality, the knowledge that you are in a simulator means that your actions have no real consequences, whereas they may have life-or-death consequences in the real environment [73]. This cognitive gap between knowing that one is in a simulation, yet being presented all of the stimuli that are equivalent to reality, is bridged by the idea of presence. Presence is another name for experiential fidelity, a form of perceptual fidelity discussed in Section 2.3.1. It refers to the subjective feeling of “being there”, and is often likened to the realism of a simulation [73]. There are many examples in the literature that examine what factors influence presence, and the effect of presence on
performance, simulator sickness, and transfer of training [76,85,90].

2.3.3 Driving Simulator Validation Studies

Due to the variety of driving simulators in terms of their technological makeup and purpose, there is no standard method for validating driving simulators. The technological makeup of simulators can vary between having a fixed or motion base, or between having a head-mounted display or projectors screens, and so on. This variety makes cross-platform validation especially difficult [91].

The common purposes of driving simulators are training and research, which might have different goals in terms of validation. Training simulators are generally focused on the transfer of training to the operational environment, which might, for example, place greater focus on equipment fidelity of the simulator [72]. Driving simulators for research, however, have a wide variety of goals which depend on the independent and dependent variables that are being considered. The independent variables considered in driving simulator research include environmental effects (e.g. fog, situation complexity), driver characteristics (e.g. age, experience), and the evaluation of new technologies (e.g. alerts system timing). Dependent variables considered in simulator research are most commonly performance measures (e.g. speed/steering control, response time, error rate) or subjective measures (e.g. mental workload, situation awareness, difficulty rating).

Due to the variety of driving simulator technologies and purposes, there are a variety of results for validation studies. For example, Blaauw measured longitudinal and lateral vehicle control on straight roads between a fixed based simulator and an instrumented vehicle. Absolute and relative validity were found for longitudinal control, but only relative validity for lateral control which was attributed to a lack of kinesthetic feedback [82]. In a similar study, Blana measured the same performance variables, but found that in the simulator participants drove faster and closer to the edge of the road as compared to their real road counterparts. Blana also measured the subjective response in terms of realism and ease of controlling the simulator, and found that participants who rated the simulator as “good” had smaller speed and lateral position variation when driving in the simulator [92]. Two other studies, one by Meuleners and Fraser and the other by Shechtman et al., evaluated simulator validity by means of type and mean driving errors. Shechtman et al. found relative validity for the vehicle type and direction of turns, and absolute validity for lane maintenance, adjustment to stimuli, and visual scanning [93]. Meuleners and Fraser, however, found only relative validity for similar tasks including visual scanning, speed control, and adherence to traffic lights and stop signs [94]. These are a few of many examples in the literature that serve to illustrate the wide variety of driving simulator validation studies (for more examples see [95–98]). Any simulator validation study is strongly dependent on the specific simulator that is used, the tasks that are under investigation, and the motivation/purpose of the simulator [91,92].

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2.4 Risk Measurement Studies

A primary motivation for the risk perception experiments within this thesis was Carol H. Tan’s thesis: An Investigation of the Comfortable Lateral Acceleration on Horizontal Curves [12]. The purpose of her thesis was to determine the friction factors corresponding to uncomfortable speeds on horizontal curves and to determine the safety margin against skidding of those friction factors.

Tan conducted an experiment where participants were passengers in a vehicle as it was driven around horizontal curves. Participants were asked to indicate when they felt “uncomfortable” by pressing a response button. “Uncomfortable” was primarily defined as feeling a sideways pitch and a desire to slow down.

Several factors were considered in Tan’s study which include: wearing a blindfold, wearing a seat belt, seat position within the vehicle, curve radius, direction of travel, and vehicle speed. Figure 2.1 provides a complete description of the treatments that were included in the study. There were 117 participants included in the study, and each one traversed each curve, speed, and direction at least three times resulting in a total of 9,582 observations.

The following are relevant findings from Tan’s thesis (quoted directly):

- As speed increased, the percentage of participants indicating discomfort increased.
- As curve radius increased:
  - The relative frequency of uncomfortable observations by the participant passengers decreased.
  - The differences between test treatments became less apparent.
- For the most part there were no statistical differences between treatments for participant gender.
- Generally, there were no statistical differences between treatments for the different age groups.
- Seat positions do significantly affect perception of discomfort (front passenger seat vs. right rear seat).
- Direction of travel was not statistically significant for any of the experimental treatments.
- The vast majority of uncomfortable passenger participants indicated discomfort before they reached the midpoint of any of the test curves.
- For the smaller radius curve, results indicated that passenger participants based their discomfort on what they “felt” - net lateral acceleration.
- For the curves with large radii, results indicated that passenger participants possibly based their discomfort more on visual cues rather than net lateral acceleration.

There are a number of additional studies that have examined the driver’s perception of risk due to acceleration. In particular, the National Cooperative Highway Research Program Report
Figure 2.1: Flowchart of study methodology used by Carol H. Tan in her thesis.

774 titled, Superelevation Criteria for Sharp Horizontal Curves on Steep Grades, provides a thorough evaluation of design specifications, recommendations, vehicles dynamics simulations, and field studies related to horizontal curves. This report provides substantial background, methods, and field data by which to compare the results of this thesis.
Chapter 3  |  Experimental Design and Methods

The goal of this experiment was to evaluate driver risk behavior in response to changes in their risk perception inputs which are manipulated by means of VR technologies. This experiment was conducted for the purely real scenario, establishing a baseline by which future, VR augmented scenarios can be compared. An adaption of this experiment was conducted for one mixed-reality scenario: wearing a video pass-through headset. Chapter 6 describes the specific adaptions made for that experimental protocol.

The scope of the baseline experiment was focused on quantifying perception of risk in speed-keeping within high-speed cornering of passenger vehicles, from a passenger’s perspective. Due to the potential for learning effects to influence risk perception, the experiment was split into two separate protocols: 1) a latent response protocol and 2) a learned response protocol. The latent response protocol refers to the first exposure of an experimental condition to a participant. This protocol was designed to replicate the experiment conducted by Carol H. Tan, so that the results could be compared [12]. The learned response protocol refers to every exposure of an experimental condition after the first, and was intended to seek the maximum speed at which a person is comfortable traversing a familiar curve.

3.1 Methods

All experiments were conducted at the Larson Institute Test Track, shown in Figure 3.1. The test track is a 1-mile long loop that includes two curves and 2 straightaways. The curve data are shown in Table 3.1. The design speeds in Table 3.1 were calculated from the curve data provided on the test track plan using Equation 3.1 which is from the American Association of State Highway and Transportation Officials’, A Policy on Geometric Design of Highway and Streets, 2011, 6th (the AASHTO Green Book) [99]:

\[ V = \sqrt{15R(f + e)} \]  

(3.1)
where, \( V = \text{design speed (mph)} \), \( R = \text{radius of curvature (ft)} \), \( f = \text{specified side friction demand} \), and \( e = \text{superelevation (ft/100 ft)} \). The standards for horizontal curves in the AASHTO Green Book were based on the same experiment as in Tan’s thesis, which was originally conducted in the 1930’s and 1940’s [12].

The vehicle used for the experiment was the Intelligent Vehicle and Systems Group mapping vehicle, shown in Figure 3.2. The global position of the vehicle was determined by a military-grade NovAtel DL-4 Differential Global Positioning System (DGPS). Differential corrections were made using a base station at the Larson Institute which was calibrated on November 13, 2016. The resulting precision error \( (1 - \sigma) \) of the Differential GPS (DGPS) was 4.6 mm in X, 5.5 mm in Y, and 3.7 mm in Z. The orientation of the vehicle was determined by a Honeywell HG1700 Inertial Measurement Unit (IMU) and a ring-laser gyroscope. The sensor readings were fused through a factory-integrated Extended Kalman Filter (EKF) to provide a state estimate. The sensors were mounted on a ridged frame on the roof of the mapping vehicle which allows for the motion of each sensor to be decoupled from the flex of the vehicle body. A GPS pulse-per-second (PPS) triggering signal was up-sampled to produce a trigger for each sensor, to ensure a common time scale among all of the sensors. The sampling rate used for all of the sensors in this experiment was 20 Hz.

The participants’ inputs were mediated through a set of Logitech G27 gaming pedals that
Figure 3.2: The Intelligent Vehicle and Systems Group mapping vehicle.

were located on the floor in front of the passenger seat in the vehicle. These pedals are shown in Figure 3.3.

An input-to-audio algorithm was developed that interprets pedal commands and uses these to cue the driver via sound to respond accordingly. The audio was delivered to the driver via in-ear headphones such that the participant could not also hear the audio cues to the driver (for safety, the driver only had a headphone in one ear so that he/she could still hear their surroundings). When the participant pressed a pedal, a 0.05 second long beeping sound was emitted repeatedly. The interval in between the beeps varied according to Equation 3.2:

\[ i = 0.5 - 0.95p \]  

where \( i \) = the interval between the beeps (seconds) and \( p \) = the percentage that the pedal is pressed (0 is not pressed, 1 is fully pressed). The throttle and brake pedals were differentiated by the pitch of the sound. The pitch was 500 Hz when the brake was pressed, and 1000 Hz when the throttle was pressed. The waveform of both sounds was a sine wave, and the code to generate the sound outputs from the pedal position is given in Appendix A.

Participants were recruited with the goal to obtain behavioral, demographic, and response variability. The experiment was advertised through the use of flyers posted around the Pennsylvania State University’s campus. Upon arrival at the Larson Institute Test Track, participants were welcomed and asked to read and sign a consent form. They were then asked to complete a short form that asked for their age, gender, and driving history. Questions about driving history included number of years driving, average number of hours driven per week, number of vehicle accidents, and time since most recent vehicle accident. After completing this form, four
anthropometric measurements were taken: height, stature, seated height, and seated eye height. Participants were then shown to the mapping vehicle and were given a set of written, step-by-step instructions that described the protocol. The protocol is given in Appendix A. All of the experiments were conducted between 3:30 pm and 7:30 pm and were before sunset. In addition, the road conditions were always dry.

Two questionnaires to be completed by the participants were prepared. Unfortunately neither questionnaire was approved by the Institutional Review Board (IRB) in time for the baseline experiment to be conducted. The questionnaires were used, however, in the video pass-through experiment described in Chapter 6.

The first questionnaire was the Driver Behavior Questionnaire (DBQ). The DBQ has been widely used in the literature since its creation in 1990 by Reason et. al. [100]. Its purpose is to characterize driver behavior based on distinct classes of driver errors and violations. The version of the DBQ used by this thesis is the Manchester DBQ developed by Lajunen, Parker, and Summala [101]. A few small alterations were made to the questionnaire to account for differences in British and American dialects, which were based on the changes proposed by Cordazzo, Scialfa, and Ross [102]. The final version of the DBQ can be found in Appendix B. The purpose of including the DBQ in this protocol was to provide a means of evaluating inter-subject variability which could be used as a covariate in the analysis. It also allows comparisons of the subject pool with future implementations of this protocol that will include virtual immersion.

The second questionnaire assessed the participants’ perceptions of risk, difficulty, and comfort after each traversal of a curve, and is shown in Figure 3.4. Questions 1 and 2 were borrowed directly from Fuller’s study regarding Risk Allostasis Theory [57]. Question 3 was developed for

Figure 3.3: G27 Gaming Pedals that were used to mediate participants’ inputs.
this thesis to evaluate how successively the current methodology was at allowing participants to find their maximum comfortable speed on the curves.

Please complete this short questionnaire to assess your perception of difficulty, risk, and comfort. Base your responses to the following questions on only the most recent traversal of the curve. Choose only one number to represent your rating. Proceed to the next task when you are done.

1. **How difficult would you find it to drive this section of road at this speed?**
   - extremely easy
   - extremely difficult

2. **How much risk would you experience driving this section of road at this speed?**
   - no risk
   - maximum risk

3. **How close was this speed to the maximum speed at which you would feel comfortable driving this section of road?**
   - exactly the same
   - not close at all

Figure 3.4: The questionnaire prepared for the participants to complete after each traversal of a curve.

### 3.2 Design of the Latent Response Protocol

The latent response protocol was designed to assess a participant’s perception of risk for their first traversal on both of the curves of the test track. Participants sat in the passenger seat of the vehicle as it was driven at a randomly-chosen value among a selection of test speeds. The vehicle began from rest at least 200 meters before the entrance to the curve. The driver accelerated to the selected speed before entering the curve and used cruise control to maintain that speed through the curve. The participants were asked to indicate when they felt uncomfortable by pressing a brake pedal that was instrumented to alert the driver. “Uncomfortable” was defined as a desire to slow down. If the participant pressed the brake pedal, the driver slowed the vehicle to a stop to end the trial.

The independent variables involved in the latent response protocol were the curve radius, the vehicle’s speed, and the direction of travel. The curve radii were 318 ft and 545 ft; more details can be found in Table 3.1. The test speeds for each curve are described in Table 3.2. The largest curve (900 ft radius) in Tan’s protocol was excluded from the current protocol because it elicited a relatively small percentage of uncomfortable responses (1.5%). The slowest test speeds in Tan’s protocol for the remaining curves (35 mph on the 318 ft radius curve; 35 mph and 40 mph on the 545 ft radius curve) were excluded from the current protocol for the same reason (less than 2% uncomfortable responses for all experimental conditions). The order of the trials for each curve and the direction of travel were counterbalanced between participants. The speed was selected
Table 3.2: Test speeds for each curve in the latent response protocol.

<table>
<thead>
<tr>
<th>Curve</th>
<th>Radius (ft)</th>
<th>Test Speeds (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>318</td>
<td>40 45 50</td>
</tr>
<tr>
<td>2</td>
<td>545</td>
<td>45 50 55</td>
</tr>
</tbody>
</table>

randomly.

The dependent variable was the binary response of the participant that indicated whether or not they felt uncomfortable at any point while traversing the curve. In the current protocol, participants indicated discomfort by pressing a brake pedal. This is in contrast to Tan’s experiment where participants indicated discomfort by pressing a hand-held button. It was assumed that the different response methods between the protocols would not significantly impact the response behavior. Furthermore, the brake pedal was preferred for the current protocol because it would also be used in the learned response protocol. In addition to considering the binary response of the participant, the location on the curve of uncomfortable responses was recorded. It was expected that the majority of uncomfortable responses would occur before the midpoints of the curves, as this was the result that was found in Tan’s experiment.

The primary motivation for designing an experimental protocol that specifically evaluates the participants’ latent perception of risk was the hypothesis that drivers aware of an upcoming curve may exhibit different behavior than with an unfamiliar curve. The latent response protocol was modelled after Tan’s experiment for two reasons: 1) Tan’s experiment included a large number of participants (117) which makes it a reliable benchmark by which to compare the results of the current protocol, and 2) the level of precision in a binary response is more appropriate for the sparse amount of data that could be collected for the latent response. In other words, the latent response protocol provides limited amounts of data, only one data point per test participant per curve, yet the binary nature of the data – the participant’s scoring a traversal as uncomfortable or not – is far more definitive than the learned response where the the participant’s time history of exposure, pedal behavior, and/or changing speeds within a curve can add uncertainty on how to interpret the participant’s response.

The hypothesis proposed for this experiment was that the results would be similar to those collected by Tan (see Section 2.4 for a summary of those results). There are a few differences in the protocols, however, which may limit the strength of the comparisons. Namely, the current protocol includes only a subset of the curve radii and test speeds used in Tan’s protocol, the response method in the current protocol is a brake pedal rather than a hand-held button, and the current protocol is limited to only the first exposure of a curve to a participant. The primary results to be compared were the percentage of observations for which the participant indicated discomfort. Of Tan’s results, only the unblindfolded and restrained treatment results were included in the comparison. It was also expected that the “comfortable speed” for the latent response protocol to be slower than for the learned response protocol. Tan did not compare the latent and learned responses, so the analysis of this comparison was limited to the current protocol.
3.3 Design of the Learned Response Protocol

The learned response protocol was designed to quantify the participants’ perception of risk over successive traversals of a curve. Participants sat in the passenger seat of the vehicle and were instructed to use the gaming pedals at their feet as if they had control over the vehicle. Their goal was to traverse the curve at the highest speed at which they felt comfortable. The driver interpreted the participants’ inputs via the input-to-audio algorithm described in Section 3.1 and attempted to match the vehicle’s pedals to the participants’ inputs. This protocol took place after the participant had completed the latent response protocol for both curves. Between the latent response and learned response protocols, the participant was provided a 5-minute practice period on the Vehicle Handling Area of the test track (see Figure 3.1) where they could become familiar with using the gaming pedals to control the vehicle’s speed.

The independent variables were the curve radius, the direction of travel, and the vehicle’s initial condition. The curve radii were the same as described in Table 3.1, and the directions of travel were either clockwise or counterclockwise. The initial condition refers to whether the vehicle was at rest or travelling at high speed before the driver began accepting the pedal inputs from the participant. When the vehicle began from rest, the starting location was at least 200 meters before the entrance of the curve. For the high speed initial condition, the vehicle began about 500 meters before the entrance of the curve and the driver accelerated the vehicle to 55 mph. At about 200 meters before the entrance of the curve, after the vehicle had reached 55 mph, the driver began accepting inputs from the participant. The participants were notified that “control” of the pedals had been transitioned to them by the driver pressing a button on the dashboard which began the recording of the vehicle’s sensors. Participants were instructed that until they pressed the pedals after control had been transitioned to them, the driver would maintain the vehicle’s speed. The purpose for including the initial condition as a factor was to evaluate whether a participant chose the same maximum comfortable speed for when they were accelerating versus decelerating towards that speed. A finding that the initial condition was not significant would increase confidence that the resulting speed for a participant accurately reflects their maximum comfortable speed.

The independent variables – curve radii, direction of travel, and initial condition – were applied in a $2^{3-1}$ fractional factorial design. Each participant completed three replicates of each treatment combination in the fractional factorial design for a total of 12 trials of the learned response protocol. The order of these 12 trials was randomized for each participant. The generator for the fractional factorial design ($I = ABC$ versus $I = -ABC$) was counterbalanced between participants. Table 3.3 describes the two halves of the fractional factorial design.

The dependent variable was the vehicle’s average and variance in longitudinal speed while on the curve. Additional variables were recorded/calculated that include the vehicle’s position, yaw rate, and standard deviation of lateral position. These variables were included to determine whether they had a significant influence on the participants’ perception of risk.

An important element in the learned response protocol was the driver’s ability to match the participants’ pedal inputs using the input-to-audio algorithm. Because the pedal position
Table 3.3: The two half-fractions of the $2^{3-1}$ fractional factorial design used in the learned response protocol. The three factors were curve radius, direction of travel, and initial condition.

<table>
<thead>
<tr>
<th>Run</th>
<th>I = ABC</th>
<th>I = –ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

was communicated via the interval between beeps, it was impossible for the driver to know the participants’ pedal position exactly. Instead, the input-to-audio algorithm was designed to make it easy for the driver to notice changes in the pedal position. This design was found to be the most effective according to subjective evaluation by the research team. The driver underwent hours of practice with the system to develop a practiced and consistent response to the passenger’s desired pedal input.

The driver also had to consider the maximum speed at which he/she was willing to traverse the curve. It was expected that since the driver had spent hours driving around the test track at high speeds, that he/she would be willing and capable of handling the vehicle at higher speeds than desired by any of the participants. However, to account for exceptions to this expectation, upper limits were imposed for each curve that the driver would not exceed. These limits were 55 mph for the 318 ft radius curve and 60 mph for the 545 ft radius curve. Participants were not told of these limits before the experiment so as to not influence their expectation that the driver would always match the participant’s pedal inputs.
Chapter 4  |
Analysis of the Latent Response Protocol Results

This chapter describes the data analysis of the experimental results for the latent response protocol. Descriptive statistics and Chi-square analyses were performed using MATLAB. An overall summary of the results for the latent response protocol is provided, followed by in-depth discussions of each of the factors included in the experiment. The results are compared to those found by Carol H. Tan in her thesis, “An Investigation of the Comfortable Lateral Acceleration on Horizontal Curves” [12]. In Tan’s thesis, treatment conditions were included for tests with and without wearing a seat belt, and for tests with and without wearing a blindfold. Only the results for the treatment with a seat belt and without a blindfold are considered in the comparisons for this thesis.

4.1 Introduction

A total of 28 participants were included in this study. Of these, 3 are excluded as outliers based on their heavy use of the throttle during the learned response protocol. Specifically, in the learned response protocol, participants used gaming pedals to indicate their desired speed. It was apparent that several participants held the throttle down for the duration of several trials. This was quantified further by calculating the integral of the throttle position for each trial during the time that the vehicle was on the curve. The integrated throttle position is divided by the maximum possible integral over the same distance to provide a value that represents the percent throttle usage. Box plots describing each participant’s percent throttle usage for each trial are shown in Figure 4.1.

The chosen exclusion criterion is that any participant who held the throttle completely down for any single entire trial should not be included in the analysis. In terms of the percent throttle usage shown in Figure 4.1, this criterion excludes the three right-most participants whose upper range equals one. This criterion was chosen because for a trial where the participant holds down the throttle, the vehicle’s speed is limited by the driver’s perception of risk rather than the
Figure 4.1: The percent throttle usage of each trial during the learned response protocol, separated by participant.

participant’s, thereby censoring the results. It was determined that this is sufficient evidence to consider these participants as outliers, and exclude their data from the analysis. Furthermore, future implementations of this experiment will screen potential participants with competitive vehicle racing experience or professional driving experience.

Figure 4.2 provides a summary of the driving history data for the 25 participants included in this study. Nearly all of the participants are in the 20-30 age range due to the fact that participants were mostly students recruited from the Pennsylvania State University campus. The gender distribution of the participants is 12 men and 13 women.

In the sections that follow, the curve boundary locations are used as landmarks to provide perspective for the participants’ responses. The curve boundaries are determined by the inflection points in the lane center yaw angle of the test track. The test track lane center and the yaw angle of the lane center are shown in Figure 4.3. The method for determining the lane center of the track is described in detail by Robert Leary [103]. Leary’s paper also describes the method by which station coordinates are calculated using GPS coordinates. This method was implemented for the data collected in the current experiment so that measurements from different trials could be compared at common locations on the track.
4.2 Data Analysis of Categorical Variables

As described in Section 3.2, the latent response protocol involved the vehicle going around a curve at a constant speed and the participant, in the passenger seat, pressing the gaming brake pedal if they felt uncomfortable. The analysis of this protocol focuses on percentage of observations where the participants indicated discomfort in response to the different categorical variables – curve radius, direction of travel, and vehicle speed.
Table 4.1: The 318 ft Radius Curve: Percent of Uncomfortable (Uncmf) Observations, Sample Sizes (N), and 95% Confidence Intervals for Vehicle Travel Variables in the Latent Response Protocol and in Tan’s study.

<table>
<thead>
<tr>
<th>Vehicle Travel Variables</th>
<th>Current Study</th>
<th></th>
<th></th>
<th></th>
<th>Tan’s Study</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent Uncmf</td>
<td>N</td>
<td>95% Conf. Interval</td>
<td>Percent Uncmf</td>
<td>N</td>
<td>95% Conf. Interval</td>
<td></td>
</tr>
<tr>
<td>Travel Direction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>23.1</td>
<td>13</td>
<td>(5.0, 53.8)</td>
<td>23.0</td>
<td>473</td>
<td>(19.3, 27.1)</td>
<td></td>
</tr>
<tr>
<td>CCW</td>
<td>16.7</td>
<td>12</td>
<td>(2.1, 48.8)</td>
<td>23.6</td>
<td>509</td>
<td>(20.0, 27.5)</td>
<td></td>
</tr>
<tr>
<td>Speed Group (mph [km/h])</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 [64]</td>
<td>7.7</td>
<td>13</td>
<td>(0.2, 36.0)</td>
<td>8.2</td>
<td>244</td>
<td>(5.1, 12.4)</td>
<td></td>
</tr>
<tr>
<td>45 [72]</td>
<td>0.0</td>
<td>4</td>
<td>(0.0, 60.2)</td>
<td>29.7</td>
<td>236</td>
<td>(23.9, 35.9)</td>
<td></td>
</tr>
<tr>
<td>50 [80]</td>
<td>50.0</td>
<td>8</td>
<td>(15.7, 84.3)</td>
<td>54.1</td>
<td>257</td>
<td>(48.7, 60.3)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.4 shows the percent of uncomfortable observations and 95% confidence intervals for the vehicle travel variables alongside the corresponding results from Tan’s study. These values are tabulated in Tables 4.1 and 4.2 for the 318 ft radius curve and the 545 ft radius curve respectively. The 95% percent confidence intervals are calculated by treating the observations as binomial trials, and are found using the binofit function in MATLAB which is based on the Clopper-Pearson method of calculating confidence intervals for a binomial distribution. The comparison between the current study and Tan’s study shows only limited agreement. Under two conditions for the current study the percent of uncomfortable observations is zero. However, this can be explained by the limited number of observations (n < 5) for those conditions.

Tan found that there was no significant difference in the percent uncomfortable responses between directions of travel at $\alpha = 0.01$, using a chi-square analysis. The same analysis for the current study also finds no significant difference between travel directions (318 ft radius curve: $\chi^2 = 0.16$, $p = 0.689$; 545 ft radius curve: $\chi^2 = 0.33$, $p = 0.568$). Although direction of travel was not significant in either study, Figure 4.4a provides further opportunity for investigation. On the 318 ft radius curve the percent uncomfortable responses in both directions is similar to that of Tan’s study. This is not true for the 545 ft radius curve, where the percent of uncomfortable responses for both directions of travel are greater than in Tan’s study. In addition, the differences between directions of travel are smaller in Tan’s study than in the current study. This is likely due to the significantly smaller number of observations in the current study than in Tan’s study. The relatively large confidence intervals for the current study reflect the limited number of observations.

The results from Tan’s study show a clear trend of the percent uncomfortable responses increasing with speed. From Figure 4.4b it appears that this trend is the same for the current study, ignoring the groups with less than five observations. On the 318 ft radius curve, the percent of uncomfortable responses in the current study are similar to that of Tan’s study. This is not true for the 545 ft radius curve where the current study has a smaller percent of uncomfortable responses than Tan’s study at the 50 mph speed group, but much larger percent of uncomfortable responses at the 55 mph speed group.

The percent uncomfortable responses were tested for significance between levels of several categorical variables – direction of travel, trial order, and gender. As discussed previously, a chi-
Table 4.2: The 545 ft Radius Curve: Percent of Uncomfortable (Uncmf) Observations, Sample Sizes (N), and 95% Confidence Intervals for Vehicle Travel Variables in the Latent Response Protocol and in Tan’s study.

<table>
<thead>
<tr>
<th>Vehicle Travel Variables</th>
<th>Current Study</th>
<th>Tan’s Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent Uncmf</td>
<td>N</td>
</tr>
<tr>
<td>Travel Direction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>23.1</td>
<td>13</td>
</tr>
<tr>
<td>CCW</td>
<td>33.3</td>
<td>12</td>
</tr>
<tr>
<td>Speed Group (mph [km/h])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>0.0</td>
<td>3</td>
</tr>
<tr>
<td>50</td>
<td>20.0</td>
<td>15</td>
</tr>
<tr>
<td>55</td>
<td>57.1</td>
<td>7</td>
</tr>
</tbody>
</table>

square test found no significant difference between directions of travel – the same result found for Tan’s study. To test for significance in the trial order (response on trial 1 versus trial 2) a McNemar test was used instead of chi-square. This is because the chi-square test assumes that the observations between variables are independent which is not true for the trial order. The McNemar tests for consistency in responses across two variables. The test was performed using the McNemarextest function in MATLAB, written by Trujillo-Ortiz et. al. [104]. The results of the McNemar test show that the trial order is not significant, suggesting that there is no learning effect within the latent response protocol ($\chi^2 = 0.167, p = 0.683$). Lastly, a chi-square test was used to check for the independence between gender and the frequency of uncomfortable responses. The results of the chi-square test found no significant difference between genders ($\chi^2 = 0.254, p = 0.615$) – the same results as in Tan’s study.
4.3 Location of Discomfort

Figure 4.5 shows the locations on the curve where participants indicated discomfort by pressing the brake. The majority of the observations occurred near or before the entrance to the curves, and the furthest observation still occurred before midpoint of the curve. Figure 4.6 shows the distribution of the brake locations relative to the curve entrances. All but one of the observations are within 40 meters of the curve entrances, and the distribution is skewed towards before the curve entrance. A similar result was found in Tan’s study – 43.7% of uncomfortable observations occurred in the first third of the curve on the 318 ft radius curve, and 64.4% on the 545 ft radius curve.

There is no clear relationship between the location where participants indicated discomfort and the speed at which they were travelling. Instead, it appears that participants felt discomfort at the same location – the curve entrance – regardless of the speed at which they were travelling. The results of Tan’s study showed that participants indicated discomfort earlier when travelling at higher speeds. The failure to find the same pattern in the current study could be due to the limited number of uncomfortable observations in the current study.

Figure 4.5: Locations where participants indicated discomfort in the latent response protocol.
Figure 4.6: Location where participants indicated discomfort in the latent response protocol relative to the curve entrances.
Chapter 5  |  Analysis of the Learned Response Protocol Results

This chapter describes the data analysis of the experimental results for the learned response protocol. Descriptive statistics were generated with MATLAB, and a mixed effect model was fit using Minitab. An overall summary of the results for the learned response protocol is provided, followed by in-depth discussions of each of the factors included in the experiment. The results are compared to those found by Carol H. Tan in her thesis, “An Investigation of the Comfortable Lateral Acceleration on Horizontal Curves” [12]. In Tan’s thesis, treatment conditions were included for tests with and without wearing a seat belt, and for tests with and without wearing a blindfold. Only the results for the treatment with a seat belt and without a blindfold are considered in the comparisons for this thesis. The latent and learned response protocols are also compared to each other to address potential learning effects.

5.1 Introduction

As described in Section 3.3, the learned response protocol involved the passengers using gaming pedals to indicate their desired acceleration to the driver. The passengers’ goal was to achieve the fastest speed at which they feel comfortable traversing the curves. Specifically, the participants were told the following exact phrase: "we are looking for the highest speed at which you feel comfortable". Documentation of the entire test protocol can be found in Appendix B. The analysis of this protocol focuses on the vehicle speed within the curve bounds in response to the different experimental conditions – curve radius, direction of travel, and initial condition.

Each of the 25 participants in this study completed 12 trials, for a total of 300 observations. Data was not recorded for 2 observations, however, due to a mechanical issue with the vehicle and an electrical issue with the sensors that interrupted those observations. The remaining 298 observations are included in the following data analysis.

Figure 5.1 shows an example of the speed and pedal usage for one participant on one of the experimental treatments combinations of the learned response protocol. The average and
percentile values summarize the three replications that each participant completes for each treatment combination. It can be seen that the vehicle accelerates up to a high speed from the start, brakes upon curve entry, then accelerates again through the remainder of the curve. This pattern is typical for the majority of the participants and for all of the treatment combinations. There is only a small difference between the 5th and 95th percentile speeds and pedal usage throughout the curve, indicating that the participant was consistent in their behavior across the three replications of this treatment combination.

Figure 5.1: Example of the average, 5th, and 95th percentile speed and pedal usage for one participant on one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from rest, travelling in the counterclockwise direction.

Figure 5.2 shows examples of the speed and pedal usage for all participants on two different experimental treatment combinations of the learned response protocol. The corresponding plots for the remaining treatment combinations can be found in Appendix C. These plots show that the average speed settles to an approximately constant speed in the latter half of the curves, indicating that the participants’ desired speed is a fixed value, and that they achieve this speed in the course of traversing the curves.

A Lilliefors test was used to check for normality in the distribution of speeds for every trial at 0.5 meter station increments. Figure 5.3 is an example of the results of the Lilliefors tests overlaid on the speed distribution for one of the experimental treatment combinations – 318 ft radius curve, starting from rest, travelling in the clockwise direction. The speeds are normally distributed at most of the locations within the boundaries of the curve. The same result is true for the other treatment combinations. The purpose of this test is to evaluate the validity of using statistical tests that assume normality when comparing the different treatment combinations.
Figure 5.2: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed and pedal usage of all participants for two of the experimental treatment combinations in the learned response protocol.

The speed distribution at an arbitrary station location in Figure 5.3, 500 meters, is presented by a histogram and normal probability plot in Figure 5.4.

The presence of the bridge on the 545 ft radius curve appears to affect the speed selection of the participants. Figure 5.5 shows that the speeds are not normally distributed near the bridge for the treatment combination of starting from high speed and travelling in the counterclockwise direction. The same is true when starting from rest, but not when travelling in the clockwise direction. This indicates that the presence of the bridge is only related to speed selection when they are located near the curve entry. Further investigation is required to better understand the relationship between critical features, such as the bridge, and risk-taking behavior in driving.

5.2 Data Analysis of Experimental Factors

5.2.1 Comparison Between Directions of Travel

Figure 5.6 shows the average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile user-selected speeds for opposing directions on the 318 ft radius curve, when starting from rest. The corresponding curves for the other treatment combinations can be found in Appendix C. The red and green bar across the bottom of the figure represents the results of a 2 sample t-Test between the speed distributions for each direction of travel at every 0.5 meter station coordinate increment at the 5\% significance level. It can be seen that the speeds for each direction of travel are not significantly different at any location between the curve boundaries. A similar result was found for the other treatment combinations, indicating that the participants’ desired speed is statistically independent of the direction of travel.
5.2.2 Comparison Between Initial Conditions

A comparison of the average speeds for the different initial conditions shows that the speeds converge to a common distribution that is independent of the initial condition. Figure 5.7 shows an example comparison of the average speeds between initial conditions for one of the treatment combinations – the 318 ft radius curve travelling in the clockwise direction. A two sample t-Test at every 0.5 meter station increment shows that the speed distributions for the different initial conditions are significantly different for an initial portion of the curve, and are not significantly different thereafter. This same pattern is present for the other treatment combinations of curve radii and directions of travel.

The location where the speed distributions for opposing initial conditions transitioned to become statistically equivalent was investigated further. Table 5.1 describes these locations in terms of the percent distance travelled into the curve for each of the treatment combinations. On average, the convergence distance in the speed distributions for opposing initial conditions is less than 50% of the curve traversal. This is evidence that there is likely a fixed speed that participants are seeking, and this speed is likely independent of the approach speed.

The distance for initial conditions to converge is greater for the larger radius curve and for clockwise direction. A possible explanation for the discrepancy between directions of travel on the 545 ft radius curve is that the presence of the bridge near the curve entrance for counterclockwise
5.2.3 Model Fit for Curve Entry Speed

The vehicle’s average speed in curve entry for each treatment combination was modelled using a nonlinear least-squares regression by fitting the data to a sinusoid profile. MATLAB’s fit function was used to calculate the nonlinear least-squares fit for a single term sine function. A common behavior observed among all trials was for the vehicle’s speed to peak just before curve entry, then drop to a slower speed that is maintained for the remainder of the curve. This results in two inflection points: one at the vehicle’s peak speed before curve entry, and one at the transition between deceleration after curve entry and acceleration through the remainder of the curve. The speed profile between these inflection points resembles a sine wave. Therefore, a sine wave was fit to the average speed of each treatment combination, between the maximum and minimum speeds in the first half of the curves. The maximum and minimum speeds used as endpoints in the fitted sine wave approximately correspond to the observed inflection points for every treatment combination. Figure 5.8 shows example plots of the fitted sine wave overlaid on the average speed.
Figure 5.5: An example of the effect of critical factors such as the bridge on the normality of the speed distribution in the learned response protocol.

for two of the treatment combinations.

Table 5.2 summarizes the properties of the sine functions fit to the average speeds in curve entry for each treatment combination. The half-period and double amplitude of the sine functions are provided for the fit of each treatment combination. The half-period is a measure of the settling distance required for the participants to find their maximum comfortable speed. The double amplitude is a measure of the total drop between the approach speed and the steady speed selected for the remainder of the curve. The double amplitudes and half-periods for opposing directions of travel are similar for each combination of curve radii and initial conditions. The double amplitudes and half-periods for the high speed initial condition are greater than for when starting from rest, indicating that starting from high speed requires greater corrective action upon curve entry. Similarly, the double amplitudes for the larger radius curve are smaller than for the other curve, for the relative initial conditions. However, there is no apparent difference between half-periods for each curve. These models provide opportunity for detailed analysis of curve entry speeds. However, further analysis is not within the scope of this thesis.

5.2.4 Analysis of Variance for Experimental Factors

The average trial speeds were analyzed for statistical significance between factors using a mixed effects model in Minitab. The response variable is the average speed of a trial after the initial condition convergence locations, described in Table 5.1. The fixed factors include the curve radius, direction of travel, and initial condition. Participant were included as a random factor.
Figure 5.6: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed of all participants for opposing directions of travel on the 318 ft radius curve, when starting from rest. The 2 sample t-Test compares the speed distributions for opposing directions at every 0.5 meter station increment at the 5\% significance level.

Table 5.2: Summary of the parameters in the least-squares fit sine functions to the average curve entry speeds for each treatment combination.

<table>
<thead>
<tr>
<th>Experimental Factors</th>
<th>Model Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve Radius</td>
<td>Initial Condition</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>318</td>
<td>Rest</td>
</tr>
<tr>
<td>318</td>
<td>Rest</td>
</tr>
<tr>
<td>318</td>
<td>High Speed</td>
</tr>
<tr>
<td>318</td>
<td>High Speed</td>
</tr>
<tr>
<td>545</td>
<td>Rest</td>
</tr>
<tr>
<td>545</td>
<td>Rest</td>
</tr>
<tr>
<td>545</td>
<td>High Speed</td>
</tr>
<tr>
<td>545</td>
<td>High Speed</td>
</tr>
</tbody>
</table>

The experimental design included 3 replications of one half of a $2^3-1$ fractional factorial design for a total of 12 trials per participant, which for 25 participants totals 300 observations. Two of the trials were not recorded due to sensor failures and 10 of the trials were protocol errors (performing the incorrect treatment combination). These 12 trials were not included in the analysis.

The trial number (1-12) and replication number (1-3) were each included as random factors in separate analyses to determine if there was a learning effect. Neither one was found to be significant at the 5\% significance level (trial number: $Z = 0.67$, $p = 0.251$; replication number
Figure 5.7: The average, 5th, and 95th percentile speed of all participants for different initial conditions on the 318 ft radius curve travelling in the clockwise direction. The 2 sample t-Test compares the speed distributions for opposing initial conditions at every 0.5 meter station increment at the 5% significance level.

\[ Z = 0.81, \ p = -.209 \]. Figure 5.9 shows box plots of the average trial speed separated by trial number and replication number. The failure to find a learning effect makes it possible to average replications of a treatment combination for each subject in order to gain back degrees of freedom for an analysis of the fixed effects. This follow-up analysis included one observation for each of the 4 treatment combinations completed by a participant for a total of 100 observation among all participants.

In the analysis of the averaged replications, only the curve radius and initial condition main effects were found to be significant at the 5% significance level (curve radius: \( F = 203.11, \ p < 0.001 \); initial condition: \( F = 5.46, \ p = 0.022 \)). Direction of travel and all of the second order effects were not significant (direction: \( F = 2.03, \ p = 0.159 \); curve*initial condition: \( F = 0.15, \ p = 0.700 \); curve*direction: \( F = 0.02, \ p = 0.890 \); direction*initial condition: \( F = 1.99, \ p = 0.163 \)). From Figures 5.6 and 5.7 it was expected that direction of travel and initial condition did not significantly affect speed selection. The failure to find this result for initial condition in the mixed effect analysis may be due to the determination of the initial condition convergence location. It is possible that using a more strict significance level when comparing the speed distributions for different initial conditions would provide convergence locations that better reflect the data.
5.3 Comparison Between the Current Study and Tan’s Study

The results of the learned response protocol were compared to Tan’s study by percentiles of the speeds at which the participants were uncomfortable. Table 5.3 summarizes this comparison. These values, however, have slightly different meanings for either study. Tan’s study was based on a threshold evaluation of comfort – participants indicated whether or not they felt uncomfortable at a constant speed through a curve. Therefore, the percent uncomfortable speeds from Tan’s study are interpolated or extrapolated values that indicate the speeds at which a given percentage of the observations were uncomfortable. The learned response protocol is based on a method of adjustments where participants indicate their desired throttle or brake position to achieve
their maximum comfortable speed throughout the curve. The average speeds within the curve boundaries for each trial, separated by curve radius, form two distributions. According to a Lilliefors test, the distribution for the 318 ft radius curve is normally distributed ($p > 0.5$) but the distribution for the 545 ft radius curve is not ($p = 0.0365$). The percent uncomfortable speeds shown in Table 5.3 are percentiles of these distributions that are calculated assuming normality.

The comparison of the percent uncomfortable speeds in Table 5.3 shows that the speeds in Tan’s protocol are consistently greater than those in the learned response protocol. This difference is visualized in Figure 5.10 by fitting normal distributions to the 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentile uncomfortable speeds in each study. The distributions are not necessarily normally distributed, but this visualization shows clearly that the uncomfortable speeds in Tan’s study are greater than in the current study. The difference between the studies is greater for the 545 ft radius curve. There are several possible explanations for the differences between the results of the two studies:

- The vehicles in the two studies are different. The vehicle in Tan’s study is a 1992 Ford Taurus, which was 13 years old at the time of the study. The vehicle in the current study is a 1997 Plymouth Grand Voyager, which was 21 years old at the time of the study. Participants may be exhibiting more caution when using an older vehicle.
- The Plymouth Grand Voyager used in this study is a minivan, whereas as the Ford Taurus of Tan’s study is a mid-size sedan. Participants may be obtaining cues from differences in vehicle dynamics, particularly roll, between these two vehicles.
- The Plymouth Grand Voyager had problems with its’ transmission causing it to lurch as it shifted gears. Participants may be more uncomfortable at higher speeds in a vehicle perceived to have transmission problems.
- The decision making processes underlying the two protocols are fundamentally different. The protocol for Tan’s study was a threshold evaluation of comfort, whereas the learned response protocol in the current study had participants actively seek their maximum comfortable speed. It is possible that these different methods would yield different results regarding the uncomfortable speeds for traversing curves. For example, participants in the current study may have felt a greater sense of responsibility for their own safety because they were “in control” of the vehicle’s speed. They may have therefore been more cautious when choosing their maximum comfortable speed.

5.4 Comparison Between Latent and Learned Response Protocols

The results of the latent response and learned response protocols were compared to determine if there is a learning effect. The comparison is based on whether or not the participants were uncomfortable in the latent response protocol, and if they chose a higher or lower average speed.
Figure 5.10: Comparison of normal distributions fit to the 10\textsuperscript{th}, 50\textsuperscript{th}, and 90\textsuperscript{th} percent uncomfortable speeds in each study.

Table 5.3: Comparison of the interpolated and extrapolated 10, 50, and 90 percent uncomfortable speeds from Tan’s study to the corresponding percentile selected speeds of the current study.

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Speed in Tan’s Study</th>
<th>Speed in Current Study</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>42.1</td>
<td>33.2</td>
<td>21.1</td>
</tr>
<tr>
<td>50</td>
<td>50.2</td>
<td>42.1</td>
<td>16.1</td>
</tr>
<tr>
<td>90</td>
<td>56.6</td>
<td>50.4</td>
<td>11.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Speed in Tan’s Study</th>
<th>Speed in Current Study</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>47.6</td>
<td>37.8</td>
<td>20.6</td>
</tr>
<tr>
<td>50</td>
<td>60.9</td>
<td>46.4</td>
<td>23.8</td>
</tr>
<tr>
<td>90</td>
<td>77.6</td>
<td>55.1</td>
<td>29.0</td>
</tr>
</tbody>
</table>

in the learned response protocol than the randomly selected speed in the latent response protocol. This creates four potential categories into which the participants can be sorted:

1. The participant indicated that they were 	extbf{uncomfortable} in the latent response protocol at one of the randomly selected speeds, then chose an average speed in the learned response protocol that was 	extbf{greater} than the speed in the latent response protocol.

2. The participant indicated that they were 	extbf{uncomfortable} in the latent response protocol at one of the randomly selected speeds, then chose an average speed in the learned response protocol that was 	extbf{less} than the speed in the latent response protocol.

3. The participant indicated that they were 	extbf{comfortable} in the latent response protocol at one of the randomly selected speeds, then chose an average speed in the learned response protocol that was 	extbf{greater} than the speed in the latent response protocol.

4. The participant indicated that they were 	extbf{comfortable} in the latent response protocol at one of the randomly selected speeds, then chose an average speed in the learned response protocol that was 	extbf{less} than the speed in the latent response protocol.

Categories 2 and 3 are expected behavior – the participant is choosing a speed in the learned
Table 5.4: The 318 ft Radius Curve: Comparison between the responses in the latent and learned response protocols.

<table>
<thead>
<tr>
<th>Response in the Latent Response Protocol</th>
<th>Relative avg. speed chosen in the Learned Response Protocol</th>
<th>Category</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncomfortable</td>
<td>higher</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>lower</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Comfortable</td>
<td>higher</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>lower</td>
<td>4</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 5.5: The 545 ft Radius Curve: Comparison between the responses in the latent and learned response protocols.

<table>
<thead>
<tr>
<th>Response in the Latent Response Protocol</th>
<th>Relative avg. speed chosen in the Learned Response Protocol</th>
<th>Category</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncomfortable</td>
<td>higher</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>lower</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Comfortable</td>
<td>higher</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>lower</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

response protocol that agrees with their response in the latent response protocol. Category 1 is indicative of a learning effect – the participant becomes more comfortable traversing the curve with more exposures, and therefore chooses a maximum comfortable speed in the learned response protocol that is greater than the speed in the latent response protocol due to greater comfort/experience at higher speeds. Lastly, Category 4 is an anti-learning behavior and has three potential explanations: 1) the participant was not consistent in their response, 2) there is statistical variation that causes a perceived discrepancy, or 3) the two protocols do not measure the same psychological response - i.e. there are one or more factors that affect speed selection in one protocol that aren’t present in the other protocol.

Tables 5.4 and 5.5 summarize the number of participants that fell into each category for either of the curve radii. For both curves, none of the participants fell into Category 1, which is the category that is indicative of a learning effect. However, Category 4 included 18 of 25 participants on the 318 ft radius curve and 7 of 25 participants on the 545 ft radius curve. Considering these relatively high participant counts, the third explanation for Category 4 is the most likely – that the two protocols do not measure the same psychological response. This result is in agreement with the findings from the comparison between the learned response protocol and Tan’s study. That comparison found that the learned response protocol yielded slower uncomfortable speeds than in Tan’s study. The common explanation for both the comparison between Tan’s and the current study and the comparison between the latent response and the learned response protocols is that there is a fundamental psychological difference between the protocols that results in different values for the participants’ uncomfortable speed.
5.5 Data Analysis of Driver Performance

The driver was a potentially significant confounding variable in this experiment. A passenger’s perception of risk in a vehicle is naturally influenced by their trust in the driver’s ability and in the driver’s performance. Furthermore, this experiment relied on the driver to respond accurately and precisely to the participants’ desired pedal inputs via the input-to-audio algorithm. To limit these potential sources of error, the same driver was used throughout the entire experiment. This driver had many hours of practice driving the test vehicle at the test track and responding to the input-to-audio algorithm. Nonetheless, the driver was likely a confounding variable in the experiment.

The driver’s performance can be characterized by the yaw rate of the vehicle. This measure corresponds to the driver’s ability to maintain smooth and consistent steering inputs. Figure 5.11 shows examples of the yaw rate and pedal usage for all participants on two different experimental treatment combinations of the learned response protocol. The presence of the bridge can be seen by the saw-tooth behavior in yaw rate at around the 1100 meter station coordinate on the 545 ft radius curve. The variance of the yaw rate is small at the curve entry and exit where the driver is making steering maneuvers. Between the curve entry and exit the yaw rate variance is relatively consistent. In addition, there does not appear to be a relationship between the participants’ pedal usage and the vehicle yaw rate. Instead, the pedal usage appears to change primarily in response to the curve entrance and to the bridge.

Figure 5.12 shows an example comparison of the average, 5th, and 95th percentile yaw rate for opposing directions of travel. The yaw rates for either direction of travel align closely. This indicates that the driver was consistent in their steering performance between different trials. However, further investigation is needed to better evaluate the driver’s performance, which is not within the scope of this thesis.

Figure 5.11: Examples of the average, 5th, and 95th percentile yaw rate and pedal usage of all participants in two of the treatment combinations of the learned response protocol – either curve radius, starting from rest, travelling in the counterclockwise direction.
Figure 5.12: The average, 5th, and 95th percentile yaw rate of all participants for different directions of travel on the 318 ft radius curve, starting from rest.

5.6 Data Analysis of Participant Throttle Usage

The analysis of the participants’ throttle usage in the learned response protocol provides unique insight into the way people control their speed on curves. A primary observation is the wide variety of pedal use strategies between participants. This is exemplified by Figure 4.1 which shows box plots of the percent throttle usage of each trial, separated by participant. There is a very wide range in both the mean and variance in the percent throttle usage between participants. Some participants only tapped the brake or throttle lightly and infrequently, whereas others alternated between holding the throttle or brake completely down. And there were many other unique pedal use strategies between those extremes without any clear patterns by which to categorize them.

The participants’ throttle usage was evaluated by the deviations in the throttle position from the average throttle position of each trial. The integral of these deviations within the curve boundaries was calculated, and the resulting distribution is shown by a histogram and normal probability plot in Figure 5.13. The histogram is overlaid by a normal distribution fit. The distribution of integrated throttle deviations has a high kurtosis value of 5.98. This is an indication that the participants tended to make only small deviations in the throttle position.
Figure 5.13: Distribution of the integrated throttle deviations from the trial averages.
Chapter 6  
Preliminary Investigation of the Effect of Video Pass-through on Vehicle Passenger Risk Perception

This chapter describes the design and results of an experiment to investigate the effect of viewing the environment through video pass-through on vehicle passenger risk perception. This experiment was an adaptation of the experiment described in Chapter 3. The adaptations included removing experimental factors that were not found to be significant in the baseline experiment, and including an additional factor for virtual immersion. The virtual immersion included in this experiment was video pass-through. Video pass-through refers to the passenger wearing a headset that displays video of the environment captured by a camera mounted on the headset. The goal of this experiment was to determine if wearing the video pass-through headset would affect the participants’ perception of risk by means of their speed selection on curves.

6.1 Experimental Design

The video pass-through experiment was designed to evaluate the effect of wearing a video pass-through headset on a passenger’s perception of risk. The experimental design was based on the learned response protocol described in Section 3.3. The latent response protocol was not included because it was determined in the baseline experiment that it measured a different psychological process resulting in uncomfortable speeds that were greater than found in the learned response protocol. Furthermore, the latent response protocol did not provide as much data since participants only gave a binary response.

The video pass-through experimental design controlled for direction of travel and initial condition because they were found to not be significant in the baseline learned response protocol.
The direction of travel was controlled to be counterclockwise, and the initial condition was controlled to have the vehicle begin from high speed. The selection of the each level of the factors was arbitrary since they were not significantly different in the learned response protocol. However, the high speed initial condition was preferred because it made it more likely for participants to be able to find their maximum comfortable speed. When starting from rest, there was the possibility that the vehicle could not accelerate to the participants’ maximum comfortable speed within the space of the curve.

Wearing the video pass-through headset was treated as a within subject variable in the experimental design. The only other factor in the experiment was the curve radius which is described in Table 3.1. Between the curve radius and the headset variable, there were four treatment combinations. Each participant completed three replications of each treatment combination for a total of 12 trials. The order of these trials was completely randomized for each participant.

The protocol was expanded to include questionnaires that address simulator sickness and to provide greater detail about the participants’ background. The background questions were expanded to include questions about video game experience, sleeping habits, and additional questions about driving experience. A complete list of the questions can be found in Appendix B. The Driver Behavior Questionnaire and the questions in Figure 3.4 were included in the this protocol as well. Participants were screened for this experiment based on two criteria: for competitive vehicle racing experience and for susceptibility to simulator sickness. Individuals with vehicle racing experience were excluded based on the finding in the baseline experiment that they were likely to have a maximum comfortable speed that was greater than the limit imposed on the driver, thereby censoring their results. Individuals who were susceptible to simulator sickness were excluded based on their answers to screening questions developed by Hoffman et. al. [105]. The questions and exclusion criteria are included in Appendix B.

A questionnaire to evaluate the participants’ level of simulator sickness during the experiment was included. The questionnaire was developed by Kennedy et. al. [106]. It asks participants to rate how much they are being affected by 16 different symptoms on the following scale: none, slight, moderate, and severe. The responses are coded on a zero to three scale and summed. The exclusion criterion was borrowed from Brown et. al. [107] which determines that an individual should be excluded if they score greater than 35 after using the simulator for an 8-minute practice period. In this experiment the practice period involved the participants wearing the video pass-through headset while sitting in passenger seat of the vehicle as it was driven slowly around the test track. Participants completed the simulator sickness questionnaire after completing the practice period and a second time after completing the entire experiment.

Video pass-through was achieved using a modified Google Daydream headset in combination with an iPhone 7+. The iPhone was prepared with the iOS-Stereoscopic-ARKit-Template application developed by Hanley Weng that is available on Github (https://github.com/hanleyweng/iOS-ARKit-Headset-View). The application uses the phone’s camera to provide stereoscopic view on the screen that is compatible with virtual reality headsets. The Google Daydream headset was used in this experiment and modified to allow the phone’s camera to look forward. Figure 6.1 shows pictures of the modified headset and Figure 6.2 shows it being worn by a passenger. The
video pass-through provides the user with a photo-realistic view of their environment. However, the user’s vision is limited by the camera in a few ways: frame rate, focus, field of view, monocular vision, and shifting the users “eye” to off-center from their face. The limited frame rate of the camera is noticeable when the user moves their head quickly, resulting in motion blur. The camera’s focus limits the users ability to transition between focusing between near and far field objects. Figure 6.3 shows an example of the application in use on the phone.

Figure 6.1: The Google Daydream headset modified to allow the phone’s camera to see forward.

6.2 Experimental Results and Analysis

A total of 8 participants were included in the video pass-through experiment. Of these, 1 participant was excluded because he/she held the throttle completely down throughout the entire curve on several trials. The speeds for those trials are censored by the speed limit imposed on the driver for safety. This is the same exclusion criterion used in the baseline experiment, and is described in Section 4.1. Of the remaining 7 participants, 3 are men and 4 are women. Figure 6.4 provides a summary of the driving history of all of the participants included in this study. Similarly to the baseline experiment, nearly all of the participants are in the 20-30 year age range. All 7 of the participants had previous experience driving a sedan and an SUV, and 4 of the 7 had experience driving a truck and a van. All 7 had experience as a passenger in a sedan, SUV, and van while 5 of 7 had experience as a passenger in a truck.

Plots comparing the average speeds with and without the headset were generated for each participant and each curve. Figure 6.5 shows two example plots of the average, 5th, and 95th
percentile speeds between with and without wearing the headset for different participants on the 545 ft radius curve. Figure 6.5a shows a participant that selected the same speeds with and without wearing the headset. The 2 sample t-Test at every 0.5 meter station increment confirms that the difference between the speed distributions for with and without wearing the headset is not statistically significant at any location within the curve boundaries. In contrast, Figure 6.5b shows a participant that selected higher speeds when they were not wearing the headset. These examples serve to highlight the variety of responses among the participants. Several showed some difference in behavior between with and without wearing the headset, while others showed none.

A Lilliefors test was used to check for normality in the distribution of speeds for every trial at 0.5 meter station increments. Figure 6.6 is an example of the results of the Lilliefors tests overlaid on the speed distribution for one of the experimental treatment combinations – 318 ft radius curve, without wearing the headset. The speeds are normally distributed at most of the locations within the boundaries of the curve. The same result is true for the other treatment combinations. The purpose of this test was to evaluate the validity of using statistical tests that assume normality when comparing the different treatment combinations.

It appears that the presence of the bridge at the curve entrance to the 545 ft radius curve had an effect on the normality of the speed distribution when participants were not wearing the headset. Figure 6.7 shows a comparison of the speed distributions for all trials between with and without wearing the headset on the 545 ft radius curve. The location of the bridge is identified as well as the results of a Lilliefors test for normality in the speed distributions at 0.5 meter station increments. It is apparent in Figure 6.6 that there is a failure to find normality in the speed
distribution near the presence of the bridge for the condition when participants were not wearing the headset. This agrees with the results of the baseline experiment as described in Figure 5.5. The effect does not appear to hold for when the participants were wearing the headset, however. Figure 6.7b shows that the speed distributions for when participants were wearing the headset are normally distributed near the bridge. A possible explanation for this difference is that the reduced field of view of the headset limited the participants’ ability to anticipate the presence of the bridge, thereby limiting any risk compensation behavior that would disrupt the normality of the speed distributions near the bridge.

Figure 6.8 shows a comparison of the average, 5th, and 95th percentile speed of all trials between with and without wearing the headset, and for both curves. The figure includes the results of a 2 sample t-Test between the speed distributions for with and without wearing the headset at every 0.5 meter station increment. The t-Test shows that the headset did not significantly effect speed selection at any location within the curve boundaries for either curve.

To confirm the result shown by Figure 6.8 – that the headset did not significantly affect speed selection – an mixed effect model was fit using Minitab. The same analysis procedure was used as for the baseline experiment. The response variable is the average speed between the initial condition convergence location from the baseline experiment and the curve exit. The initial condition convergence locations are described in Table 5.1 and the values corresponding to either curve and the counterclockwise direction are used. The fixed factors are the curve radii and whether or not the participant was wearing the headset. The participants are included as a
random factor. Each of the seven participants completed three replications of the four treatment combinations between curve radius and wearing the headset for a total 84 observations.

The trial number (1-12) and replication number (1-3) were each included as random factors in separate analyses to determine if there was a learning effect. Neither one was found to be significant at the 5% significance level (trial number: \( Z = 0.34, p = 0.975 \); replication number \( Z = 0.28, p = -0.390 \)). Figure 6.9 shows box plots of the average trial speed separated by trial number and replication number. The failure to find a learning effect makes it possible to average replications of a treatment combination for each subject in order to gain back degrees of freedom for an analysis of the fixed effects. This follow-up analysis included one observation for each of the 4 treatment combinations completed by a participant for a total of 28 observation among all participants.

In the analysis of the averaged replications, only the curve radius was found to be significant at the 5% significance level (curve radius: \( F = 124.35, p < 0.001 \)). The headset and the second order effect was not significant (headset: \( F = 3.23, p = 0.089 \); curve*headset: \( F = 0.94, p = 0.346 \)). From Figure 6.8 it was expected that the headset did not significantly affect speed selection. However, the p-value for the headset main effect is close to being significant. This indicates that it is possible to find significance by recruiting a larger number of participants.

The headset appears to affect the participants’ perception of risk, difficulty, and speed. After each traversal of a curve participants were asked to respond to three questions, shown in Figure 3.4. The first two questions address how much difficulty and risk they would feel to drive the most recent curve at the speed they had selected. The third question asked how close that
speed was to their maximum comfortable speed. The average responses to all questions and both curves were greater for when the participants were wearing the headset. This indicates that they felt greater difficulty, greater risk, and further from their maximum comfortable speed. These responses are summarized by Figures 6.10, 6.11, and 6.12. The responses were analyzed for statistical significance using the Wilcoxon Signed Rank Test – a non-parametric test for an ordinal dependent variable in response to a 2-level independent variable when the responses are paired. This test only found a significant headset effect for the questions regarding risk and difficulty, on the 318 ft radius curve.

Figure 6.13 shows each participant’s response to the Simulator Sickness Questionnaire on both of the evaluations – after the practice period with the video pass-through headset and after the entire experiment. Three of the 7 participants’ responses showed an increase in symptoms after the entire experiment. Another 3 of the 7 showed no change between the two evaluations, including one participant who reported feeling no symptoms on either evaluation. The single remaining participant reported a decrease in his/her symptoms after the entire experiment. Overall, all of the responses were well below the exclusion criteria for simulator sickness: 35.
Figure 6.6: Example of the test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the video pass-through protocol – 318 ft radius curve, without wearing the headset.

(a) Without headset  
(b) With headset

Figure 6.7: Comparison between with and without wearing the headset on the normality of the speed distributions near the bridge on the 545 ft radius curve.
Figure 6.8: Comparison of the average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed of all participants between with and without wearing the headset in the video pass-through experiment. The 2 sample t-Test compares the speed distributions for with and without wearing the headset at every 0.5 meter station increment at the 5% significance level.

Figure 6.9: Box plots of the average trial speeds after the initial condition convergence locations separated by trial number and replication number.
Figure 6.10: Comparison of the participants’ average responses to the question – “How difficult would you find it to drive this section of road at this speed?” – for with and without wearing the headset on both curve radii. Scale: 1 = “extremely easy”; 10 = “extremely difficult”. The asterisk indicates a significant difference between headset conditions according to the Wilcoxon Signed Rank Test at the 5% significance level.
Figure 6.11: Comparison of the participants' average responses to the question – “How much risk would you experience driving this section of road at this speed?” – for with and without wearing the headset on both curve radii. Scale: 1 = “no risk”; 10 = “maximum risk”. The asterisk indicates a significant difference between headset conditions according to the Wilcoxon Signed Rank Test at the 5% significance level.
Figure 6.12: Comparison of the participants’ average responses to the question – “How close was this speed to the maximum speed at which you would feel comfortable driving this section of road?” – for with and without wearing the headset on both curve radii. Scale: 1 = “exactly the same”; 10 = “not close at all”. There was no significant difference between headset conditions according to the Wilcoxon Signed Rank Test at the 5% significance level.
Figure 6.13: Comparison of each participant’s response to the Simulator Sickness Questionnaire for the evaluation after the practice period with the video pass-through headset and for the evaluation after the entire experiment.
Chapter 7  |  Conclusions

This chapter presents an overview of the research completed for this thesis. Section 7.1 describes the motivation and goals of the research as well as summarizes the experiments that were conducted. 7.2 presents the key findings from each of the experiments. Section 7.3 suggests future areas of research.

7.1 Overview

This researched investigated the effect of virtual immersion on vehicle passengers. New vehicle technologies have introduced increasing layers of abstraction between the driver and the driving task, which may result in an associated risk compensation. These technologies include parking assistance technologies (e.g. rear-view video camera systems), augmented reality Head Up Displays (HUDs), and automatic collision avoidance systems. Furthermore, the design of these technologies is often informed by driving simulator studies due to the inherent risk of many driving scenarios. Because driving simulators are fundamentally different than naturalistic driving, the validity of simulations to make conclusions about true driver behavior must be carefully considered.

The primary goal of this thesis is to provide the groundwork necessary to evaluate the relationship between risk compensation behaviors and levels of immersion in virtual and mixed-reality environments. This includes designing an experiment by which risk perception can be measured and compared across different levels of virtual immersion. It was the intent of this study to duplicate the methodology used by Carol Tan in her thesis, “An Investigation of the Comfortable Lateral Acceleration on Horizontal Curves”. This experiment was conducted for the real-world scenario, providing a baseline by which to compare with risk compensation behaviors in virtual and mixed-reality scenarios. In addition, a second experiment was conducted to investigate the effect of wearing a video pass-through headset on vehicle passenger risk perception.

The review of the literature showed a widespread use and reliance on VR simulators in the areas of training, design, and research for a variety of fields including aerospace, medicine, and vehicle technology. These uses of VR simulators have prompted questions about their validity. However, there is a lack of standards for determining the validity of VR simulators. Any VR
simulator validation study is strongly dependent on the specific simulator that is used, the tasks that are under investigation, and the motivation/purpose of the simulator. These issues provided the rational for developing an experiment designed to evaluate the relationships between virtual immersion, the perception of risk, and risk compensation behaviors.

The scope of the experiment was focused on quantifying perception of risk in speed-keeping within high-speed cornering of passenger vehicles, from a passenger’s perspective. Due to the potential for learning effects to influence risk perception, the experiment was split into two separate protocols: 1) a latent response protocol and 2) a learned response protocol. The latent response protocol refers to the first exposure of an experimental condition to a participant. This protocol was designed to replicate the experiment conducted by Carol H. Tan, so that the results could be compared. Specifically, the latent response protocol was a threshold evaluation of the participants’ comfort traversing a curve at a randomly-chosen value among a selection of test speeds; participants were asked to indicate when they felt uncomfortable by pressing a brake pedal that was instrumented to alert the driver. “Uncomfortable” was defined as a desire to slow down. Participants completed the protocol for two curve radii (318 ft and 545 ft). The order of the curves and the direction of travel were counterbalanced between participants.

The learned response protocol refers to every exposure of an experimental condition after the first, and was intended to seek the maximum speed at which a person is comfortable traversing a familiar curve. Participants sat in the passenger seat of the vehicle and were instructed to use the gaming pedals at their feet as if they had control over the vehicle. Their goal was to traverse the curve at the highest speed at which they felt comfortable. The driver interpreted the participants’ inputs via the input-to-audio algorithm described in Section 3.1 and attempted to match the vehicle’s pedals to the participants’ inputs. The independent variables included were the curve radius, direction of travel, and initial condition (the vehicle starting from rest or from high speed). The primary dependent variable was the vehicle’s speed while on the curve.

The latent and learned response protocols were conducted without virtual immersion to provide a baseline for vehicle passenger risk perception. A second experiment was conducted that included the use of a headset with video pass-through capability. The experimental design was an adaptation of the learned response protocol that removed direction of travel and initial condition. The use of the headset was added as a within subjects variable. The goal of the experiment was to determine if the use of a video pass-through headset significantly effects the passengers’ perception of risk in terms of their speed selection.

7.2 Findings

7.2.1 Latent Response Protocol

The percent of uncomfortable observations showed similar trends between categorical variables to the trends in Tan’s study.

- The relative frequency of uncomfortable observations increased as speed increased.
• There were relatively fewer uncomfortable observations for the larger radius curve radius than for the smaller radius curve.

• There were no statistical differences between direction of travel, trial order, or gender.

Each of these trends were also present in Tan’s study.

The values of the percent of uncomfortable observations do not agree between the current study and Tan’s study for all conditions. The 45 mph speed groups on both curves show zero percent uncomfortable observations, but this is most likely due to the limited number of observations (n < 5) for those conditions. Even for the other conditions, however, the limited agreement between Tan’s and the current study could be attributed to the relatively small number of observations in the current study. Other possible explanations for differences between the studies include: 1) the current study was limited to participants’ first exposure to the curves whereas Tan’s study included many exposures, and 2) different vehicles and drivers were used in either study.

7.2.2 Learned Response Protocol

The average maximum comfortable speed selected by participants among all observations was independent of both the direction of travel and the initial condition. This determination was made by comparing the speed distributions between levels of each factor. A 2 sample t-Test between distributions at every 0.5 meter station increment showed that the distributions were not significantly different at most locations within the curve boundaries. Additionally, the interactions between the curve radius and either factor were not significant.

The selected speeds in the learned response protocol were slower than the corresponding interpolated or extrapolated uncomfortable speeds in Tan’s protocol. One of the key differences between these studies was the vehicle used – the vehicle used in the current study was older, larger, and in poor condition relative to the vehicle used in Tan’s study. The other key difference was that the Tan’s protocol was a threshold evaluation of comfort whereas the learned response protocol had participants actively choose their maximum comfortable speed throughout each traversal of a curve.

A comparison of the learned response protocol to the latent response protocol showed that a relatively large number of participants selected slower average speeds in the learned response protocol than speeds at which they were comfortable in the latent response protocol. This is further evidence that the threshold evaluation of comfort used in the latent response protocol and Tan’s study yields different results for uncomfortable speeds from the methodology used in the learned response protocol.

This difference is likely attributable to the fundamental change in the test-subject’s participation: in the latent response, the test subject is simply exposed to someone else’s speed choice – which assumes the driver is responsible for and comfortable with the traversal speed. In the learned protocol, the test subject is presented with a speed choice for which only she/he is responsible. This explanation suggests that risk acceptance appears to be stronger when more than one individual is involved with risk-taking, than when individuals are acting alone. This result
could have severe implications for the deployment of autonomous vehicles wherein individuals may treat computer-driven vehicles as trusted drivers.

The driver was a potentially significant confounding variable in this experiment. It is expected for a passenger’s perception of risk in a vehicle to be influenced by their trust in the driver’s ability and in the driver’s performance. This trust would vary for different participants. Furthermore, this experiment relied on the driver to respond accurately and precisely to the participants’ desired pedal inputs via the input-to-audio algorithm. No evidence was found to suggest that the driver significantly affected the participants’ perception of risk. However, further investigation is required to understand the effect, if any, the driver has on the passenger’s perception of risk.

7.2.3 Video Pass-through Experiment

The results of the video pass-through experiment showed that the headset had significantly different effects on the speed selection for different participants. Some participants chose the same speed with and without the headset, while others chose significantly different speeds. The headset did not significantly the average selected speeds as a function of the location within the curve. However, the headset was a significant factor in the analysis of variance for the average speeds of each trial. These results suggest that the video pass-through may affect speed selection, but possibly for only certain individuals or under certain conditions. Further investigation is required to determine if there is a significant covariate that affects an individual’s response to wearing the video pass-through headset. In addition, the small number of participants (N = 7) may have limited the ability to draw conclusions about the effect of the video pass-through headset.

It appears that the video pass-through headset did affect the participants subjective evaluation of the driving task. The average ratings for difficulty and risk regarding each traversal of the curve were higher when participants were wearing the headset. These differences were only significant on the smaller curve, however. This suggests that there is an interaction between the perception of risk and the curve radius. Furthermore, the failure to find conclusive evidence that the headset affects speed selection suggests that the headset more strongly affects the users perception than it affects their performance.

Video pass-through is a minimal level of virtual immersion relative to the spectrum between real and virtual environments. The evidence that video pass-through affects risk perception motivates the need to understand the relationship between risk perception and virtual immersion. It is still unclear which specific factors related to virtual immersion affect risk perception. Video pass-through affects several factors related to visual cuing such as field of view, focus, and motion blur. Further research is necessary to understand which factors are more relevant, and the relative importance of visual cues compared to auditory, vibration, and inertial cues.

7.3 Future Research

This experiment was designed to be replicated with different levels of virtual immersion. The different levels could include any manipulations of different sensory inputs – visual, auditory,
inertial, and vibrational. For example, limiting hearing by ear plugs and earmuffs, or presenting virtual or video playback visuals, or sitting in a vehicle versus at desktop simulator. Such experiments could be used to identify which cues people use to inform their perception of risk. The experiment was designed to replicable for a wide variety of conditions, including but not limited to manipulations of sensory inputs. Other conditions could include vehicle teleoperation, choosing different passenger seats within the vehicle, or manipulation of the trust in the driver.
Appendix A

Input-to-Audio Algorithm

The following functions, `playSound` and `genSoundWave`, are functions written in Python to generate audio based on pedal inputs. The `playSound` function controls the parameters of a beeping sound (duration, interval, pitch, and bitrate) and the `genSoundWave` function generates the sound accordingly.

```python
def playSound(self, pedals, lastTime, stream):
    # pedals = [throttle value, brake value] # 0-1 scale
    # sound parameters
    intercept = 0.5
    slope = 0.95 * intercept
    length = 0.05
    BITRATE = 16000

    # pedal dependent sound parameters
    # check if brake is pressed
    if pedals[1] != 0:
        frequency = 500  # some low value
        delay = intercept - slope * pedals[1]
        doNothing = False
        # check if throttle is pressed
    elif pedals[0] != 0:
        frequency = 1000  # some value value
        delay = intercept - slope * pedals[0]
        doNothing = False
    else:
        doNothing = True
        delay = 0

    timePassed = time.time() - lastTime
```

```
# pedal dependent sound parameters
# check if brake is pressed
if pedals[1] != 0:
    frequency = 500  # some low value
    delay = intercept - slope * pedals[1]
    doNothing = False
# check if throttle is pressed
elif pedals[0] != 0:
    frequency = 1000  # some value value
    delay = intercept - slope * pedals[0]
    doNothing = False
else:
    doNothing = True
    delay = 0

timePassed = time.time() - lastTime
```
if timePassed > delay and doNothing is False:
    self.genSoundWave(stream, BITRATE, frequency, length)
lastTime = time.time()
print('playing_sound')

def genSoundWave(self, stream, BITRATE, FREQUENCY, LENGTH):
    if FREQUENCY > BITRATE:
        BITRATE = FREQUENCY+100

    NUMBEROFFRAMES = int(BITRATE * LENGTH)
    RESTFRAMES = NUMBEROFFRAMES % BITRATE
    WAVEDATA = ''

    #generating waves
    for x in xrange(NUMBEROFFRAMES):
        WAVEDATA = WAVEDATA+chr(int(math.sin(x/((BITRATE/FREQUENCY)/math.pi))*127+128))

    for x in xrange(RESTFRAMES):
        WAVEDATA = WAVEDATA+chr(128)

    stream.write(WAVEDATA)
Appendix B
Institutional Review Board Protocol

B.1 Protocol
HRP-591 - Protocol for Human Subject Research

Protocol Title:
Provide the full title of the study as listed in item 1 on the “Basic Information” page in CATS IRB (http://irb.psu.edu).
Analysis of risk compensation in driving

Principal Investigator:
Name: Matt Parkinson
Department: Engineering Design
Telephone: (814) 863-9079
E-mail Address: parkinson@psu.edu

Version Date:
Provide the date of this submission. This date must be updated each time the submission is provided to the IRB office with revisions.
May 10, 2018

Clinicaltrials.gov Registration #:
Provide the registration number for this study, if applicable.
Not applicable

Important Instructions for Using This Protocol Template:
1. Add this completed protocol template to your study in CATS IRB (http://irb.psu.edu) on the “Basic Information” page, item 7.
2. This template is provided to help investigators prepare a protocol that includes the necessary information needed by the IRB to determine whether a study meets all applicable criteria for approval.
3. Type your protocol responses below the gray instructional boxes of guidance language. If the section or item is not applicable, indicate not applicable.
4. For research being conducted at Penn State Hershey or by Penn State Hershey researchers only, delete the instructional boxes from the final version of the protocol prior to upload to CATS IRB (http://irb.psu.edu). For all other research, do not delete the instructional boxes from the final version of the protocol.
5. When making revisions to this protocol as requested by the IRB, please follow the instructions outlined in the Study Submission Guide available in the Help Center in CATS IRB (http://irb.psu.edu) for using track changes.

If you need help...

University Park and other campuses:
Office for Research Protections Human Research Protection Program
The 330 Building, Suite 205
University Park, PA 16802-7014
Phone: 814-865-1775
Fax: 814-863-8699
Email: irb-orp@psu.edu

College of Medicine and Hershey Medical Center:
Human Subjects Protection Office
90 Hope Drive, Mail Code A115, P.O. Box 855
Hershey, PA 17033
(Physical Office Location: Academic Support Building Room 1140)
Phone: 717-531-5687
Fax number: 717-531-3937
Email: irb-hspo@psu.edu
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Objectives

1.1 Study Objectives
Describe the purpose, specific aims or objectives. State the hypotheses to be tested.

The objective of this study is to quantify the risk compensation of a vehicle passenger as a function of the vehicle speed and turning radius. Future studies will replicate this study with different levels of virtual immersion to identify the relationship between risk compensation and levels of immersion. The long-term goal is to enable the improved design of man-machine systems that use virtual and mixed-reality environments.

1.2 Primary Study Endpoints
State the primary endpoints to be measured in the study. Clinical trials typically have a primary objective or endpoint. Additional objectives and endpoints are secondary. The endpoints (or outcomes), determined for each study subject, are the quantitative measurements required by the objectives. Measuring the selected endpoints is the goal of a trial (examples: response rate and survival).

Anthropometry:
- Stature
- Body mass
- Sitting height
- Sitting eye height

Vehicle Behavior:
- Longitudinal speed
- Lateral acceleration
- Position
- Yaw rate

Passenger Pedals: Used by the subject to indicate to the driver a desire to go faster or slower.

Subjective ratings of difficulty, risk, and comfort.

1.3 Secondary Study Endpoints
State the secondary endpoints to be measured in the study.

Verbal feedback of subject.

1.0 Background

1.1 Scientific Background and Gaps
Describe the scientific background and gaps in current knowledge.

Immersive environments are used broadly, with applications from entertainment to design. They provide a safe training environment for high-risk scenarios faced by soldiers, pilots, and surgeons. They are also used to assess potentially risky behaviors in man-machine systems (e.g. driving simulator) and potential interventions (e.g. collision avoidance, surgical planning). As immersion varies from purely virtual to purely real, the behavior of the man-machine system changes, particularly for scenarios in which the designed artifact exposes humans to risk. The question of how best to design these systems is difficult to answer because artifacts that involve risk generally use testing mediated by risk-free virtual interactions.

As a result, risk compensation and other effects can confound the results of design assessments, training, and remote operator performance – particularly in the acceptance or avoidance of risk when interactions...
are mediated in novel ways. The current research is limited to comparing the behavior in fully virtual and fully real tests, but the user behavior has to be evaluated in mixed-reality environments as these are becoming more popular in high-risk situations.

1.2 Previous Data
Describe any relevant preliminary data.

A similar study titled “An investigation of comfortable lateral acceleration on horizontal curves” has been conducted at The Pennsylvania State University by Carol H. Tan. Subjects travelled as passengers in a car driven through the curves on The Larson Institute Test Track. The point of discomfort identified by the subjects were used to determine the comfortable lateral acceleration on horizontal curves.

1.3 Study Rationale
Provide the scientific rationale for the research.

The effect of risk on user behavior, once studied, can be used to evaluate the relevance of simulator based studies, training, and testing whose results have been used to design different man-machine systems. Knowing the effects of the user’s anthropometric measures on their vehicle driving preferences allows to observe potential relations between body measures and risk-taking behavior. Recreating the previously mentioned study provides a baseline for risk perception of vehicle passengers. Future experiments will replicate this study for different levels of virtual immersion, which can then be compared to the baseline case.

2.0 Inclusion and Exclusion Criteria
Create a numbered list below in sections 3.1 and 3.2 of criteria subjects must meet to be eligible for study enrollment (e.g., age, gender, diagnosis, etc.). Indicate specifically whether you will include any of the following vulnerable populations: (You may not include members of these populations as subjects in your research unless you indicate this in your inclusion criteria.) Review the corresponding checklists to ensure that you have provided the necessary information.

- Adults unable to consent
  - Review “CHECKLIST: Cognitively Impaired Adults (HRP-417)” to ensure that you have provided sufficient information. HRP-417 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

- Individuals who are not yet adults (infants, children, teenagers)
  - If the research involves persons who have not attained the legal age for consent to treatments or procedures involved in the research (“children”), review the “CHECKLIST: Children (HRP-416)” to ensure that you have provided sufficient information. HRP-416 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

- Pregnant women
  - Review “CHECKLIST: Pregnant Women (HRP-412)” to ensure that you have provided sufficient information. HRP-412 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

- Prisoners
  - Review “CHECKLIST: Prisoners (HRP-415)” to ensure that you have provided sufficient information. HRP-415 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

- Neonates of uncertain viability or non-viable neonates
  - Review “CHECKLIST: Neonates (HRP-413)” or “CHECKLIST: Neonates of Uncertain Viability (HRP-414)” to ensure that you have provided sufficient information. HRP-413 and HRP-414 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).
2.1 Inclusion Criteria
List the criteria that define who will be included in your study.

Any drivers above the age of 18 holding a valid driver’s license will be recruited for participation.

2.2 Exclusion Criteria
List the criteria that define who will be excluded in your study.

Individuals below the age of 18 and those who do not hold a valid driver’s license will be excluded. In addition, individuals with experience racing vehicles will be excluded.

If a participant is to wear a Head-Mounted Display (as determined randomly by the experimental protocol, see Section 6.1) then any participant with who is very susceptible to motion sickness (as determined by the screening questions) will be excluded.

2.3 Early Withdrawal of Subjects

2.3.1 Criteria for removal from study
Insert subject withdrawal criteria (e.g., safety reasons, failure of subject to adhere to protocol requirements, subject consent withdrawal, disease progression, etc.).

If the participant is unable to complete the tasks identified, they may verbalize at any time to be removed from the study.

2.3.2 Follow-up for withdrawn subjects
Describe when and how to withdraw subjects from the study; the type and timing of the data to be collected for withdrawal of subjects; whether and how subjects are to be replaced; the follow-up for subjects withdrawn from investigational treatment.

Not applicable

3.0 Recruitment Methods

3.1 Identification of subjects
Describe the methods that will be used to identify potential subjects or the source of the subjects. If not recruiting subjects directly (e.g., database query for eligible records or samples) state what will be queried, how and by whom.

Driver’s license holders will be identified as source of the subjects.

3.2 Recruitment process
Describe how, where and when potential subjects will be recruited (e.g., approaching or providing information to potential subjects for participation in this research study).

The study will be advertised through posters on bulletin boards in Penn State University Park campus. Interested participants would contact the researchers who will then provide them with necessary details to participate.
The Recruitment Script will be used when speaking with or emailing potential participants known to the research group.

### 3.3 Recruitment materials

List the materials that will be used to recruit subjects. Add recruitment documents to your study in CATS IRB ([http://irb.psu.edu](http://irb.psu.edu)) on the “Consent Forms and Recruitment Materials” page. For advertisements, upload the final copy of printed advertisements. When advertisements are taped for broadcast, attach the final audio/video tape. You may submit the wording of the advertisement prior to taping to preclude re-taping because of inappropriate wording, provided the IRB reviews the final audio/video tape.

- Script – verbal, email.
- Poster

### 3.4 Eligibility/screening of subjects

If potential subjects will be asked eligibility questions before obtaining informed consent, describe the process. Add the script documents and a list of the eligibility questions that will be used to your study in CATS IRB ([http://irb.psu.edu](http://irb.psu.edu)) on the “Consent Forms and Recruitment Materials” page.

The participant’s driver’s license will be verified. This will take place in the administration building at the Larson Institute Test Track, prior to the experiment.

During the recruitment process, participants will be asked if they have any experience racing vehicles. This question is included in the Screening Questions document and will asked verbally or by email, before the consent process. Individuals who have experience racing vehicles in any organized form will be ineligible to participate in this study.

If the participant is to where a head-mounted display during the experiment as determined randomly according to the experimental protocol (see Section 6.1), then the participant will be screened for their susceptibility for simulator sickness (similar to motion sickness). Two sets of screening questions will be used and are included in the supporting documents. They are titled, “Simulator Sickness Screening Questions” and “Simulator Sickness Questionnaire”.

The screening questions will be asked by telephone or by email with a prospective participant. The accept/reject criteria are included in the screening questions document. These questions were taken from a study performed at the Turner-Fairbank Highway Research Center (reference included in the document).

The Simulator Sickness Questionnaire (SSQ) will be administered on-site twice during the experimental procedure. These times are 1) after an 8-minute practice period wearing the head-mounted display while sitting in the passenger seat of the vehicle as it is being driven, and 2) after the entire experimental protocol is complete. If the participant does not meet the accept criterion (provided in the document) after the practice period they will be excluded from the experiment. The SSQ has been used in over 800 scientific articles as of 2012 – sources for the original SSQ and for the accept/reject criterion are included in the document.

### 4.0 Consent Process and Documentation

Refer to “SOP: Informed Consent Process for Research (HRP-090)”, for information about the process of obtaining informed consent from subjects. HRP-090 can be accessed by clicking the Library link in CATS IRB ([http://irb.psu.edu](http://irb.psu.edu)).
4.1 Consent Process

4.1.1 Obtaining Informed Consent

4.1.1.1 Timing and Location of Consent
Describe where and when the consent process will take place.

Informed consent will be obtained at the beginning of the session. It will be at the Larson Institute Test Track, in a private office.

4.1.1.2 Coercion or Undue Influence during Consent
Describe the steps that will be taken to minimize the possibility of coercion or undue influence in the consent process.

Participants will not be coerced since informed consent is obtained at the beginning of the experiment. The participant can also choose to decline participation without any penalty.

4.1.2 Waiver or alteration of the informed consent requirement
If you are requesting a waiver or alteration of consent (consent will not be obtained, required information will not be disclosed, or the research involves deception), describe the rationale for the request in this section. If the alteration is because of deception or incomplete disclosure, explain whether and how subjects will be debriefed. Add any debriefing materials or document(s) to your study in CATS IRB (http://irb.psu.edu) on the “Supporting Documents” page. NOTE: Review the “CHECKLIST: Waiver or Alteration of Consent Process (HRP-410)” to ensure you have provided sufficient information for the IRB to make these determinations. HRP-410 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

We request an alteration of the consent process in order to deceive participants by withholding information about the maximum speed at which they will be able to travel on the test track. This alteration is made according to the first set of criteria of HRP-410. Those criteria listed here:

- The research is NOT FDA-regulated
- The research does NOT involve non-viable neonates
- The research does NOT involve newborn dried blood spots
- The research involves no more than Minimal Risk to the subjects. This determination is made by the fact the test vehicle will never exceed the maximum speed at which the drivers have practiced for the experimental scenario (60 mph). This limit is imposed as a safety precaution, but knowledge of its presence will be withheld from the participants. This experiment involves the same level of risk that is present when travelling in a vehicle by a licensed driver.
- The alteration will NOT adversely affect the rights and welfare of the subjects. This determination is made by the fact that the speed limit is a safety precaution. Having no knowledge of the speed limit would lead participants to expect the same level of risk that is present in typical, day-to-day driving. The alteration serves to limit this risk by limiting extreme risk taking behavior that may be exhibited by any participants. The research could NOT practically be carried out without the alteration. This determination is made because goal of the study is to evaluate the participants natural perception of risk while travelling in a vehicle. Knowledge of a safety limit that is not present in typical driving may affect the participants’ perception of risk, thereby biasing the results.
Whenever appropriate, the subjects will be provided with additional pertinent information after participation. Participants will be debriefed according to the debriefing form that can be found among the supporting documents.

4.2 Consent Documentation

4.2.1 Written Documentation of Consent

Refer to “SOP: Written Documentation of Consent (HRP-091)” for information about the process to document the informed consent process in writing. HRP-091 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

If you will document consent in writing, describe how consent of the subject will be documented in writing. Add the consent document(s) to your study in CATS IRB (http://irb.psu.edu) on the “Consent Forms and Recruitment Materials” page. Links to Penn State’s consent templates are available in the same location where they are uploaded and their use is required.

The participant will review the consent document with the individual conducting the study, who is a team member who is authorized to administer the consent form and sign the consent form after any questions from the participant are answered. An additional copy of the consent form will be made available for the participant to keep for their records.

4.2.2 Waiver of Documentation of Consent (Implied consent, Verbal consent, etc.)

If you will obtain consent (verbal or implied), but not document consent in writing, describe how consent will be obtained. Add the consent script(s) and/or information sheet(s) to your study in CATS IRB (http://irb.psu.edu) on the “Consent Forms and Recruitment Materials” page. Links to Penn State’s consent templates are available in the same location where they are uploaded and their use is required. Review “CHECKLIST: Waiver of Written Documentation of Consent (HRP-411)” to ensure that you have provided sufficient information. HRP-411 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

If your research presents no more than minimal risk of harm to subjects and involves no procedures for which written documentation of consent is normally required outside of the research context, the IRB will generally waive the requirement to obtain written documentation of consent.

Not applicable

4.3 Consent – Other Considerations

4.3.1 Non-English Speaking Subjects

Indicate what language(s) other than English are understood by prospective subjects or representatives.

If subjects who do not speak English will be enrolled, describe the process to ensure that the oral and written information provided to those subjects will be in that language. Indicate the language that will be used by those obtaining consent.

Indicate whether the consent process will be documented in writing with the long form of the consent documentation or with the short form of the consent documentation. Review the “SOP: Written Documentation of Consent (HRP-091)” and the “Investigator Manual (HRP-103)”
Not applicable

4.3.2 Cognitively Impaired Adults

Refer to “CHECKLIST: Cognitively Impaired Adults (HRP-417)” for information about research involving cognitively impaired adults as subjects. HRP-417 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

4.3.2.1 Capability of Providing Consent

Describe the process to determine whether an individual is capable of consent.

Not applicable

4.3.2.2 Adults Unable To Consent

Describe whether and how informed consent will be obtained from the legally authorized representative. Describe who will be allowed to provide informed consent. Describe the process used to determine these individual’s authority to consent to research.

For research conducted in the state, review “SOP: Legally Authorized Representatives, Children and Guardians (HRP-013)” to be aware of which individuals in the state meet the definition of “legally authorized representative”. HRP-013 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

For research conducted outside of the state, provide information that describes which individuals are authorized under applicable law to consent on behalf of a prospective subject to their participation in the procedure(s) involved in this research. One method of obtaining this information is to have a legal counsel or authority review your protocol along with the definition of “children” in “SOP: Legally Authorized Representatives, Children, and Guardians (HRP-013).” HRP-013 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

Not applicable

4.3.2.3 Assent of Adults Unable to Consent

Describe the process for assent of the subjects. Indicate whether assent will be required of all, some or none of the subjects. If some, indicate which subjects will be required to assent and which will not.

If assent will not be obtained from some or all subjects, provide an explanation of why not.

Describe whether assent of the subjects will be documented and the process to document assent. The IRB allows the person obtaining assent to document assent on the consent document and does not routinely require assent documents and does not routinely require subjects to sign assent documents.

Not applicable
4.3.3 Subjects who are not yet adults (infants, children, teenagers)

4.3.3.1 Parental Permission

Describe whether and how parental permission will be obtained. If permission will be obtained from individuals other than parents, describe who will be allowed to provide permission. Describe the process used to determine these individual’s authority to consent to each child’s general medical care.

For research conducted in the state, review “SOP: Legally Authorized Representatives, Children and Guardians (HRP-013)” to be aware of which individuals in the state meet the definition of “children”. HRP-013 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

For research conducted outside of the state, provide information that describes which persons have not attained the legal age for consent to treatments or procedures involved in the research, under the applicable law of the jurisdiction in which research will be conducted. One method of obtaining this information is to have a legal counsel or authority review your protocol along with the definition of “children” in “SOP: Legally Authorized Representatives, Children, and Guardians (HRP-013).” HRP-013 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

Not applicable

4.3.3.2 Assent of subjects who are not yet adults

Indicate whether assent will be obtained from all, some, or none of the children. If assent will be obtained from some children, indicate which children will be required to assent. When assent of children is obtained describe whether and how it will be documented.

Not applicable

5.0 HIPAA Research Authorization and/or Waiver or Alteration of Authorization

This section is about the access, use or disclosure of Protected Health Information (PHI). PHI is individually identifiable health information (i.e., health information containing one or more 18 identifiers) that is transmitted or maintained in any form or medium by a Covered Entity or its Business Associate. A Covered Entity is a health plan, a health care clearinghouse or health care provider who transmits health information in electronic form. See the “Investigator Manual (HRP-103)” for a list of the 18 identifiers. HRP-103 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

If requesting a waiver/alteration of HIPAA authorization, complete sections 6.2 and 6.3 in addition to section 6.1. The Privacy Rule permits waivers (or alterations) of authorization if the research meets certain conditions. Include only information that will be accessed with the waiver/alteration.

5.1 Authorization and/or Waiver or Alteration of Authorization for the Uses and Disclosures of PHI

Check all that apply:

☒ Not applicable, no identifiable protected health information (PHI) is accessed, used or disclosed in this study. [Mark all parts of sections 6.2 and 6.3 as not applicable]
Authorization will be obtained and documented as part of the consent process. [If this is the only box checked, mark sections 6.2 and 6.3 as not applicable]

☐ Partial waiver is requested for recruitment purposes only (Check this box if patients' medical records will be accessed to determine eligibility before consent/authorization has been obtained). [Complete all parts of sections 6.2 and 6.3]

☐ Full waiver is requested for entire research study (e.g., medical record review studies). [Complete all parts of sections 6.2 and 6.3]

☐ Alteration is requested to waive requirement for written documentation of authorization (verbal authorization will be obtained). [Complete all parts of sections 6.2 and 6.3]

5.2 Waiver or Alteration of Authorization for the Uses and Disclosures of PHI

5.2.1 Access, use or disclosure of PHI representing no more than a minimal risk to the privacy of the individual

5.2.1.1 Plan to protect PHI from improper use or disclosure

Include the following statement as written – DO NOT ALTER OR DELETE unless this section is not applicable because the research does not involve a waiver of authorization. If the section is not applicable, remove the statement and indicate as not applicable.

Not applicable.

5.2.1.2 Plan to destroy identifiers or a justification for retaining identifiers

Describe the plan to destroy the identifiers at the earliest opportunity consistent with the conduct of the research. Include when and how identifiers will be destroyed. If identifiers will be retained, provide the legal, health or research justification for retaining the identifiers.

Not applicable

5.2.2 Explanation for why the research could not practicably be conducted without access to and use of PHI

Provide an explanation for why the research could not practicably be conducted without access to and use of PHI.

Not applicable

5.2.3 Explanation for why the research could not practicably be conducted without the waiver or alteration of authorization

Provide an explanation for why the research could not practicably be conducted without the waiver or alteration of authorization.

Not applicable

5.3 Waiver or alteration of authorization statements of agreement
6.0 Study Design and Procedures

6.1 Study Design

Describe and explain the study design.

The experiment is split into two parts: the latent response and the learned response. The latent response is addressed first. The vehicle will start on a straight-away, about one quarter mile before the entrance to the curve. Subjects will be driven around the curve at a constant speed, and will be asked to indicate if or when they feel uncomfortable. In this context, “uncomfortable”, is defined as a desire to slow down. If or when the subject indicates discomfort, the driver will slow down.

The speed will be randomly chosen from a subset of the speeds used in experiments done by Carol H. Tan, which are described in “An investigation of comfortable lateral acceleration on horizontal curves”. The subset of speeds chosen for this study are summarized in Table 1. One of the three speeds for a given curve will be randomly chosen, and the driver will accelerate to the chosen speed, and use cruise control to maintain that speed throughout the curve, unless indicated by the subject that they feel uncomfortable. If or when the subject indicates discomfort, the driver will slow down to below 30 mph for the remainder of the curve. These experiments will be conducted at the Larson Institute Test Track, the same location used for Tan’s work. This test will be conducted once per curve, per subject. The order of the presentation of the curves and the directions of travel (clockwise vs. counterclockwise) will be randomized between subjects.

<table>
<thead>
<tr>
<th>Curve Radius (ft)</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>318</td>
<td>40 45 50</td>
</tr>
<tr>
<td>545</td>
<td>45 50 55</td>
</tr>
</tbody>
</table>

After the latent response test, the learned response is addressed. The subject will be driven around the curve again, and will indicate whether they want to go faster or slower. The driver will continuously adjust the speed according the subject’s input. The subject’s goal is to achieve the maximum speed at which they feel comfortable. The subjects will not be provided with any external motivation to drive faster, as this would bias the assessment of their feeling risk. The vehicle may either begin from rest, or from high speed (60 mph). The decision for this initial condition will be made randomly for each trial.
There are four total treatment combinations resulting from the two levels of the initial condition (vehicle starting from rest or from high speed) and the two levels of the curve radii. There will be three replications of these treatment combinations creating 12 total trials. The order of the trials will be randomized. The direction of travel (clockwise vs. counterclockwise) will also be randomized for each trial.

After every traversal of a curve (in both the latent and learned response protocols) the subjects will be asked to answer the questions on the General Questionnaire document. These questions are intended to assess the subjects’ perception of difficulty, risk, and comfort for each trial.

Upon completion of the entire experiment, subjects will be asked to complete the Driver Behavior Questionnaire. This questionnaire is commonly used in the literature to characterize driver behaviors.

An additional factor will be the use of a Head Mounted Display (HMD) by which the participant will see their surroundings. The HMD may show either 1) pass through video to the wearer from a camera mounted on the headset (Figure 1, left); 2) a virtual representation of the test track (Figure 1, right); or 3) an augmented reality environment that combines elements of the camera images and the virtual environment. A fourth option is for the participant to not wear the HMD at all. The determination of which of the four options the participant will use will be made randomly. All other elements of the protocol will remain the same.

Screenshots of the virtual environment can be seen in Figure 1. The perspective of the virtual environment displayed by the head-mounted display will update in real time to reflect the vehicle’s position on the test track. In other words, if one was at the test track in one of the locations pictured on the left of Figure 1, they would see the corresponding view on the right of Figure 1 when they put on the head-mounted display.

The augmented reality environment will combine elements of the virtual environment and camera images. An example is presenting the interior of the vehicle using virtual reality, but everything that can be seen through the windshield of the vehicle would be camera generated. The opposite scenario, real vehicle interior but virtual surroundings, is another possibility.
**Figure 1.** On the left are photos taken at 2 different locations on the test track. On the right are screenshots of the virtual environment that correspond to the same locations on the test track. The use of the head-mounted display by the subject will not affect the driver. The driver will always be viewing their surroundings directly (not via virtual reality). Therefore, the driver will be able to react to any unexpected events while driving.

All trials will only be conducted when the test track is dry. This is due to the potential for wet roads to affect the participants’ perception of risk.

### 6.2 Study Procedures

Provide a description of all research procedures being performed and when they are being performed (broken out by visit, if applicable), including procedures being performed to monitor subjects for safety or minimize risks. Include any long-term follow-up procedures and data collection, if applicable.

Describe where or how you will be obtaining information about subjects (e.g., medical records, school records, surveys, interview questions, focus group topics, audio or video recordings, data collection forms, and collection of specimens through invasive or non-invasive procedures to include the amount to be collected and how often). Add any data collection instruments that will be seen by subjects to your study in CATS IRB (http://irb.psu.edu) in the “Supporting Documents” page.

**6.2.1 EXAMPLE: Visit 1 or Day 1 or Pre-test, etc. (format accordingly)**

The subjects will be assigned a unique number and asked to complete a pre-test, which will be administered by paper. Their stature is then measured using a stadiometer. Body mass is measured by allowing them to stand on a regular bathroom scale. They are then allowed to sit on a chair with flat surface where their sitting height will be measured using an anthropometer along with their seated eye height.

The subject will then sit in the front passenger seat of the vehicle. All instructions that must be provided to the participant while they are in the vehicle will be given by paper for the participant to read. Driver interaction with the participant will be kept at the bare minimum. The driver will only speak to the participant in the following situations:

- if there is an emergency
- instructing the participant to fasten their seatbelt
- ensuring that the participant’s view of the speedometer is obscured
- ensuring that the participant is reading from the correct page of the instructions
- for learned response protocol only: informing the participant whether the vehicle will begin from rest or from high speed.
- For the high speed initial condition of the learned response protocol: the driver will say “When I hit the button, you will be in control of the pedals.” as a reminder to the participant

If the subject has been randomly selected to wear a head-mounted display for the experiment, they will then be asked to wear the head-mounted display for an 8-minute practice period as the vehicle is driven around the skid pad of the test track. The vehicle will not exceed 30 mph during this practice period. After the practice period, the subject will be asked to complete the Simulator Sickness Questionnaire to determine if they are fit to continue with the experiment. The questionnaire will be administered by paper.
The subject will then be driven around a curve at a constant speed. They will be asked to press the brake pedal anytime they feel uncomfortable. In this context, “uncomfortable”, is defined as a desire to slow down. If or when the subject indicates discomfort, the driver will slow down. This will then be repeated for the second curve.

The subject will then be given 5 minutes to practice using the pedals to control the vehicle’s speed. Pressing these pedals will indicate to the driver if the subject wants to go faster or slower. This practice time will take place on the skid pad of the test track, which is a large, open, and paved area.

Then the subject will be driven around a curve again, but will instead indicate if they want to go faster or slower using the throttle and brake pedals. The driver will continuously adjust the speed according the subject’s input. The test may begin with the vehicle at rest or at high speed. The test may also be for either radius curve, and in the clockwise or counterclockwise direction. The subject will be told which scenario to expect before the start of the test. This test will be repeated up to twelve times.

After every traversal of a curve for both parts of the procedure, the subjects will be asked to answer the questions on the General Questionnaire document. These questions are intended to assess the subjects’ perception of difficulty, risk, and comfort for each trial. The questionnaire will be administered by paper.

Upon completion of the entire experiment, subjects will be asked to complete the Driver Behavior Questionnaire. This questionnaire is commonly used in the literature to characterize driver behaviors. The questionnaire will be administered by paper.

If the subject was selected to wear the head-mounted display during the experiment, they will complete the Simulator Sickness Questionnaire for a second time. The questionnaire will be administered by paper.

The driver will be a member of the research team. They hold valid driver’s licenses and have practiced driving around the track. This practice includes over 5 hours of driving on the track, spread out between September 2017 and February 2018. It also includes driving at high speeds (up to 55 mph on the 318 ft radius curve; up to 60 mph on the 545 ft radius curve). Since the drivers have not practiced above these speeds, they will not exceed them at any time during the experiment.

Participants will not be told of the upper speed limits imposed on the drivers. This is because knowing of the upper speed limit may influence the participant’s feeling of risk. Specifically, participants may interpret the upper speed limit as an indication that the driver may disregard some of the participant’s inputs, allowing the participant to act more recklessly than they would if they were driving. Although it is true that the driver will disregard the participant’s inputs if they conflict with the speed limits, we do not want to provide this information to the participants, and thereby influence their behavior. As assessing their latent feeling of risk is the goal of this experiment, it is necessary to withhold information about the upper speed limit.

No data observing the participant will be recorded. This includes eye tracking, video, etc.

The participants will be required to wear a seatbelt at all times while in the vehicle.
The vehicle that will be used is the Intelligent Vehicles and System Group’s Mapping Van. It is a 1997 Plymouth Grand Voyager that has been equipped with a variety of sensors. The vehicle will not be altered between tests.

6.2.2 EXAMPLE: Visit 2 or Day 2 or Post-test, etc. (format accordingly)

Provide a description as defined above and format accordingly.

Not applicable, only one visit

6.3 Duration of Participation

Describe the duration of an individual subject’s participation in the study.

Experiment 1: 1 hour

For subjects who are asked to wear the head-mounted display, it is possible for the protocol to take longer to complete. The total time, however, will still not exceed 1 hour.

7.0 Subject Numbers and Statistical Plan

7.1 Number of Subjects

Indicate the total number of subjects to be accrued.

If applicable, distinguish between the number of subjects who are expected to be enrolled and screened, and the number of subjects needed to complete the research procedures (i.e., numbers of subjects excluding screen failures.)

12 to 20 subjects are required to determine the statistical power of the experiment. The results obtained will then be used to determine the total number of participants required, which will not exceed 50.

7.2 Sample size determination

If applicable, provide a justification of the sample size outlined in section 8.1 – to include reflections on, or calculations of, the power of the study.

The number of subject required to determine the statistical power is based on previous research. 50 which is the maximum number of subjects for the experiment is based on similar previous research and budget constraints.

7.3 Statistical methods

Describe the statistical methods (or non-statistical methods of analysis) that will be employed.

Descriptive statistics will be generated.

8.0 Confidentiality, Privacy and Data Management

For research being conducted at Penn State Hershey or by Penn State Hershey researchers only, the research data security and integrity plan is submitted using “HRP-598 – Research Data Plan Review Form Application Supplement”, which is available in the Library in CATS IRB [http://irb.psu.edu]. Refer to Penn State College of Medicine IRB’s “Standard Operating Procedure Addendum: Security and Integrity of Human Research Data”,

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which is available on the IRB’s website. In order to avoid redundancy, for this section state “See the Research Data Plan Review Form” in section 9.0 if you are conducting Penn State Hershey research and move on to section 10.

For all other research, in the sections below, describe the steps that will be taken to secure the data during storage, use and transmission.

8.1 Confidentiality

8.1.1 Identifiers associated with data and/or specimens

List the identifiers that will be included or associated with the data and/or specimens in any way (e.g., names, addresses, telephone/fax numbers, email addresses, dates (date of birth, admission/discharge dates, etc.), medical record numbers, social security numbers, health plan beneficiary numbers, etc.).

If no identifiers will be included or associated with the data in any way, whether directly or indirectly, please indicate this instead.

No identifying information with be included.

8.1.1.1 Use of Codes, Master List

If identifiers will be associated with the data and/or specimens (as indicated in section 9.1.1 above), describe whether a master record or list containing a code (i.e., code number, pseudonyms) will be used to separate the data collected from identifiable information, where that master code list will be stored, who will have access to the master code list, and when it will be destroyed.

If identifiers are included or associated with the data as described in section 9.1.1 above, but no master record or list containing a code will be used, it will be assumed by the IRB that the investigator plans to directly link the identifiers with the data.

Not applicable

8.1.2 Storage of Data and/or Specimens

Describe where, how and for how long the data (hardcopy (paper) and/or electronic data) and/or specimens will be stored. NOTE: Data can include paper files, data on the internet or websites, computer files, audio/video files, photographs, etc. and should be considered in the responses. Refer to the “Investigator Manual (HRP-103)” for information about how long research records must be stored following the completion of the research prior to completing this section. HRP-103 can be accessed by clicking the Library link in CATS IRB (http://irb.psu.edu).

Please review Penn State’s Data Categorization Project for detailed information regarding the appropriate and allowable storage of research data collected according to Penn State Policy AD71. Although the IRB can impose greater confidentiality/security requirements (particularly for sensitive data), the IRB cannot approve storage of research data in any way or using any service that is not permissible by Penn State Policy AD71.
Paper files will be locked in a filing cabinet at the Energy and the Environment Laboratory, University Park, PA in a locked office. Computer files will be password protected. De-identified data will be kept indefinitely with the expectation that it will be used for future research.

8.1.3 Access to Data and/or Specimens

Identify who will have access to the data and/or specimens. This information should not conflict with information provided in section 9.1.1.1 regarding who has access to identifiable information, if applicable.

The team members listed on the project and the PI's will have access.

8.1.4 Transferring Data and/or Specimens

If the data and/or specimens will be transferred to and/or from outside collaborators, identify the collaborator to whom the data and/or specimens will be transferred and how the data and/or specimens will be transferred. This information should not conflict with information provided in section 9.1.1.1 regarding who has access to identifiable information, if applicable.

Not applicable

8.2 Subject Privacy

This section must address subject privacy and NOT data confidentiality.

Indicate how the research team is permitted to access any sources of information about the subjects.

Describe the steps that will be taken to protect subjects’ privacy interests. “Privacy interest” refers to a person’s desire to place limits on whom they interact with or to whom they provide personal information.

Describe what steps you will take to make the subjects feel at ease with the research situation in terms of the questions being asked and the procedures being performed. “At ease” does not refer to physical discomfort, but the sense of intrusiveness a subject might experience in response to questions, examinations, and procedures.

Data collection will take place at the Larson Institute Test Track, where the subjects will be participating individually. The information gathered will be kept confidential and free of identifying information. Participants will be given this information when scheduling an appointment to participate in the experiment and they are allowed to decline participation if they feel their privacy is compromised.

9.0 Data and Safety Monitoring Plan

This section is required when research involves more than Minimal Risk to subjects. As defined in “SOP: Definitions (HRP-001)”, available in the Library in CATS IRB (http://irb.psu.edu), Minimal Risk is defined as the probability and magnitude of harm or discomfort anticipated in the research that are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. For research involving prisoners, Minimal Risk is the probability and magnitude of physical or psychological harm that is normally encountered in the daily lives, or in the routine medical, dental, or psychological examination of healthy persons. Please complete the sections below if the research involves more than minimal risk to subjects OR indicate as not applicable.

9.1 Periodic evaluation of data

Describe the plan to periodically evaluate the data collected regarding both harms and benefits to determine whether subjects remain safe.
9.2 **Data that are reviewed**
Describe the data that are reviewed, including safety data, untoward events, and efficacy data.

9.3 **Method of collection of safety information**
Describe the method by which the safety information will be collected (e.g., with case report forms, at study visits, by telephone calls and with subjects).

9.4 **Frequency of data collection**
Describe the frequency of data collection, including when safety data collection starts.

9.5 **Individuals reviewing the data**
Identify the individuals who will review the data. The plan might include establishing a data and safety monitoring committee and a plan for reporting data monitoring committee findings to the IRB and the sponsor.

9.6 **Frequency of review of cumulative data**
Describe the frequency or periodicity of review of cumulative data.

9.7 **Statistical tests**
Describe the statistical tests for analyzing the safety data to determine whether harms are occurring.

9.8 **Suspension of research**
Describe any conditions that trigger an immediate suspension of research.

10.0 **Risks**
List the reasonably foreseeable risks, discomforts, hazards, or inconveniences to the subjects related the subjects’ participation in the research. For each potential risk, describe the probability, magnitude, duration, and reversibility. Consider all types of risk including physical, psychological, social, legal, and economic risks. If applicable, indicate which procedures may have risks to the subjects that are currently unforeseeable. If applicable, indicate which procedures may have risks to an embryo or fetus should the subject be or become pregnant. If applicable, describe risks to others who are not subjects.
Please keep in mind that loss of confidentiality is a potential risk when conducting human subject research and should be addressed as such.

This study presents only minimal risk. The subject might be uncomfortable providing information on height, weight, or sitting height. The rest of the experiment is conducted either in a controlled environment where the subject sits in the front passenger seat of a moving car on a test track closed to outside traffic. The regular risks involved in travelling in a car driven by a licensed driver exist. These include the risk of a crash. The subject will be wearing a seat belt while travelling in the car.

Simulation of a moving virtual environment can cause symptoms of simulator sickness in a small number of individuals. Those symptoms include nausea, sweating, and temporary dizziness. The effects of simulator sickness are not serious and are alleviated when looking away from the display screen. Any simulator sickness a participant may feel is temporary and is not a health risk. These risks are only applicable to subjects who are randomly selected to wear the head-mounted display for the experiment.

11.0 Potential Benefits to Subjects and Others

11.1 Potential Benefits to Subjects

Describe the potential benefits that individual subjects may experience from taking part in the research. If there is no direct benefit to subjects, indicate as such. Compensation is not considered a benefit. Compensation should be addressed in section 14.0.

You will receive no material benefits for allowing us to include your data in the study.

11.2 Potential Benefits to Others

Include benefits to society or others.

Identify the relevance of results from driving simulator based studies on actual driving. Analysis of driver’s behavior on curves.

12.0 Sharing Results with Subjects

Describe whether results (study results or individual subject results, such as results of investigational diagnostic tests, genetic tests, or incidental findings) will be shared with subjects or others (e.g., the subject’s primary care physicians) and if so, describe how it will be shared.

Not applicable

13.0 Subject Stipend (Compensation) and/or Travel Reimbursements

Describe the amount and timing of any subject stipend/payment or travel reimbursement here. If there is no subject stipend/payment or travel reimbursement, indicate as not applicable.

If course credit or extra credit is offered to subjects, describe the amount of credit and the available alternatives. Alternatives should be equal in time and effort to the amount of course or extra credit offered.

If an existing, approved student subject pool will be used to enroll subjects, please indicate as such and indicate that course credit will be given and alternatives will be offered as per the approved subject pool procedures.
Subjects will be compensated a fixed rate of $40 for their participation.

14.0 Economic Burden to Subjects

14.1 Costs

Describe any costs that subjects may be responsible for because of participation in the research.

None

14.2 Compensation for research-related injury

If the research involves more than Minimal Risk to subjects, describe the available compensation in the event of research related injury.

If there is no sponsor agreement that addresses compensation for medical care for research subjects with a research-related injury, include the following text as written - DO NOT ALTER OR DELETE:

It is the policy of the institution to provide neither financial compensation nor free medical treatment for research-related injury. In the event of injury resulting from this research, medical treatment is available but will be provided at the usual charge. Costs for the treatment of research-related injuries will be charged to subjects or their insurance carriers.

For sponsored research studies with a research agreement with the sponsor that addresses compensation for medical care for research-related injuries, include the following text as written - DO NOT ALTER OR DELETE:

It is the policy of the institution to provide neither financial compensation nor free medical treatment for research-related injury. In the event of injury resulting from this research, medical treatment is available but will be provided at the usual charge. Such charges may be paid by the study sponsor as outlined in the research agreement and explained in the consent form.

Not applicable

15.0 Resources Available

15.1 Facilities and locations

Identify and describe the facilities, sites and locations where recruitment and study procedures will be performed.

If research will be conducted outside the United States, describe site-specific regulations or customs affecting the research, and describe the process for obtaining local ethical review. Also, describe the principal investigator’s experience conducting research at these locations and familiarity with local culture.

The experiment will be conducted on the Larson Institute Test Track. Pre-test procedures will be conducted in the administration building at the test track.

15.2 Feasibility of recruiting the required number of subjects

Indicate the number of potential subjects to which the study team has access. Indicate the percentage of those potential subjects needed for recruitment.
There are around 1000 potential subjects. All team members may have access to all potential subjects. The team is confident in securing 50 participants which is the maximum number of participants required due to the large number of potential subject available.

15.3 **PI Time devoted to conducting the research**

Describe how the PI will ensure that a sufficient amount of time will be devoted to conducting and completing the research. Please consider outside responsibilities as well as other ongoing research for which the PI is responsible.

The PI’s will hold weekly meetings with the team and will have regular communication with the research team to ensure the project progress.

15.4 **Availability of medical or psychological resources**

Describe the availability of medical or psychological resources that subject might need as a result of their participation in the study, if applicable.

Not applicable

15.5 **Process for informing Study Team**

Describe the training plans to ensure members of the research team are informed about the protocol and their duties, if applicable.

The team members will be working very closely throughout the project. Changes made to the protocol and members’ duties will be made after discussion with every team member.

17.0 **Other Approvals**

17.1 **Other Approvals from External Entities**

Describe any approvals that will be obtained prior to commencing the research (e.g., from cooperating institutions, community leaders, schools, external sites, funding agencies).

Not applicable

17.2 **Internal PSU Committee Approvals**

Check all that apply:

- Anatomic Pathology – Hershey only – Research involves the collection of tissues or use of pathologic specimens. Upload a copy of HRP-902 - Human Tissue For Research Form on the “Supporting Documents” page in CATS IRB. This form is available in the CATS IRB Library.

- Animal Care and Use – All campuses – Human research involves animals and humans or the use of human tissues in animals

- Biosafety – All campuses – Research involves biohazardous materials (human biological specimens in a PSU research lab, biological toxins, carcinogens, infectious agents, recombinant viruses or DNA or gene therapy).

- Clinical Laboratories – Hershey only – Collection, processing and/or storage of extra tubes of body fluid specimens for research purposes by the Clinical Laboratories; and/or use of body fluids that had been collected for clinical purposes, but are no longer needed for clinical use. Upload a copy of
HRP-901 - Human Body Fluids for Research Form on the “Supporting Documents” page in CATS IRB. This form is available in the CATS IRB Library.

☐ Clinical Research Center (CRC) Advisory Committee – All campuses – Research involves the use of CRC services in any way.

☐ Conflict of Interest Review – All campuses – Research has one or more of study team members indicated as having a financial interest.

☐ Radiation Safety – Hershey only – Research involves research-related radiation procedures. All research involving radiation procedures (standard of care and/or research-related) must upload a copy of HRP-903 - Radiation Review Form on the “Supporting Documents” page in CATS IRB. This form is available in the CATS IRB Library.

☐ IND/IDE Audit – All campuses – Research in which the PSU researcher holds the IND or IDE or intends to hold the IND or IDE.

☐ Scientific Review – Hershey only – All investigator-written research studies requiring review by the convened IRB must provide documentation of scientific review with the IRB submission. The scientific review requirement may be fulfilled by one of the following: (1) external peer-review process; (2) department/institute scientific review committee; or (3) scientific review by the Clinical Research Center Advisory committee. NOTE: Review by the Penn State Hershey Cancer Institute Scientific Review Committee is required if the study involves cancer prevention studies or cancer patients, records and/or tissues. For more information about this requirement see the IRB website at: http://www.pennstatehershey.org/web/irb/home/resources/investigator

18.0 Multi-Site Research

If this is a multi-site study (i.e., the study will be conducted at other institutions each with its own principal investigator) and you are the lead investigator, describe the processes to ensure communication among sites in the sections below.

18.1 Communication Plans

Describe the plan for regular communication between the overall study director and the other sites to ensure that all sites have the most current version of the protocol, consent document, etc. Describe the process to ensure all modifications have been communicated to sites. Describe the process to ensure that all required approvals have been obtained at each site (including approval by the site’s IRB of record). Describe the process for communication of problems with the research, interim results and closure of the study.

Not applicable

18.2 Data Submission and Security Plan

Describe the process and schedule for data submission and provide the data security plan for data collected from other sites. Describe the process to ensure all engaged participating sites will safeguard data as required by local information security policies.

Not applicable
### 18.3 Subject Enrollment

Describe the procedures for coordination of subject enrollment and randomization for the overall project.

Not applicable

### 18.4 Reporting of Adverse Events and New Information

Describe how adverse events and other information will be reported from the clinical sites to the overall study director. Provide the timeframe for this reporting.

Not applicable

### 18.5 Audit and Monitoring Plans

Describe the process to ensure all local site investigators conduct the study appropriately. Describe any on-site auditing and monitoring plans for the study.

Not applicable

### 19.0 Adverse Event Reporting

#### 19.1 Reporting Adverse Reactions and Unanticipated Problems to the Responsible IRB

By submitting this study for review, you agree to the following statement – DO NOT ALTER OR DELETE:

In accordance with applicable policies of The Pennsylvania State University Institutional Review Board (IRB), the investigator will report, to the IRB, any observed or reported harm (adverse event) experienced by a subject or other individual, which in the opinion of the investigator is determined to be (1) unexpected; and (2) probably related to the research procedures. Harms (adverse events) will be submitted to the IRB in accordance with the IRB policies and procedures.

### 20.0 Study Monitoring, Auditing and Inspecting

#### 20.1 Auditing and Inspecting

By submitting this study for review, you agree to the following statement – DO NOT ALTER OR DELETE:

The investigator will permit study-related monitoring, audits, and inspections by the Penn State quality assurance program office(s), IRB, the sponsor, and government regulatory bodies, of all study related documents (e.g., source documents, regulatory documents, data collection instruments, study data etc.). The investigator will ensure the capability for inspections of applicable study-related facilities (e.g., pharmacy, diagnostic laboratory, etc.).

### 21.0 Future Undetermined Research: Data and Specimen Banking

If this study is collecting identifiable data and/or specimens that will be banked for future undetermined research, please describe this process in the sections below. This information should not conflict with information provided in section 9.1.1 regarding whether or not data and/or specimens will be associated with identifiers (directly or indirectly).
21.1 **Data and/or specimens being stored**
Identify what data and/or specimens will be stored and the data associated with each specimen.

Not applicable

21.2 **Location of storage**
Identify the location where the data and/or specimens will be stored.

Not applicable

21.3 **Duration of storage**
Identify how long the data and/or specimens will be stored.

Not applicable

21.4 **Access to data and/or specimens**
Identify who will have access to the data and/or specimens.

Not applicable

21.5 **Procedures to release data or specimens**
Describe the procedures to release the data and/or specimens, including: the process to request a release, approvals required for release, who can obtain data and/or specimens, and the data to be provided with the specimens.

Not applicable

21.6 **Process for returning results**
Describe the process for returning results about the use of the data and/or specimens.

Not applicable

22.0 **References**
List relevant references in the literature which highlight methods, controversies, and study outcomes.

Not applicable
B.2 Informed Consent Document
CONSENT FOR RESEARCH
The Pennsylvania State University

Title of Project: Analysis on risk compensation in driving using VR

Principal Investigator: Matt Parkinson

Address: Engineering Design
213 Hammond Building
University Park, PA 16802

Telephone Number: (814) 863-9079

Subject’s Printed Name: _____________________________

We are asking you to be in a research study. This form gives you information about the research.
Whether or not you take part is up to you. You can choose not to take part. You can agree to take part and later change your mind. Your decision will not be held against you.
Please ask questions about anything that is unclear to you and take your time to make your choice.

1. Why is this research study being done?

We are asking you to be in this research because we need experienced and inexperienced car drivers over 18 years of age.

This research is being done to study the behavior of people while using a driving simulator and travelling in a real car so that these can be compared. This allows to better use simulators and virtual or augmented reality headsets as a substitute to observing actual driving for further studies. The effect of immersion levels on the experience and behavior of the users are studied to help inform design of such systems. It also looks at how your body measurements affect your behavior and risk perception.

Approximately 50 people will take part in this research study at local site.

2. What will happen in this research study?

Your height and weight are measured followed by your sitting height and seated eye height, measured by allowing you to sit on a flat chair. You will then sit in the passenger seat of a car driven by a licensed driver on a test track. You will be required to wear a seat belt at all times while in the vehicle.

There are two parts to the procedure. In the first part, the driver will maintain a constant speed while going around a curve. There will be throttle and brake pedals at your feet. You will press the brake pedal at any time you feel uncomfortable. Uncomfortable in this case means a desire to slow down.
When you press the brake, the driver will be notified, and he or she will slow the vehicle to a stop. This will then be repeated on a different radius curve.

In the second part of the procedure, we want to find the fastest speed at which you feel comfortable going around the curve. You will again be travelling in the front passenger seat of the car as it is driven around the curve. You will use the throttle and brake pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input. The vehicle may either begin from rest, about one quarter mile before the start of the curve, or the driver will accelerate to a high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when they push a red button mounted to the dashboard, which will emit a short beeping sound. In the case where the vehicle begins at high speed, if you do not push either of the pedals after the red button is pushed, then the driver will continue driving at high speed. You will be informed before the start of the test whether the vehicle will be starting from rest or from high speed. This test will be repeated up to twelve times.

After every traversal of a curve for both parts of the procedure, you will be asked to answer three questions. These questions are intended to assess your perception of difficulty, risk, and comfort for each trial. The questionnaire will be administered by paper.

You can ask the driver to stop at any time if you do not want to continue with the experiment.

Upon completion of the entire experiment, you will be asked to complete the Driver Behavior Questionnaire. This questionnaire is commonly used in the literature to characterize driver behaviors. The questionnaire will be administered by paper.

This will take no more than 1 hour.

☐ Participant will be wearing a head-mounted display. Please disregard the following if the box is not checked.

You may be asked to wear a head-mounted display (HMD) while you are travelling in the vehicle which will show:

- video pass-through of your surroundings.
- virtual reality representation of your surroundings.
- augmented reality representation of your surroundings.

While wearing the HMD you may experience feelings of motion sickness such as nausea. If you do experience any motion sickness feelings, please let the driver know. You can also ask to stop at any time if you do not want to continue with the experiment.

You will be asked to complete a Simulator Sickness Questionnaire at two times during the protocol. The first time will be after completing an 8-minute practice period wearing the HMD while in the passenger seat of the vehicle as it is being driven. The second time will be after completing the entire protocol. The purpose of this questionnaire is to determine your susceptibility for simulator sickness.
If it is determined by the Simulator Sickness Questionnaire that you are too susceptible to simulator sickness after the practice period, then you will not complete the rest of the experimental protocol. However, you will still be compensated $40.

3. What are the risks and possible discomforts from being in this research study?

You might be uncomfortable providing information on height, weight, or sitting height. This study contains the regular risks associated with travelling in a car driven by a licensed driver on a track closed to outside traffic. This includes the risk of a crash. You will be required to wear safety belts while participating. You might feel somewhat anxious being driven around.

If you are asked to wear the headset while participating in the experiment then you may experience feelings of simulator sickness (similar to motion sickness). Those symptoms include nausea, sweating, and temporary dizziness. The effects of simulator sickness are not serious and are alleviated when looking away from the display screen. Any simulator sickness you may feel is temporary and is not a health risk.

4. What are the possible benefits from being in this research study?

4a. What are the possible benefits to you?

You will receive no material benefits for allowing us to include your data in the study.

4b. What are the possible benefits to others?

Better design of vehicles in the future.

5. What other options are available instead of being in this research study?

You may decide not to participate in this research.

6. How long will you take part in this research study?

It will take you about 1 hour to complete this research study.

7. How will your privacy and confidentiality be protected if you decide to take part in this research study?

Your research records will be labeled with a random ID and will be kept on a password protected computer. There will be no record kept that associates your participant ID number with your personal identity. In this way, the data collected from this experiment will be completely de-identified.

In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

The de-identified data collected from this experiment will be used for future research.

We will do our best to keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people may find out about your participation in
this research study. For example, the following people/groups may check and copy records about this research.
• The Office for Human Research Protections in the U. S. Department of Health and Human Services
• The research study sponsor, The National Science Foundation
• The Institutional Review Board (a committee that reviews and approves research studies) and
• The Office for Research Protections.

Some of these records could contain information that personally identifies you. Reasonable efforts will be made to keep the personal information in your research record private. However, absolute confidentiality cannot be guaranteed.

8. What happens if I am injured as a result of taking part in this research study?

In the unlikely event you become injured as a result of your participation in this study, medical care is available. It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

9. Will you be paid or receive credit to take part in this research study?

You will be compensated $40 for your participation in this experiment.

10. Who is paying for this research study?

This research is being sponsored by National Science Foundation.

11. What are your rights if you take part in this research study?

Taking part in this research study is voluntary.
• You do not have to be in this research.
• If you choose to be in this research, you have the right to stop at any time.
• If you decide not to be in this research or if you decide to stop at a later date, there will be no penalty or loss of benefits to which you are entitled.

12. If you have questions or concerns about this research study, whom should you call?

Please call the head of the research study (principal investigator), Matt Parkinson at (814) 863-9079 if you:
• Have questions, complaints or concerns about the research.
• Believe you may have been harmed by being in the research study.

You may also contact the Office for Research Protections at (814) 865-1775, ORProtections@psu.edu if you:
• Have questions regarding your rights as a person in a research study.
• Have concerns or general questions about the research.
• You may also call this number if you cannot reach the research team or wish to offer input or to talk to someone else about any concerns related to the research.
Optional part(s) of the study
This research group may wish to contact you again to ask additional questions regarding this study. The research group may also wish to contact you to ask if you would be willing to participate in additional experiments related to this study.

Please initial below to indicate whether or not you are willing to have this research group contact you again regarding this study. You can be in the main part of the research without agreeing to be in this optional part.

_______ Yes, I am willing to be contacted again regarding this research.

_______ No, I am not willing to be contacted again.
INFORMED CONSENT TO TAKE PART IN RESEARCH

Signature of Person Obtaining Informed Consent

Your signature below means that you have explained the research to the subject or subject representative and have answered any questions he/she has about the research.

___________________________  __________  ________________
Signature of person who explained this research     Date     Printed Name
(Only approved investigators for this research may explain the research and obtain informed consent.)

Signature of Person Giving Informed Consent

Before making the decision about being in this research you should have:
• Discussed this research study with an investigator,
• Read the information in this form, and
• Had the opportunity to ask any questions you may have.
Your signature below means that you have received this information, have asked the questions you currently have about the research and those questions have been answered. You will receive a copy of the signed and dated form to keep for future reference.

Signature of Subject

By signing this consent form, you indicate that you voluntarily choose to be in this research and agree to allow your information to be used and shared as described above.

___________________________  __________  ________________
Signature of Subject     Date     Printed Name
B.3 Poster
Do you want to participate in a driving study?

✓ Do you hold a valid Driver’s license?

✓ Are you 18 years old?

We are looking for volunteers to take part in a study on passenger risk perception. Drivers of all experience levels are welcome.

Your participation would involve travelling in a real car around the Larson Institute Test Track.

Transportation will NOT be provided to and from the Larson Institute Test Track, which is 10-15 minutes from campus.

In appreciation of your time for participating in a one-hour long session, you will be paid $40.

For more information, or to participate in the study, contact:

Nicholas Dow
Mechanical Engineering
vrstudyps@gmail.com

This study has been reviewed by and received approval from The Pennsylvania State University Institutional Review Board.
B.4 Recruiting Script
Recruiting Script
(to be read aloud, or sent by email)

Hi! We are seeking participants for a research experiment conducted at Penn State University, that will observe the behavior of drivers while using a driving simulator. Since the study aims to look at behavior of different types of drivers, drivers of any expertise level who are 18 years or older and possess a valid driver’s license are qualified to participate.

As a research participant, we would first ask you a few pre-test questions about your driving experience and age. We will not record your name or note other identifiers.

Your height, weight, sitting height and seated eye height will be then measured. Next, you will be asked to travel in a car driven around a test track by a licensed driver. The total time of participation will be no more than 1 hour. You will be paid $25.40 for this 1 hour.

If you are uncomfortable with the physical or cognitive requirements of the task you should not participate.

We will use this data in future publications on driving. Any reporting of the data will be completely anonymous.

At any point in the procedure, you may choose to end the experiment if you feel uncomfortable.

Thank you.

This study will be supervised by:

Matt Parkinson (the principal investigator – “PI”)  
213 Hammond Building  
University Park, PA 16802  
parkinson@psu.edu
B.5 Screening Questions

The following screening questions were only included in the video pass-through experiment.
Screening Questions

1. Are you 18 years of age or older?
   If the participant answers no, then they are ineligible to participate in this study.

2. Do you hold a valid driver’s license?
   If the participant answers no, then they are ineligible to participate in this study.

3. Do you have any experience in competitive vehicle racing? If yes, please explain.
   If the participant answers yes and claims substantial experience as a competitive racing driver, then they are ineligible to participate in this study. Use discretion to determine whether or not the participant’s experience meets the criteria. It may be necessary to probe for further details about their experience. For example, if they only raced a few times among friends on Go-Karts, then they should not be excluded.
Simulator Sickness Screening Questions

For your safety, we need to assess the risk that you might become ill in our driving simulator. Please consider the following questions that best characterize your experience.

1. Do you experience motion sickness when flying in an airplane?
   Never  Seldom  Often  Always
   If Never, proceed to 2. If Always, stop and reject. If Seldom or Often, probe to determine how frequently the person flies, and under what conditions the sickness occurs. If the person flies frequently, but only experiences illness under severe turbulence, proceed with questions, but weight additional positive symptoms as favoring rejection.

2. Do you experience motion sickness on boats?
   Never  Seldom  Often  Always
   If Never, proceed to 3. If Always, stop and reject. If Seldom or Often, probe to determine how frequently the person sails, and under what conditions the sickness occurs. If the person sails frequently, but only experiences illness in high seas, proceed with questions, but weight additional positive symptoms as favoring rejection.

3. Do you experience motion sickness on trains?
   Never  Seldom  Often  Always
   If Never, proceed to 4. If Always, stop and reject. If Seldom or Often, probe to determine how frequently the person rides the rails, and under what conditions the sickness occurs. If the person rides frequently, but only experiences illness under extreme conditions, proceed with questions, but weight additional positive symptoms as favoring rejection.

4. Do you experience motion sickness when riding in the back seat of cars?
   Never  Seldom  Often  Always
   If Never, proceed to 5. If Always, stop and reject. If Seldom or Often, probe to determine how frequently the person rides as a passenger (front or back seat), and under what conditions the sickness occurs. If the person rides frequently, but only experiences illness under extreme conditions, proceed with questions, but weight additional positive symptoms as favoring rejection.
5. Do you experience motion sickness in a simulator?

Never  Seldom  Often  Always

*If Never, proceed to 2. If Always, stop and reject. If Seldom or Often, probe to determine how frequently the person performs tasks in a simulator, and under what conditions the sickness occurs. If the person uses a simulator frequently, but only experiences illness under extreme conditions, proceed with questions, but weight additional positive symptoms as favoring rejection.*

**Scoring Criteria:**

1. If answered Never to all questions, accept.

   ![Accept](accept.png)

2. If answered Seldom to one or more questions and exposure was significant (e.g. flew once, experience motion sickness once), reject. If there are clear mitigating factors (e.g. turbulence was severe) participant may be accepted, but include rationale below.

   ![Accept](accept.png)
   ![Reject with explanation](reject.png)

3. If answered Often to one question, then reject, unless clear mitigating factors are present (e.g. flies several times a year and rarely experiences symptoms, and then only in the most severe turbulence). If the symptoms are severe, such as vomiting or prolonged symptoms, then reject. Note rationale below.

   ![Accept](accept.png)
   ![Reject with explanation](reject.png)

4. If answered Often to two or more questions, reject regardless of mitigating factors.

   ![Reject](reject.png)

Rationale for exception to rule (where allowed):

_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

**Reference:**

B.6 Questionnaires

The following questionnaires were only included in the video pass-through experiment.
## Simulator Sickness Questionnaire

Instructions: Circle how much each symptom below is affecting you **right now**.

<table>
<thead>
<tr>
<th></th>
<th>General discomfort</th>
<th>Fatigue</th>
<th>Headache</th>
<th>Eye Strain</th>
<th>Difficulty focusing</th>
<th>Salivation increasing</th>
<th>Sweating</th>
<th>Nausea</th>
<th>Difficulty concentrating</th>
<th><em>“Fullness of the Head”</em></th>
<th>Blurred vision</th>
<th>Dizziness with eyes open</th>
<th>Dizziness with eyes closed</th>
<th>Vertigo</th>
<th><em><strong>Stomach awareness</strong></em></th>
<th>Burping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td></td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>11</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>12</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>13</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>14</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>15</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
<tr>
<td>16</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>None</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>None</td>
<td>Slight</td>
<td>None</td>
</tr>
</tbody>
</table>

* Fullness of head is an awareness of pressure in the head.
** Vertigo is experienced as loss of orientation with respect to vertical upright.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

**Scoring Criteria:**

Total: sum items 1-16 (scale of 0 to 3)

- “Nausea”: items 1 + 6 + 7 + 8 + 12 + 13 + 14 + 15 + 16
- “Ocular-motor”: items 2 + 3 + 4 + 5 + 9 + 10 + 11

If a participant has a total score greater than 35 after practicing with the head-mounted display they are to be rejected from participating in the experiment. This criterion is borrowed from the following reference:

Instructions:
No one is perfect. Even the best drivers make errors or commit violations at some time or another. Many of these are trivial, but others are potentially more dangerous. This questionnaire is concerned with assessing drivers’ perceptions of their own ‘bad behaviors’. The questionnaire is very simple. It lists a number of errors and violations that people have experienced or observed while driving. For each item, you are required to indicate how often, if at all, this kind of thing has happened to you—say, over a period of about the last year. You do this by circling ONE of the numbers to the right of each item. These numbers range from 0-5, and have the following meanings: 0= NEVER, 1= HARDLY EVER, 2= OCCASIONALLY, 3= QUITE OFTEN, 4= FREQUENTLY, 5= NEARLY ALL THE TIME. It is, of course, impossible for you to give precise answers: we are only interested in your general impressions. So, don’t spend too long thinking about each item. Simply give your best guess as quickly as possible by CIRCLING the number you think most appropriate. If, after giving a response, you change your mind, simply put a cross through your first answer and circle another number.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Never</th>
<th>Hardly Ever</th>
<th>Occasionally</th>
<th>Quite Often</th>
<th>Frequently</th>
<th>Nearly all the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Hit something when reversing that you had not previously seen</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2  Intending to drive to destination A, you “wake up” to find yourself on the road to destination B</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3  Get into the wrong lane approaching a roundabout or an intersection</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4  Signal to turn left onto a main road, you pay such close attention to the main stream of traffic that you nearly hit the car in front</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5  Fail to notice that pedestrians are crossing when turning into a side street from a main road</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6  Sound your horn to indicate your annoyance to another road user</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7  Fail to check your rear-view mirror before pulling out, changing lanes, etc.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8  Brake too quickly on a slippery road or steer the wrong way in a skid</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>9  Pull out of an intersection so far that the driver with right of way has to stop and let you out</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>10 Disregard the speed limit on a residential road</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>11 Switch on one thing, such as the headlights, when you meant to switch on something else, such as the wipers</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>12 On turning left nearly hit a cyclist who has come up on your inside</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>13 Miss “Yield” signs and narrowly avoid colliding with traffic having right of way</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>14 Attempt to pass someone that you had not noticed to be signaling a left turn</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>15 Become angered by another driver and chase him/her with the intention of giving him/her a piece of your mind</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>16 Stay in a highway lane that you know will be closed ahead until the last minute before forcing your way into the other lane</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17 Forget where you left your car in a parking lot</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>18 Pass a slow driver on the outside (right side)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>19 Race away from traffic lights with the intention of beating the driver next to you</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>20 Misread the signs and exit from a roundabout on the wrong road</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>21 Drive so close to the car in front that it would be difficult to stop in an emergency</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>22 Cross an intersection knowing that the traffic lights have already turned red</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>23 Become angered by a certain type of a driver and indicate your hostility by whatever means you can</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>24 Realize that you have no clear recollection of the road along which you have just been travelling</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>25 Underestimate the speed of an oncoming vehicle when passing</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>26 Disregard the speed limit on a highway</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>27 Try to pass in risky circumstances when stuck behind a slow-moving vehicle on a two-lane highway</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Subject ID: _____________
B.7 Pretest

B.7.1 Baseline Experiment
Title of Project: Analysis on risk compensation in driving

Principal Investigator: Matt Parkinson

Address: Engineering Design
213 Hammond Building
University Park, PA 16802

Telephone Number: (814) 863-9079

Unique subject ID: ________________

1. Age (years):

2. Gender: M F

3. Subject holds a valid driver’s license?

4. Subject holds a professional driver’s license (e.g. CDL)?

5. How many years of driving experience do you have?

6. On average, how many hours do you drive per week?

7. Have you ever participated in a driving experiment?

8. How many vehicle accidents have you been in?

9. When did the most recent vehicle accident you were in occur?
10. Stature (mm):

11. Mass (kg):

12. Sitting height (mm):

13. Seated eye height (mm):
B.7.2 Video Pass-through Experiment
EXPERIMENT PARTICIPANT INFORMATION SHEET
The Pennsylvania State University

Title of Project: Analysis on risk compensation in driving
Principal Investigator: Matt Parkinson
Address: Engineering Design
213 Hammond Building
University Park, PA 16802
Telephone Number: (814) 863-9079

Unique subject ID: _______________

TO BE COMPLETED BY PARTICIPANT

1. Age (years): ______

2. Gender (circle one): Male Female

3. Do you have a valid driver’s license? □ Yes □ No

4. Do you have a professional (commercial) driver’s license (e.g. CDL)? □ Yes □ No

5. How many years of driving experience do you have? ______ years _____ months

6. On average, how many hours do you drive per week? ______ hours _____ minutes

7. What types of vehicles have you driven? (Check all that apply)
   As a driver:
   □ SUV □ truck □ van □ car

   As a passenger:
   □ SUV □ truck □ van □ car

8. In the last three years, how many vehicle accidents have you been in?
   As a driver? _______ As a passenger? _______

9. In the last three years, how many driving tickets or citations have you received?
   Tickets? _______ Citations/Warnings? _______

10. When did the most recent vehicle accident you were in occur? ______ years ______ months ago

11. Have you ever participated in a driving experiment? □ Yes □ No
12. How often do you play video games on your computer or TV? (choose one)
□ Never □ Very Rarely □ Sometimes □ Often □ Very Often

13. Please rate your skill at playing video games that require driving (choose one).
□ Never played a driving game
□ Very Poor □ Poor □ Satisfactory □ Good □ Excellent

14. Please rate your skill at playing video games in general (choose one).
□ Very Poor □ Poor □ Satisfactory □ Good □ Excellent

15. How many hours of sleep did you get last night? ________ hrs _________ mins

16. How many hours of sleep do you usually get? ________ hrs _________ mins

TO BE COMPLETED BY EXPERIMENTER

17. Stature (mm):

18. Mass (kg):

19. Sitting height (mm):

20. Seated eye height (mm):
B.8 Instructions

B.8.1 Verbal Instructions

These instructions were read to the participant prior to beginning the experiment.
Instructions

This experiment will take no more than 1 hour. At any point in the procedure, you may choose to end the experiment if you feel uncomfortable. If you are uncomfortable with the physical or cognitive requirements of the task then you should not participate. We will use this data in future publications on driving. Any reporting of the data will be completely anonymous. Feel free to ask questions at any time.

[Obtain written consent from the participant]

Before we begin, we will ask you a few questions.

[Ask questions in pre-test and record answers]

Thank you for your answers. Now I need to take a few body measurements.

[Measure stature, weight, sitting height and seated eye height]

Now we move on to the next stage where you will be travelling in the front passenger seat of a car driven by a licensed driver around a test track. You will be given instructions to read that explain each part of the experiment. Please read these instructions carefully.

[If participant will be wearing the head mounted display]: You will be wearing a headset while you are travelling in the vehicle which will show video pass-through/virtual reality representation of/augmented reality representation of your surroundings. While wearing the headset you may experience feelings of motion sickness such as nausea. If you do experience any motion sickness feelings, please let the driver know. You can also ask to stop at any time if you do not want to continue with the experiment.

[Subject will sit in the front passenger seat of the vehicle. They will be given the instructions in the “In-Vehicle Instructions” document. They will follow these instructions to completion.

[Return to the briefing room]

The last part of this experiment is a questionnaire for you to complete. Please read the instructions at the top and respond to the questions to the best of your ability.

[Provide Driver Behavior Questionnaire for the participant to complete]

You have now completed the experiment. Please sign here to indicate that you have received the compensation amount.

[Provide compensation amount and obtain signature for receipt of compensation]

[Read Debriefing document to the participant]

Thank you for participating.
B.8.2 In-vehicle Instructions for Baseline Experiment
In-Vehicle Instructions

Notes: The following pages are step-by-step instructions for the participant to read and follow while they are in the vehicle. The driver will ensure that the participant is on the correct task at all times. The task title, “Threshold Evaluation”, refers to the latent response protocol and the task title, “Method of Adjustments” refers to the learned response protocol. These name changes were made in order to make it clearer for the participants.

Tasks with repeated task numbers (3-14) were made to be redundant so that the order of the initial conditions for the learned response protocol could be randomized. Participants will only receive one set of the instructions.

The General Questionnaire will be interspersed with these instructions so that the participants may complete the questionnaire after each task.
Task 1: Threshold Evaluation – Curve 1

Now we begin the first part of the experiment. You will be travelling in the front passenger seat of a car driven by a licensed driver around a test track.

You must wear your seatbelt. The car will be driven through a curve at a constant speed. At your feet you will find gas and brake pedals. You will press the brake pedal at any time you feel uncomfortable. Uncomfortable in this case means a desire to slow down. When you press the brake, the driver will be notified and will slow the vehicle to a stop.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

Task 2: Threshold Evaluation – Curve 2

You will now repeat the threshold evaluation task on a different curve. The instructions are repeated here:

You must wear your seatbelt. The car will be driven through a curve at a constant speed. At your feet you will find gas and brake pedals. You will press the brake pedal at any time you feel uncomfortable. Uncomfortable in this case means a desire to slow down. When you press the brake, the driver will be notified and will slow the vehicle to a stop.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Practice

Now we move on to the next stage where pressing the pedals will indicate to the driver if you want to go faster or slower.

You will be given 5 minutes to practice using these pedals to control the vehicle’s speed. This practice time will take place on the skid pad of the test track, which is a large, open, and paved area. The driver will steer in a large circle that is marked by a yellow line.

Let the driver know when you feel that you have gotten enough practice and are comfortable using the pedals. You will then begin the next part of the experiment.

The driver will tell you when to flip the page.

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Task 3: Method of Adjustments – Starting from rest

Now we move to the second part of the experiment where we are looking for the highest speed at which you feel comfortable. You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 3: Method of Adjustments – Starting from high speed

Now we move to the second part of the experiment where we are looking for the highest speed at which you feel comfortable. You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
**Task 4: Method of Adjustments – Starting from high speed**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

---

**Task 4: Method of Adjustments – Starting from rest**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 5: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are read to proceed with this part of the experiment.

The driver will tell you when to flip the page.

---

Task 5: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are read to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 6: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

Task 6: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 7: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

Task 7: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 8: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

---

Task 8: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 9: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 9: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 10: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

---

Task 10: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 11: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.
Let the driver know when you are ready to proceed with this part of the experiment.
The driver will tell you when to flip the page.

Task 11: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.
Let the driver know when you are ready to proceed with this part of the experiment.
The driver will tell you when to flip the page.
Task 12: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

Task 12: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 13: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.

Task 13: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.

Let the driver know when you are ready to proceed with this part of the experiment.

The driver will tell you when to flip the page.
Task 14: Method of Adjustments – Starting from high speed

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin at high speed.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment.
Let the driver know when you are ready to proceed with this part of the experiment.
The driver will tell you when to flip the page.

Task 14: Method of Adjustments – Starting from rest

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, the vehicle will begin from rest.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The vehicle will begin from rest, about one quarter mile before the start of the curve. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound.

You can ask to stop at any time if you do not want to continue with the experiment.
Let the driver know when you are ready to proceed with this part of the experiment.
The driver will tell you when to flip the page.
B.8.3 In-vehicle Instructions for Video Pass-through Experiment
In-Vehicle Instructions

Notes: The following pages are step-by-step instructions for the participant to read and follow while they are in the vehicle. The driver will ensure that the participant is on the correct task at all times. The task title, “Threshold Evaluation”, refers to the latent response protocol and the task title, “Method of Adjustments” refers to the learned response protocol. These name changes were made in order to make it clearer for the participants.

Tasks with repeated task numbers (3-14) were made to be redundant so that the order of the initial conditions for the learned response protocol could be randomized. Participants will only receive one set of the instructions.

The General Questionnaire will be interspersed with these instructions so that the participants may complete the questionnaire after each task.
**Practice**

You must wear your seatbelt.

At your feet you will find gas and brake pedals. Pressing the pedals will indicate to the driver if you want to go faster or slower.

You will be given 5 minutes to practice using these pedals to control the vehicle’s speed. This practice time will take place on the skid pad of the test track, which is a large, open, and paved area. The driver will steer in a large circle that is marked by a yellow line.

Let the driver know when you feel that you have gotten enough practice and are comfortable using the pedals. You will then begin the next part of the experiment.

The driver will tell you when to flip the page.
Task 1: Method of Adjustments – Without the headset

The goal of this experiment is to find the highest speed at which you feel comfortable. Uncomfortable in this case means a desire to slow down. You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You will **not** be wearing the headset for this task.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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Task 1: Method of Adjustments – With the headset

The goal of this experiment is to find the highest speed at which you feel comfortable. Uncomfortable in this case means a desire to slow down. You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You will be wearing the headset for the duration of this task.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 2: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will **not** be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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Task 2: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 3: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 3: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 4: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 4: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 5: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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Task 5: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 6: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 6: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
**Task 7: Method of Adjustments – Without the headset**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will **not** be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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**Task 7: Method of Adjustments – With the headset**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 8: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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Task 8: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 9: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will not be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 9: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 10: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will **not** be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

Task 10: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
Task 11: Method of Adjustments – Without the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will **not** be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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Task 11: Method of Adjustments – With the headset

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
**Task 12: Method of Adjustments – Without the headset**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will **not** be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.

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**Task 12: Method of Adjustments – With the headset**

We will now repeat the method of adjustments task where we are looking for the highest speed at which you feel comfortable. This time, you will be wearing the headset.

You will use the pedals as if you had control over the vehicle. The driver will adjust the vehicle’s speed according to your input.

The driver will accelerate to high speed before accepting inputs from your pedals. You will know that the test has begun and that the driver will accept inputs from your pedals when the driver pushes the red button mounted to the dashboard, which will emit a short beeping sound. The driver will maintain the vehicle’s speed after the red button is pushed until you press one of the pedals.

You can ask to stop at any time if you do not want to continue with the experiment. Let the driver know when you are ready to proceed with this part of the experiment. The driver will tell you when to flip the page.
B.9 Debriefing Form
Debriefing Form

Thank you for your participation in this study. It is necessary to inform you that you were engaged in research that used a form of deception. Deception refers to providing false or misleading information. Deception was used in this study by withholding the information that the driver would never exceed a speed limit of 60 mph on the test track, regardless of what you, the participant, indicated. This limit was imposed because it is the highest speed at which the driver had practiced for this test track.

This deception by withholding information was necessary to elicit naturalistic behavior. The purpose of this research is to evaluate a person’s natural perception of risk, and we did not want to bias your perception of risk by informing you of this speed limit.

If you feel a need to speak to a professional concerning any uncomfortable feelings from your participation in this research, you may contact the Substance Abuse and Mental Health Services Administration (SAMHSA) National Hotline at 1-800-662-4357. Or if you are a Penn State student, you may contact Penn State’s Counseling and Psychological Services (CAPS) at 814-863-0395.

You now have the choice of either having your data included in the research study, or to be withdrawn from the research study.
Appendix C
Supplemental Figures of the Experimental Results

C.1 Learned Response Protocol

C.1.1 Normality in Speed Distributions

Figure C.1: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from high speed, travelling in the counterclockwise direction.
Figure C.2: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from high speed, travelling in the clockwise direction.
Figure C.3: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from rest, travelling in the counterclockwise direction.
Figure C.4: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from rest, travelling in the clockwise direction.
Figure C.5: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from high speed, travelling in the counterclockwise direction.
Figure C.6: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from high speed, travelling in the clockwise direction.
Figure C.7: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from rest, travelling in the counterclockwise direction.
Figure C.8: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from rest, travelling in the clockwise direction.
C.1.2 Comparison of Speed Distributions Between Directions of Travel

Figure C.9: The average, 5th, and 95th percentile speed of all participants for opposing directions of travel on the 318 ft radius curve, when starting from high speed. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing directions at every 0.5 meter station increment at the 5% significance level.
Figure C.10: The average, 5th, and 95th percentile speed of all participants for opposing directions of travel on the 318 ft radius curve, when starting from rest. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing directions at every 0.5 meter station increment at the 5% significance level.
Figure C.11: The average, 5th, and 95th percentile speed of all participants for opposing directions of travel on the 545 ft radius curve, when starting from high speed. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing directions at every 0.5 meter station increment at the 5% significance level.
Figure C.12: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed of all participants for opposing directions of travel on the 545 ft radius curve, when starting from rest. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing directions at every 0.5 meter station increment at the 5\% significance level.
Figure C.13: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed of all participants for opposing initial conditions on the 318 ft radius curve, travelling in the clockwise direction. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing initial conditions at every 0.5 meter station increment at the 5\% significance level.
Figure C.14: The average, 5th, and 95th percentile speed of all participants for opposing initial conditions on the 318 ft radius curve travelling in the counterclockwise direction. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing initial conditions at every 0.5 meter station increment at the 5% significance level.
Figure C.15: The average, 5th, and 95th percentile speed of all participants for opposing initial conditions on the 545 ft radius curve travelling in the clockwise direction. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing initial conditions at every 0.5 meter station increment at the 5% significance level.
Figure C.16: The average, 5th, and 95th percentile speed of all participants for opposing initial conditions on the 545 ft radius curve travelling in the counterclockwise direction. The bar across the bottom represents the results of a 2 sample t-Test (red=fail; green=pass) comparing the speed distributions for opposing initial conditions at every 0.5 meter station increment at the 5% significance level.
C.1.4 Model Fit for Curve Entry Speeds

Figure C.17: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from high speed, travelling in the counterclockwise direction.
Figure C.18: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from high speed, travelling in the clockwise direction.

Figure C.19: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from rest, travelling in the counterclockwise direction.
Figure C.20: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 318 ft radius curve, starting from rest, travelling in the clockwise direction.

Figure C.21: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from high speed, travelling in the counterclockwise direction.
Figure C.22: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from high speed, travelling in the clockwise direction.

Figure C.23: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from rest, travelling in the counterclockwise direction.
Figure C.24: Nonlinear least-squares fit of a sine function to the average speed upon curve entry for one of the experimental treatment combinations in the learned response protocol – 545 ft radius curve, starting from rest, travelling in the clockwise direction.
C.1.5 Vehicle Yaw Rate

Figure C.25: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile yaw rate and pedal usage of all participants in two of the treatment combinations of the learned response protocol – the 318 ft radius curve, starting from high speed, and either direction of travel.

Figure C.26: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile yaw rate and pedal usage of all participants in two of the treatment combinations of the learned response protocol – the 318 ft radius curve, starting from rest, and either direction of travel.
Figure C.27: The average, 5th, and 95th percentile yaw rate and pedal usage of all participants in two of the treatment combinations of the learned response protocol – the 545 ft radius curve, starting from high speed, and either direction of travel.

Figure C.28: The average, 5th, and 95th percentile yaw rate and pedal usage of all participants in two of the treatment combinations of the learned response protocol – the 545 ft radius curve, starting from rest, and either direction of travel.
Figure C.29: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile yaw rate of all participants for different directions of travel on the 318 ft radius curve, starting from high speed.

Figure C.30: The average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile yaw rate of all participants for different directions of travel on the 318 ft radius curve, starting from rest.
Figure C.31: The average, 5th, and 95th percentile yaw rate of all participants for different directions of travel on the 545 ft radius curve, starting from high speed.

Figure C.32: The average, 5th, and 95th percentile yaw rate of all participants for different directions of travel on the 545 ft radius curve, starting from rest.
C.1.6 Throttle Usage

Figure C.33: Histogram of the percent throttle usage of each trial during the learned response protocol.

C.2 Video Pass-through Experiment
Figure C.34: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the video pass-through protocol – 318 ft radius curve, without wearing the headset.
Figure C.35: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5\textsuperscript{th}, and 95\textsuperscript{th} percentile speed and pedal usage of one of the experimental treatment combinations in the video pass-through protocol – 318 ft radius curve, with wearing the headset.
Figure C.36: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the video pass-through protocol – 545 ft radius curve, without wearing the headset.
Figure C.37: Test results for normality in the speed distributions of all trials at every 0.5 meter station increment overlaid on the average, 5th, and 95th percentile speed and pedal usage of one of the experimental treatment combinations in the video pass-through protocol – 545 ft radius curve, with wearing the headset.
Bibliography


[18] Marken, R. S. (2007), “Absorbing and developing qualified fighter pilots: the role of the advanced simulator,” URL http://psu.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwjV1NT8JAEJ0oXDQeFFEKGpEPIgpLbVwV5Inx5GXTjyO2oZSUmuiv8485s22BKgvlvhe1uO70vvyZI7nX


