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ADVANCED VIRTUAL REALITY HEADSET BASED TRAINING TO IMPROVE YOUNG DRIVERS' LATENT HAZARD ANTICIPATION ABILITY

Ravi Agrawal

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**ADVANCED VIRTUAL REALITY HEADSET BASED TRAINING TO
IMPROVE YOUNG DRIVERS' LATENT HAZARD ANTICIPATION ABILITY**

A Thesis Presented

By

RAVI AGARWAL

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfilment
of the requirements for the degree of

MASTER OF SCIENCE IN INDUSTRIAL ENGINEERING & OPERATIONS
RESEARCH

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Mechanical & Industrial Engineering

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ABSTRACT

ADVANCED VIRTUAL REALITY HEADSET BASED TRAINING TO IMPROVE YOUNG DRIVERS' LATENT HAZARD ANTICIPATION ABILITY

September 2019

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Driving safety among young novice driver is one of the largest concern in the transportation domain. Many Paper-based or PC- based training program have been developed over the years to train the young novice driver to improve their driving skills (Hazard Anticipation). This training programs does help young novice driver to improve their *situational* awareness and so the hazard anticipation skills. But, there is one common problem with most of the currently available training programs. They are not very immersive, because such training program mostly provide plain view of the training scenario's along with some description about the scenario and the subject trained in such training method needs to translate the provided knowledge in the plain view into the real-world driving.

An Advanced training program on risk awareness and perception was developed and evaluated in Oculus rift platform. The primary objective is to train the young novice driver in the Virtual reality headset based risk awareness and perception training program and evaluate the trained driver in the driving simulator against the placebo trained young novice driver. The Virtual reality headset based risk awareness and perception training program (V-RAPT) is based on 3M Error-based Training approach where the driver will have 80 horizontal degrees' and 90 vertical degrees' field of view.

Thirty-six drivers will receive training in the respective training methods- V-RAPT (Virtual reality headset based risk awareness and perception training), RAPT (PC- based risk awareness and perception training) and placebo training. Twelve young novice driver trained in the V-RAPT group will served as experimental group. Twenty-four other young novice will receive training in the RAPT and Placebo training respective will serve as control group. After training all three-group trained driver will be evaluated in the advanced driving simulator and the eye movement of the all thirty-six participants are recorded and measured. Vehicle measures such as acceleration, velocity and brake position is also recorded. The drivers' score will based on whether or not their eye-fixations indicated recognition of potential risks in different high risk driving situations. The evaluation driver included six scenarios used in the V-RAPT training (near transfer scenarios) and four scenarios that were not used in the V-RAPT training (far transfer scenarios).

Drivers who received the V-RAPT training are expected to drive more safely than the drivers who received either training. The V-RAPT trained drivers are expected to glance on regions (Hazard anticipation) where potential risks might appear than the drivers' trained in the RAPT and Placebo training method. Further, The V-RAPT trained drivers are expected have slower average velocity and better brake position (Hazard mitigation) are compared to the driver trained in the other two training method.

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CHAPTER 1

INTRODUCTION

Driving is a dynamic, complex task (visual, manual and cognitive elements) that requires drivers to continuously monitor the forward roadway in order to obtain safety-critical information indicating the potential presence or the actual incidence of a threat or hazard on the immediate roadway in front of the driver. Literature notes that situation awareness plays a critical role in the drivers' ability to anticipate, detect and respond to hazards on the roadway [McKnight and McKnight, (2003)]. Several studies have been conducted, both in the driving simulator and on the open road, that examine the specific safety-critical skills that younger drivers are poor at compared to more experienced, middle-aged drivers [Crundall & Pradhan (2016)]. Studies have shown that young drivers are not only poor at appropriately scanning for latent threats, they additionally exhibit poor lane positioning, inappropriate speed management strategies and incomplete decision-making processes.

The young drivers' inability to accurately detect latent threats on the forward roadway has been shown to be one of a strong predictor of crash and near crash risk [NHTSA, 1994]. There exist several driver training programs and interventions aimed at improving young driver behavior. Specifically, there currently exists several training programs on various platforms that have undergone significant evaluation at various phases and have shown to be effective at improving driver behavior. RAPT (Risk Awareness & Perception Training) was one of the first driver training programs developed to address human failures to appropriately scan and detect latent threats present/emerging on the forward roadway [Fisher et al., 2002]. The training program was developed on a PowerPoint platform and delivered on a PC. Driving simulator and on road assessments of

the training program (and all its subsequent versions: RAPT3, Distractology 101, SuperRAPT, , CalRAPT, SimRAPT) have exhibited significant ability to improve the average young drivers' ability to detect threats that have not yet necessarily materialized on the forward roadway, compared to a control cohort (with similar experimental characteristics as the training conditions) [Pollatsek et al., 2006; Zhang et al., 2016; Thomas et al., 2013; Thomas et al., 2016; Vlakoveld et al., 2011]. Subsequently, RAPT was adapted and modified by State Farm into a training suite called RoadAware™, which also was shown to be effective at improving driver behavior in complex driving scenarios. Recently, training programs have been developed on other modalities such as tablets (Engaged Driver Training System), smartphones and alternate novel platforms that can accelerate the delivery of the training curriculum and also allow for widespread dissemination, both locally and nationally [Zafian et al., 2016]. The tablet-based training program was developed to train drivers to not only anticipate hazards appropriately, but also to train them on how to regulate the non-performance of secondary tasks in critical situations (presence of a latent hazard) on the roadway.

In summary, training programs targeting hazard anticipation have shown improvements in safe behaviors (glances towards the latent hazard) and decreases in crashes. Training programs targeting both hazard anticipation and hazard mitigation have shown, along with improvements in hazard anticipation, improvements in hazard mitigation. Curiously, most of the training programs targeting hazard anticipation have fallen short of getting novice drivers to the point where they anticipate the great majority of the hazards. For example, RAPT-trained drivers correctly anticipate threats about 60% of the time compared to their placebo-trained peers (a 30 percentage point gain). Although this is a doubling in performance among the trained drivers, the performance of the trained

drivers is still nowhere near ceiling. There is a need to identify strategies of training that can further improve hazard anticipation performance while not detracting from hazard mitigation performance.

The primary focus of my thesis will be on investigating alternate training mediums aimed at remediating the younger drivers' failures to detect latent hazards. The goal is to deliver training on a platform that addresses some of the shortcomings among the currently available training programs. I propose to develop a latent hazard anticipation training program using low-cost, Virtual Reality headsets. There are a number of reasons that can explain why novice drivers fail to detect latent hazards. The presence of distractions (in-vehicle, external or cognitive), levels of cognitive workload (modulated by the performance of a non-driving related secondary task) and vision-related deficiencies (affecting peripheral scanning and bottom-up threat detection) can all impact a drivers' ability to appropriately scan for and mitigate threats. Very often, it is a combination of issues affecting multiple faculties, that result in a partial loss in the drivers' ability to detect and mitigate for potential hazards. The ensuing literature review is organized into three related sections-

First, the drivers' situational awareness is examined. Endsley's model of SA is explained and the three levels of SA are outlined [Endsley, 1995]. I discuss why situation awareness is important for a driver to scan and perceive latent hazards in a complex roadway environment. Hazard anticipation can be a predictor of situational awareness that is critical to avoiding conflicts. A better understanding of SA allows for the development of mitigation mechanisms that can train drivers to be more situationally aware in conflict situations, thereby allowing them to scan for latent (peripheral and foveal) threats in an efficient and optimal manner.

Second, I examine the various training programs that have been previously developed to improve young drivers' anticipation abilities. I discuss at-large the methodology and approach used for training in previous studies. I will utilize an error-based training approach for developing the advanced training medium [Fisher et al., 2002; Gregersen, 1996]. Briefly, many anticipation studies have employed a 3M training approach based on the three tenets of Mistakes, Mediation and Mastery. Participants are first allowed to make a mistake, they are shown what mistake they made and how to correct the error and finally, participants are offered the opportunity to master the correct behaviors. This training approach (error training or 3M training) has been successfully validated in several previous training studies [Zafian et al., 2016; Taylot et al., 2011; Diverkar at el., 2016; Yamani et al., 2017; Pradhan et al., 2009; Ivancic et al., 2000]. The specific training scenarios for the proposed VR headset-based training program will be built off the scenarios developed and evaluated in another training program, Risk Awareness and perception training (RAPT), which has proved to be a highly effective medium through which the hazard anticipation skills of novice drivers can be improved. RAPT is a computer based training program which provides top down views of several environments to the user and allows them interact with the program in the real time. (More details regarding the RAPT training program have been discussed in RAPT of the literature review) [Fisher et al., 2002].

Finally, I provide a review about the different types of virtual reality headset systems, their examples and their use in various modalities. In this thesis, I will only focus on the fully immersive systems. The examples reviewed show how a virtual reality headset-based training was successful in the enhancement of cognitive skills. I also briefly examine advantages and disadvantages to VR headset-based training.

The goal of my thesis is to develop an advanced VR headset-based training interface that can overcome the shortcomings to existing training programs and deliver a platform that can further accelerate learning and offer more widespread dissemination potential. I will develop a training program using Unity 3D to be delivered on a Oculus VR headset. The efficacy of the training will then be ascertained via a driving simulator study. 36 young drivers will be evaluated on a fixed-base driving simulator across 10 total scenarios. Both, the near transfer effects of training, as well as transfer to generic scenario types will be assessed. The eye movements for all participants will be recorded using a head mounted, eye tracker for scanning pattern analysis. The training will be deemed to be effective if the VR headset-trained drivers anticipate a greater proportion of latent hazard post-training compared to drivers in the control and pseudo-control conditions.

CHAPTER 2

SITUATIONAL AWARENESS AND HAZARD ANTICIPATION

In the United states, Novice drivers (16 year olds with 6 months driving experience or less) continue to have the highest crash involvement rates per 100 million vehicle miles [McKnight and McKnight, (2003); Cerrelli, 1998; Pradhan et al,2003] than other drivers between the ages of 30 and 74 [Cerrelli, 1998]. The male novice driver is about nine times and the female driver is almost eight times more likely to be involved in a crash than their older and more experienced counter parts. Earlier in the 1990's, risk taking behaviors such as drunk driving, excessive speeding of vehicle or other rash driving behaviors were cited as the primary reason for crashes. But, now enough literature and statistics are available, that completely contradict this hypothesis [NHTSA, 2002]. McKnight and McKnight (2003) reviewed almost 1000 crashes in which novice drivers were involved and the findings of the study showed that the most common reasons for the crashes were: 1) failures to search ahead, to the side, and to the rear, which combined to account for almost 42.7% of the crashes; 2) failures to pay attention (23.0%); and 3)last but not the least failures to adjust the speed of the vehicle which accounted for about 20.8% of the crashes. The findings of Treat et al, 1979 reported that the major causes of novice driver crashes are visual search, speed adjustment and attention. While another study Gregersen (1996) estimated that about 70% of the novice driver errors were due to inexperience and a lack of situational awareness. The primary failures listed above may all be attributed to a lack of situational awareness.

Situational awareness can be understood as a person's perception of relevant situational elements in the immediate environment (Endsley, M. R., 1995). Situational awareness is an essential prerequisite for the performance of safe behaviors (hazard

anticipation) within complex dynamic systems [Endsley., 1995; Optale et al., 2010; Sarter & woods., 1991; Endsley., 1999]. Situational awareness is very well defined in the aviation area but, not in the driving domain. It is believed that driving task requires more human processing memory than flying due to the higher frequency and sheer complexity of hazards in driving. Ma & Kaber., 2005, have evaluated how situational awareness is impacted while in automated driving modes or when using cell phone while driving [Ma & Kaber., 2005,]. It is believed that automation will provide improved situational awareness [Endsley., 1995; Endsley., 2000] due to the reduced cognitive memory use albeit only when the operator is paying complete attention to the automation. For complete situational awareness, an individual must possess all three levels of situational awareness; perception of cue, comprehension of the information and projection of future events to successfully anticipate or detect and respond to hazard. Existing literature demonstrates how the situational awareness of novice drivers may be improved by providing them with appropriate training interventions. I have discussed the RAPT Training program in the remediation section of this literature (RAPT was shown effective at improving the visual search, speed choice behaviors and the attention maintenance abilities of the young novice driver. The current study will only focus on how to improve the visual search behaviors (hazard anticipation) of the novice driver.

Hazard anticipation is defined in a variety of ways. In the current context, I will use the definition provided by Pradhan and colleagues in their seminal work that examines differences in novice and experienced drivers using an eye tracker on a driving simulator [Fisher et al., 2002; Pradhan et al., 2003]. Latent hazard anticipation is defined as the ability of drivers to perceive the presence of potential threats on the forward roadway. The threats may or may not materialize. Various explicit clues and implicit cues indicate or denote the

potential presence of a threat. Hazard anticipation may be most easily understood with an appropriate scenario description. Suppose that you are travelling in the right-most lane of a four-lane roadway. There are two lanes in either direction of the roadway and the environment is of an urban or commercial type with significant traffic density and foot traffic. There is a curb on either side of the roadway and both directional roadways are separated by a divider as well. As the driver approaches an intersection with a pedestrian crossing (Pedestrian sign is appropriately located), there are vehicles stopped in the left-lane immediately in front of the pedestrian crossing that obscure the driver's view of any potential pedestrians entering the crosswalk from the left side. The driver must glance towards the left side of the roadway to scan for any potential hazards as he/she approach the intersection. With a good knowledge (situational awareness) of the roadway environment, one can easily process this information for the appropriate anticipation and mitigation of the hazard. Thus, to assess situational awareness we will index a driver's ability to successfully anticipate a latent hazard.

CHAPTER 3

PREVIOUS TRAINING INTERVENTIONS

Risk awareness and perception training was developed and tested in university of Massachusetts, Amherst and was used to study the effect of imparting risk perception training to novice drivers [Fisher et al., 2002]. There are two version of RAPT training program RAPT 2.0 and RAPT 3.0. RAPT training is basically a computer training program which provide top down or plan view of the scenario. The scenarios can be understood with an example described in the Fishers et al,2004; participant saw a pain view of a scene with one or more vehicle and pedestrian, along with the three red circles and three yellow ovals. They had to drag the yellow oval to any area of the scene which contain a latent hazard and may materialize as they traveled forward and Second task is to drag the red circle to the area of the scene which they should monitor more or less continuously.

Fisher et al, 2002 showed that a PC-based risk awareness training can improve the braking performance (5 of the 15 trained driver) of the novice driver compare to untrained driver (1 of the 15 untrained drivers) and can make their performance as good as experienced driver (4 of the 15 experienced drivers). In another study Fishers (2004) have shown that participants after RAPT training have placed the red circle and indicated they knew where to gaze continuously 40% times better than before. While they performed yellow oval task 70% better, which is pretty close to the results shown by Pradhan (2006) indicating improvement in the performance of young trained driver for the overall score of 44.3%. This results are backed by the Pradhan et al., 2003; Pradhan et al., 2005 which indicated that after the training, young driver recognizes hazard or risk 50% of the time more than without training. While interestingly far term effect of RAPT training was evaluated by Pollatsek (2006), Taylor (2011) and found out that results are pretty consistent

in near and far term evaluation and very close to significance. So, we can say that once a novice driver is trained to scan for a crucial area they will continue to retain the training for the long time.

Engaged Drivers Training Program (EDTS) is another training program to improve young novice driver hazard anticipation ability and help them increase distracting activities i.e. attention maintenance activities. Engaged Drivers Training program is a computer tablet-based program that utilizes error feedback mechanism to teach latent hazard anticipation and attention maintenance skills in the high risk scenario [Zafian et al., 2016]. EDTS was tested both in the laboratory and field study, Laboratory study conducted with 20 young novice drivers. The participants were first provided with the driver training in the I-pad and then evaluation was conducted in the simulator with 10 simulator based scenario and the participants were asked to perform secondary tasks (operating the defroster and talking on a cell phone) when they feel safe to do it. Results show trained driver detect more latent hazard and less willingness to engage in the distracting activities in the presence of such hazards, [Zafian et al., 2016].

Field study was an on-road study conducted to test if the result from the simulator study does represent driver behavior on road. The road study was conducted with 43 participants. All the 43 drivers were newly licensed driver. The on-road evaluation shows that EDTS- trained drivers shows better hazard anticipation on-road than the placebo-trained teens.

Finally, I would like to talk about the Road Aware® (RA) training program to put the point that Training program in the past was proved to be an effective tool in improving young driver hazard anticipation and attention maintenance skill and VR headset- based

training will further help to improve driver hazard anticipation and attention maintenance because VR headset training offer better visual flow, better immersion and include more human subject senses than any other training program. Road Aware® is a flash-based, PC training program that runs on the web. Road Aware® was developed by the State farm. A simulator based evaluation was conducted with 48 participants in the University of Massachusetts, Amherst. 24 participants were provided with RA training and 24- participants was provided with the placebo based training. Result from the study show some interesting results like trained driver anticipated more hazard than the untrained or placebo trained drivers in the near and as well as in the far transfer scenario. The Road Aware® is every effective tool for the driver training and it can be used to train, young as well as old driver. Which lot of the training program does not offer [Cite].

CHAPTER 4

TRAINING METHODOLOGY & 3M ERROR-BASED TRAINING APPROACH

Drivers are often overconfident, believing that they are relatively good. Various training methodologies may be used to train behaviors. Some are more effective than the others. Not surprisingly, lectures by themselves appear to have no effect on driver's behavior [Romoser & Fisher, 2009]. However, drivers who witness themselves making mistakes, either in a virtual world through which they navigate [Vlakyeld et al., 2011], an abstract representation of the world with which they need to interact [Pradhan et al., 2009], a filmed version of the real world with which, again, they must interact [Pradhan et al., 2011], or in the real world itself [Romoser & Fisher., 2009], learn quickly that their overconfidence is misplaced.

Training programs like RAPT have used a 3M training mechanism. 3M Training mechanisms have been shown to be critical for the success of a driver training program and are employed here as well. There are three critical elements in a 3M training method: these elements include allowing drivers to make **m**istakes, explaining to the driver how to appropriately **m**ediate the mistake, and allowing the driver to **m**aster the scenario in which a mistake was made. Training programs which combine these three elements – mistake, mediation and mastery – are referred to as 3M programs.

Mistakes are an integral component of any learning. Permitting mistakes allows for a more nuanced explanation of why an action is necessary to mediate a threat. Mediation is an educational approach to training that both, provides feedback to the trainee whenever he or she makes a mistake, and explains why an incorrect response is wrong. For example, in a hazard anticipation training program such as RAPT, plan (top down) views of scenarios

are presented to drivers. Drivers must drag a yellow oval to an area of the plan view where a potential hazard might be hidden. If the response is incorrect, then it can be explained that the response was incorrect, why a hidden object was likely to be positioned at a particular location, and why it posed a potential threat to the driver. Although the method of correcting the mistake (dragging an oval on a plan view) in the training program is not one that the driver executes on the open road, it is still instructive because drivers can generalize what they learn from the plan view to the relevant critical behaviors on the open road (moving their eyes to areas from which potential hazards could emerge).

Mastery learning is an educational approach to training in which the same task is repeated until it is executed correctly. Some skills are learned in only a single trial. Others require several trials. For example, in RAPT the trainee is asked to drag a yellow oval to an area of a plan view in which a potential threat might appear. Then after a mistake is made and mediation is offered, the same scenario will be given until the trainee responds correctly.

These three elements (mistakes, mediation and mastery) in combination, were used throughout the training program. However, how the content is delivered and, therefore, how exactly the mistakes are measured, the mediation method made clear, and the mastery of action encouraged, could vary widely among different skills.

CHAPTER 5

CURRENT STATE OF VIRTUAL REALITY IN TRAINING APPLICATIONS

Levels of Immersion in Virtual Reality Systems

Various Virtual Reality systems have differing levels of immersion. There exist non-immersive, semi immersive and fully immersive systems. Non-immersive systems can be made available in any desktop system and requires the least amount of user attention [Costello et al., 1997]. They are the most basic type of the VR headset systems currently available in the virtual reality environment. High end graphics is not mandatory for Non-immersive systems and one can create such systems using the very basic equipment required for a desktop system such as, but not limited to, mouse, keyboard, or other 3D integrating devices. Semi-immersive systems provide better graphics than the Non-immersive systems. Semi immersive systems may be compared with a multiple projector system or a large screen projector system [Costello et al., 1997]. Liquid shutter glasses is one example of a semi immersive system and is heavily utilized in commercial 3D pictures or movies. Fully immersive systems are a major application area of the VR headset based technology. Head mounted displays have gained global attention over the past couple of years and an increasing amount of research is on-going on fully immersive systems/ head mounted display [Costello et al., 1997].

Virtual Reality (VR) technology has emerged as an innovative medium for the evaluation and training of cognitive functions, and allows the researcher to study their overall impact on the day to day life of a human, in a controlled manner [Anguera et al., 2013]. In recent times, scholars have explored the use of VR headset due to the multitude of advantages offered by the technology such as, a safe realistic environment with realistic images and sounds, high-level immersion without any risk of actual injury, systematic

delivery and control of stimuli to customize training to individual skill, and an engaging and fun learning environment. Further, VR training can be administered with minimal supervision and monitoring. An elaborate literature search reveals several studies utilizing a VR intervention. However, most of these studies are from a healthcare, post-operative or surgical environment. There are several VR applications in rehabilitation, autism interventions, surgical training, and classroom learning settings. In this review, an application most consistent with driver training is considered: - young pedestrians crossing behaviors.

Nearly three quarters of the pedestrian injuries involving children under the age of 10 years are the result of the child either improperly crossing intersections or dashing out to the street between intersections. One major reason children have an increased pedestrian injury risk compared to adults is because crossing a street requires sophisticated cognitive and perceptual processing, skills that develop during childhood. Below, four key studies are discussed, which focus on behavioral training in a VR environment. Specifically, these studies have focused on the training of young pedestrians' crossing behaviors in a simulated VR platform. Each of these studies have contributed to the utility of VR, and have demonstrated its efficacy at training for higher order cognitive behaviors in an optimal manner.

Previous research suggests children can learn to be safer pedestrians. McComas and team developed a desktop VR program, designed to train children on safe intersection crossing behaviors [McComas, MacKay, & Pivik, 2002]. They conducted a study to determine whether children can learn pedestrian safety skills while working in a virtual environment and whether pedestrian safety learning in VR successfully transfers to real world behavior. Following focus groups with several experts, the authors developed eight

interactive intersections. Ninety-five children from an urban and a suburban school participated in a community trial. Half were assigned to a control group and received an unrelated VR program, while the other half received a pedestrian safety VR intervention. Real-world street crossing behaviors of all children was observed, a week before and a week after training. Significant change was observed in the performance of children following three trials with the VR intervention. Children were found to learn safer street crossing behaviors, and the learning was found to transfer to the real world in the suburban population but not the children from an urban school.

In the most extensive published evaluation of a VR pedestrian safety training program, Schwebel and colleagues conducted a randomized controlled trial of 240 seven and eight-year-old children who received six 30 minute sessions within a VR environment, either through individualized street side training by an adult or in a VR environment, or computer-based games, or, as a control group [Schwebel, McClure, & Severson, 2014]. Results were found to vary across outcomes. However, children trained individually by an adult at street side locations or through the VR environment demonstrated better learning than those trained through games/videos or the control group. More specifically, children trained in VR environment showed decreases in unsafe crossings and delays in entering gaps. Increases in attention to traffic while waiting to cross were observed in simulator assessments while decreases in attention to traffic were reported in field assessments.

A more recent study by Schwebel and colleagues extended previous research using VR to train children on pedestrian safety skills in two ways: by redefining a previously developed and validated system into a more mobile virtual environment; and by conducting a pragmatic trial of the VR training in a field setting under real world circumstances [Schwebel *et al.*,2016]. The children were trained at schools and community centers. The

study utilized a within subject design with evaluations both, before and after training. The VR training sessions itself included six 15-minute sessions. As hypothesized by the authors, pedestrian performance was found to reflect quicker decision making with regards to gap acceptance following training. No significant differences were found in the rate of unsafe crossings following training. It was surmised that the pattern of results reflects more confident crossing decisions made by children without sacrificing safety. The study strongly supports the use of VR to teach child pedestrian safety but however, suggests that more research including replication of cognitive-perceptual processes of street crossing and adaptive feedback for safe behaviors need to be tested to completely train children.

In another study, Thomson et al. examined the long-term influence of VR training on the roadside crossing behavior of child pedestrians. One hundred and twenty-nine children (ages 7, 9 and 11) undertook a VR training program and 70% of them were evaluated before and after training on the road both, immediately following training, and in a long term follow up evaluation [Thomson et al., 2005]. A separate control group from the matched control school in the area, underwent a delayed follow up test. A simulated environment was designed to replicate the small-town neighborhood in which a child avatar had to complete several journeys and the participants' task was to help the avatar do it safely. Eight crossing situations were presented for each training session, and each traffic animation was continuously looped for up to 20s. Vehicle speeds were set relative to the scale of the road and its surroundings, with average speed of 30 mph. The training objectives were to encourage the child to focus on time rather than distance-speed and to improving the understanding of the time required to cross the road. Significant effect of age was found for three variables: starting delay, tight fits and conceptual understanding. Older children were found to perform better on all the aspects than younger children. A

significant main effect between the before and after evaluations showed that the crossing time decreased by 0.6 s from before training to after training. This effect was found on both, accepted gap size and starting delay, as the trained group was found to accept a smaller gap and step into the gap more optimally.

While several researchers are currently engaged in the development of appropriate VR-based training interventions for improving driver/ bus operator behaviors, there currently exists no peer-reviewed research demonstrating the effectiveness and efficacy of such interventions for the driving population. However, given the demonstrated success of VR at training young children on better crossing behaviors, and the success in the healthcare domain utilizing VR-based rehabilitation, there is every reason to anticipate the translation of such success to driving-related outcomes. Non-VR driver training (such programs have focused on improving higher order cognitive skills such as hazard anticipation and mitigation, that are critical to safe behavior) has been extensively developed, and shown to be effective, and therefore the relevant training content exists. The challenges are merely on the software side and even those limitations are trivial with the rapid advancements in technology. With the lessons learnt from the other domains in their utility of VR for training, and the availability of existing and effective driver training content, the research world is well equipped to develop a VR driving simulator to train all road users. VR technology immersed as an innovative medium for evaluation of the cognitive functions such as Hazard anticipation, Hazard mitigation and Attention maintenance and allows researcher to study their impact on day to day life in controlled manner [Anguera et al., 2013]. Using VR technology dynamic, multisensory “Real life” stimulus environment can be generated and within that all behavior responding can be recorded [McComas, MacKay, & Pivik, 2002].

Lengenfelder et al., 2002 used Virtual Reality to evaluate the influence of divided attention on driving performance (speed control). In this study, they recruited three participants with traumatic brain injury (TBI) and three participants with healthy control (HC) from the hospital staff. Mean age of TBI participants was 38 years old and onset between the TBI and time of testing was 12.67 years while mean year of education was 13.3 years. Mean age of HC group was 38 years and mean age of education was 16 years. TBI and HC group were matched for age, education and gender.

All the participants, asked to drive a simple VR Driving route of 1.75 miles long, two directional roadways with driving lane approximately 12 feet wide and containing four curves. Participant had to perform two tasks: primary task and secondary task. In the primary task, participant had to perform simple driving task maintaining center of the road and their speed was recorded every 100 milliseconds. Secondary task includes a four-digit number displayed on the computer screen at an interval of 300ms while subject drove the VR driving route. Subject asked to speak the number out loud immediately the number displayed on the screen and their response was recorded. Five driving divided attention condition were present to the participants, a baseline condition and the four divided attention condition. Initial results do not indicate any difference in relative speed between TBI and HC on any of the divided condition. It is also observed that speed for both the group increases when secondary task was added to driving and suggests that complexity of visual attention required to perform secondary task does not impact on driving speed.

There are several **advantages** associated with the use of VR. VR headset-Based study offers multiple advantages for studies performed in a controlled, simulated environment. First of all, a virtual reality device is handy, compact and at the same time offers higher

vertical and horizontal viewing angles. VR headset devices offer higher resolution image quality, regulated visual flow with realistic experimental environment like feel at a significantly lower price as compared to a driving simulator. VR headset devices offer more flexibility and ability to transport from one place to another without any hassle which is not the case with most driving simulators. There also exist certain **disadvantages** associated with VR-based approaches. Costello et al, 1997 discussed physical, psychological and physiological side-effects associated with the study performed in the control and simulated environment. For this study, we will only discuss about the fully-immersive systems and number of potential health issue that may be associated with the Fully immersive systems. There can be a physical discomfort with the use of VR Headset for extensive periods in a single experimental session due to its weight and fitting problem. Physiological issues are a major concern in our research area as 90 percent of the data in a driving simulator are visual and the occurrence of some visual temporal visual lag may cause simulator sickness. Psychological effect may also be associated with the VR system such as hallucinations, dissociation, and lateralization.

CHAPTER 6

RESEARCH IMPLICATION, STUDY HYPOTHESES & DEPENDENT VARIABLES

Research Implication

As we have discussed above, RAPT training is very useful and effective for the performance enhancement of the novice driver. However, the only perceived disadvantage of RAPT training is that it does not involve all the human senses in the training program and gives an overview (Top down) of the plan view of the environment and what could be the potential hazard(s) in that environment. So, it is my hypothesis that though RAPT is very effective for the near term and far term evaluation, the novice driver can still perform better than currently shown by the RAPT training, if we develop a training that involves all of their senses in the training component.

So, I propose a virtual reality headset based Risk awareness and perception training program or V-RAPT. We have already reviewed literature supporting virtual reality headset based training program to be more effective than other training program for other domains. V-RAPT will allow participants to control the vehicle and in the same time provide them with important information about the environment, such as how they can improve their driving performance i.e. hazard anticipation skill and visual search.

Study Hypotheses

After reviewing the research in this field and conducting experiment in the related field, the following are the hypotheses that are proposed to be evaluated with an experiment:

Hypothesis 1: The V-RAPT-trained drivers will anticipate a greater proportion of the latent hazards than both the RAPT and placebo-trained drivers in both the near-transfer and far-transfer evaluation scenarios.

Hypothesis 2: The V-RAPT-trained drivers will also demonstrate better hazard mitigation ability - as measured by their average velocity, standard deviation of velocity, and average absolute acceleration near the latent threat - than the RAPT and placebo-trained drivers.

Dependent Variables

The current experiment utilizes a state-of-art driving simulator that offers extreme flexibility to record a variety of measured data like throttle position, velocity, lane position and braking for the participants' vehicle (ownership). The eye-tracker in the HPL collects and records eye behaviors including fixation and glance data from participants. But, the value of dependent variable for each scenario is determined by the glance location of the drivers as he or she approaches the latent hazard. Specifically, a target zone was defined as that area of the forward roadway where a potential or actual threat may be present while the launch zone was defined as that area of the roadway whence the driver should glance towards the target zone in order to be able to successfully detect and mitigate for both latent hazard types (pedestrian and vehicle). A driver's latent hazard detection for each scenario is binary scored as either a 0 (miss) if they fail to glance towards the target zone in the launch zone, or a 1 (hit) if they successfully glance towards the target zone in the launch zone.

CHAPTER 7

METHODOLOGY

The following section describes the complete study methodology including the participant demographic evaluated, the equipment used for data collection and recording, the training and assessment scenarios used and the experimental design and procedure. This experimental study will consist of three treatment groups. One group will be trained with V-RAPT (VR headset-based risk awareness and perception training), a second group will be trained with the RAPT program (Risk awareness and perception training program – Fisher et al., 2002) and the third group will be provided with the placebo training program (all 3 training programs are described below in the Training Programs section). All three groups will be assessed for training effectiveness on a full-scale driving simulator at the Human Performance Lab in the University of Massachusetts, Amherst. The driving simulator is a fixed base version and collects and records various vehicular data such as lane position, acceleration, velocity etc.

Participants

Thirty-six subjects aged 18-25 were recruited for this study which had full approval from the University of Massachusetts Amherst Institutional Review Board. Data from one subject were excluded due to technical failures while two other participants dropped out from the study due to simulator sickness during the evaluation portion of the study (one V-RAPT and one RAPT participant). The 12 participants in the V-RAPT group had a mean age of 20.50 years ($SD = 1.24$) and a mean driving experience of 3.79 years ($SD = 1.09$). The 12 drivers in the RAPT training group had a mean age of 21.333 years ($SD = 1.87$) and mean driving experience of 3.63 years ($SD = 1.99$). The 12 drivers in the placebo training group had a mean age of 20.25 years ($SD = 1.13$) and mean driving experience of

3.43 years ($SD=1.81$). There was no statistical difference among the ages of the drivers by training group or their months of licensure. All participants were recruited from the town of Amherst and surrounding areas and were remunerated for their participation in the study.

Apparatus

The current experiment will utilize an oculus rift, a fixed-base driving simulator, and an eye tracker to train and assess behavior and to collect and record appropriate behavioral data.

Oculus Rift

The Oculus Rift is developed and manufactured by Oculus VR and comes with a Virtual reality headset, motion sensor, remote and Xbox One wireless controller (Figure 1: Oculus Rift). The Rift has an OLED display which offers rich HD resolution of 1080x1200 per eye with refresh rate of 90 Hz. The screen provides 100 degrees' field of view. Integrated headphones in the Rift provide a 3D audio effect. The motion sensing performs rotational and positional tracking using a USB stationary infrared sensor. The infrared sensor picks up the light that is emitted by the IR LED integrated in the display of the headset. The sensor needs to be kept stationary. With the use of the sensor, the Oculus Rift creates a virtual 3D space where the user can sit, move or walk around. The Oculus rift works only with a 64- Bit Windows PC with a Windows 7 Operating System or newer, Other minimum requirements for the Oculus are: NVIDIA GTX 970 graphic card, Intel i5-4590 or greater, HDMI 1.3 video output, 3*USB 3.0 ports, 1*USB 2.0 port and 8 Gigabytes of RAM or more).



Figure 1: Oculus Rift

Driving Simulator

The driving simulator setup consists of a fully equipped 1995 Saturn sedan placed in front of three screens subtending 135 degrees horizontally. The virtual environment is projected on each screen at a resolution of 1024 x 768 pixels and at a frequency of 60Hz (Figure 2). The images themselves are updated 60 times a second using a network of four advanced RTI simulator servers which parallel process the images projected to each of the three screens using high end, multimedia video chips. The participant sits in the car and operates the controls, just like he or she would in a normal car. These controls move him or her through the virtual world according to his or her inputs to the car. The audio is controlled by a separate system which consists of two mid/high frequency speakers located on the left and right sides of the car and two sub woofers located under the hood of the car. This system provides realistic wind, road and other vehicle noises with appropriate direction, intensity and Doppler Shift.



Figure 2: Driving Simulator (RTI)

Eye tracker

A portable lightweight eye tracker (Mobile Eye developed by ASL) was used to collect the eye-movement data for each driver (**Figure 3**). It consists of a pair of goggles that contain miniaturized optics – a camera for viewing the eye, another for viewing the scene ahead, an ultraviolet light source, and a small reflective spectacle to allow the eye camera to record an image of the eye without being directly in front of the participant's eye. The images from these cameras are interleaved and recorded on a remote system, thus ensuring no loss of resolution. The interleaved video can then be transferred to a PC where the images are separated and processed. The eye movement data is converted into a crosshair, representing the driver's point of gaze, which is superimposed upon the scene recorded during the drive. This provides a record of the driver's point of gaze on the driving scene while in the simulator. The remote recording system is battery powered and is capable of recording up to 90 minutes of eye and scene information at 60 Hz in a single trial.

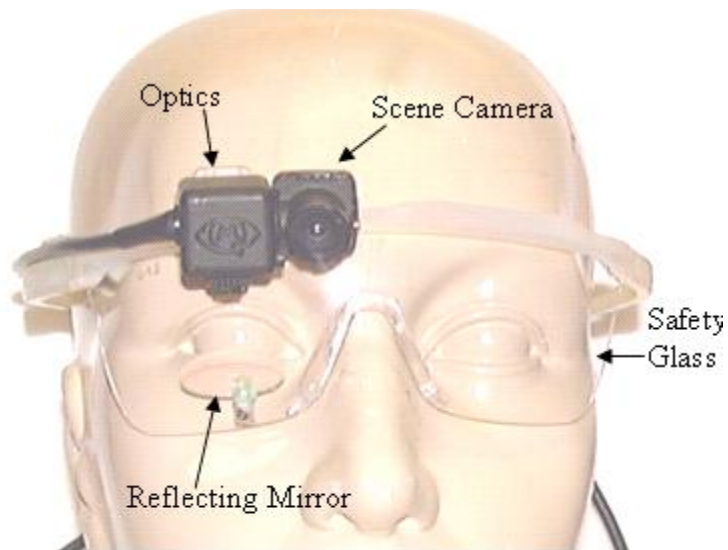


Figure 3: ASL Mobile Eye Tracker

Training Programs

Three training programs will be used in the current study: a) a placebo program, b) the RAPT training program, and c) the latest VR headset-based augmentation of RAPT (V-RAPT). All training programs are described below. V-RAPT and RAPT use contextually identical scenarios for training. Images and descriptions are provided for the scenarios used in V-RAPT while only a brief description is provided for RAPT itself (the differences between the two training programs exist in the visual representation, level of immersion, and user interface aspects).

RAPT

The Rapt Training program has five sections- Instruction, Pre-Test, Training, Questions and Post-Test.

The *Instructions section* familiarized the user with the layout and interface. This section included three practice sessions that showed the top-down view in relation to the regular perspective views and provided practice in dragging and dropping the yellow ovals

and red circles. The user was also familiarized with answering questions in the relevant text boxes.

During the *Pre-Test Section* the participant was presented with 7 scenarios in sequence and the user was expected to drag the red circles and yellow circles to the relevant areas in the plain views. In this section the participant was not provided with the feedback with respect to their responses.

The *Training Section* showed three to four different slides per scenario. In the first slide, the subject Response screen (e.g., Figure 4, without the red circles or yellow ovals positioned in the correct location), the participant was shown a plain view of the scenario with one or more vehicles and/or pedestrians. This slide had three red circle and three yellow ovals on a side panel. The participant was instructed to drag the red circle and yellow ovals onto the relevant areas on the screen.

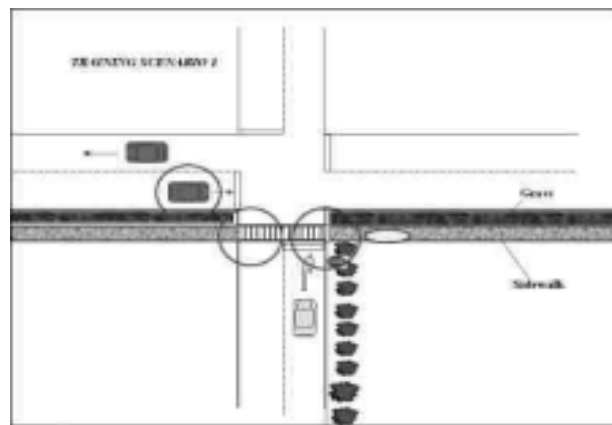


Figure 4- RAPT- SUBJECT RESPONSE SCREEN

Next, the Vision Obstruction Screen (Figure 5) was shown that indicated the areas of the roadway occluded from the driver's view and provided explanations of the various risks that could arise in the scenario due to the hidden elements.

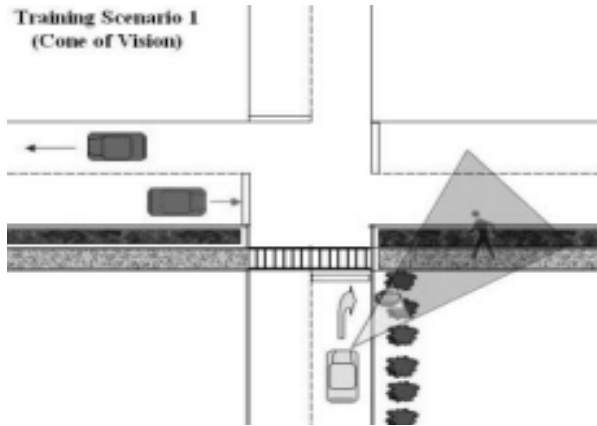


Figure 5- RAPT- Vision Obstruction Screen

Finally, the Answer Explanation Screen was shown that marked acceptable locations for the yellow ovals and the red circles along with detailed reasons and explanations for the choice of those locations. For some scenarios, an additional visualization screen (Figure 6) was shown. This screen contained a perspective view along with the plan view to explain the scenario better and to aid in the visualization of the scenario.

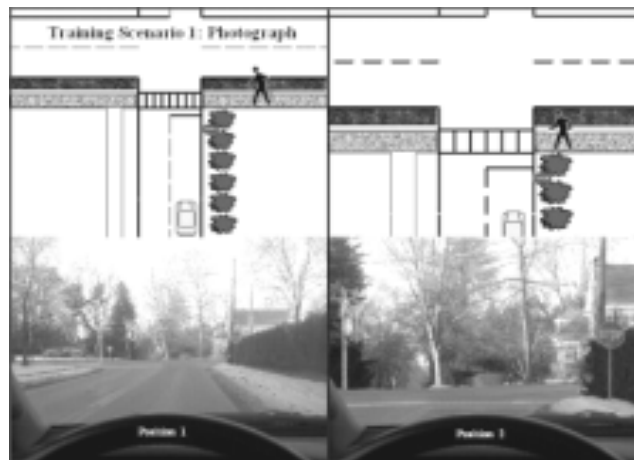


Figure 6- RAPT- VISULIZATION SCREEN

In the *Question Section* the participant are presented with the 7 scenarios again, but this time the participant are asked about the risk in the scenarios. The participants are

supposed to type in the answers in provided text boxes. The program then gave feedback after each scenario's questions were answered.

Finally, the *Post- Test Section* presented the plain view of the scenarios to the participants again and, as in the pre-test section, they were instructed to move the red circle and yellow ovals to appropriate locations. These locations were then compared to the locations recorded in the pre- Test section.

Placebo

The placebo Training program have three different sections- Instruction, pre-test and Training. The instruction section includes practice drive and provide the user an opportunity to developed familiarity with training program interface. During the pre-test sections the participant are provided with different driving scenarios and the participants are required to clique in the most obvious area in the screen where hazard might appear. In this section the participants are also provided with some very general driving scenarios like changing the flat tires etc. The training section does provide the participant with thee general information about the scenarios. It should be noted that the user is not provided with the active feedback at any point during the placebo training.

Simulation Drives

V- RAPT Training Drives

V-RAPT training has four different modular phases for each of the six scenarios chosen for training. The first module is the mistake module. In this module, the participant navigate through each of the virtual scenarios using the Oculus Rift. Their drive in the first section was be recorded for subsequent reference in other modules. In the second module, the participant was trained about the latent hazard specific to each scenario in the section.

There were six scenarios in total. The training details delivered in the second module is provided in

Table 1: Audio script in the mediation **section**. As a part of the third module, immediately after training in the second module, the subject will be shown the recorded video from the first module. If the participant correctly scanned for the latent hazard, they will be complimented for the good performance and safe driving. However, if the participant failed to make a correct anticipatory glance at the latent hazard, then a general description about the latent hazard in the current scenario will be provided. The fourth module is a mastery section where the participant again navigate through the driving scenario in the Oculus Rift. While navigating, if the participant makes correct anticipatory glances at the target zone then, the participant was assigned the next training scenario. There were a total of 6 training scenarios administered in a modular manner. The four modules was delivered for each scenarios individually. The full description of all six scenarios are provided below with respective images of the latent hazard (perspective view) in each of those scenarios.

Scenario1 : The driver is approaching a T-intersection on a two lane road way with one travel lane in either direction. The connecting road in the intersection is also a two lane road with one travel lane in either direction. There is a vehicle waiting in the forward lane inn the opposite direction and another vehicle on the connecting road (cross street). The vehicle on the cross street is blocking the view of the potential pedestrian. The driver needs to appropriately scan for the pedestrian.



Scenario 1

Scenario 2: The driver is on a straight section 4 lane road with 2 travel lanes in either direction. There is a crosswalk ahead and a stopped truck on the right side of roadway (at the cross street) that obscures the view of a potential pedestrian who may approach from the right side of the roadway. There is a pedestrian sign posted. and the participant must scan towards the right for the pedestrian sign, and then scan straight ahead at the cross road for the potential pedestrian.



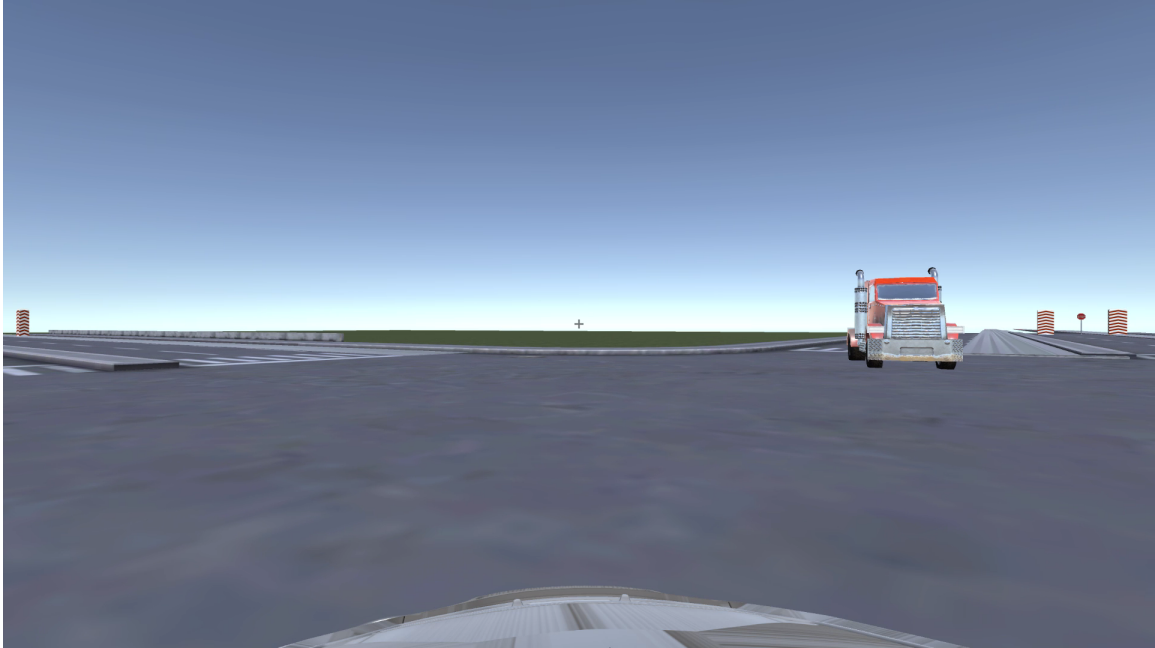
Scenario 2

Scenario 3: This is an example of a scenario where the pedestrian is obscured by a truck travelling in the opposite lane and is waiting to take a left turn to the parking lot on the right hand side. The truck is stopped just in front of a mid-block crosswalk. The driver needs to scan towards the forward roadway and then towards the right-side of the roadway for any unexpected hazards. There are two cues that can help the participant driver: first cue is on the right(a sign indicating a pedestrian mid-block crosswalk) and a second one in front of them on the roadway (the pavement striping).



Scenario 3

Scenario 4: This scenario comprises of a vehicle obscured by another large vehicle from the driver as the driver. While taking a left turn, the driver cannot see past the truck, where a car or motorcyclist might be passing the truck. The driver needs to negotiate the left turn slowly and carefully while scanning for any oncoming traffic from the forward roadway. The roadway environment is a four-lane roadway with two travel lanes in each direction. There is a curb on both sides of the road, and a service lane is also present on either side of the roadway. The speed limit is 45 mph.



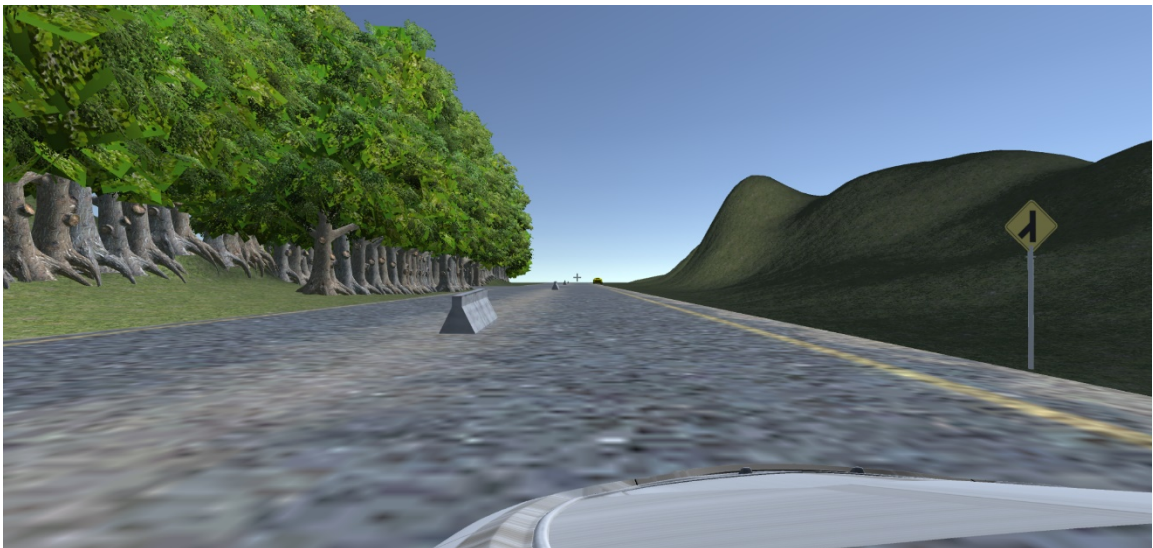
Scenario 4

Scenario 5: As the scenario begins, there is a line of vehicles in the right-most lane of a four lane highway with two travel lanes in each direction. The driver is in the left lane and should pay attention towards the line of vehicles in the right most lane. The driver in this scenario should keep scanning towards the right most lane for any potential threat such as any vehicle that can change the lane (right to left) for rash passing. The perspective views are included in the images below.



Scenario 5

Scenario 6: The driver is travelling on a two lane road way separated by a median to divide the road for traffic in both directions, and the driver passes a left lane merge warning sign. The lane merging sign provides the driver with a cue of the potential threat. The driver should start scanning for any unexpected traffic that might emerge from the left. The merging street is stop controlled.



Scenario 6

Table 1: Audio script in the mediation section

| Scenario | Approaching Launch Area | Beginning of Launch Zone | End of Launch Zone |
|--|---|---|--|
| Scenario 1: Curve + T Intersection | There is a sign on the right indicating that pedestrians are crossing the road somewhere ahead of you. You should start scanning the forward roadway for a crosswalk. | You can just barely see a crosswalk ahead of you in front of the car in the opposing lane. However, your view of the pedestrian on the right side of the road could be hidden by the truck on the right waiting to turn. You should keep scanning towards the front edge of the truck on the right for a pedestrian while keeping your speed slow. | Keep your speed slow and keep scanning towards the front edge of truck on the right for any potential pedestrian that might enter the crosswalk. |
| Scenario 2: Mid-block crosswalk + pedestrian | There is a sign on the right indicating that pedestrians are crossing the road somewhere ahead of you. You should look for an obvious place where that might occur. | The truck parked in the right most lane can block your view of a potential pedestrian entering the crosswalk in front of the truck. You should keep scanning towards the right front edge of the truck and you should slow down. | Keep your speed slow and continue scanning towards the truck on your right for a pedestrian that might enter the crosswalk. |
| Scenario 3: midblock cross walk | There is a sign on the right indicating that pedestrians are crossing the road ahead. You should keep scanning towards the left and right side of the road in the area of the crosswalks for pedestrians. | There is a sign on the right indicating a pedestrian crosswalk ahead. The truck in the opposing left lane waiting to make a turn towards the parking lot on your right is blocking your view of a potential pedestrian behind the truck who is in the crosswalk. You should slow down and scan towards the left most and right most edge of the truck for any obscured pedestrian | You should keep scanning for any potential pedestrian by the truck while keeping your speed slow. |
| Scenario 4: Left turn at 4-way stop controlled intersection + vehicle in opposing left turn lane | Since you are turning left, you want to glance at traffic across the intersection that might collide with your vehicle. | The truck in the opposing left lane might obstruct your view of other vehicles in the lane adjacent to the truck. These other vehicles could strike you as you are turning left. You should slow down and look to the right. | As you proceed to turn left, slow down enough until you can determine whether there is any oncoming traffic on the right hidden by the trucks. |
| Scenario 5: Signal controlled intersection + line of vehicles | The signal in the upcoming intersection is red. You should watch for vehicles that might change lanes in front of you as you approach the signal. | The vehicle in front of you has a clear path to through the intersection if the driver changes into your lane and may be in a hurry. You should continue to glance | As you are passing the vehicle keep scanning towards your right as you might be in the blind spot of the vehicle on your right. |

| | | | |
|--|---|--|--|
| | | towards this vehicle for any possible sudden moves. | |
| Scenario 6: Road entering from the left side | There is a sign on the right side indicating that traffic may be entering from the left. You should be alert at this point and keep scanning for where traffic might enter from the left. | The traffic entering from the left is obscured by trees. The trees might hide your view of the driver of the vehicle waiting to merge into your lane. Slow down and keep scanning on your left for any vehicle trying to merge into your lane. | Keep your speed slow and keep scanning towards the edge of the tree line on your left for entering vehicles. |






Simulator Drives

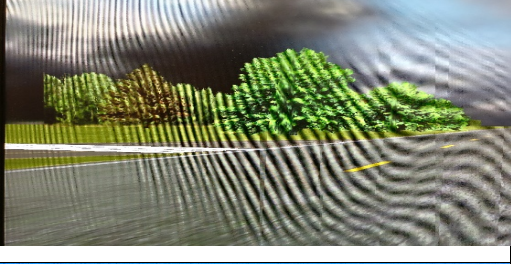




Two types of virtual simulation drives were developed and will be used in the current experiment. Specifically, a practice drive and an evaluation drive. The practice drive was developed to serve several purpose like (I) to familiarize the participant with the RTI driving simulator, e.g., the simulator car – adjustable seat, gas pedal, brake pedal, steering wheel, turn signals, speedometer, rear and side mirror positions on the screen, (II) to give the participant practice driving so that he or she get familiar with the new world of virtual driving and at the same time the participant gets familiar with any kind of visual instruction provided during the experiment. There will be only one practice drive and of around 3-4 minutes’ duration so all the participant will have the same practice drive and if any participant feels he need more practice at the end of drive, the same practice drive will be repeated until the participant feels safe enough to perform the evaluation drive.

There are a total of eleven simulator scenarios- 6 near-transfer scenarios which identically represent the six scenarios provided for training (these scenarios evaluate learning on the situations that were explicitly taught) ; and 5 far-transfer scenarios which differ from the training scenarios in build, traffic conditions, and general characterizations, and test if the knowledge provided in the training is transferable to other scenarios in

general real-life driving. All the evaluation scenarios are briefly described along with their perspective views for illustrations in Table 2 **Error! Reference source not found.** below:

Table 2: Simulator Evaluation Scenario

| Scenario Name | Scenario Description | Perspective Scenario Views |
|-----------------------------|--|--|
| N1 (Training Scenario 1) | The driver is approaching a T-intersection where there is a vehicle waiting in the forward lane in the opposite direction and another vehicle on the connecting road (cross street). The vehicle on the cross street is blocking the view of a potential pedestrian. The driver needs to scan for the pedestrian. |  |
| N2 (Training Scenario 2) | The driver on a straight 4 lane road, 2 lanes in either direction. There is a mid-block crosswalk ahead (downstream of the truck). There is also a pedestrian ahead sign that is on the right side of the road. The participant must scan towards the right for the pedestrian ahead sign, and then scan to the right as the truck is passed for a potential pedestrian. |  |
| N3 (Training Scenario 3) | In this scenario, the participant is driving on a two-lane road with one travel lane in either direction. The truck in the opposing lane is waiting to take a right turn into the parking lot. The truck is stopped just after a crosswalk obscuring the view of a potential pedestrian on the left, towards which the driver should scan when passing the truck. |  |
| N4 (Training Scenario 4) | The driver is taking a left turn at a signalized intersection. A large truck across the intersection in the left turn lane obscures a motorcyclist who might be passing the truck on its right side, potentially colliding with the turning driver. The driver should slow and glance towards the left of the truck as he or she completes the turn to the left. |  |
| N5 (Training Scenario 5) | There is a line of vehicles in the right lane of a roadway with 2 travel lanes in either direction. A signalized intersection is ahead. The driver is in the left lane. A vehicle ahead and in the right lane may change lanes and move into the left lane immediately ahead of the driver. The participant needs to scan towards the right lane for vehicles that may emerge as a potential hazard. |  |

| | | |
|-------------------------------------|---|--|
| <p>N6 (Training Scenario 6)</p> | <p>The driver passes a traffic sign that shows a road entering from the left side. Often such signs are present because drivers entering from the side road are difficult to see (obscured by vegetation or geometry) or are unexpected. The driver should glance to the left for potential vehicles entering from that direction.</p> |  |
| <p>F1</p> | <p>The scenario begins with the participant driving down a four-lane road (two travel lanes in each direction). There is a parking lot on the right side of the road. A car is waiting to pull out from the parking lot. The driver needs to pay attention to the right side of the road for any vehicle that may pull out from the parking lot.</p> |  |
| <p>F2</p> | <p>The scenario starts on a two-lane curved road. As the driver approaches the apex of the curve, immediately following the apex there is a truck in the emergency lane with its emergency flashers activated just in front of a crosswalk. The driver needs to pay attention to pedestrians that might emerge from in front of the truck.</p> |  |
| <p>F3</p> | <p>The driver is on a two-lane suburban road. The driver passes a traffic sign that indicates that pedestrians may be present at the school zone. Ahead is a bus that is stopped on the left side at a marked mid-block cross walk for a potential pedestrian that may enter the cross walk.</p> |  |
| <p>F4</p> | <p>The driver is travelling on a four-lane roadway. A vehicle on the right at the intersection is obscured from the driver by another large vehicle on the right. As the driver will go straight through this intersection, the driver cannot see past the truck where a car or motorcyclist might be passing the truck and might emerge as a potential hazard.</p> |  |

Experimental Design

The experiment utilizes a between-subject design. The participant is either trained in the Virtual reality headset based training program (V-RAPT), or the Risk Awareness (RAPT) training program, or they were provided with a computer based placebo training program. After being administered the training program, all the participants navigated six near term

and five far term simulator-based scenarios. The ordering of the ten simulator scenarios was counterbalanced using the Latin square sequencing as shown in the **Table 3** below.

Counterbalancing

Drives are counterbalanced both, within participant and across participants using a Latin square matrix. The Latin Square matrix have been widely used to counterbalance multiple scenarios for each participant and across the group. Latin square in general is a $n \times n$ array filled with 'n' different symbols or numbers. Each entry occurs exactly once in each column and row. The formula used here is 1, 2, n, 3, n-1..., but there is not exactly one formula to calculate a Latin array. The Latin square used for this study is showed in the Table 3 below.

Table 3: Counterbalancing using Latin square

| Participant/Drives | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| 1 | 1 | 2 | 10 | 3 | 9 | 4 | 8 | 5 | 7 | 6 |
| 2 | 2 | 3 | 1 | 4 | 10 | 5 | 9 | 6 | 8 | 7 |
| 3 | 3 | 4 | 2 | 5 | 1 | 6 | 10 | 7 | 9 | 8 |
| 4 | 4 | 5 | 3 | 6 | 2 | 7 | 1 | 8 | 10 | 9 |
| 5 | 5 | 6 | 4 | 7 | 3 | 8 | 2 | 9 | 1 | 10 |
| 6 | 6 | 7 | 5 | 8 | 4 | 9 | 3 | 10 | 2 | 1 |
| 7 | 7 | 8 | 6 | 9 | 5 | 10 | 4 | 1 | 3 | 2 |
| 8 | 8 | 9 | 7 | 10 | 6 | 1 | 5 | 2 | 4 | 3 |
| 9 | 9 | 10 | 8 | 1 | 7 | 2 | 6 | 3 | 5 | 4 |
| 10 | 10 | 1 | 9 | 2 | 8 | 3 | 7 | 4 | 6 | 5 |
| 11 | 1 | 2 | 10 | 3 | 9 | 4 | 8 | 5 | 7 | 6 |

| | | | | | | | | | | |
|----|---|---|---|---|----|---|---|---|---|---|
| 12 | 2 | 3 | 1 | 4 | 10 | 5 | 9 | 6 | 8 | 7 |
|----|---|---|---|---|----|---|---|---|---|---|

Procedure

Participants was provided a brief overview of the study at the onset following which they were asked to read an Informed Consent form and provide written consent to participate in the experiment as per the Institutional Review Board norms. Participant were then randomly assigned to any one of the training programs (V-RAPT, RAPT or Placebo). Following training, the participants were outfitted with an eye tracker which is calibrated within the simulator. After the calibration, participants were given a practice drive to familiarize them with the functions of the driving simulator. The practice drive includes no hazard anticipation scenarios to prevent sensitization. After the practice drive, ten simulator evaluation scenarios were given to the participant. Participants were then provided a demographic questionnaire that collects participants' driving history, and some demographic information like age, sex, and race. The entire session averages an hour in total duration.

CHAPTER 8

RESULTS & ANALYSES

Latent hazard anticipation

In this experiment, an analysis of the driver's latent hazard anticipation is undertaken to compare the performances of the participants in the three treatment groups. The data is binary-coded to determine whether or not a driver has glanced towards the appropriate target zone while he/she is travelling within the launch zone.

A target zone may be defined as that area of the roadway where a potential hazard may or may not appear, depending upon the type of the hazard. Example a latent hazard never materializes. Whereas the launch zone may be defined as that area wherein the participant should start scanning towards the target zone to successfully anticipate for the hazard and to take the necessary steps to mitigate it.

Therefore, the proportion of latent hazards anticipated (dependent variable) was binomially distributed since, the participant was scored in a binary manner; 1-if they glanced towards target zone while travelling through launch zone and 0- if they did not glance towards target zone while travelling through the launch zone.

The binary-coded, binomially distributed eye movement data were analyzed using a logistic regression model within the framework of Generalized Estimating Equations (GEE). The model included participants as a random effect, scenarios as a within subject variable, and treatment (three training groups) as a between-subjects factor. A significant main effect of treatment was observed, Wald $X_3^2 = 19.218$; $p < .001$. The main effect was consistent with our hypothesis. The main effect was consistent with out hypothesis as evident in the Figure 7. The V-RAPT trained drivers anticipated a greater proportion of

latent hazards across all scenarios as compared to the RAPT trained drivers (87.57% vs 60.50%) which is a statistically significant difference, Wald $X_3^2 = 6.68$; $p < .001$. The RAPT trained drivers were also found to anticipate a significantly greater proportion (60.5% vs 28.88%) of hazards as compared to their placebo trained peers, Wald $X_3^2 = 21.83$; $p = .001$. Also significant is the difference in the proportion of hazards anticipated by the V-RAPT group compared to the placebo-trained group (87.57% to 28.88%), Wald $X_3^2 = 19.21$; $p < .001$.

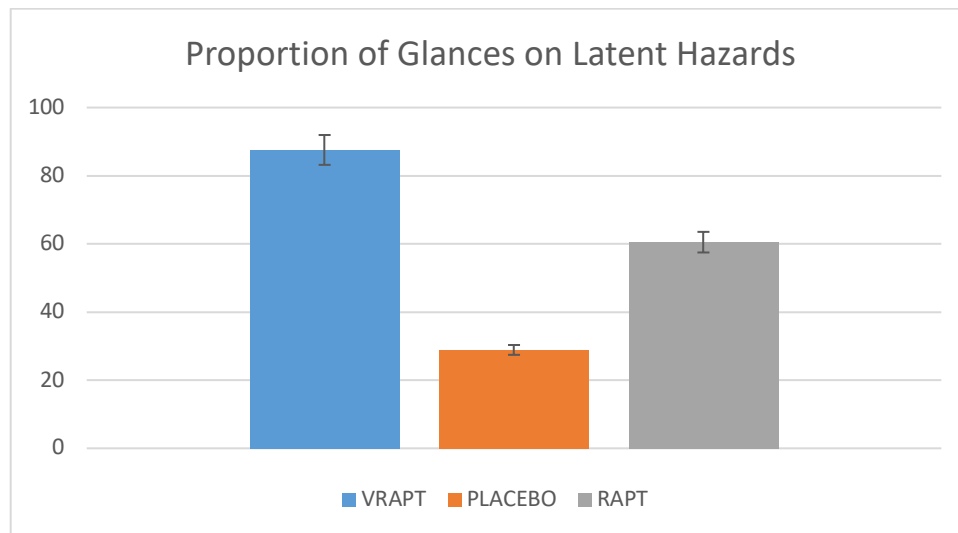


Figure 7 Overall Proportion of Latent Hazards Anticipation

As noted above, the near transfer scenarios are the six simulator evaluation scenarios that are similar conceptually to the training scenarios. A significant main effect of treatment was observed for near transfer scenarios, Wald $X_3^2 = 26.94$; $p < .001$. The difference in the percentage of hazards anticipated in near transfer scenarios between V-RAPT and RAPT trained drivers (91.67% vs 57.12% – a difference of 34.55 percentage points) was statistically significant, Wald $X_3^2 = 15.802$; $p < .003$. The RAPT trained drivers

anticipated a significantly higher proportion of hazards in the near transfer scenarios (57.12% vs 27.87%) as compared to their placebo trained peers Wald $X_3^2 = 76.472$; $p < .001$. The difference in the proportion of hazards anticipated by the V-RAPT-trained drivers in the near transfer scenarios compared to the placebo-trained drivers is a statistically significant, a difference of 63.8 percentage points, Wald $X_3^2 = 106.180$; $p < .001$.

Far transfer scenarios include the four simulator evaluation scenarios that were not closely related to the training scenarios. A significant main effect of treatment was also observed for far transfer scenarios using the same logistic regression model, Wald $X_3^2 = 26.341$; $p < .001$. The V-RAPT trained drivers anticipated a greater proportion of latent hazards across the four far transfer scenarios (82.50%) compared to the RAPT trained drivers (65.15%), Wald $X_3^2 = 10.244$; $p = .009$. Both, the RAPT (Wald $X_3^2 = 13.208$; $p < .005$) and V-RAPT-trained (Wald $X_3^2 = 74.691$; $p < .001$) drivers anticipated a significantly greater proportion of latent hazards across all four far transfer scenarios compared to their placebo trained peers (30.3%). The proportion of latent hazard anticipation across near and far transfer scenarios is evident in the Figure 8.

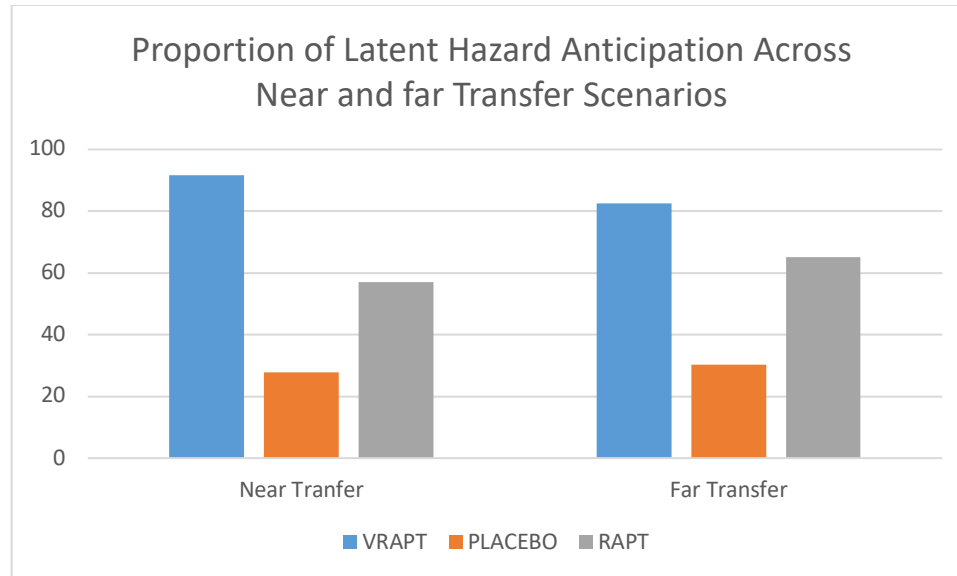


Figure 8 Overall Proportion of Latent Hazard Across Near and Far Transfer Scenarios

Vehicle Measures

Multiple vehicle measures were analyzed. Such as velocity, acceleration, lane offset and others. All the vehicle measures are collected when the driver is about to enter the launch zone or about 10 seconds prior to the potential hazard for all subjects across all scenarios.

The average velocity between a point about 100 feet prior to a latent hazard and a point 50 feet after the latent hazard was analyzed using an ANOVA with treatment (training) as a between-subjects factor. A main effect of treatment was revealed, $F(2, 316) = 9.94$, $\eta^2 = 0.99$, $p < .005$. The average velocity of the V-RAPT ($M = 32.42$, $SD = 7.39$) and placebo ($M = 37.69$, $SD = 4.82$) groups, $F(1, 210) = 20.60$, $\eta^2 = 0.994$, $p < .005$, did differ significantly, suggesting V-RAPT trained drivers' learn to mitigate hazards by driving slowly when approaching the hazard. However, the average velocity of V-RAPT and RAPT ($M = 34.18$, $SD = 6.49$) trained drivers did not differ significantly [$F(1, 209) = 2.075$, $\eta^2 = 0.951$, $p = 0.15113$], suggesting that the RAPT and V-RAPT trained drivers are

equally good at hazard mitigation. Finally, we looked at the average velocity of RAPT and placebo trained drivers and the differences were significant, $F(1, 213) = 8.299, \eta^2 = 0.988, p < .005$, suggesting RAPT trained drivers mitigate hazard significantly better compared to placebo trained drivers'. The proportion of average velocity is evident in the Figure 9:

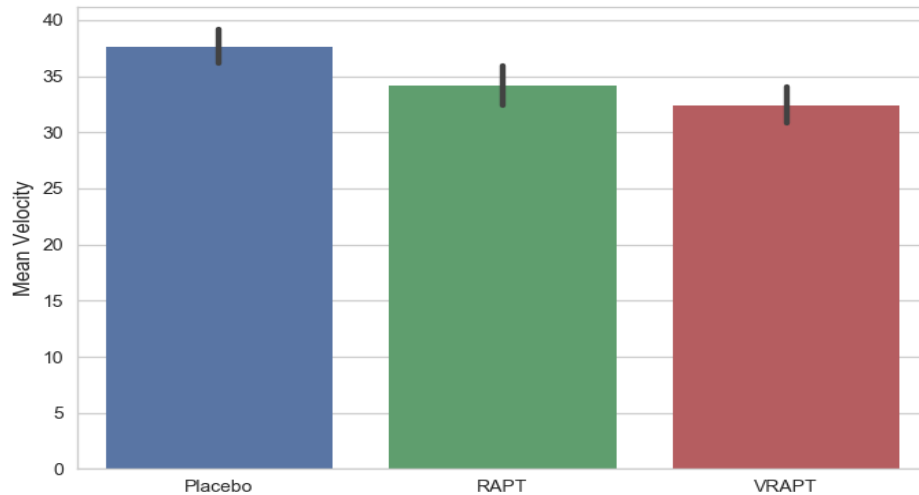


Figure 9 Average velocity of three experimental group

The standard deviation of velocity between a point 100 feet prior to a latent hazard and a point 50 feet after the latent hazard was analyzed with the same ANOVA model. Again, a main effect of treatment was revealed, $F(2, 316) = 9.22, \eta^2 = 0.979, p < .005$. The standard deviation of velocity of the V-RAPT ($M = 7.39, SD = 3.94$) and placebo ($M = 4.82, SD = 4.48$) groups, $F(1, 210) = 19.51, \eta^2 = 0.974, p < .005$, did differ significantly. Additionally, the standard deviation of velocity of the V-RAPT and RAPT ($M = 6.49, SD = 4.78$) trained drivers did not differ significantly [$F(1, 209) = 2.18, \eta^2 = 0.678, p = 0.140$], suggesting the RAPT and V-RAPT trained drivers are no different at mitigating hazards in terms of their modulation of velocity in the vicinity of the latent threat. Finally, we looked at the standard deviation of velocity of the RAPT and placebo trained drivers and the

differences were significant, $F(1, 213) = 6.98$, $\eta^2 = 0.921$, $p < .005$, suggesting RAPT trained drivers mitigate hazards significantly better than placebo trained drivers. The SD of velocity is shown in Figure 10:

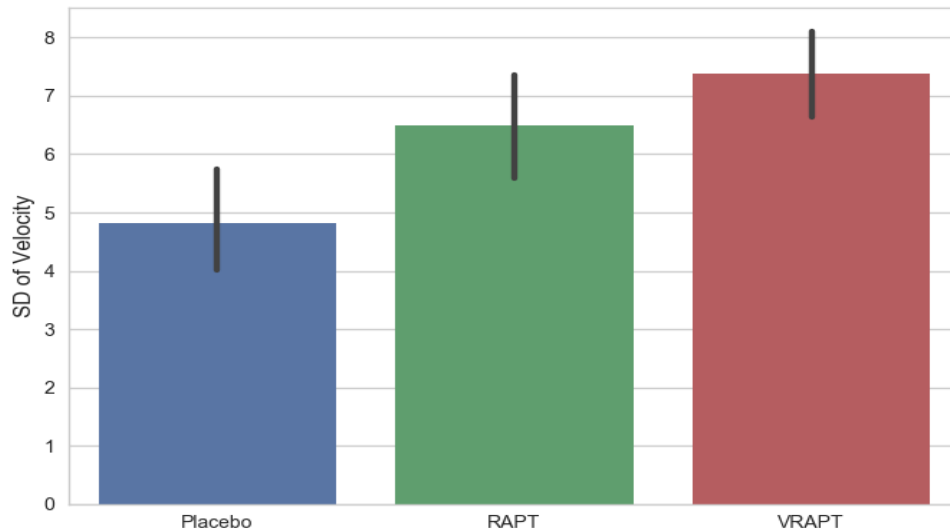


Figure 10 SD of velocity for three experimental group

Finally, the average absolute acceleration between a point 100 feet prior to a latent hazard and a point 50 feet after the latent hazard was analyzed with the same ANOVA model with treatment as a between-subjects factor. Again, a main effect of treatment was revealed, $F(2, 316) = 10.58$, $\eta^2 = 0.987$, $p < .005$. The average absolute acceleration of the V-RAPT ($M = 0.64$, $SD = 0.53$) and the placebo ($M = 0.42$, $SD = 0.35$) groups, $F(1, 210) = 22.71$, $\eta^2 = 0.973$, $p < .005$, differed significantly. Additionally, the average absolute acceleration of the V-RAPT and RAPT ($M = 0.54$, $SD = 0.46$) trained drivers differed significantly ($F(1, 209) = 4.323$, $\eta^2 = 0.727$, $p = 0.038$). Finally, the average absolute accelerations of the RAPT and placebo trained drivers were significantly different $F(1, 213) = 6.003$, $\eta^2 = 0.946$, $p < .015$. The absolute average acceleration is evident in Figure 11

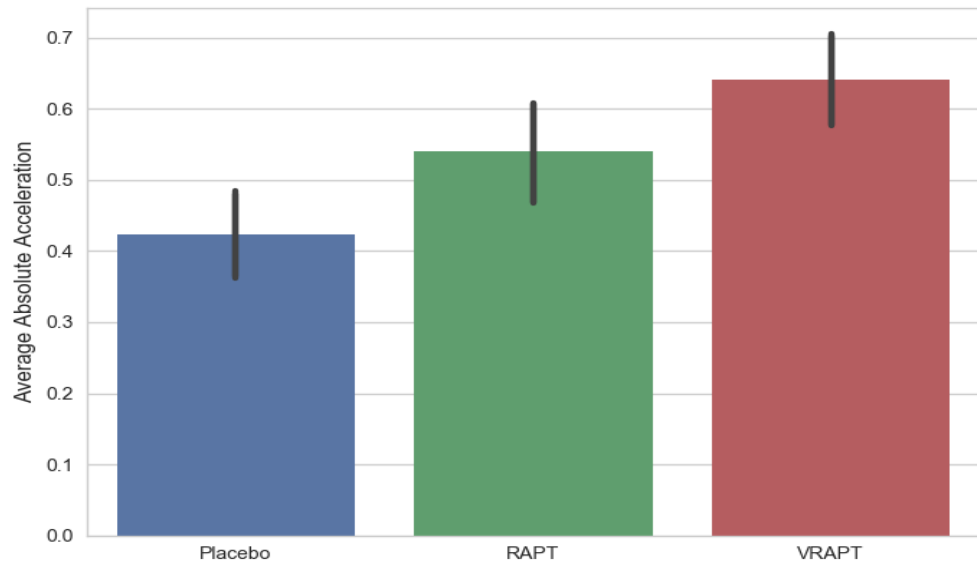


Figure 11 Average Absolute Acceleration across all three experimental group

CHAPTER 9

DISCUSSION

The current experiment investigates the effectiveness of the newly developed, virtual reality, headset-based hazard anticipation and hazard mitigation training program (V-RAPT) for young drivers. Previous studies have shown that the young driver fails to scan adequately for latent hazards [Pradhan et al., 2003]. And it has been shown that young drivers can be trained to double the likelihood that they scan for latent hazards, reducing the gap between untrained novice drivers and experienced drivers by half in just an hour of training [Taylor et al., 2011]. However, this still left lots of room for improvement. It was with this in mind that V-RAPT was developed, in theory enhancing the mentoring that is delivered and thereby the value of training. Consistent with the first hypothesis, drivers that received V-RAPT anticipated a significantly greater proportion of latent hazards compared to the placebo trained driver and the RAPT trained drivers. In particular, V-RAPT almost tripled the performance of the untrained novice drivers, considerably higher than is typically observed in the evaluation of similar hazard anticipation training programs delivered on other platforms [Pradhan et al., 2003; Taylor et al., 2011; Zafian et al., 2016]. Further, the results demonstrate that participants trained on V-RAPT anticipate a greater proportion of latent hazards both on scenarios which are similar (near transfer) to those trained upon, and on scenarios dissimilar (far-transfer) from those trained upon. Transferability is an important characteristic to assess the effectiveness of the training since ultimately, there are only a finite number of situations that can be trained upon and evaluated for in a controlled manner. The proportion of latent hazards anticipated by the RAPT-trained drivers was 60.50% and was in line with that shown by previous studies [Crundall & Pradhan., 2016; Lengenfelder et al., 2002; Fisher et al., 2017;].

To examine the second hypothesis, three related measures of driver vehicle behaviors were analyzed. All were consistent with the superiority of V-RAPT to no training. Surprisingly, the improvement in the hazard mitigation behavior of the V-RAPT trained drivers did not differ from that of the RAPT trained drivers when either speed or the standard deviation of speed was used as the dependent variable, but did differ when the absolute acceleration was used as the dependent variable. Three points are worth discussing. First, although the differences between the V-RAPT and RAPT groups when the dependent measures were speed and the standard deviation of speed were not statistically significant, the direction of the differences was as predicted.

Second, no previous studies had evaluated the effect of hazard anticipation training alone on hazard mitigation behaviors. Thus, the fact that participants were able to learn both information about how better to anticipate hazards and mitigate those hazards (V-RAPT) in the same time as they were able to learn only about hazard anticipation (RAPT) indicates that V-RAPT does not increase hazard anticipation skills at the expense of hazard mitigation skills.

Third, the finding that the absolute acceleration differentiates the V-RAPT trained drivers from the RAPT trained and placebo trained drivers is worth a brief comment, even if it is only speculative at this point. Drivers who slow less will have a smaller standard deviation of velocity. This would explain why the RAPT drivers have a smaller standard deviation of velocity than the V-RAPT trained drivers. Moreover, if the drivers who are in the V-RAPT condition slow gradually whereas the drivers who are in the RAPT conditions slow precipitously in the presence of the latent threat, then the absolute acceleration will be larger for drivers in the V-RAPT condition than for drivers in the RAPT condition.

There are important limitations associated with the training program. First, the V-RAPT training program currently lacks a user interface which is entirely automated. The interface as it is now configured requires an instructor always to be present. Having said this, although the instructor needs to start and stop the scenarios, the training instructions provided during the scenarios are incorporated into the virtual scenarios, in the form of computer-readable audio files. Second, the current evaluation examines the effectiveness of training for young drivers 18-25 years old. But it is young drivers in their teens who are most risk. Third, the number of scenarios used in training and in the near and far evaluation of the effectiveness are relatively small in number and not necessarily representative of the types of crashes in which young drivers are over represented. Fourth, the number of teens is small and certainly not representative of the entire population of drivers. Fifth, there was no assessment of the long-term retention of the training. And sixth, there was no assessment in the field of the effect of training on hazard anticipation and hazard mitigation training or of the effect on crashes.

In summary, this study shows that a virtual reality, headset based hazard anticipation and hazard mitigation training program can lead to potentially much larger improvements in these behaviors than training programs delivered on other platforms drivers [Crundall & Pradhan., 2016; Willis., 1998; Anguera et al., 2013; Rizzo et al., 2000]. Additionally, it is important to comment on simulator sickness since this could be a barrier to adoption of programs like V-RAPT. Typically, the reported simulator sickness rates in virtual reality, headset-based interventions are very high. But, in this experiment, only a single V-RAPT trained participant dropped out due to simulator sickness. There may be several reasons for the observation of low simulator sickness rates including the use of optimized micro-scenarios (scenarios which occurred over seconds instead of minutes or

hours), and the provision of short 30 second breaks between each scenario, or if required, between the different modules of the scenario, a proven method for reducing simulator sickness [Schneider et al., 2016]. Another reason for the low simulator sickness rates of the V-RAPT group could be the specific instructions provided to participants to not make sudden and jerking head movements during the training simulation.

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