Virtual Reality Headset Training: Can It be Used to Improve Young Drivers' Latent Hazard Anticipation and Mitigation Skills

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ABSTRACT

Young drivers are overrepresented in motor-vehicle crashes compared to experienced drivers. Research shows that the young drivers are generally clueless, not careless, failing to anticipate and mitigate latent hazards. There are several error-feedback training interventions that emphasize the teaching of latent hazard anticipation skills (e.g., RAPT) and a few that emphasize both the teaching of hazard anticipation and hazard mitigation skills (e.g., ACCEL). In the current study, a virtual reality, headset-based latent hazard anticipation and mitigation training program (V-RAPT) was developed on a head-mounted display (Oculus Rift). The headset provides the participant with 100-degree wide field of view of six high-risk driving scenarios, the view changing appropriately as the participant rotates his or her head. Thirty-six young drivers were exposed to one of three training programs – V-RAPT, RAPT and placebo – and then evaluated on a driving simulator. Eye movement and vehicle data were collected throughout the simulator evaluation. The drives included the six scenarios used in training and four other scenarios dissimilar to the ones used in training, but previously validated as measures of hazard anticipation. The drivers trained on V-RAPT were found to anticipate a significantly greater proportion (86.25%) of latent hazards than the RAPT (62.36%) and placebo (30.97%) trained drivers. The V-RAPT trained drivers were also found to be better at mitigating potential threats. The virtual reality, headset-based training program holds out the promise of improving the drivers' ability to anticipate and mitigate latent threats and thereby reduce crashes.

Keywords: Driver Training, Virtual Reality, Eye Movement, Latent Hazard Anticipation Driving Simulation, Young Drivers

1. INTRODUCTION

Young drivers are at a greater risk of being involved in crashes than any other age group of drivers [1]. The National Highway Traffic Safety Administration states that the younger drivers' lack of experience, increased willingness to take risks, and greater immaturity are the primary reasons for this over-involvement in crashes [2]. McKnight and McKnight reviewed over 1000 crashes and identified inexperience as a major contributor towards crashes among young drivers [3] Specifically, failures to scan for the hazard ahead, to the front, the side and the rear contributed to nearly 42.7 percent of the crashes in which young drivers are involved.

Previous driving simulator based studies examining young drivers' hazard anticipation skills also suggest inexperience as a major factor, where younger drivers fail to recognize both hazards that are visible and materialize as a threat at the very last second and hazards that are not visible, but are likely to materialize [4]. The latter are typically referred to as latent threats. Latent threat hazard anticipation may be best explained by an example scenario [5, 6]. Imagine a two-lane roadway (one travel lane in either direction) with a truck that is stopped on the right side in a parking lane in front of a marked mid-block crosswalk. A driver is approaching the crosswalk. The truck is blocking the driver's view of a potential pedestrian in the crosswalk. Therefore, to safely navigate, the driver should scan towards the right front edge of the truck to identify the presence of any potential pedestrians. The results from a simulator study by Pradhan et al. demonstrate that experienced drivers (57.6%) were more likely to scan towards the right front edge than were younger drivers (28.6%) [6]. The experienced drivers were also better at mitigating hazards as they were more likely to steer further towards the left as they passed in front of truck [5].

Various training programs have been developed in recent years to improve young drivers' latent hazard anticipation ability and many of these programs have been shown to be effective through driving simulator studies and on-road evaluations [7, 8, 9, 10, 11, 12, 13, 14]. RAPT (Risk Awareness & Perception Training) was one of the first driver training programs developed to address novice drivers' failure to appropriately scan and detect latent threats present/emerging on the forward roadway. The initial version of the training program was developed on a PowerPoint platform, delivered on a PC, and evaluated on a driving simulator. Subsequent versions of RAPT have been developed on advanced platforms such as smartphones, tablets, and driving simulators. Driving simulator and on road assessments of the RAPT training program (and all its subsequent versions: RAPT3 [15], Distractology 101 [16], SuperRAPT [17], CalRAPT [18]), SimRAPT [19] have shown that not only can RAPT increase hazard anticipation skills as measured on a driving simulator and in the field [5, 6, 9, 10, 20], but it is the first program in some 50 years to show an actual reduction in crashes. The reduction in crashes in both studies [17, 19] was about 20%.

Training programs have also been designed to address both latent hazard anticipation and its subsequent mitigation [21, 22]. Hazard anticipation is a necessary precursor of hazard mitigation and so it is always taught along with hazard mitigation (though the converse is not necessarily true). Referring back to the scenario described above where the driver's view of the pedestrian entering the crosswalk is obstructed by a parked truck, a driver should slow when passing the parked vehicle and move slightly to the right. Evaluations of training programs targeting hazard anticipation and hazard mitigation have shown clear benefits, improving both skills when the effects are evaluated on a driving simulator [e.g., Driver ZED, 5; ACCEL, 23]. No training programs targeting both hazard anticipation and hazard mitigation have been evaluated in the field yet, using either vehicle behaviors or actual crashes as the dependent measures.

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.

In order to understand what might be done additionally with hazard anticipation training, one needs to understand the current training methods. We will focus here on training programs that utilize what is called error training in some contexts [24, 25] or 3M training in other contexts [5, 6]. Specifically, 3M training includes three critical modules: a mistake, a mentoring and a mastery module. In the mistake module, participants are presented with the opportunity to make a mistake (where a mistake is a failure to anticipate a latent threat). In the mentoring module, an explanation is provided of why a potential threat is not visible and what the participant should do in terms of glancing behaviors. In the mastery module, participants are provided with the opportunity to master the correct behaviors which were explained in the mentoring module. This training approach (error training or 3M training) has been successfully validated in several previous training studies [9, 10, 11, 12, 20, 25].

The question we asked is how could one enhance the hazard anticipation training and still maintain the same level of hazard mitigation training as other programs have achieved. Assuming that one could record an individual participant's trip through a virtual world from the participant's perspective, including the participant's eye glances (or head movements), and speed, one has all of the data one needs to identify the effects of hazard anticipation and hazard mitigation training. Additionally, assuming one can play back an individual's trip through the virtual world in real time, one can then enhance the mentoring module described above. In particular, the participant could see where he or she did not look and, as the latent threat was passed, reveal to the participant the threat which was hidden and did not materialize. This means that the errors become truly salient events and can motivate further learning (26). None of the current training programs provide this level of salience. Usually, the reason for the error is explained during the mentoring module. But, the participant is not taken back through a drive, shown where he or she made an error, and also shown the latent threat which could possibly have materialized.

The above enhancement to 3M training could be made in any virtual reality environment. But we wanted to do it in an environment that was immersive, could be potentially broadly disseminated, and had a proven track record. Virtual reality headsets (VRHs) represent a new technology with just this possibility. They have been successfully utilized as a training platform in other domains [27, 28, 29, 30, 31]. They are relatively inexpensive compared to even the least expensive of driving simulators by almost at least two orders of magnitude. They can be widely disseminated. They can be used to create immersive worlds through which a participant can travel and in which the participant's head movements (hazard anticipation) and speed (hazard mitigation) can be recorded. Moreover, a participant's actual trip through the virtual world can easily be recorded and replayed. With this in mind it was decided to explore the use of virtual reality headsets as a training tool for hazard anticipation and hazard mitigation.

2. METHOD

Thirty-six young drivers were randomly and equivalently assigned to one of three training conditions (twelve in each group). One group of young drivers was trained on the VRH-based Risk Awareness and Perception Training program (V-RAPT), a second group of young drivers was trained using the PC-based Risk Awareness and Perception Training Program (RAPT) and the last group received a PC-based placebo training program. The scenarios used to train hazard anticipation in V-RAPT and RAPT were conceptually identical to one another (i.e., the latent hazards were the same). The critical difference was the medium used to deliver the training (one a VRH through which the participant could navigate in real time, one a single screen of a PC with a static display). Following the training, all the participants were immediately evaluated on a driving simulator to identify the effectiveness of the training program using eye movements and speed as the dependent variables. Some of the hazard anticipation scenarios evaluated on the driving simulator were similar to those trained in V-RAPT and RAPT (referred to as *near transfer* scenarios); others of the hazard anticipation scenarios were quite dissimilar (referred to as *far transfer* scenarios).

2.1 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.

2.2 Apparatus

The current experiment utilized a three screen, full cab, fixed-base driving simulator, (Realtime Technologies Inc), a head mounted, eye tracker (Applied Science Technologies Mobile Eye) and a virtual reality headset (an Oculus Rift). The simulator and eye tracker have been described in other publications [17]. The Oculus Rift is used in this study to deliver the V-RAPT training comes with a virtual reality headset, motion sensor, Oculus remote, and an Xbox One wireless controller. The Rift has a rich OLED screen with 1080 x1200 resolution per eye and a refresh rate of 90 Hz. The Rift screen provides 100 degrees field of view relative to the head (a full 360 is available as the head rotates) and the integrated headphones in the Rift provide a 3D audio effect. The motion sensing platform performs rotational and positional tracking using a USB stationary infrared sensor. With the use of the sensor, the Oculus Rift creates a virtual 3D space where the user can sit, move or walk around.

2.3 Training

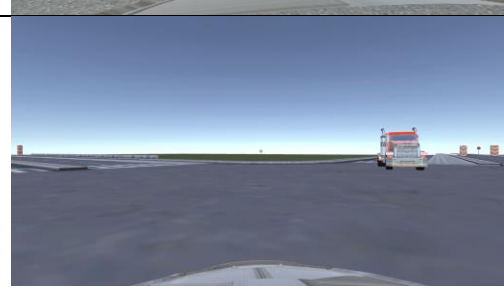
The three training programs, V-RAPT, RAPT and placebo, are described in more detail below.

2.3.1 V-RAPT

The V-RAPT training program contains computer generated videos displayed from the driver's eyepoint of six hazard anticipation scenarios that were used in RAPT (which had static, top-down views). The training program, described above, utilizes the enhanced 3M approach that is error and feedback driven [5, 6]. The scenarios are descried first and then a more detailed description is given of each of the three modules.

V-RAPT Scenarios. As noted above, a total of six scenarios were developed for V-RAPT. They are displayed below in Table 1. Descriptions are given of each scenario, the latent threat, and what the driver should do.

Table 1. List of virtual reality headset scenarios with perspective views.

Scenario	Scenario Description	Perspective Scenario Views
Scenario 1: Curve + T Intersection	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.	
Scenario 2: Mid-block crosswalk + pedestrian	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.	
Scenario 3*:* midblock cross walk	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.	
Scenario 4: Left turn at 4-way stop controlled intersection + vehicle in opposing left turn lane	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.	

Scenario 5: Signal controlled intersection + line of vehicles	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 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.	
Scenario 6*:* Road entering from the left side	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.	

V-RAPT Training. As noted above, V-RAPT has three different modular phases for each of the six scenarios chosen for training. The first module is the mistake module. In this module, the participants navigate through each of the virtual scenarios using the Oculus Rift. Their drive in the first section is recorded for subsequent reference in the other modules. The participants can control the speed of the vehicle, but not the location.

In the second module, the participant is first trained about the latent hazard, training which is specific to each scenario. The instructions given in the training section for each of the six scenarios are provided in the *Table 2*. These instructions are given while a video (not the participants) is played in real time from the driver's perspective of the scenario. The instructions include information about the feature of the environment which suggests that a latent threat appears ("approaching launch area", i.e., the area where the driver should "launch" an eye movement or head turn), information about where the driver should look and what the driver should do in the immediate vicinity of the launch area, and information about the driver should do after exiting the launch area. Immediately after receiving information about the potential threat, the participants is shown the recorded video from the first module. If the participant correctly scanned for the latent hazard, he or was 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 was provided. Modules 2 and 3 combine to provide mediation to the user. The fourth module is a mastery section, where the participant again navigated the driving scenario in the Oculus Rift. While navigating, if the participant made the correct anticipatory glances at the target zone, the participant was assigned the next training scenario, and if participant fails to make the correct anticipatory glance then the participant was retrained on the same scenario. There is a total of 6 training scenarios administered in a modular manner. The scenario was counterbalanced across subject and the four modules will be delivered for each scenario individually.

Table 2 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 towards this vehicle for any possible sudden moves.	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.

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.

2.3.2 Risk Awareness and Perception Training

RAPT was developed and tested at the University of Massachusetts Amherst and was used to study the effect of providing risk perception training to novice drivers. It is a PC-based program using static views that has been described in detail elsewhere [32].

2.3.3 Placebo Training

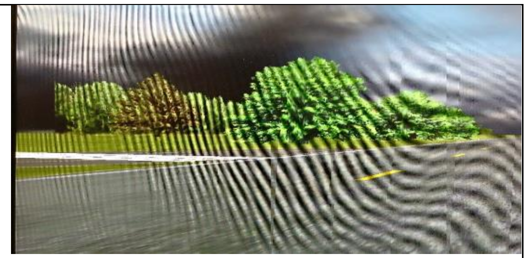
The placebo training program is also a PC-based training program and is designed and presented in a modular manner like the other training programs. In this program, the driver navigates through the virtual drives on the PC. However, unlike in the V-RAPT and RAPT training, placebo trained drivers receive no feedback on their performance and no instruction on how to anticipate and mitigate the latent hazard and become a safer driver. Further, the placebo training also presents information on how to gauge tire pressure. On average, the program takes 30 minutes to complete.

2.4 Simulator Evaluation Scenarios

Following training, to evaluate the effectiveness of the training programs, the participants were asked to navigate ten scenarios, (six near transfer scenarios, N1-N6, and four far transfer scenarios, F1-F4) each of which lasted approximately two minutes in duration. All ten scenarios contained a single latent hazard. The scenarios are briefly described along with their perspective views for illustration in *TABLE 3*. The descriptions of the first six simulator scenarios are identical to those of the first six training scenarios, though the virtual worlds are quite different in detail (compare the perspective views). The descriptions are included a second time to make it easier for the reader to map the training to the simulator scenarios.

TABLE 3 List of simulator scenarios with perspective views.

Scenario Name	**Scenario Description**	**Perspective Scenario Views**
N1 (Training Scenario1)	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 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.	

N6 (Training Scenario 6)	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.	
F1	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.	
F2	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.	
F3	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.	
F4	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.	

2.5 Experimental Design

The experiment utilizes a between-subject design. The participant is either trained in the virtual reality headset-based hazard anticipation and mitigation training program (V-RAPT), the PC-based hazard anticipation (RAPT) training program, or PC-based placebo training program. After being administered the appropriate training program, all the participants navigated ten scenarios (six near transfer and four far transfer) on the driving simulator. The ordering of the ten simulator scenarios was completely counterbalanced across participants using a Latin square [32, 33].

2.6 Procedure

Participants first completed an informed consent form to provide written consent to participate in this study. Then, they were randomly assigned to one of three training programs. After the completion of the training program, participants were fitted with an eye tracker, had their eyes calibrated, and were provided with a practice drive in the simulator to get them acclimated to the controls of the simulator cab and the simulator environment. Following this, all participants navigated 10 virtual scenarios on the simulator. They also completed a single post study questionnaire and a stipend voucher. The entire study session ranged in duration from an hour to an hour and a half, depending on the training group that the participants were assigned to.

2.7 Dependent variables

Two dependent variables were measured, one indexing hazard anticipation and one indexing hazard mitigation. First, the dependent variable indexing latent hazard anticipation for each scenario was whether the driver glances towards the potential hazard. A driver's latent hazard detection performance for each scenario is scored as either a 0 (miss) if he or she fails to glance towards the target zone in the launch zone, or a 1 (hit) if he or she successfully glance towards the target zone whilst in the launch zone. The launch zone and target zone used in this experiment were previously utilized and validated in other experiments for the evaluation of latent hazard anticipation [34].

A drivers' hazard mitigation behavior was captured starting about 100 feet prior to a latent hazard and ending 50 feet after the latent hazard by examining average velocity, the standard deviation of velocity, and average absolute acceleration. The average absolute acceleration is defined as the average of the absolute value of the acceleration at each point that was measured 100 feet prior to the latent hazard and 50 feet after the latent hazard. Previous work has shown that these measures are predictive of crashes and/or the severity of crashes [35, 36].

2.8 Hypotheses

There are two main hypotheses in this study. The first hypothesis is motivated by the enhancements to the 3M training discussed above. The second hypothesis follows from the fact that V-RAPT does train hazard mitigation in addition to hazard anticipation, while RAPT focuses only on hazard anticipation training.

- **H1**: 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.
- **H2:** 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.

3. RESULTS

Below, we present first the results on hazard anticipation and next the results on hazard mitigation.

3.1 Hazard Anticipation Results

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 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 $X_3{}^2 = 19.21$; $p < .001$.

The same statistical model was used to observe separate hazard anticipation effects for the 6 near and 4 far transfer scenarios.

3.1.1 Near-transfer scenarios

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 $X_3{}^2 = 106.180$; $p < .001$.

3.1.2 Far-transfer scenarios

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%).

3.2 Hazard Mitigation Results

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, η^2 =

0.988, $p < .005$, suggesting RAPT trained drivers mitigate hazard significantly better compared to placebo trained drivers'.

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.

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, $\eta^2 = 0.946$, $p < .015$.

4. 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 [6]. 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 [9]. 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 [6, 9, 12]. 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 [4, 22, 29].

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 [4, 20, 27, 28]. 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 [37]. 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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