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Article

Evaluation of the Effectiveness of a Gaze-Based Training Intervention on Latent Hazard Anticipation Skills for Young Drivers: A Driving Simulator Study

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Abstract: A PC-based training program (Road Awareness and Perception Training or RAPT; Pradhan et al., 2009), proven effective for improving young novice drivers' hazard anticipation skills, did not fully maximize the hazard anticipation performance of young drivers despite the use of similar anticipation scenarios in both, the training and the evaluation drives. The current driving simulator experiment examined the additive effects of expert eye movement videos following RAPT training on young drivers' hazard anticipation performance compared to video-only and RAPT-only conditions. The study employed a between-subject design in which 36 young participants (aged 18–21) were equally and randomly assigned to one of three experimental conditions, were outfitted with an eye tracker and drove four unique scenarios on a driving simulator to evaluate the effect of treatment on their anticipation skills. The results indicate that the young participants that viewed the videos of expert eye movements following the completion of RAPT showed significant improvements in their hazard anticipation ability (85%) on the subsequent experimental evaluation drives compared to those young drivers who were only exposed to either the RAPT training (61%) or the Video (43%). The results further imply that videos of expert eye movements shown immediately after RAPT training may improve the drivers' anticipation skills by helping them map and integrate the spatial and tactical knowledge gained in a training program within dynamic driving environments involving latent hazards.

Keywords: hazard anticipation; training; driving simulation; eye movement; young driver

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1. Introduction

The number of deaths per 100 million miles in the United states has declined to roughly one third in 2015 compared to 1980 among drivers overall [1]. Drivers younger than 24 years are yet overrepresented in fatal crashes: more than 33% of fatal vehicular crashes were caused by young drivers [1], highlighting further need for research to reduce the number of crash-related deaths among young drivers. Various factors have been identified to influence young drivers' driving behavior including experience, distraction, gender and cognition [2]. Research indicates that the elevated risk of crashes among young drivers can be largely attributed to their cognitive factors such as attention and decision making [3,4]. For example, McKnight and McKnight [3] analyzed 1000 crashes involving young novice drivers and found that attentional and visual search failures contribute to more than 65% of their vehicular crashes. Moreover, other contributors such as adjusting speed (20.8%) and maintaining space (9.8%) that require active scanning of the driving scenes further underscore the criticality of appropriate scanning for young driver safety [5].

Previous research using a driving simulator developed and evaluated training programs for improving young drivers' hazard anticipation skill [6,7]. Hazard anticipation is defined as the ability to scan the visual areas of the roadway that contain a latent hazard, a hazard that has not yet fully materialized while driving (e.g., a pedestrian attempting to cross the street occluded by a truck). Young, novice drivers anticipate latent hazards far less often than experienced drivers—a difference of nearly 37 percentage points [6]. Pradhan and colleagues [6] then developed a computer-based program, Road Awareness and Perception Training (RAPT) [8], which aimed to increase the anticipatory glances toward latent hazards through an error-based training feedback approach [9]. RAPT allows trainees to make errors (Mistake), correct their behavior (Mitigate) and learn the correct behavior (Mastery), or 3M approach as previously defined in the driver training literature (e.g., [6,10]). A subsequent on-road evaluation showed that the RAPT-trained drivers anticipated the hazard more accurately than the Placebo-trained drivers (M = 64% vs. 37%). A recent large-scale evaluation study of RAPT compared the number of crashes between roughly 2500 RAPT- and 2500 Placebo-trained drivers and showed its effectiveness on reducing the number of crashes for male but not for female young drivers [11]. This gender-specific effectiveness of RAPT might have arisen from a male advantage on visual-spatial working memory, a measurable and significant effect found in a recent meta-analysis [12]. RAPT demands visuospatial working memory of trainees because trainees must remember and understand various spatial locations of potential hazards in driving scenery. Trainees of RAPT learn latent hazards on a map in a top-down, exocentric view but are evaluated in a driving simulator from a driver perspective, egocentric view of the driving scene, which requires transformation of visuospatial information regarding the location of the learned latent hazards. Strikingly, Voyer and colleagues' data suggest that the gender difference in visual-spatial working memory begins to arise between 13 and 17 years of age. This age group displayed the largest effect size compared to other age groups, implicating gender as a factor that moderates the effect of RAPT on road crashes, especially for young drivers.

One of the outstanding issues in this line of research is, what can be done to further improve young drivers' latent hazard anticipation following RAPT training? Pradhan and colleagues [6] reported that, for example, RAPT produced a 27 percentage points increase in hazard anticipation. Yet, the RAPT-trained drivers correctly glanced toward the critical areas only 64% of the time even though the evaluation scenarios closely mimicked the training scenarios. One reason for the below-ceiling training effects may be that the drivers may have failed to effectively *map* the knowledge and their mental models gained from the static scene perception in RAPT to a dynamic road environment. Following RAPT that provides a top-down, or exocentric, view, of each hazardous driving scenario, a driver presumably needs to transform the geometrical information of the latent hazard to a perspective, or geocentric, view in order to correctly anticipate the hazard while driving. Providing both egocentric and exocentric spatial representations of the driving scenarios may further facilitate their learning from RAPT.

Previous research examined the utility of video clips of driving scenes to train drivers' visual scanning. Chapman and colleagues [13], for example, used video clips of dynamic, potentially hazardous driving environments to improve young drivers' hazard anticipation skills (or hazard perception; [14]). In the study, drivers viewed five video clips of potentially hazardous scenarios played at half speed and verbally described what they were looking at and what they thought was potentially hazardous during the training session. Then, the drivers viewed the same videos again at full speed and drivers' eye movements were measured with the expectation that trained drivers exhibit a broader distribution of fixation locations than untrained drivers [5,15]. The results of the on-road evaluation of the program indicate that the video-based training program decreased the fixation durations, reflecting more effective hazard perception. Simultaneously, horizontal variance in fixation locations increased, reflecting a broader distribution of visual attention in driving scenes. Such increased extent of visual search for trained drivers may reflect development of mental models of surrounding driving environments [16].

Researchers in other applied domains including radiology and aviation [17,18] and collaborative visual search [19,20] have also demonstrated that another person's eye movements can improve detection of a target item in complex visual displays. For example, Litchfield and colleagues [17] asked participants to perform a visual search task in which they judged the presence of nodules of different size, shape and conspicuity on normal or abnormal chest X-ray images. Results suggest that knowledge of the locations where another person searched for pulmonary nodules improves visual performance in the nodule detection task, implying that viewing another person's eye movement patterns can influence an observer's distribution of visual attention.

In the current context, video clips of dynamic driving environments with expert eye movements may serve as an important addition to the toolbox for training young novice drivers [21]. As an example, Mackenzie and Harris [22] reported that a 10-min exposure to video clips of driving scenes with expert eye movements increased horizontal scanning and saccade lengths, resulting in a pattern of eye movements similar to that expected for experienced drivers [16]. Therefore, the current study aims to augment the effectiveness of RAPT by providing trainees with a 10-min video clip of expert eye movements in dynamic driving scenes immediately after they complete RAPT (RAPT-V condition) where participants are taught scene perception in a static environment. We hypothesize that (1) a 10-min video clip of dynamic driving environments with expert eye movements further increases the proportion of correct anticipatory glances among young drivers (RAPT-V vs. RAPT conditions) and (2) this effect arises only when trainees view the video after they completed RAPT training (RAPT-V vs. Video conditions). Furthermore, following the gender effect on the effectiveness of RAPT (cf. [11]), we hypothesize (3) the effect of Video becomes larger for the female than the male drivers. To further explore the extent to which the training programs affect drivers' eye movements and their ability to control the vehicle, we examine mean fixation duration, number of fixations, variability in fixation locations and mean travel speed across the three training conditions.

2. Results

Proportion accuracy and mean travel speed were computed for each participant for each of the four anticipation scenarios and analyzed. We employed default Bayesian tests [23] instead of null-hypothesis significance tests (NHSTs). Bayes factors are the measure of evidence for an effect of interest, reported as B_{10} [23]. Bayes factors are ratios of likelihood of the obtained data favoring a model including an effect of interest to that excluding the effect. Bayes factors below 3 mean only "anecdotal" evidence for an effect, indicating that data are indifferent between the two competing models while those greater than 3 indicate that data have strong evidence for the presence of the effect and greater values of Bayes factors indicate greater evidence for the effect. Terminologies for describing the magnitude of each effect come from Jeffreys [24].

2.1. Eye Movements

Data were submitted to a 3 × 2 Bayesian analysis with Training (RAPT, Video, RAPT-V) and Gender (Male vs. Female) as the between-participant factors, separately for hazard anticipation, mean fixation duration, number of fixations and variance of horizontal and vertical fixation locations.

2.1.1. Hazard Anticipation

Figure 1 illustrates the mean proportion of correct anticipatory glances for the three groups. The proportions of correct anticipatory glances decisively differed across the three training groups [F (2, 30) = 14.85, η^2 = 0.43, B_{10} = 2.59×10^2]. The effect of Training was mainly driven by the RAPT-V condition producing proportions greater than the other two conditions. Specifically, the RAPT-V condition improved hazard anticipation performance decisively when compared to the Video condition [M = 0.85 vs. 0.43, *independent-samples* t (22) = 4.91, B_{10} = 2.95×10^2] and substantially when compared to the RAPT condition [M = 0.85 vs. 0.61, *independent-samples* t (22) = 2.88, B_{10} = 5.78]. The proportions between the Video and RAPT conditions did not differ substantially [M = 0.61 vs. 0.43, *independent-samples t* (22) = 1.97, B_{10} = 1.45]. The main effect of Gender and the interaction effect were both not substantial [Gender, *F* (1, 30) = 3.71, η^2 = 0.05, B_{10} = 1.51; Interaction, *F* (2, 30) = 2.37, η^2 = 0.07, B_{10} = 1.97].

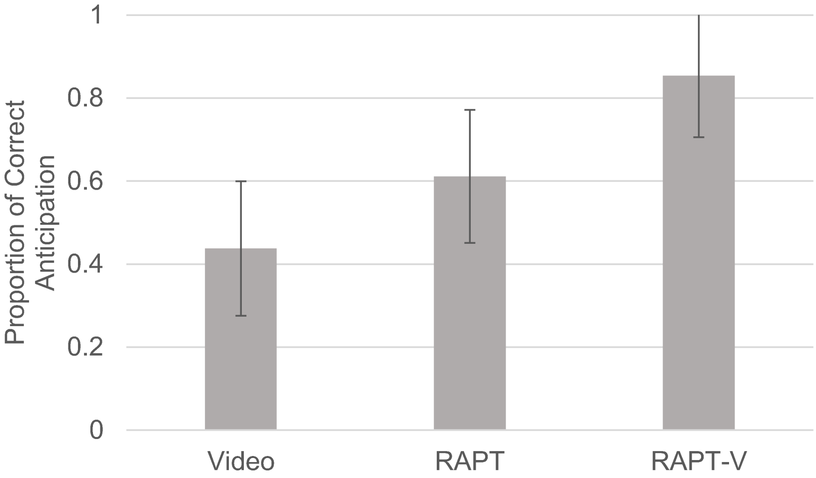


Figure 1. Mean proportion of correct anticipation performance across the training conditions (Video, RAPT and RAPT-V conditions). Error bars represent between-participant 95% confidence intervals.

2.1.2. Mean Fixation Duration

The data indicated evidence substantially against the effects of Condition and Gender [both *Fs* < 1; Condition, B_{10} = 1/3.58; Gender, B_{10} = 1/3.69] and strongly against the interaction effect [*F* < 1, B_{10} = 1/10.30].

2.1.3. Number of Fixations

The participants in the RAPT-V condition numerically made a greater number of fixations during the drive than those in the other two conditions [M = 1375, 1232, vs. 1038, for RAPT-V, RAPT and Video conditions respectively] but the data gave anecdotal evidence trending the null [*F* (2, 30) = 1.65, η^2 = 0.09, B_{10} = 1/2.28].

The data favored the statistical model excluding the effect of Gender [*F* < 1, B_{10} = 1/3.75] and the interaction effect [*F* < 1, B_{10} = 1/35.71].

2.1.4. Variance of Horizontal and Vertical Fixation Locations

The data indicated substantial evidence against all the effects [*Fs* < 1, 1/7.51 < B_{10} < 1/3.05].

2.2. Vehicle Control Behavior

Mean Travel Speed

Data were submitted to a mixed Bayesian analysis with Timing (Pre- vs. Post-hazard) as a within-participant factor and Training (Video, RAPT, vs. RAPT-V) as a between-participant factor for each scenario separately.

Residential: Mean velocity was decisively less in Pre-hazard than Post-hazard periods [M = 5.20 vs. 9.86 mph; *F* (1, 33) = 27.24, η^2 = 0.38, B_{10} = 7.04 × 10^5], a difference decisively greater in the Video condition than the RAPT and RAPT-V conditions [*F* (1, 33) = 5.65, η^2 = 0.15, B_{10} = 61.97]. Data did not indicate substantial evidence for the main effect of Training [*F* (1, 33) = 7.76, η^2 = 0.32, B_{10} = 1.73].

Town: Even though numerically small in magnitude, the traveling velocity was decisively greater in Pre-hazard than Post-hazard periods [M = 30.01 vs. 29.74; *F* (1, 33) = 25.08, η^2 = 0.42, B_{10} = 1.60 × 10^3]. The data did not give substantial evidence for the remaining effects [both B_{10} < 1].

Highway: The data gave substantial evidence against the interaction [B_{10} = 1/5.09]. Training or Timing did not produce substantial difference on the velocity [B_{10} = 1/1.14 and B_{10} = 1/2.84, respectively].

Rural: The data indicate substantial evidence against the main effect of Timing [B_{10} = 1/3.82] and the interaction [1/3.80] but were indifferent to the effect of Training [B_{10} = 1.06].

3. Discussion

The current experiment examined the effectiveness of videos displaying expert eye movements on young drivers' hazard anticipation performance in a medium-fidelity driving simulator. The drivers in the RAPT-V condition anticipated latent hazards more frequently than their peers in the RAPT and the Video conditions, indicating that viewing the videos after completing RAPT further enhanced their hazard anticipation skills. Interestingly, the drivers in the Video condition performed the worst, signifying that a mere preview of the driving scenes, even with the expert's eye movements, was not sufficient to train the young drivers. This suggests the necessity of providing young drivers with opportunities to make a mistake and mitigate the mistake in order to master higher cognitive skills like hazard anticipation. The other measures of eye movements such as mean fixation duration and variability in fixation locations [16] and the mean travel speed did not differ across the conditions, suggesting that the benefit of the video of expert eye movements beyond the effect of RAPT is specific to the scenarios evaluated but the program may not alter their general scanning strategy while driving.

How did the drivers in the RAPT-V condition achieve nearly ceiling-level performance in the evaluation drive? We speculate that, following the completion of RAPT, the videos with expert eye movements might have enabled the drivers to *map* the location of latent hazard that they learned and *mastered* in RAPT to a more dynamic driving environment. Although RAPT offers an opportunity to practice identifying locations of latent hazards using a series of snapshots, drivers may not have yet developed a skill to (1) analyze dynamic driving scenes in a continuous drive, (2) identify the target zone and (3) anticipate the hazard in a timely manner. Performance of all aspects of safe mitigation of a threat requires the complete development of spatial mental models. Furthermore, the evaluation drive requires all the three skills above while controlling the vehicle, thereby increasing drivers' cognitive load, which in turn might have compromised their anticipation performance. The videos might have allowed participants to practice without the demand of vehicle control, cementing the anticipation skill for immediate application to evaluation drives in a driving simulator. Eye movement data from novice and experienced drivers [16] support the view that mental models are underdeveloped in young drivers. The use of expert eye movement videos may allow for the accelerated development of mental models in young drivers which would otherwise be only developed through extensive experience.

The data were ambiguous to the effect of gender on hazard anticipation performance, with a trend consistent with the recent wide-scale evaluation study [11]: Male drivers tended to benefit more from the training programs than female drivers (M = 0.75 vs. 0.47 for RAPT condition; M = 0.95 vs. 0.78 for RAPT-V condition). This data pattern suggests that the gender differences obtained in the evaluation field study [11] may not be simply due to the fact that male drivers had more room to improve than female drivers. Instead, these differences between male and female drivers may potentially arise from gender differences in processing the materials of RAPT, such as differences in visuospatial abilities [12]. Further research should identify cognitive loci of the male advantage on the effectiveness of RAPT with greater sample sizes [11]. Furthermore, appending a short video of expert eye movements may offset the gender difference that was apparent on the crash data for the RAPT-trained drivers. More research is necessary to assess the abilities of training programs to deliver contents that allow for easy visuospatial mapping.

There are a number of limitations in this study. First, as with other driving simulator studies, the current results may not necessarily generalize to drivers on the road. Second, the additive effect of the video with expert eye movement may arise only when the orders of the anticipation scenarios in the training and the simulated environment match. That is, when the video presentation precedes

RAPT, transformation of exocentric spatial information to an egocentric spatial frame may not occur as effectively as the opposite order. Future research could manipulate the orders of the anticipation scenarios between the training and the simulated environment to test the generalizability of the current finding. Third, the effects observed here may not persist over the long term. Fourth, the expert eye movement videos themselves could be further improved to provide additional auditory and multi-modal instruction designed to deliver scenario-specific and context-relevant content. Fifth, it is not known whether the use of eye movement videos of the average driver would elicit performance benefits following training, equivalent to that observed for expert eye movement videos in this study. Sixth, though "young drivers" are often defined as drivers aged 16–18 years, due to the current protocol and the challenges associated with recruiting high-school students in a University research environment, we were unable to recruit participants within the target driver group (16–18). However, this does not necessarily undermine the current results as drivers older than 18 years of age are generally expected to show better hazard anticipation performance and the current study demonstrates that the expert eye movement videos can further enhance the hazard anticipation performance of drivers aged 18 and above. It could be surmised that novice drivers below the age of 18 given their inexperience with driving would likely benefit even more than the drivers in our sample did when exposed to the same training interventions. Finally, it is unclear whether the benefit of eye movement videos transfers to novel driving scenarios. Further research is necessary for addressing these limitations and examining the retention and persistence of the effect of eye movement videos on hazard anticipation performance.

In practice, the current results imply that a short video clip with expert eye movements following the traditional training program such as RAPT can further augment the benefit of a training program employing the 3M (Mistake, Mitigation and Mastery) method by adding Mapping as an additional phase in the training mechanism. In effect, a 4M mechanism may allow for better effectiveness of the training intervention than the 3M mechanism, by employing a *mapping* phase where drivers can visually practice and map the anticipation skill without the demand of vehicle control. Visualized representations of where an experienced driver would glance on the roadway can allow for the quicker development of mental models in young drivers, which in turn can allow young drivers to scan more effectively in situations that involve a latent hazard. While further research is required to fully validate the effectiveness of expert eye movement-based training interventions, the current study provides a glimpse into the potential of such interventions for accelerating training and improving appropriate visual search strategies in young drivers.

4. Materials and Methods

4.1. Participants

Thirty-six young drivers (20 females; mean age = 19.2 years, *SD* = 1.12 years, range = 18–21; mean number of years since licensure = 2.87 years, *SD* = 1.21) were recruited from the community of Old Dominion University for the current study. All participants held a valid US driver's license, reported normal or corrected-to-normal visual acuity and drove less than 10,000 miles traveled since the licensure. Participants were remunerated for their participation.

4.2. Apparatus

4.2.1. Driving Simulator

The STISIM Drive (Systems Technology, Inc., Hawthorne, CA, USA) was used for the experiment. The system consisted of a computer, Dell Studio XPS with Windows Vista x64 Enterprise, a gaming Playseat and Logitech G27 racing wheel and pedals. A DPL 1800 MP Front Projector was used to project the simulated environments on a 76-inch white smart board screen. The drivers viewed the screen from a distance of approximately 177 cm. The system also simulated sound for environment using a surround speaker system.

4.2.2. Eye Tracker

An ASL Mobile Eye (Applied Science Laboratories, Inc., Bedford, MA, USA) head-mounted eye tracker was used for tracking the drivers' eye movements. The eye tracker consisted of two cameras—one that records the driver's eye and the other that records the scene image. The data were sampled at 60 Hz and the system software processed the recorded scene and eye images into a single video of the scene with a crosshair that represented the location of gaze in each frame. The eye tracker possesses an accuracy of up to 0.5 degrees of visual angle.

4.2.3. Simulator Scenarios

All participants completed a single driving simulator evaluation of their hazard anticipation skill, immediately after completing a training program (either one of RAPT, Video, or RAPT-V). Each participant navigated a single drive consisting of four virtual environments (Highway, Town, Rural and Residential) each of which involved one hazard anticipation scenario (see Table 1 for details). The scenarios used in the current experiment were identical to those of our previous work [7]. All four hazard anticipation scenarios involved a latent hazard existing within a *target zone* that could materialize as a vehicle approaches the *launch zone* (Figure 1). A *launch zone* here is defined as that section of the roadway where one should begin scanning for potential latent threats that may materialize on the forward roadway, while a *target zone* represents those areas on the roadway where a potential threat could materialize. The launch and target zones used in the current study have been validated in several previous studies [7,25].

4.2.4. Training Program

The latest version of RAPT (RAPT-3) (available for download at http://www.ecs.umass.edu/hpl/software.html) was used for both the RAPT and RAPT-V groups. RAPT-3 assesses a driver's ability to examine hazardous scenarios and trains them to effectively scan visual areas of the roadway that contain latent hazards, particularly those elevating a risk of collision with other vehicles and vulnerable road users [6]. RAPT-3 uses nine different scenarios validated in previous studies and offers the training in a sequential format involving three sections: pre-test, training and post-test. In the pre-test, drivers view a sequence of snapshots of each scenario from on-road perspective—egocentric views—and are asked to click on the areas where they would attend without any feedback. In the training section, the program presents a top-down—exocentric—view of the scenario with narrative explanations of the risk in each scenario. Following the explanation given, the program allows the participants to practice identifying the areas of risk on the sequence of snapshots for up to four times. In the post-test section, the participants again view the sequences of the snapshots for the nine scenarios identical to those in the pre-test section. The RAPT program took about 40 min to complete. Full description for the RAPT training is detailed in [6]).

Table 1. In schematic representation of each scenario, the dotted square depicts the launch zone and the graded cone depicts the target zone. A perspective view with a crosshair indicating the location of a correct glance toward the target zone.

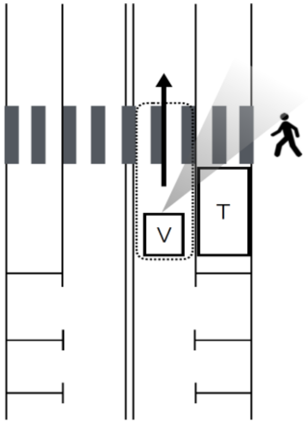
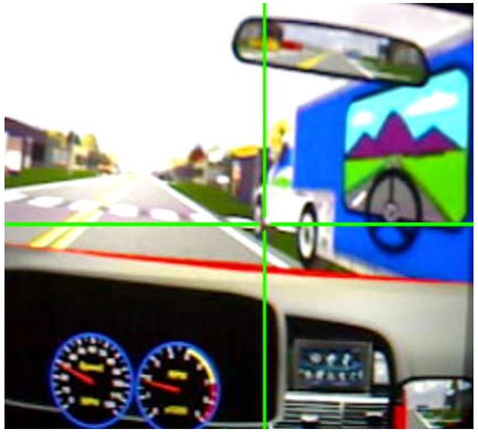
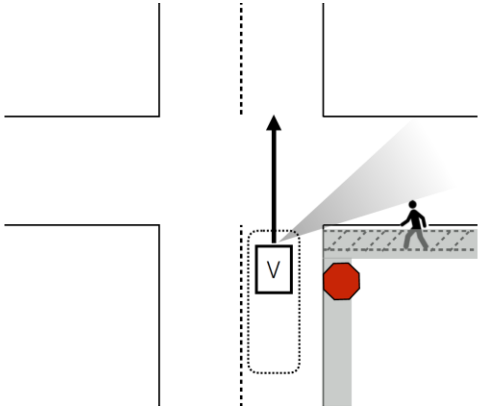
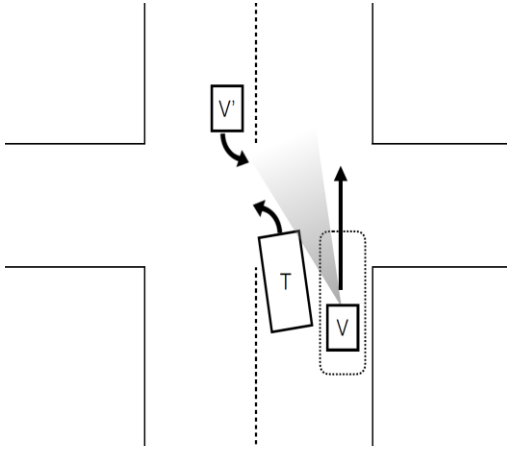
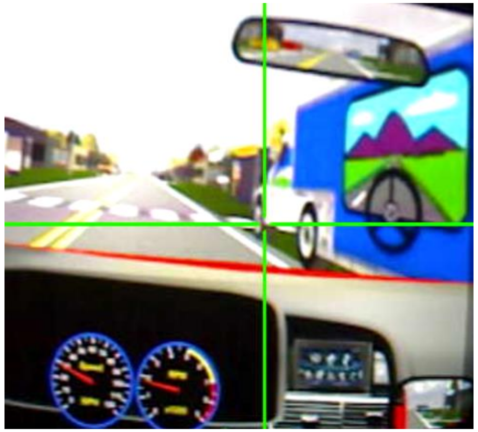
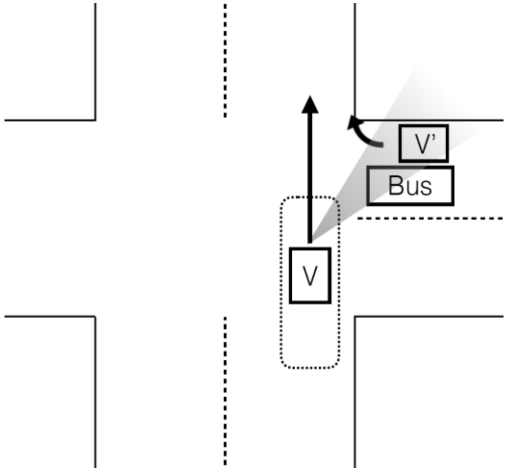
Truck Crosswalk Scenario Subject vehicle (V) approaches a crosswalk and the driver should monitor the area behind the truck for hidden hazards (e.g., pedestrians).		
Hedge Scenario Subject vehicle approaches a stop sign-controlled intersection. After a full stop, the driver should look for a hidden hazard that might be occluded by hedges on the right side of the travel lane.		

Table 1. *Cont.*

Adjacent Truck Intersection Scenario. The driver travels straight in the right lane on a two-lane road and should look for a hidden hazard (e.g., cross traffic; V') across the intersection in the opposing lane that might be occluded by a left-turning truck (T) in the adjacent left lane.		
Multiple-lane Intersection Scenario. While crossing a signal-controlled intersection, the driver should look for a hidden hazard (e.g., cross traffic; V') that might be occluded by a bus approaching from the right, traveling in the left lane of the two travel lanes.		

4.2.5. Eye Movement Video

The first author participated as an expert driver and completed the four experimental drives with his eyes tracked. These eye movement videos were used for the video and RAPT + Video groups. In each video, the first author demonstrated correct anticipation behavior by fixating at the target zone in each hazard anticipation scenario while within the appropriate launch zone. The eye movement video demonstrates the location of hazards and corresponding appropriate anticipation behaviors. The length of each video was roughly 10 min and included all the scenarios used in the RAPT training in the order that was evaluated.

4.3. Procedure

The participants were randomly assigned either to the RAPT, Video, or the RAPT-V condition. Their demographics were not different across the three groups (Table 2). Participants in the Video and RAPT-V conditions viewed the eye movement video of the scenarios in the order of their occurrence in the evaluation drive. They completed the assigned training program, followed by a 5-min practice drive to familiarize them with the simulator system. The practice drive did not include any hazard anticipation scenarios to prevent learning effects and biases. After the practice drive, participants drove a single evaluation drive involving four hazard anticipation scenarios on the simulator. The order of the scenarios in the evaluation drive was counterbalanced across participants using a Latin square method. Participants were instructed to drive as they would on an actual road following all traffic rules, installed signs and specified speed limits.

Table 2. Demographics information for the three groups. Numbers in parentheses indicate 1 standard deviation. M represents males and F represents females.

	RAPT	**VIDEO**	**RAPT-V**
Gender	5M, 7F	6M, 6F	5M, 7F
Age	19.58 (1.24)	19.41 (1.08)	19.08 (1.08)
Years Licensed	3.59 (1.25)	2.95 (0.95)	2.06 (0.94)

4.4. Dependent Variables

The eye movements of all participants were recorded and were manually coded (double blind) by two independent raters to determine whether participants successfully glanced at the predetermined target zone while in the launch zone. If the two raters disagreed, they discussed such glances and resolved the disagreement. The variable was binary coded: a correct anticipatory glance as ‘1’ and an incorrect glance as ‘0.’

Mean fixation durations, numbers of fixations and variance in horizontal and vertical fixation locations were calculated using the saccades package for R [26].

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Conflicts of Interest: The authors declare no conflict of interest.

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