NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Evaluation of PC-Based Novice Driver Risk Awareness

Final Report

NHTSA
www.nhtsa.gov

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 810 926		

4. Title and Subtitle	5. Report Date
Evaluation of PC-Based Novice Driver Risk Awareness	April 2008
	6. Performing Organization Code
7. Author(s) Donald L. Fisher	8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Mechanical and Industrial Engineering University of Massachusetts Amherst, MA 01003	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTNH22-04-H-01421
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

Ian Reagan served as the NHTSA Contracting Officer's Technical Representative for the study.

16. Abstract

Newly licensed drivers are at an especially high risk of crashing. The first six months of solo driving are the most dangerous for teens; however, it appears that novice drivers improve their driving in a relatively short period of time as crash rates begin to drop dramatically during this time period of increasing experience. We have known for some time that failures of hazard anticipation, attention maintenance, and speed management are the primary causes of these crashes. Still, we have not seen a dramatic reduction in the inflated risk during the first several months with the current driver education programs and licensing restrictions, which indicates that we are not teaching newly licensed drivers all they need to know. With this in mind, we engaged in a series of five experiments designed to identify major differences in the hazard anticipation and attention maintenance skills of newly licensed drivers. On a driving simulator, we found that newly licensed drivers were up to six times less likely to anticipate hazards than much more experienced drivers. And they were up to three times more likely than experienced drivers to glance away from the forward roadway for more than two seconds. We then developed a hazard anticipation training program. We showed that this training program could increase the likelihood that newly licensed drivers would anticipate hazards, both on the driving simulator and the open road.

22. Key Words	18. Distribution Statement
Teen Drivers .Hazard Anticipation .Attention Control	

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

TECHNICAL SUMMARY

CONTRACTOR	CONTRACT NUMBER
University of Massachusetts at Amherst	DTNH22-04-H-01421
REPORT TITLE	REPORT DATE
Evaluation of PC-Based Novice Driver Risk Awareness	March 2008
REPORT AUTHOR(S)	
Donald L. Fisher	

BACKGROUND

Teen drivers 16 and 17 years old are at an especially high risk of crashing. The first six months of solo driving are the most dangerous for these teens (Mayhew, Simpson, & Pak, 2003; McCartt, Shabanova, & Leaf, 2003; Sagberg 1998). Reductions of up to six fold in the crash rate over the first six months have been reported (e.g., McCartt et al., 2003). Standard drivers' education programs, initially thought to make a difference, usually do not (Nichols, 2003). Such programs, which typically involve 30 hours of classroom instruction and 10 hours in the vehicle (4 hours of observation and 6 hours behind the wheel), have, until recently, been the primary way teens learned to drive. Unfortunately, evaluations undertaken over the last 40 years have shown little effect of such programs on the crash rates of *newly licensed drivers* (Mayhew & Simpson, 2002; Nichols 2003) 16 and 17 years old during their first six months of solo driving.

Graduated driver licensing (GDL) programs are one response to the problem. Novice drivers must first spend a period of time, six months or more depending on the State, learning how to drive with an adult in the car (the *learner's permit stage*) before they can drive on their own. Once teens are allowed to drive by themselves, there are restrictions added to their licenses that limit the hours of the day and the number of passengers they can have in the car (*restricted or intermediate license stage*). Finally, teens receive licenses without any restrictions (*unrestricted or full license stage*). The GDL programs have now been evaluated. They clearly reduce crash rates among 16-year-olds by limiting exposure, achieving reductions of between 18% to 21% in per capita fatal crash involvements in States where the five most effective components of the GDL programs have been implemented (Baker, Chen, & Li, 2006). And during the first six months of driving they reduce the number of crashes per licensed driver anywhere between 9% (Raymond, Johns, Golembiewski, Furst Seifert, Nichols, & Knoblauch, 2007) and 14% (Mayhew et al., 2003). However, although there is a significant reduction in the number of crashes per licensed driver during the first six months of solo driving, there appears to be no reduction in the difference between the monthly crash rates per vehicle mile in the first six months post-licensure (Mayhew, Simpson, Williams, & Desmond, 2002).

This leads one to ask whether one can identify the types of crashes in which novice drivers are involved and then target those crash types for training. There have been a number of studies of the causes of teen driver crashes. Perhaps the most extensive information has been reported in a study in which McKnight and McKnight (2003) reviewed 2,000 police accident reports: 1,000 reports of crashes involving drivers 16 and 17 years old and 1,000 reports of crashes involving drivers 18 and 19 years old (the reports do not include the date of licensure, so it is not possible to know precisely how many years of driving experience each cohort had on average). The 16- and 17-year-olds were about three times as likely to be involved in a crash as the 18- and 19-year-old drivers. In absolute terms, inferred failures to search ahead, to the side, or to the rear were implicated in 43% of the crashes. Inferred failures of attention were implicated in 23% of the crashes. Finally, inferred failure of speed management -- driving too fast for the road conditions, especially on curves and slick surfaces – were inferred to be a causal factor in 21% of the crashes. Note that alcohol was observed to be a factor in only 2% of the crashes and very high speeds (greater than 70 mph) in only 1% of the crashes among the 16- and 17-year-olds, contrary to what might be more widely perceived as the major problems. The distribution of inferred causes did not differ between the younger and older teens, only the absolute number. McKnight and McKnight's findings are in agreement with an earlier study reported by Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, and Castellan (1979) in which, in order, visual search, speed control, and attention were implicated as causes of driver crashes. The findings are also in broad agreement with a study reported by Gregersen (1996) which estimated that some 70% of the novice driver errors were due to inexperience. Finally, in a recent study of 100 instrumented cars completed at the Virginia Tech Transportation Institute (VTTI), 241 drivers 18 years old and over were filmed inside their vehicles. The drivers logged over two million miles. Inattention due to involvement in a secondary task was estimated to be the cause of 22% of the crashes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006), similar to what McKnight and McKnight observed. The crash rate for inattention related crashes among 18- to 20-year-olds (the youngest cohort) was up to five times larger than older drivers. Given the above agreement on the importance of hazard anticipation (recognizing a situation as potentially hazardous and scanning appropriately), attention maintenance (constant short, frequent glances at driving related information that appears on the side of the road, in the mirrors, and elsewhere and only very short glances inside the vehicle for safety related information), and speed control (adjusting speed based on the environment, roadway and traffic patterns) in experienced teen and older drivers, it is tempting to conclude that the same errors are present in newly licensed drivers, only greatly inflated (although see Sagberg & Bjørnskau, 2006).

As helpful as the above information is, it does not lead to specific training strategies. Telling novice drivers to scan the roadway better, pay more attention, and drive defensively is already being done. Teens know in broad terms the behaviors that decrease the likelihood that they will be in a crash. We need to know more concretely exactly what behaviors are putting the newly licensed driver at such a high risk of crashing during the first six months. The research that had been done before the start of this contract was primarily in the area of *strategic scanning*. Strategic scanning we define as the scanning pattern a driver executes when there is nothing in the scenario that suggests something out of the ordinary is present. There are both spatial and temporal components of strategic scanning that need to be identified. Spatially, an ideal scanning pattern should include, in addition to frequent attention to the forward roadway, a relatively large number of glances to the sides of the road and the rear- and side-view mirrors. The three relevant studies of the spatial component of strategic scanning behaviors, all undertaken in the field, suggest that experienced drivers: (a) scan more broadly from side to side, especially when changing lanes (Mourant & Rockwell, 1972); (b) have, on average, more widely spaced eye movements as measured along the horizontal axis (Crundall & Underwood, 1998); and (c) are more likely to make consecutive fixations on objects in the periphery (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). These results are consistent with the results from the studies of police accident reports described above (e.g., McKnight & McKnight, 2003) which indicate that failures of search are a primary cause of newly licensed driver crashes. Temporally, the driver should rarely if ever focus away from the center roadway for more than a second or a second and one-half since longer glances are associated with an increase in crash risk (Klauer et al., 2006; Wikman et al., 1998).

Research on *tactical scanning* is more recent. Tactical scanning we define as the scanning pattern a driver employs when a threat might potentially materialize or actually does materialize. Again, there are spatial and temporal components of tactical scanning. Much of the research on the spatial component of tactical scanning has been done using an advanced driving simulator (e.g., Figure 1) and associated eye-tracking equipment (e.g., Figure 2, Figure 9). Specifically, it has been determined that newly licensed drivers were less likely to anticipate hazards than experienced drivers, as evidenced by their scanning behaviors (Pradhan, Hammel, DeRamus, Pollatsek, Noyce, & Fisher, 2005). It has also been determined that newly licensed drivers could be trained to anticipate hazards using a simple PowerPoint training program running on a stand-alone PC which we called the Risk Awareness and Perception Training (RAPT-1) program (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Narayanaan, 2005). The training program presented only plan views (top down views) of risky driving scenarios in which a hazard was difficult to identify. More generally, tactical scanning is one component of good *hazard anticipation*. Hazard anticipation we define as the composite set of behaviors which reduce the likelihood of a collision once a potential threat has been identified. Thus, drivers should not only scan the roadway ahead for hidden hazards but drivers should also maneuver their vehicles in ways that minimize a collision when they anticipate a hazard. It was found that experienced drivers are more likely than novice drivers to engage in such anticipatory vehicle behaviors (Fisher, Laurie, Glaser, Connerney, Pollatsek, Duffy, & Brock, 2002).

During the execution of either a strategic or tactical scanning pattern, the driver can glance overlong on some stimulus inside or outside of the cabin of the automobile. We refer to this as a failure of *attention maintenance*. One field study had been undertaken on attention maintenance prior to the initiation of this contract. In this field study (Wikman, Nieminen, & Summala, 1998), experienced (29 to 44 years old, mean 36; 50,000 – 2,000,000 km; median 200,000 km) and inexperienced (18 to 24 years old, mean 19; 400 – 16,000 km, median 200 km) drivers each drove a course through city streets and rural roads that took approximately three hours. After about 90 minutes, three in-vehicle tasks were introduced at 10-minute intervals on a two-lane roadway by an experimenter riding with the participant. Particular attention was paid to the percentage of the participants with long glance durations. It was found that only 13% of the experienced drivers had glance durations longer than 2.5 s whereas fully 46% of inexperienced drivers had glance durations of at least this length. Moreover it was found that no experienced drivers had glance durations longer than 3 s whereas 29% of the inexperienced drivers had glance durations of at least this length. Such long glances away from the forward roadway are particularly problematic as indicated by the VTTI study described briefly above (Klauer et al., 2006). The total time the drivers' eyes were off the forward roadway for crashes and near-crashes was calculated five seconds prior to and one second after a precipitating event (e.g., a lead vehicle braking). While the odds ratio for eye glances away from the forward roadway for a total of less than 2.0 seconds was not significantly greater than 1.0, it was significantly greater than 1.0 for glances greater than a total of 2.0 seconds (odds ratio 2.19). Moreover, it was estimated that such glances away from the forward roadway for more than 2.0 seconds were the cause of more than 23% of the crashes and near-crashes (population attributable risk). Of particular interest to us is how the number of inattention-related crashes and near crashes for high and low involvement drivers varied as a function of the age of the drivers. There were 78 drivers involved in three or fewer crashes (the low-involvement drivers; mean of .95 crashes; median of 1 crash; average age 30) and 27 drivers involved in more than three crashes (the high-involvement drivers; mean of 7.6 crashes; median of 6 crashes; average age of 38). Among just the high-involvement drivers between the ages of 18 and 20, the absolute number of inattention-related crashes was more than five times that of the safest cohorts of drivers, a result that was significant. Presumably newly licensed drivers would have been just as over-involved, if not more so.

OBJECTIVES AND RESULTS

In this project, we extended our earlier work both with the analysis of the tactical scanning behaviors of newly licensed drivers required effectively to anticipate hazards and with the evaluation of the effectiveness of alternative training programs. This earlier work was confined to the lab, the training effects were evaluated immediately after drivers were exposed to the training, and the training program itself did not take advantage of the advances in technology that had made training with low-cost driving simulators a real possibility. Thus, we set out to determine: (a) whether training effects observed with RAPT-1 in the laboratory on the driving simulator were present not only immediately after exposure to the training program, but also up to one week later (Experiment 1); (b) whether training effects were observed on the open roads as well as in the laboratory (Experiment 2); (c) whether the training effects we observed on the driving simulator were similar to what we observed on the open road (Experiment 3); and (d) whether training could be improved by using a low cost driving simulator (Experiment 4). We found that training was effective in all cases: (a) it proved as effective when participants were evaluated one week after being exposed as it did when participants were evaluated immediately after being exposed (Experiment 1); (b) it proved as effective in the field as it did in the laboratory (Experiment 2); and (c) the effects observed in the laboratory differed little from the effects observed in the field (Experiment 3). Moreover, (d) training in a low-cost driving simulator (SIMRAPT; Experiment 4) produced better performance than training with plan views (RAPT-1; Pollatsek et al., 2006), plan views and still photographs (RAPT-2; Experiment 1) or plan views and sequences of still photographs (RAPT-3; Experiments 2 and 3). This conclusion needs to be more fully qualified and the details are provided below.

In this project, we also began work on a comparison of the attention maintenance skills of newly-licensed and experienced drivers. Just as with hazard anticipation (Pradhan et al., 2006), we needed first to determine whether we could find differences on our driving simulator in the attention maintenance skills of newly-licensed and experienced drivers that we knew were present on the open road, both from controlled field studies (Wikman et al., 1998) and naturalistic studies (Klauer et al., 2006). We need to find differences in the driving simulator that reflect those that are identified on the open road because ultimately we want to evaluate the effects of programs that train attention maintenance skills. The effects of such programs can in general only be evaluated safely and efficiently on a driving simulator. Ultimately, of course, one wants to validate the effects of the training program in the field, much as we have done with the hazard anticipation training programs (Experiment 3). Given the scope of the contract, we were able to run one attention maintenance experiment on the driving simulator (Experiment 5). We found large differences in the number of long glances away from the forward roadway of novice and experienced drivers in the expected direction, suggesting that we now have a good tool for evaluating attention maintenance training programs.

HAZARD ANTICIPATION

We want to make clear at the outset the relation between our different training programs and the experiments in which these training programs were used. Specifically, in our studies of the effects of training on the tactical scanning patterns of novice drivers, we have developed four different versions of RAPT, starting with just top-down plan views prior to work on the contract (RAPT-1, Pollatsek et al., 2006) and moving to the occasional single still photographs (RAPT-2), to sequences of still photographs (RAPT-3), and finally to a low-fidelity driving simulator

(SIMRAPT). RAPT-2 was used in Experiment 1, RAPT-3 in Experiments 2 and 3, and SIMRAPT in Experiment 4.

In Experiment 1, we wanted to determine whether the effects of training that were present when newly trained licensed drivers were evaluated immediately after training on a driving simulator (Pollatsek et al., 2006) were still present and just as large one week later. We designed a new training program, RAPT-2, that presented teen drivers not only with top down views, but also a single perspective view. Some scenarios were especially difficult to train with just top down views and so we added perspective views. When we compared the scanning behaviors of the trained newly licensed drivers with untrained newly licensed drivers one week after training with RAPT-2, we found training effects as large as we had found when drivers were evaluated immediately after training.

In Experiment 2, we wanted to determine whether the effects of training would generalize from the driving simulator to the open road. Moreover, we wanted to make what improvements to RAPT-2 we could based on the results from Experiment 1. Although the newly licensed drivers trained with RAPT-1 and RAPT-2 were performing as well as more experienced drivers when anticipating hazards, their performance was still much less than perfect. Thus, we designed a new training program, RAPT-3, where we asked newly licensed drivers to look at sequences of still photographs each displayed for a short period of time and click on the areas in the photograph where a hazard might materialize. We hoped that by cognitively loading the newly licensed driver as he or she was being trained and by limiting the time to respond in RAPT-3, we would get a stronger training effect than we had observed when the time that drivers had to respond during training was unlimited (RAPT-1, RAPT-2). When we compared the scanning behaviors of the trained newly licensed drivers with the untrained new-licensed drivers, this time on the open roadway, we again found a large effect of training.

In Experiment 3, we wanted to determine whether the results that we were finding in the field when we trained drivers with RAPT-3 were the same as we were finding in the simulator. Since we had not yet evaluated drivers on the simulator using RAPT-3, we did such in this experiment. We found that among the untrained novice drivers, 39% tested in the field recognized the risk compared with 37% tested in the simulator. Among the trained novice drivers, 63% tested in the field recognized the risk compared with 76% tested in the simulator. We then differentiated between *near transfer* and *far transfer* scenarios in the analyses. In the near transfer scenarios, what the trained drivers saw in the field or on the driving simulator was very similar to what they had seen in the training program (RAPT-3). In the far transfer scenarios, there were clear differences in the scenarios that had been trained with RAPT-3 and the scenarios that were evaluated on the driving simulator and in the field. In this regard, on the near transfer scenarios a very similar increase in the percentage of participants scanning appropriately was observed in the field and on the simulator.

In Experiment 4, we wanted to determine whether a more extensive hazard anticipation training program, SIMRAPT, one that was delivered both on a PC and on an inexpensive driving simulator, could bring newly licensed drivers closer to ceiling performance. Although in Experiments 1 and 2 on the driving simulator we were finding that trained novice drivers could perform as well as experienced drivers, experienced drivers were themselves some distance from 100% recognition of risks. (We do not know whether trained novice drivers are performing as well as experienced drivers in the field because we have never collected data on experienced drivers in the field.) So, we decided that we needed participants to practice the actual hazard anticipation behaviors in a driving simulator where they were required to make the same head and eye maneuvers on the simulator as they would in actual practice. In RAPT-1, RAPT-2 and

RAPT-3 the novice drivers never actually had to move their eyes while driving to the given region of a scenario where a threat might potentially materialize. In SIMRAPT such a movement (along with an associated head movement) was required. The drivers trained with RAPT-1 (Pollatsek et al., 2006) recognized the risks 57.7% of the time in the near transfer scenarios and 35.4% of the time in the far transfer scenarios. The drivers trained with SIMRAPT recognized the risks 72.4% of the time in the near transfer scenarios and 46.9% of the time in the far transfer scenarios.

ATTENTION MAINTENANCE

In Experiment 5, we turned our focus to attention maintenance. Here our question is whether novice teen drivers are more likely to spend too long glancing away from the forward roadway than are more experienced, older drivers. As noted above, Wikman et al. (1998) had found that inexperienced drivers between the ages of 18 and 24 were more likely to glance away from the forward roadway than were more experienced drivers between the ages of 29 and 44. The study was undertaken on the open road. We wondered whether newly licensed teen drivers between the ages of 16 and 18 would be more likely than older, more experienced drivers to glance away from the forward roadway for periods of time that would generally be considered too long. And we wondered whether these differences would be obtained on a driving simulator rather than the open road for the reasons articulated above (i.e., we will want to train attention maintenance and believe we can do so safely only in a driving simulator so it is important to know that drivers behave in the simulator as they do on the open road). So, we had both newly licensed and more experienced drivers perform five in-vehicle tasks on the driving simulator and monitored their eye movements throughout the experiment. Newly licensed drivers were almost three times more likely (56.7%) to glance away from the forward roadway for more than two seconds than were experienced drivers (20%).

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

EXPERIMENT 1.[1] EVALUATING THE DURATION OF TRAINING EFFECTS

Younger novice drivers are overrepresented in fatal (Insurance Institute for Highway Safety 2005) and non-fatal (Mayhew et al., 2003; McCartt et al.; Sagberg, 1998) crashes. A major cause appears to be the failure of this cohort to scan for information in locations where potential threats may appear (McKnight & McKnight, 2003). Recent studies have assessed whether PC-based training in risk perception helps novice drivers to identify high-risk locations while they are driving in a simulator. In particular, the Risk Awareness and Perception Training (RAPT-1) program was designed to teach novice drivers about the different types and categories of risky situations normally encountered in driving. RAPT-1 is a PC-based interactive presentation with plan views of roadways that demonstrates risky scenarios (Narayanan, 2005). It provides information about the inherent risks in each scenario and indicates areas where attention should be allocated to detect the risks. A prior study showed that RAPT-1 training produced improved scanning behavior by novice drivers in a driving simulator immediately after training (Pollatsek et al., 2006). The present study (Experiment 1) evaluated the effects of slight modifications to the training program (RAPT-2) an average of four days after training. One group of novice drivers was trained using RAPT-2 and subsequently tested on a driving simulator; a matched control group was evaluated without prior training. The test contained 16 scenarios; each had information vital to safe navigation. An eye-tracker recorded the drivers' point of gaze during the drives.

METHOD

The new version of the training program (RAPT-2) is more streamlined and user friendly in terms of the interface, with the platform moving from Microsoft PowerPoint to a stand-alone executable file programmed using Macromedia Director. This version was also designed so that there would be a minimum of intervention required on the part of the researcher and all data collection for the program would be taken care of internally.

The training program contained 10 scenarios that fall into three basic categories. The scenarios were selected so that they (a) represent a driving situation that is common in everyday travel and (b) have certain elements of risk that require specific risk prediction abilities that we believe are learned with experience. The aim was to use these scenarios to illustrate to novice drivers the various types of risks they will encounter while driving and to provide information about each risk and what behaviors would minimize the risk, especially indicating those aspects of the scene to which attention should be directed. The potential risks were in one of three categories: (1) Complete Obstruction of Threat (a vehicle or other traffic elements including vegetation obscured the participant driver's view of a risk, e.g., a stopped truck obscured a driver's view of a pedestrian crossing in front of the truck; the driver should predict the threat based on the clear presence of a marked crosswalk and adjacent sidewalk); (2) Advance Obstruction of Threat (e.g., a road entering from the left was obscured until the last minute; the driver should predict traffic on this road given a Stop Sign Ahead sign is clearly visible before the left fork); and (3) No Obstruction of Threat (e.g., a vehicle immediately ahead of the driver and turning to the right or left into a driveway might stop suddenly to avoid hitting a pedestrian on the sidewalk that crosses the driveway; the driver should predict the sudden stopping of the vehicle ahead given that the driver scans the sidewalk for pedestrians). Note in all cases the environment provided the information that the driver needed in order to predict the threat.

---

[1] Pradhan, A. K., Fisher, D. L., & Pollatsek, A. (2006). Risk Perception Training for Novice Drivers: Evaluating Duration of Effects on a Driving Simulator. *Transportation Research Record, 1969,* 58-64.

These scenarios in the training program were displayed as a top-down schematic (a plan view). Additionally, in some cases in RAPT-2 (but never in RAPT-1), snapshots of actual driving scenes were shown with the plan views to describe a scenario better (the perspective views used in RAPT-2 were largely of those scenarios in RAPT-1 where performance was particularly poor). The task of the participants was to use the mouse to position both red circles and yellow ovals over the plan view of the scenario in appropriate locations. Specifically, they were instructed to drag the red circles to areas of the scenario that should be monitored more or less continuously by a driver and the yellow ovals to areas on the scenario that contained any object that would be hidden from the driver at his/her present location but which could have relevance for the driver's path of travel subsequently. For example, Figure 3a contains a representation of what we refer to as the Hidden Sidewalk Scenario. A pedestrian or bicyclist could emerge suddenly from behind the bushes. The participant should have positioned a yellow oval behind the bushes. The participant should have positioned a red circle immediately to the right of the bushes since that is the area from which a potentially hidden pedestrian could emerge. After positioning the ovals and circles, the participants were also asked to type in answers to 2-3 questions relevant to each scenario and the possible risks.

Once the training program was completed, the participants returned after an interval of four days (on average) and were tested on an advanced fixed-base driving simulator. There were 16 virtual scenarios on the driving simulator, 10 of which were similar to the scenarios in the training program (the set of *near transfer simulator scenarios*). The remaining 6 scenarios differed significantly from the training program scenarios and were included to test for generalization of the training (the set of *far transfer simulator scenarios*). The participants' eye movements were recorded and superimposed as real-time point of gaze on the driving scene. A set of matched untrained drivers was also tested on the driving simulator, driving through the same set of scenarios and having their eye movements recorded similarly.

PARTICIPANTS

Thirty-two drivers were recruited from local area driving schools for the experiment. The drivers were randomly assigned to the control or the experimental groups, resulting in 16 drivers in each group, evenly balanced for gender. The requirement for recruiting was that the drivers all have learner's permits and be between the ages of 16 and 18. The mean age of the trained experimental group was 16.86 years and that of the untrained control group was 16.52 years.

EQUIPMENT

An advanced fixed-base driving simulator was used for the driver evaluation. The simulator has a fully equipped 1995 Saturn sedan placed in front of three screens on which the virtual environment is projected. The screens subtend 135 degrees horizontally and the virtual world is displayed on each screen at a resolution of 1024 × 768 pixels at a frequency of 60 Hz (see Figure 1). The participant sits in the car and operates the controls, moving through the virtual world according to his or her inputs to the car. The sound is controlled by another computer, the Acoustetron, and 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. The system provides realistic road, wind, and other vehicle noises with appropriate direction, intensity, and Doppler shift.

Figure 1. University of Massachusetts at Amherst Driving Simulator

The simulator is integrated with an eye (ASL 5000) and head tracking (Ascension Flock of Birds) system (Figure 2). The participant was fitted with the eye-tracker during the simulation. The eye-tracker recorded the eye-movements of the participant at 60 Hz and converted the input to point of gaze information which was in turn superimposed as crosshairs onto a real-time video of the drive, thus indicating the position of the driver's gaze in the visual field.

Figure 2. ASL 5000 Eye Tracker

TRAINING PROGRAM

The training program (RAPT) has five sections: Instruction, Pre-Test, Training, Questions and Post-Test.

- The *Instruction 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.
- The *Pre-Test Section* presented the 10 scenarios in sequence and the user was expected to drag the red circles and yellow ovals over to the relevant areas in the plan views. No feedback was provided to the participants in this section 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 3a, without the red circles or yellow ovals positioned in the correct location), the participant was shown a plan view of the scenario with one or more vehicles and/or pedestrians. This slide had three red circles 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. Next, the Vision Obstruction Screen (Figure 3b) 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. 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 3c) 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.

- The *Question Section* presented the 10 scenarios again to the participant, but this time with questions about the risks in the scenario. The participant was 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 plan views of the scenarios to the participants again and, as in the Pre-Test section, they were instructed to move the red circles and yellow ovals to appropriate locations. These locations were then compared to the locations recorded in the Pre-Test section.

Figure 3. RAPT-2 Training Slides

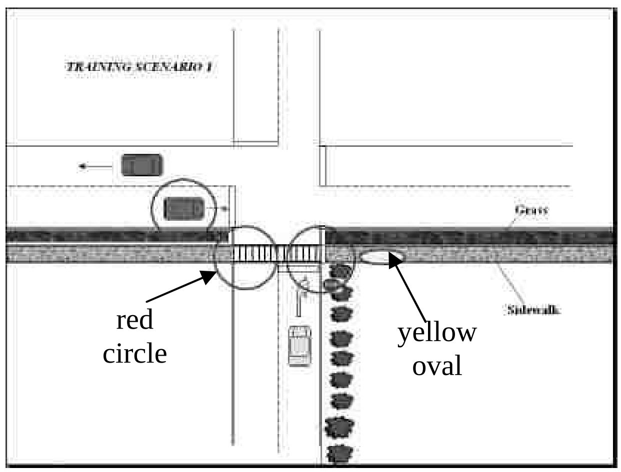


Figure 3a. Training Program - Subject Response Screen

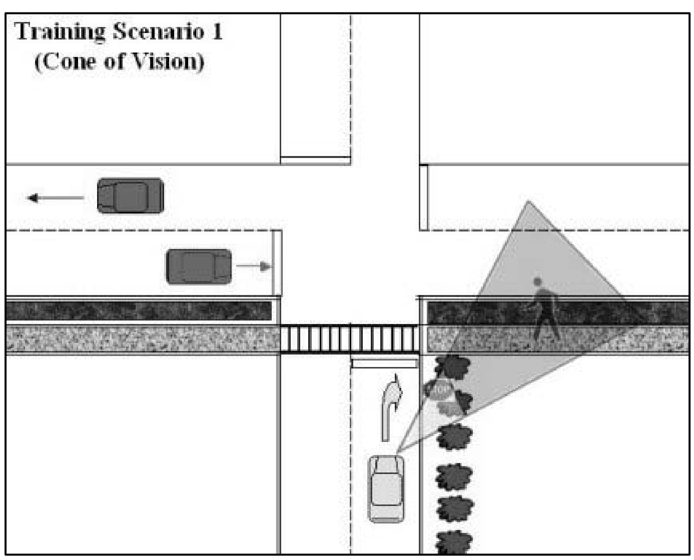


Figure 3b. Training Program – Vision Obstruction Screen

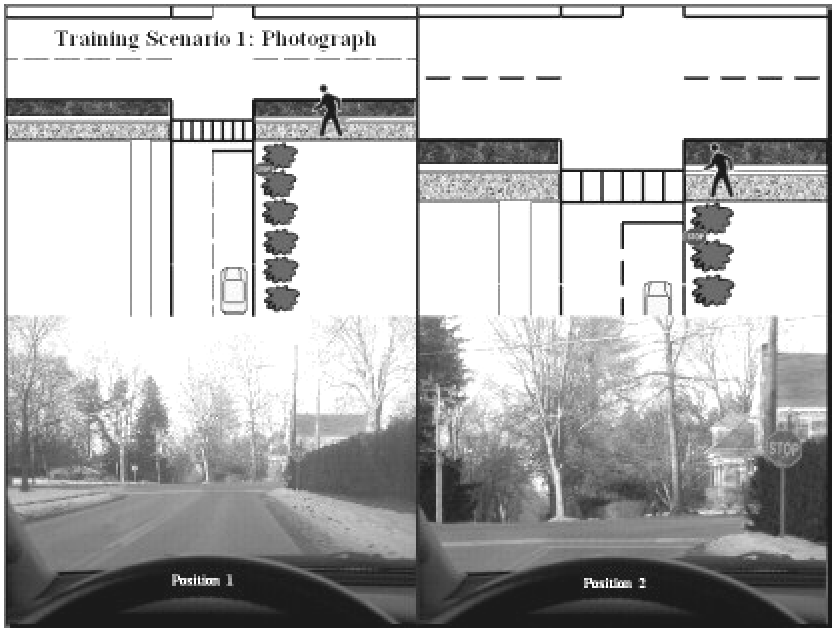


Figure 3c. Training Program – Visualization Screen

This training program was about 90 minutes long. The participant was then scheduled to return in three to five days for the simulator testing.

DRIVING SIMULATION

The participants in both groups were evaluated on the simulator. They were given both written and verbal instructions with respect to driving in the simulator at the beginning of the session. They were then fitted with the eye-tracking system and the calibration process was completed. Once the eye-tracker had been calibrated, the drivers were asked to drive a practice scenario. This scenario was designed to contain all the elements of the virtual environment that a driver would experience during the actual experimental scenarios including intersections, traffic situations and other elements. This practice scenario also served to acclimate the participant to the specific handling characteristics of the vehicle used in the driving simulator. The participants were encouraged to drive the practice scenario as many times as necessary until they were comfortable with vehicle handling, especially left and right turns and braking situations.

The 16 experimental scenarios in the driving simulation were laid out evenly in four blocks of four scenarios each and the order of the blocks was counterbalanced within each group. The 16 scenarios contained 10 of the scenarios that were used for the PC training and 6 scenarios that did not resemble the PC training scenarios. The 6 additional scenarios were used to test for the possible generalization of the training. These 6 could also be roughly separated into the three categories mentioned earlier: Obstruction, Sign Ahead and Visible Pedestrian/Vehicle. The participants drove through the four blocks with rests in between blocks. The eye movements and various vehicle parameters were recorded during the drives.

RESULTS

EVALUATION OF TRAINING ON THE PC

Dependent Variables and Scoring

The participants' answers in the pre- and post-test were scored based on the correct position of the red circles and yellow ovals (Figure 3a). As pointed out in the introduction to this experiment, the red circles had to be dragged to areas that should be monitored more or less continuously and the yellow ovals had to be dragged to areas that could contain a risk and are hidden from the participant driver's view. In each scenario, there were between one and three red circles and one and three yellow ovals that the participants could use to mark the critical areas. A participant was scored one for each circle or oval that was placed at the correct spot, and zero for each area that was critical but not marked with a red circle or yellow oval. There was no deduction of points if a circle or oval was placed at an area that is not critical.

Analysis

As a check that participants showed they had attended to the training and had learned the ideas, we compared performance on the PC pretest to the PC post-test. In fact, there was a sizeable improvement in the ability of the participants to correctly place the red circles and yellow ovals on the plan views of the scenarios, indicating an improvement in their ability to identify areas in the scenarios that should be monitored carefully and areas that could have obstructed or hidden risks. (Of course, this test was not taken under time pressure or with a competing task like driving.) The improvement was significant for the overall scores, 44.3% to 70.5%, $t(15) = 9.04$, $p < 0.001$, and for the red circles and yellow ovals separately: 39.27 % to 66.25 %, $t(15) = 5.73$, $p < 0.001$, and 52.18 % to 81.15 %, $t(15) = 7.05$, $p < 0.001$ respectively. Improvement was about the same in the *obstruction*, *sign ahead* and *visible pedestrian/vehicle* categories.

EVALUATION ON THE DRIVING SIMULATOR

Dependent Variables and Scoring

The eye tracker was used to determine whether the driver was fixating on particular regions in the driving environment. Each of the scenarios was designed to have a key moment in the unfolding of the scenario when the eye movement pattern could be examined for an indication either that attention is given to a risk, or to an advance signal warning of an upcoming potential risk. The key behavior was usually defined as the participant making at least one fixation on an appropriate region of the environment within a certain temporal window; however, for some scenarios, a more extended look was needed to qualify as appropriate attention to the potential risk. A detailed description of the criteria for each of the scenarios was developed. For example in the Truck Crosswalk Scenario, the driver should have fixated on the side of the truck that is stopped in front of the crosswalk, as pedestrians might appear in front of it (Figure 8). In the Curved Stop Ahead Scenario a more extended look was required, as the driver should have repeatedly fixated to the right side of bushes while negotiating the turn.

The target region was defined by the angle between the region and a "default region." The "default region" was the part of the screen the driver is most likely to look at when driving the car. Usually and for most of the scenarios, the default region was looking straight ahead (e.g., such as in Figure 27b). For some scenarios, such as executing a turn, it was shown that the default region was somewhat off to one side. There was always a reasonable distance between the default region and the target region that would be scored as fixating the risk. The visual angle in all of the scenarios between the default region and the target region was at least 5 degrees and in most of the scenarios was over 10 degrees (these values represent the average angle over the temporal

Figure 1. University of Massachusetts at Amherst Driving Simulator

The simulator is integrated with an eye (ASL 5000) and head tracking (Ascension Flock of Birds) system (Figure 2). The participant was fitted with the eye-tracker during the simulation. The eye-tracker recorded the eye-movements of the participant at 60 Hz and converted the input to point of gaze information which was in turn superimposed as crosshairs onto a real-time video of the drive, thus indicating the position of the driver's gaze in the visual field.

Figure 2. ASL 5000 Eye Tracker

TRAINING PROGRAM

The training program (RAPT) has five sections: Instruction, Pre-Test, Training, Questions and Post-Test.

- The *Instruction 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.
- The *Pre-Test Section* presented the 10 scenarios in sequence and the user was expected to drag the red circles and yellow ovals over to the relevant areas in the plan views. No feedback was provided to the participants in this section 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 3a, without the red circles or yellow ovals positioned in the correct location), the participant was shown a plan view of the scenario with one or more vehicles and/or pedestrians. This slide had three red circles and three yellow ovals on a side

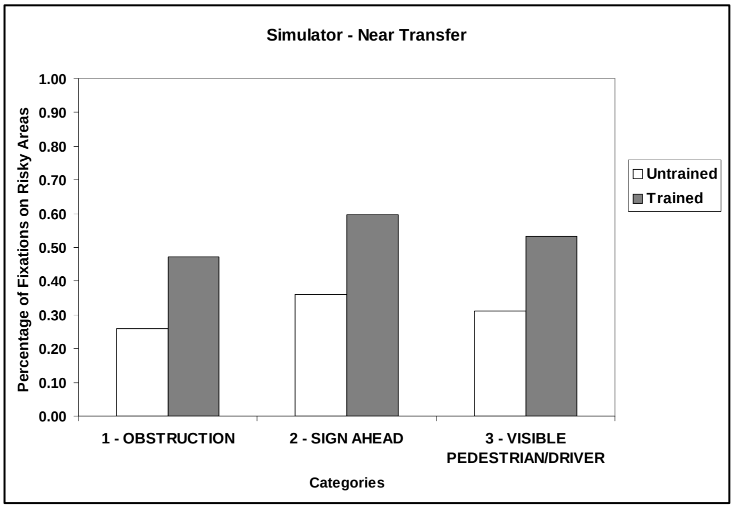


Figure 4b. Simulator Results – Near Transfer Scenarios

As mentioned earlier, 10 of the driving simulator scenarios resembled the scenarios that were included in the training program (*near transfer*) and the remaining 6 scenarios were significantly different (*far transfer*). The reason for this separation was to see if the driver, using the knowledge, strategies, or rules learned from the near transfer scenarios, would show a difference in risk awareness (as evidenced by scanning behavior) even in scenarios on which they were not explicitly trained (far transfer scenarios). When the near transfer set of scenarios was analyzed separately, the trained group recognized 51.8% of the risks as compared to 28.75% for the untrained group (Figure 4b) and an analysis of the far transfer set of scenarios showed that the trained group recognized 53.1% of the risks as compared to 27.1% for the untrained group (Figure 4c). This effect was significant for both the analyses with $F(1,30) = 9.0$, $p = 0.005$, and $F(1,30) = 8.12$, $p = 0.008$, for the near transfer and the far transfer scenarios respectively. As can be seen from the figures, the training was about equally effective in the three categories of scenarios.

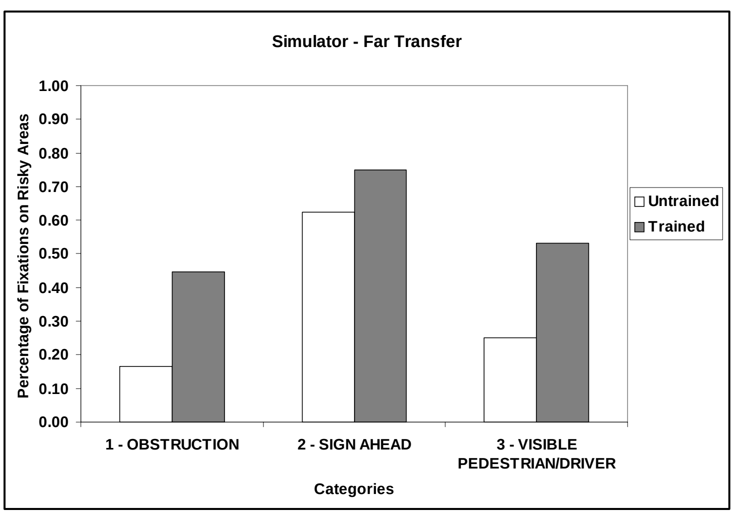


Figure 4c. Simulator Results – Far Transfer Scenarios

DISCUSSION

The results for the PC training program clearly show that the training by itself is successful in imparting the necessary knowledge to the novice drivers so that, using a plan view schematic of a driving scenario, they are able to identify locations in which hazards are reasonably probable to occur. However, without further testing, one could argue that these results are just the effect of a short-term retention of certain rules and instructions, thus leading to the improvement in scores between pre-test and post test performance on the PC. Hence the results obtained in the subsequent evaluation on a driving simulator are of critical importance. Those results show a markedly superior performance of the trained drivers over their untrained counterparts in terms of their ability to search for regions of a scenario during a simulated driving task which they have been taught are risky ones in a PC-based training program. This indicates that there is a transfer of the knowledge gained from the PC training using top-down views to the more realistic environment of the driving simulator that uses perspective views.

The transfer that we observed is especially notable because the static plan views provided in the training material were obviously quite different from the dynamic images of the driving simulator. Even in the scenarios in the near-transfer group, which were based on the training program scenarios, the participants needed to visualize what they had learned from a static top down view on a PC and transfer this knowledge to a similar situation in a more realistic and dynamic environment. In the far transfer scenarios, not only were the form of the representation and the environment different on the driving simulator but the content of the test scenarios was quite different from the training scenarios. As the improved performance of the trained group was almost identical in both the near and far transfer scenarios, this indicates that what was learned in training generalized well beyond learning specific features of the scenarios during training.

The most significant feature of the results is that the trained drivers were evaluated on the simulator after an average gap of four days after training, and the effects of training were about as large as those in which the simulator evaluation was carried out immediately after the training program had been completed (Fisher, Narayanaan, Pradhan, & Pollatsek, 2004; Pollatsek et al., 2006). Thus, it appears as if there is very little loss of the effect of training over four days. Specifically, when PC training was evaluated on the driving simulator immediately after training (Pollatsek et al., 2006), 57.7% of this group recognized the risks whereas only 35.4% of the control group recognized the risks, a difference of 22.3 percentage points. When PC training was evaluated in this experiment four days after training, the difference between the trained and untrained group was 24.0 percentage points. Obviously one would like the training to persist more than four days. However, given that the great disparity in crash rates lasts only six months, the fact that there is no loss of the training effect over four days is a hopeful sign. More generally, one would like to see the results generalize to driving in the real world. Experiment 2 below is an attempt to answer this question.

As a final question, one might ask how the trained novice drivers compare to experienced drivers. In this experiment the trained novice drivers recognized 52.1% of the risks. This is almost identical to the percentage of risks that young experienced drivers (between the ages of 19 and 29) recognized (50.3%) and some 14% less than older more experienced drivers (66.2%) in a related experiment (Pradhan et al. 2005). We believe that further improvement in the training program is possible.

LIMITATIONS

The fixation of an area that is important because it signals a risk is not a *sufficient* condition for safe driving. The driver needs to recognize that a risk could occur and then, based on that recognition, needs to mobilize an appropriate response if he or she is going to avoid a crash. Thus, we do not know whether the training program will reduce crashes. Having said this, we have every reason to believe that the novice drivers who fixated a risky area in the near transfer scenarios recognized the particular risk that could occur because of the training that they had received. We are less sure that drivers who fixated a risky area in the far transfer scenarios understood the specific risk that might materialize. However, as noted immediately above, we believe that the trained drivers in the far transfer scenarios must have learned something general about the three classes of risks, enough to know that the area should be fixated because it was potentially risky (say could obscure their view of a potential threat), if not exactly enough to know how a risk might materialize. Regardless of whether the trained drivers recognized the specific risks in the risky areas upon which they fixated, we think that fixations upon risky regions are likely to be a *necessary* condition for safe driving. There is now quite a bit of research in scene perception indicating that objects in scenes can rarely, if ever, be identified unless there is a fixation quite near to the object (Hollingworth & Henderson, 2002; Nelson & Loftus, 1980). Thus, drivers who do not fixate the risky areas are much less likely to recognize a risk.

EXPERIMENT 2. EVALUATING TRAINING IN THE FIELD

Experiment 1 indicates that this training lasts at least a week using a slightly different version of RAPT (RAPT-2) evaluated on a driving simulator. In Experiment 2 we are interested in knowing whether the effects of training generalize to the open road. A new version of RAPT (RAPT-3) was used for the field training. Specifically, young drivers between the ages of 18 and 21 were trained in the laboratory using RAPT-3 and then their eye movements measured in a vehicle on the open road as they are driving through real-world scenarios similar to what they have seen on the driving simulator.

Unlike existing studies of drivers' eye movements in a moving vehicle which measure the variability of fixations (Crundall & Underwood, 1998; Mourant and Rockwell, 1972) or the distribution of fixations and likelihood of fixation transitions inside and outside of the vehicle averaged across several minutes of driving (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003), this study assesses whether a driver in a specific scenario fixates on a predefined region of risk at a particular point in time, just as in the driving simulator (Pollatsek et al., 2006; Experiment 1).

METHOD

PARTICIPANTS

The 24 participants were all recruited from the student body of the University of Massachusetts, Amherst campus. They were between 18 and 21 years old and all held a valid U.S. driver's license for at least one year. The 12 male and 12 female participants were separately randomly assigned to the trained group or the untrained group, so that there were 6 male and 6 female participants in each group. Due to the difficulty in calibrating the eye-tracker when people wear eye-glasses, all participants either had normal vision or vision corrected to normal with contact lenses.

TRAINING PROGRAM

The participants in the trained group were trained on PCs using the Risk Awareness and Perception Training (RAPT) program developed at the University of Massachusetts, Amherst. The current version (RAPT-3) was developed for this study. RAPT-3, like earlier versions of RAPT, was designed to illustrate different categories of scenarios that are hazardous (but with no obvious signal of danger) and to train drivers to focus their attention on critical regions that, if scanned, would reduce the likelihood of a crash.

RAPT-3 contained nine driving scenarios in which there was an inherent risk of a collision with another vehicle or pedestrian. The same three categories of risks occurred in RAPT-3 as occurred in earlier versions of RAPT. The scenarios were selected from a set used in our prior studies, but since perspective views had to be photographed, safety issues made it necessary to select only those that did not directly involve a moving vehicle as the inherent risk in a scenario. In addition, in order to portray several of the scenarios accurately, some staging with other vehicles was necessary so that all the elements in the scenario would appear in the snapshots. (The complete training program can be accessed at www.ecs.umass/hpl. Left click on younger drivers.)

The *hidden sidewalk* scenario illustrates the general idea of the training as it occurred in RAPT-3 (see Figure 5), as well as make it clear how this training differed from the training in RAPT-1 as discussed above. In this scenario, the driver is approaching an intersection with a stop sign. There is a pedestrian crosswalk at the intersection which is located after the stop line. The stop line and crosswalk are themselves relatively distant from the intersection with the road on which cross traffic travels. On the right just beyond the stop line there is a high hedge that hides a sidewalk which emerges onto the crosswalk. The risk is that a bicyclist or a pedestrian, hidden behind the hedge, could suddenly enter the crosswalk. The scenario is one that is difficult to predict as hazardous. When setting up the test course, the authors studied this particular test intersection in downtown Amherst. Of the 20 drivers they observed, all drivers both failed to stop at the stop line and look to the right as they passed by the bushes, instead proceeding over the crosswalk and directly up to the boundary with the cross road.

Figure 5. Hidden Sidewalk Perspective View

There is not room to present all of the 9 training scenarios in detail that appeared in RAPT-3, but we do want to say something about the other 4 training scenarios (in addition to the hidden sidewalk scenario) that actually appeared in the field course (what we label below as the *near transfer* scenarios; see the Web site for a more complete description of the RAPT-3 scenarios; www.ecs.umass.edu/hpl). In the *left fork* scenario, the sequence of still photographs showed a driver approaching a road on the left that was obscured by bushes and other vegetation. A sign well ahead of the road indicated that traffic was entering from the left. It was critical that the driver glance to the left for any potential traffic. In the *right turn* (*reveal*) scenario, the sequence of still photographs depicted a driver approaching a stop sign at a T intersection and then taking a right hand turn. The road to the left was visible for only a very short distance because it crested a hill and then dropped down out of sight. Thus, drivers had only a couple of seconds to see cars approaching from the left before turning right. It was critical that drivers look far to the left to the crest of the hill before taking a right hand turn. In the *left turn* (*reveal*) scenario, the sequence of still photographs showed a driver approaching a road on the left onto which a left turn was made. The main road ahead crested a hill and the driver had only a couple of seconds to see cars in the opposing lane coming over the hill as the left turn was being made onto the side street. It was critical that the driver look to the right while turning left to determine whether any cars had crested the hill. Finally, in the *abrupt lane change* scenario, the sequence of still photographs depicted a driver passing a row of cars stopped in the left hand travel lane waiting to take a left turn. There was a chance that one of the cars might abruptly change into the driver's lane. It was critical that the driver scan the row of cars occasionally to determine whether there was any movement suggestive of an abrupt lane change.

The RAPT-3 training program started with instructions and an initial practice section to familiarize the participant with the displays and the tasks they were to perform. This was followed by the three main sections of the training: pretest, training and posttest. In the *pretest* each scenario was presented as a sequence of snapshots displaying the driver's view from a vehicle traversing through a particular driving situation (see Figure 6, panels a - h). A scenario contained 5 to 12 snapshots depending on the length and complexity of the situation. Each snapshot was displayed for three seconds. The participants used the mouse to click on areas of each snapshot to which they would have to pay particular attention if they were actually driving through the scenario. The coordinates of the click and time at which the click was made were internally recorded by the program. In the pretest section the participants received no feedback on their performance.

Figure 6. Hidden Sidewalk Sequence of Stills: RAPT-3

Figure 6a. (1) Driveway; (2) Regulatory Sign; (3) Driveway

Figure 6b: (1) Regulatory Signs; (2) Driveway

Figure 6c. (1) Stop Sign; (2) Side Street

Figure 6d. (1) Crosswalk (2) Cross Traffic

Figure 6e: (1) Cross Traffic From Left; (2) Area From Which Hidden Pedestrian May Emerge

Figure 6f. (1) Cross Traffic From Left; (2) Crosswalk

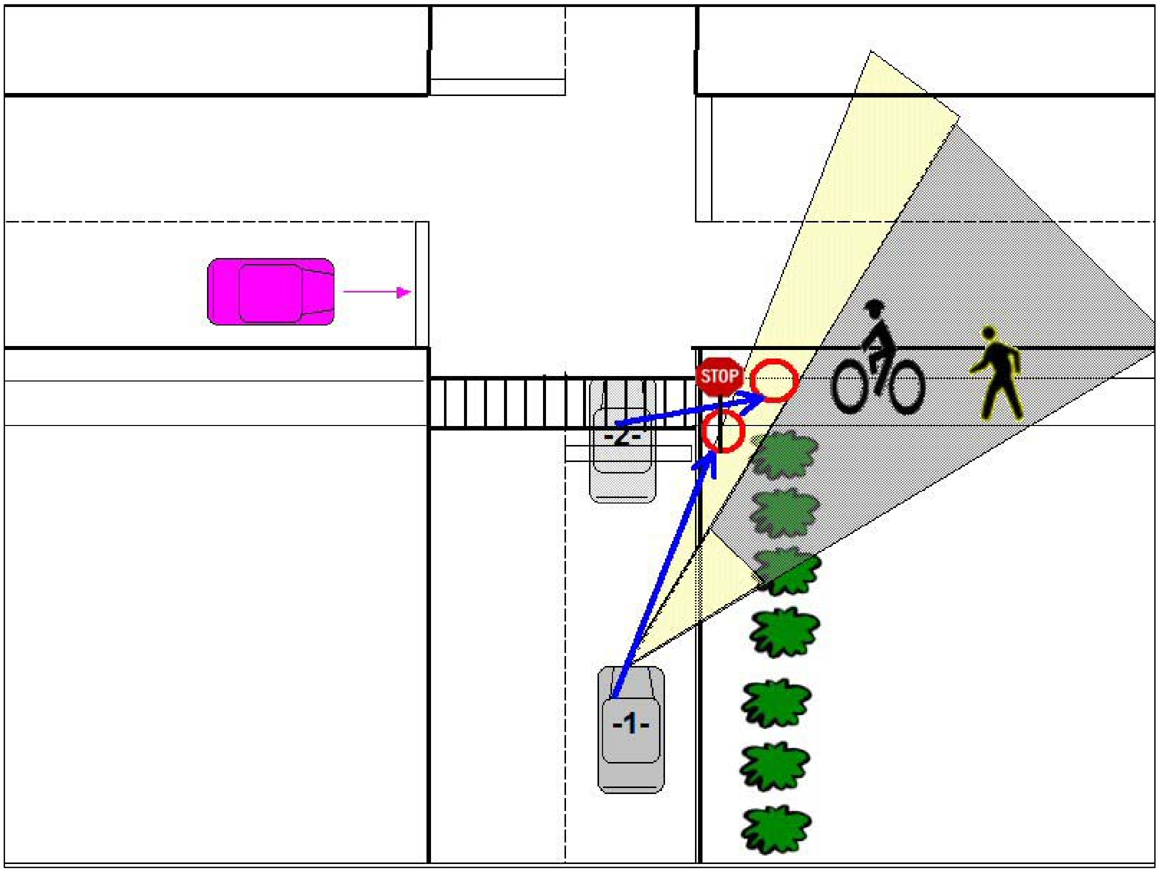
Figure 6g. (1) Left Side View

Figure 6h. (1) Right Side View – Cross Traffic; (2) Right Side View – Pedestrians And/Or Bicycles

The snapshots were generally of views straight ahead of the car, but in situations where it was necessary for a driver to look to the left or the right (e.g., at an intersection), the participant could click on buttons provided on the left or right margins of the snapshot which would show the corresponding left or right views (e.g., Figure 6h). These side views materialized only for situations where the driver would need to have a view of the left or right; the side view buttons were always displayed but clicking on them in other situations did not change the view. The red circles in the snapshots in Figure 6 represent the areas of risk upon which the participants were likely to click, but the main area of interest was the circle labeled "2" in Figure 6e.

The *training* came next. The user was first shown a top-down schematic view of a scenario accompanied with explanations about the risky aspects of the particular scenario (see Figure 7). This was similar to the plan views and explanations that were used in RAPT-1. After these explanations, the user was again presented with the sequence of perspective view snapshots for that scenario. As noted above, the relevant responses (clicks of the mouse) in a snapshot were internally recorded as correct if they were positioned in the critical area; otherwise they were recorded as incorrect. The size and location of the critical areas varied according to the scenarios, with scenarios having smaller or larger areas according to the various factors regarding the possible risk. These areas were always rectangular and included a slight tolerance to account for mouse positioning inaccuracy. If the user could successfully identify the critical areas, the program moved onto the next scenario. If not, the user was taken back to the training part of the scenario with the schematic view and corresponding explanations. The user was given up to four opportunities to identify correctly the areas of risk on the sequence of snapshots using the mouse.

Figure 7. Plan View of Hidden Sidewalk Sequence



Finally, in the *post-test* section, the user was once again presented with the nine sequences of photographs and asked to use mouse-clicks to identify areas of potential risk. As in the pre-test, the click coordinates and times were recorded for this section and no feedback was provided to the user. (We did not use the times in scoring.)

The training program was presented on a laptop computer running Microsoft Windows XP using a mouse as the pointing device. It was developed using Macromedia Director and was designed to operate on any Microsoft Windows operating PC. Although the program was a single executable file and can be deployed on CD-ROMs or over the Internet, it was administered on the same computer in the driving laboratory to all trained participants.

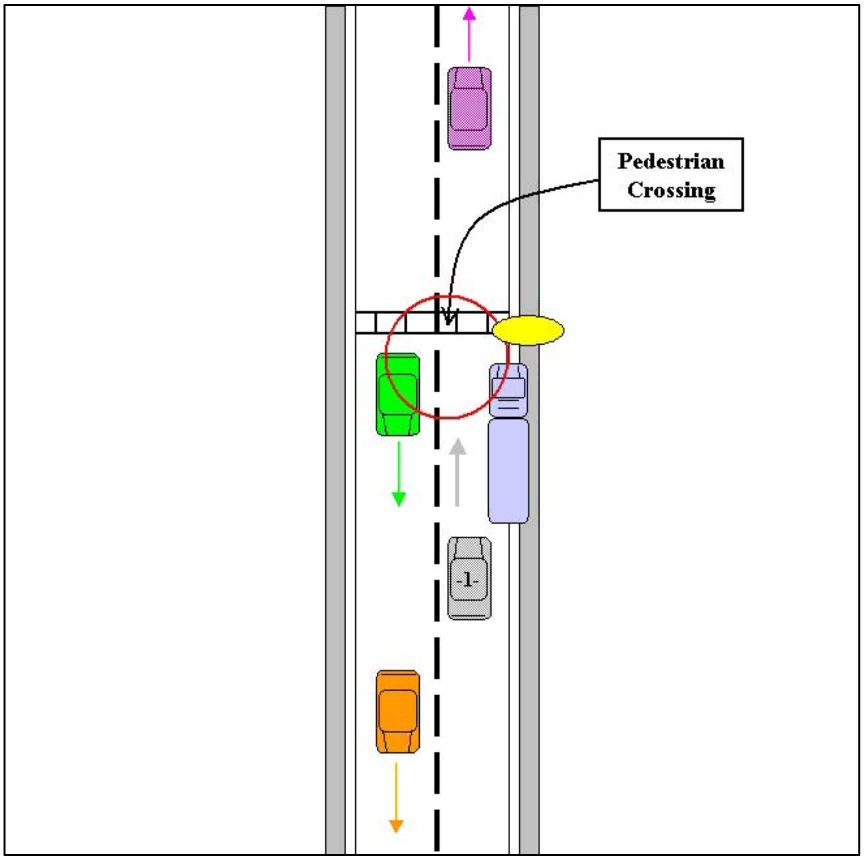
FIELD DRIVING ROUTE

The route driven by the participants was a 16-mile course plotted in and around Amherst, Massachusetts, and it included major arterials, a variety of intersections, and covered rural, residential, city and highway driving situations. It was designed to include 10 situations of interest (*scenarios*) that would be analyzed. They were all embedded naturally within the driving course so that the participant had no indication that these were the primary areas of interest to the researchers. Five of the scenarios, the *near-transfer scenarios*, were the same concept as scenarios in the training program; four of them involved photographs of the same location and the other one involved basically the same scenario as in training but in a different location.

The remaining 5 scenarios, the *far-transfer scenarios*, were different from the scenarios that were seen during training but embodied similar concepts. For example, one of the far transfer test scenarios (*truck crosswalk*) involved a truck parked with its front end just before a crosswalk so that pedestrians would be hidden until just before they appeared in front of the test vehicle (see Figure 8)[2]. This is clearly similar to the hidden sidewalk scenario described above (see Figure 7) in that there is an object that may be occluding a pedestrian, but the occluding object is a truck rather than the hedge in the training scenario. Another of the far transfer scenarios also involved a truck (*truck blocking travel*), this time one parked on the side of a road in a suburban area of town. In this case, the truck driver may have emerged from in front of the truck suddenly and so have presented a similar danger to the participant. Again, this is similar to the near transfer hidden sidewalk scenario. Two of the far transfer scenarios (the *blind driveway* and *curved stop ahead* scenarios) involved a warning sign which indicated to drivers that they needed to pay particular attention to the roadway ahead. Both were similar, but certainly not identical, to the near transfer left fork scenario. Finally, in the fifth far transfer scenario (*hidden drive),* a driveway leading onto the road is situated such that even though the road itself is evident to the drivers, the drivers' view of possible emerging cars is obstructed due to vegetation and/or parked vehicles. The drivers have to be aware of this occlusion and pay particular attention to these driveways for suddenly emerging vehicles. This particular scenario is also similar to the hidden sidewalk scenario except that the vegetation is occluding possible vehicles rather than pedestrians.

[2] This scenario was used in earlier versions of our training program. However, it was not used in the current training program, but was used as one of the test scenarios.

Figure 8. Plan View of Truck Crosswalk Scenario



Ten measures were extracted from these scenarios, one from each of the five near transfer scenarios and one from each of the five far transfer scenarios. In particular, the driver was scored as recognizing the potential threat if he or she looked at the location from which a threat might emerge; otherwise the driver was scored as not recognizing the threat.

APPARATUS

A portable lightweight eye-tracker (Mobile Eye developed by Applied Science Laboratories) was used to collect the eye-movement data for each driver during the on-road drives (Figure 9). It has a lightweight optical system consisting of an eye camera and a color scene camera mounted on a pair of safety goggles. The images from these two 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 are converted to a crosshair, representing the driver's point of gaze, which is superimposed upon the scene video recorded during the drive. This provides a record of the driver's point of gaze on the driving scene while maneuvering the on-road driving course. The remote recording system is battery-powered and is capable of recording up to 90 minutes of eye and scene information in a single session. This eye tracker records data at 30 Hz and has a system accuracy of 0.5 degrees visual angle and a resolution of 0.1 degrees visual angle.

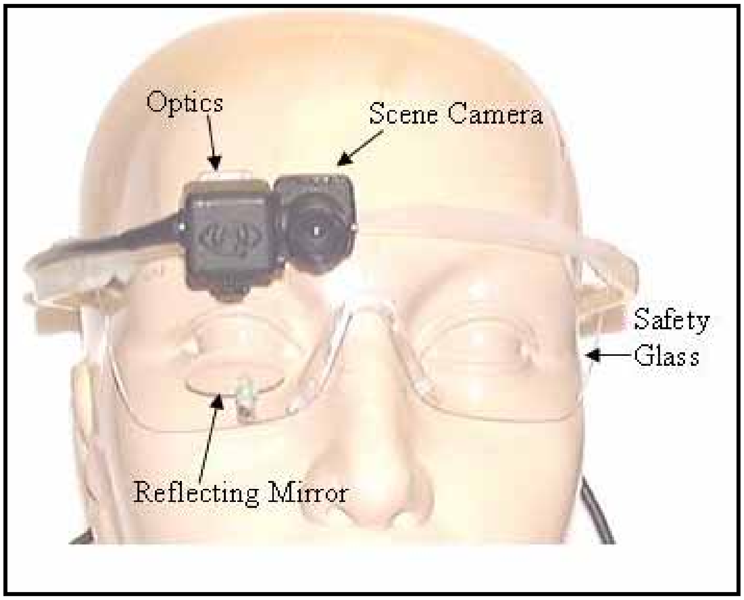


Figure 9. ASL Mobile Eye

Each participant drove a four-door sedan with automatic transmission (a 2002 Chevy Prizm or a 2000 Chevrolet Cavalier). The vehicles were rented from a local area driving school and had a secondary braking system that could be operated by a certified driving instructor (who was sitting in the front passenger seat solely for safety reasons).

PROCEDURE

All the participants first completed an informed consent form. The participants in the trained group were then given written instructions about the training program after which they completed RAPT-3 on a PC. The program took about 30-45 minutes to finish. The participants in the control group did not take part in the training program.

Immediately after completing RAPT-3, the participants from the trained group were given written instructions about the on-road driving part of the study. The instructions touched on basic traffic safety (e.g., posted speed limits and traffic rules) and emphasized that the driver should keep conversation or other interaction with the driving instructor or the researcher in the car to a minimum. The participants from the control group were given these same instructions as soon as they came to the laboratory. The driver (control or trained) was then fitted with the eye-tracker and the necessary calibration process was carried out, which took about five minutes. The participant then drove through the course with the driving instructor in the front passenger seat and a researcher in the back seat. The researcher provided the participant with information about where to turn at appropriate points in the course. The drive through the entire course took about 45-55 minutes to complete. To control for time-of-day effects and traffic conditions, the drives were all at 9am or 10 am on weekdays. The eye-tracking system recorded the point of gaze data, which served as the primary dependent measure, along with a video record of the driver's view of the roadway during the entire drive.

Other than telling the driver where to make turns, the drive was not scripted in any way except that the parked truck in the truck blocking travel far-transfer scenario was placed there by an experimenter. The only other way in which the experimenter perturbed the drive was when the calibration was lost because the safety glasses on which the optics were mounted shifted, either due to a sudden motion of the car or because the participant inadvertently touched the glasses. In that case, the participant was told to pull over to the side of the road as quickly as convenient and then glasses were recalibrated. This occurred only four times among all participants.

RESULTS

The novice drivers who were trained with RAPT were more likely in the field to glance at the critical areas in both the near and far transfer scenarios. The difference was larger in the near transfer scenarios (38.1%) than in the far transfer scenarios (17.9%); however, both differences were sizable and statistically significant.

One measure of the effectiveness of the RAPT training is a comparison of the post-test scores with the pre-test scores for the experimental group. This is, in some sense, a manipulation check: an indicator of whether the participants were attending to the training and learned where the areas of potential risk were and could demonstrate this knowledge on perspective views in a PC-based environment. In fact, there was a large improvement from pre-test to post-test: 32.4% correct vs. 80.6% correct, $t(11) = 9.60$, $p < .001$.

The more important issue, of course, is whether the knowledge acquired during training is applied in on-road driving. The eye-movement data were analyzed for all drivers at the predetermined locations in the on-road course that we are terming *scenarios*. Specifically, the eye-movement fixations were identified and the coordinates of the point of gaze were converted to a crosshair that was superimposed on a video of the scene. This point of gaze information was then manually analyzed for the presence of fixations on certain, pre-determined areas or objects of interest in the scenarios (the *target zones*) at pre-determined driver and vehicle positions (the *launch zones*). Stringent guidelines were laid out to define these areas of interest (i.e., the target and launch zones) and the appropriate patterns of fixations for each particular scenario. These areas of interest were those from where a driver could extract important information regarding any probable risks present in the scenario. For example, in the hidden sidewalk scenario we recorded whether the participant looked at the left hand edge of the bushes (Figure 6e, the area indicated by the arrow labeled 2). A binary scoring method was used for recording the glance behavior of the drivers. If a driver exhibited the pre-defined appropriate eye-movement behavior for a scenario (i.e., the target area of potential risk was fixated upon by the driver when the driver was in the launch zone), the driver was assumed to have recognized the areas of probable risk in the scenario and was given a score of “1” for that scenario. If the eye movement pattern did not cover the area of potential risk while the driver was in the launch zone, the driver was given a score of “0” for that scenario.

Initially, the scoring was conducted independently by three different raters. To prevent observer bias, the raters were blind with respect to which group (trained vs. untrained) the driver was assigned. The raters agreed on the rating in a large majority of cases because the difference in behavior between glancing appropriately and not glancing appropriately was not subtle. In almost all cases, a score of 0 meant that the driver continued to look straight ahead. Moreover, in virtually all of the scenarios, a score of 1 meant that the driver looked at least 5 degrees to the left or right (whichever was appropriate for that scenario). In the relatively small minority of cases where the raters did not all agree on the score (see below), they went over the data from the scenario together to determine whether they could reach a consensus. When they could, that consensus score was used; when they could not reach consensus, the data from that scenario for that participant was not used (usually because something like glare made the eye movement pattern difficult to score). There were some other scenarios that were not scored for a particular driver because the potential risky situation did not materialize for that driver (for example, the abrupt lane change scenario depended on cars being in the lane to the left of the driver and some of the time there were no such vehicles). However, the number of trials not scored was relatively small and about the same for the two groups (16 for the trained group and 18 for the untrained group out of a total possible of 144 measures in each group – 12 measures for each of the 12 participants).

The trained group was almost twice as likely to glance at the pre-defined area of risk on the road in a scenario (60.6%) as the untrained group (31.8%), $t(22) = 4.58$, $p < .001$ (a difference of 28.8 percentage points). As indicated above, the scenarios in the on-road course were divided into near-transfer and far-transfer scenarios. Analyzed separately, the training effect was significant for both sets of scenarios. For the five near transfer measures that were entered into the analysis, the difference between trained (72.7%) and untrained (34.6%) drivers was 38.1 percentage points, $t(22) = 5.36$, $p < .001$, and for the five far transfer measures, the difference between the trained (46.0%) and untrained (28.1%) drivers was 17.9 percentage points, $t(22) = 2.62$, $p < .01$. In addition, the results were quite consistent across scenarios (see Table 1): the trained group scored higher than the untrained group for each of the five near transfer measures and for four of the five far transfer measures. Gender differences were very small (t statistics < 0.5). Averaged over trained and untrained drivers, the score for men was 3.8 percentage points higher (52.2% vs. 48.4%) and the difference between trained and untrained drivers was 5.0 percentage points larger for women (29.9% vs. 24.9% training effects).

Table 1. Comparison of Trained and Untrained Groups on Individual Scenarios: Field[3] Study

	Scenario	**Name**	**Performance in Trained Group**	**Performance in Untrained Group**	**Percentage Point Difference Between Trained and Untrained**
Near Transfer	**1**	Left Fork	50.0%	18.2%	31.8%
	3	Right Turn (Reveal)	75.0%	58.3%	16.7%
	4	Left Turn (Reveal)	100.0%	41.7%	58.3%
	8	Abrupt Lane Change	55.0%	25.0%	30.0%
	9	Hidden Sidewalk	75.0%	25.0%	50.0%
Far Transfer	**2**	Blind Driveway	36.4%	8.3%	28.0%
	5	Truck Blocking Crosswalk	28.8%	4.2%	24.6%
	6	Hidden Drive	20.0%	36.4%	-16.4%
	7	Curve Stop Ahead	62.5%	57.1%	5.4%
	10	Truck Blocking Travel	90.0%	62.5%	27.5%

[3] Note that the average of the scenarios is not exactly the same as the average over participants reported in the text because of missing data cells.

DISCUSSION

The results of Experiment 2 clearly indicate that the RAPT-3 training procedure was effective in changing where the inexperienced licensed younger drivers looked during potentially hazardous situations on the road. We think this is noteworthy, as the training took less than an hour and was in an environment quite different from actual driving (i.e., on a PC making manual responses unrelated to those in driving). We want to make four additional comments on these findings and then discuss a few more general concerns.

First, we are claiming that the untrained younger drivers did not know that the situations in these scenarios were potentially hazardous rather than that they knew the situations were hazardous but were too involved in the driving task to recognize or respond to them as such. The reasoning is as follows. If limitations due to driving skill were the cause of the poor performance of the untrained drivers, the trained novice drivers should also have been too involved in the driving task as well to fixate appropriately in the scenarios. In fact, it does not appear that the difference in the driving skills of novice and experienced drivers had any impact on the absolute performance of the trained novice drivers. Specifically, in our tests on the simulator, trained younger drivers in one study (Pollatsek, 2006) performed as well as (untrained) experienced drivers did in another study on the same set of scenarios (Pradhan, 2005).

Second, we found that tactical training produced benefits on the road not only in those scenarios which resemble the ones that have been trained on the PC, but also in scenarios which are quite dissimilar from those that have been trained on the PC except for the defining characteristics of the three categories of scenarios. We can ask at this point whether the trained drivers were scanning more in general than the untrained drivers or instead were scanning only in the areas where the risk was highest. The latter would suggest that the tactical training does not spill over into a more general strategy of looking to the side more often, whereas the former would suggest the possibility that the training largely taught drivers generally to scan more widely and more frequently. For example, Chapman et al. (2002) found that their training produces drivers who scanned more frequently in all situations, and not just in more risky situations. (The latter is not necessarily a bad thing as long as the drivers aren't too distracted from fixating on the road in front of them.)

In order to test whether the training produced situation-specific changes in eye-movement behavior, we analyzed the videotapes of trained and untrained drivers in (control) areas of the roadway where there were no obvious risks and compared these data to the scenarios we have reported above where there were potential risks. In some of the experimental scenarios, the appropriate response was to scan to the left. We found that the trained drivers scanned to the left more often than they scanned to the left in control portions of the scenario (see Table 2; a difference of 24.8 percentage points). Similarly, in other scenarios, the appropriate response was to scan to the right, and in these scenarios, they scanned to the right when such can reduce the likelihood of a crash more often than in the control regions (a difference of 29.6 percentage points). The average of these two scores was computed for each participant (this average presumably measures how much more they are looking at the appropriate place in the hazardous scenario than in the control nonhazardous scenario). The value of this average for the trained participants was 27.2%, $t(10) = 3.92$, $p < .005$, whereas for the untrained participants, it was 10.6%, $t(10) = 1.84$, $p > .05$. Thus, we can conclude that training caused the trained participants to look to the appropriate side in the scenario. The data for the untrained participants indicates that they are not performing at chance and are looking at the right spot a bit more than one would predicted by their base rates of general scanning.

Table 2. Percent of Times that Trained and Untrained Drivers Looked to the Left and Right in Hazardous and Nonhazardous Scenarios

Side	Condition		
	In scenario	**Not in scenario**	**Percentage Point Difference**
	Experimental (Trained) Participants		
Left	52.7%	27.9%	24.8%
Right	54.3%	24.7%	29.6%
Average			27.2%
Control (Untrained) Participants			
Left	27.3%	18.2%	9.1%
Right	30.3%	18.2%	12.1%
Average			10.6%

Third, although we found that the training produced a 28.7-percentage-point improvement overall, the trained drivers were still appropriately responding to only 60.6% of the risks in the near and far transfer scenarios. This figure could be increased considerably, we assume, if we trained drivers on a larger sample of potentially risky scenarios. Note that in the near transfer scenarios, the trained drivers recognized 72.7% of the risks. However, the rate was considerably less (46.0%) in the far transfer scenarios, the ones that had not specifically been trained on the PC. Nonetheless, when training was evaluated on our driving simulator, the overall performance of the trained inexperienced drivers was approximately equal to that of experienced drivers. This comparison may be compromised because we might expect drivers to behave differently on the simulator than they do on the road. These are serious concerns that we will address below.

Fourth, we should note that the above findings address an additional potential weakness with the evaluation of the effects of training on the driving simulator. During the evaluation, the participants were asked to take a break three times in the middle of testing (to reduce simulator induced vertigo). Perhaps during these breaks they were able to reflect back on their training, something that would not be as easy were the simulated drive a continuous one. However, the field study, which was a continuous drive, and potentially still more demanding, did not show a reduced effect of training. Thus, it does not appear like the presence of breaks on the driving simulator magnified the effect of training.

LIMITATIONS

First, one might be concerned that drivers may simply have been matching what they saw in the perspective views of RAPT-3 with what they saw in the real world and didn't really learn anything about hazard anticipation in general. This concern arises because some sequences of perspective views used in the PC-based training in the present study (e.g., Figure 6) were very similar to what the driver might have seen out in the field (depending on the time of day, what traffic was present, and so on). However, there was strong evidence of learning in the far transfer scenarios where there were no surface features in common between the test scenario and any of the training scenarios. Second, one might be concerned that the present effects of training are as strong as they are because the participants had the road test immediately after training. Perhaps if the evaluation had been done several days after training the effects would not have been so large.

The effects of an earlier version of our training program (RAPT-2) were as large when the simulator test was several days after training (Pradhan et al., 2006) as when the simulator test was immediately after training (Pollatsek et al, 2006). Given that it appears that the effects of training are virtually the same when tested on the road as when tested on the simulator, there is no reason to expect that the effects of training would dissipate any faster in the road test than in the simulator test. There is no reason to expect that the effects of the RAPT-2 training would endure for several days, but not the RAPT-3 training, because both used plan views to explain why it was that a scenario was potentially hazardous.

Third, one might have some concern that the results from this study where the participant is riding with a driving instructor may not transfer to situations in which the participant was not riding with a driving instructor. In this study, both the trained and untrained drivers had a driving instructor in the front seat and the experimenter in the back seat. Thus, any effects due to the driver being on their best behavior should occur in both groups.

Fourth, a recent study published by Sagberg and Bjørnskau (2006) suggests that hazard perception is only a minor factor in the rapid decrease in crash risk observed among newly licensed drivers, a claim directly counter to what we are arguing. As such, it is important to understand the difference between what they did and what we did. Briefly, the hazard detection perception/response times of licensed younger drivers 1, 5 and 9 months post licensure to critical situations which appeared in videos were compared with those of much more experienced drivers (on average 27.1 years post licensure, a minimum of 10). Overall, there was no difference in the response times of the novice and experienced drivers averaged across 31 critical situations. Everything else being equal, we would have predicted much longer response times for the novice drivers. However, a more detailed analysis of their scenarios indicates the potentially critical source of the difference. In their scenarios, the hazards were always moving and usually obvious. In our scenarios, the hazards were never moving and almost never visible (only potential threats). Consistent with this interpretation, when looked at individually, the novice drivers in the Sagberg and Bjørnskau (2006) study were slower to respond in six of the 31 critical situations. As we would predict, most of these were situations in which for the most part it appears that the hazard materialized at the last minute and therefore would have been difficult to anticipate. Another aspect of the study that we should mention is that participants were merely watching a video and making manual responses; thus the hazard detection task was not competing with other tasks – as it is when one is driving.

Fifth, one might be concerned that the results we obtained were with drivers between the ages of 18 and 21 and would not be obtained with younger drivers between the ages of 16 and 17, the population of drivers in which we are most interested. This may well be true and is clearly an empirical question. All of our evidence suggests to date that we would expect to find larger training benefits with the younger teens (16 and 17). This is because experience does improve drivers' hazard anticipation skills and so older teen and young adult drivers (18 to 21) are already better at anticipating hazards than younger teen drivers (Pradhan et al. 2006). Thus, they are already closer to criterion performance and so the absolute difference between their baseline and criterion performance must necessarily be smaller than this differences is for 16- and 17-year-old teen drivers.

Finally, the current study does not allow us to conclude that the PC-based training program is successful in reducing crashes. Training drivers to look in the right place when they come to a potentially hazardous situation does not guarantee that they will be able to avoid a crash, but not looking in the right place almost certainly guarantees that they will not react to the risk appropriately. The evidence from many cognitive psychology experiments on scene perception indicates that even though viewers can quickly get the gist of an entire scene from a brief glance (e.g., Potter, Staub, Rado, & O'Connor, 2002; Boyce & Pollatsek, 1992), objects have to be fixated in order for their identities to be registered and remembered even seconds later (e.g., Henderson & Hollingwsorth, 1999). Thus, we feel confident in positing that although fixating appropriately during a scenario doesn't guarantee that the driver will take appropriate action if the risk in fact appears, not fixating appropriately during the scenario virtually guarantees either that the driver will not take appropriate action if the risk appears or take some hurried action that could actually make things worse (e.g., swerving into an incoming car).

EXPERIMENT 3[4]. COMPARING TRAINING EFFECTS ON A DRIVING SIMULATOR AND IN THE FIELD

Eye behaviors have been used on a driving simulator to evaluate: (a) the effectiveness of novice and older driver training programs (Romoser, Fisher, Mourant, Wachtel & Sizov, 2005; Pollatsek et al., 2006), (b) signs, signals and pavement markings (Knodler & Noyce 2005), and (c) electronic devices operated inside the vehicle cabin including cell phones (Muttart, Fisher & Pollatsek, in press; Strayer & Johnston, 2001) and intelligent vehicle information systems (Victor, Harbluk & Engström, 2005). Driving simulators are often favoured when drivers must be placed in risky situations. Yet, there has never been a study of whether the eye behaviors that are observed on a driving simulator in risky scenarios are also observed in the field. To remedy this, we had both trained and untrained young drivers with one year of driving experience maneuver a relatively restricted set of 10 scenarios on a driving simulator that were similar to ones that a different set of matched drivers had gone through on the open road (Experiment 2). Five scenarios were the direct focus of training (near transfer) and the other 5 were used to evaluate transfer of training (far transfer). Drivers who looked in the region of a scenario where they could gather information which would reduce their likelihood of a crash were scored as recognizing the risk. Among the untrained young drivers, 39% tested in the field recognized the risk compared with 37% tested in the simulator. Among the trained young drivers, 63% tested in the field recognized the risk compared with 76% tested in the simulator. Perhaps of more significance, on the near transfer scenarios a very similar increase in the percentage of participants scanning appropriately was observed in the field and on the simulator.

METHOD

The simulator experiment used the same training program as the field experiment (RAPT-3). Furthermore, the test (which had 18 scenarios) contained 10 scenarios that were similar to the 10 field scenarios, five of which were classified as near transfer simulator scenarios and 5 of which were classified as far transfer simulator scenarios. The same simulator was used here as was used in Experiment 1 (see Figure 1). The same eye tracker was used that was used in Experiment 2.

PARTICIPANTS

A total of twelve participants, six men and six women, were all recruited from the student body of the University of Massachusetts, Amherst campus. They were between 18 and 21 years old and all held a valid U.S. Driver's license for at least one year (the same age range used in Experiment 2, the field study). Equal numbers of men and women were assigned to the trained and untrained groups. Again, because of difficulties with the eye-tracker calibration, no participants were

[4] Fisher, D. L., Pradhan, A. K., Pollatsek, A., & Knodler, M. A. Jr. (in press). Empirical evaluation of hazard anticipation behaviors in the field and on a driving simulator using an eye tracker. *Transportation Research Record*.

recruited who wore eyeglasses. The mean ages of the control and the experimental group were 20.28 and 19.71 respectively, with standard deviations of 0.57 and 0.85.

DRIVING SIMULATION

The participants in both groups were evaluated on the simulator. They were given written instructions and verbal instructions with respect to driving in the simulator at the beginning of the session. They were then fitted with the ASL Mobile Eye eye-tracking system and the calibration process was completed. Once the eye-tracker had been calibrated, the drivers were asked to drive a practice scenario. This scenario was designed to contain all the elements of the virtual environment that a driver would experience during the actual experimental scenarios including intersections, traffic situations and other elements. This practice scenario also served to accustom the participant to the specific handling characteristics of the vehicle used in the driving simulator. The participants were encouraged to drive the practice scenario as many times as necessary until they were comfortable with vehicle handling, especially left and right turns and braking situations.

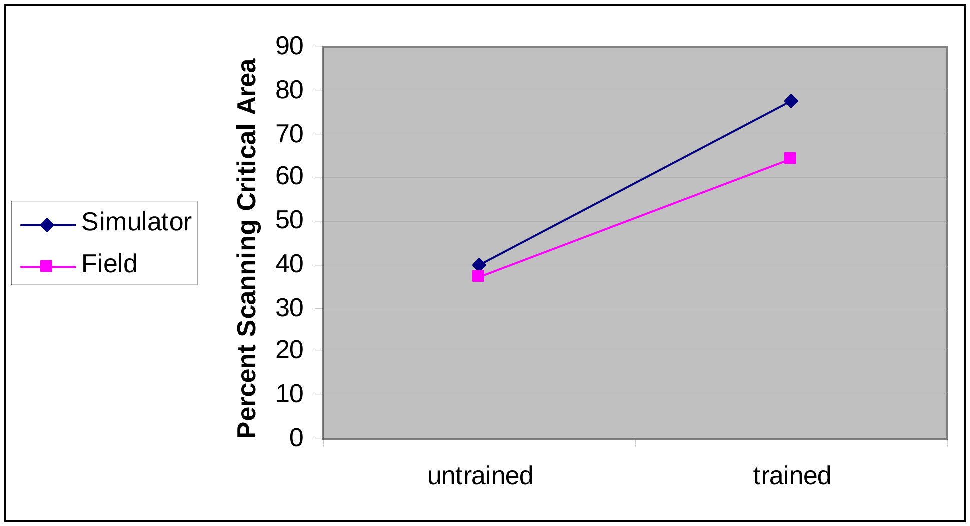
There were 18 experimental scenarios in the driving simulation. These scenarios were laid out in three blocks of six scenarios each. The blocks were counterbalanced evenly within the groups. The 18 scenarios were comprised of 9 of the scenarios that were used for the PC training, the near-transfer scenarios, and 9 other scenarios that were different from those used in the training, the far-transfer scenarios. The far-transfer scenarios were used to test for possible generalization of the PC training. The databases were designed such that each block contained three near-transfer and three far-transfer scenarios. The participants drove through the three blocks with rest between blocks. During the entire drive the eye-movements of the participants and various vehicle parameters were constantly being recorded.

Of the 18 scenarios that were presented to the participants in the driving simulator, 10 of the scenarios were similar to the scenarios in the field study (Experiment 2), 5 near-transfer and 5 far-transfer. The scenarios were all embedded in the three blocks with stretches of regular driving between scenarios. The experimental scenarios were all located and designed in such a manner that it would not be obvious to the participant that he or she was traversing an area of interest to the researcher.

RESULTS: SIMULATOR AND FIELD

Averaged over all 18 scenarios, there was a large and significant effect of the RAPT-3 training. There was an overall training effect of 37.4 percentage points, $t(22) = 4.12$, $p < .001$; the trained group fixated the critical region 77.4% of the time, whereas the control group fixated the critical region only 40.0% (see the blue line in Figure 10). The training effect was 41.7 percentage points for the 9 near transfer tests (77.4% vs. 35.7%) and 32.6 percentage points for the 9 far transfer tests (76.8% vs. 44.2%), $t(22) = 4.96$, $p < .001$, and $t(22) = 2.88$, $p < .01$, respectively. Although the training effect appeared to be somewhat larger for the near transfer scenarios, the 11.6 percentage point difference between the two training effects was not significant, $t(22) = 1.02$, $p > .20$. The overall training effects were somewhat larger than the overall averages observed in the field study. In the field study the training effect was 27.1 percentage points (64.4% vs. 37.3%; pink line, Figure 10), the near transfer effect was 38.8 percentage points (79.2% vs. 40.4%), and the far transfer effect was 20.1 percentage points (58.3% vs. 38.2%). All three training effects in the field study were significant. The near transfer effect was only marginally significantly bigger than the far transfer effect ($p < .10$).

Figure 10: Percent Scanning Critical Region in Simulator and Field Studies as a Function of Training.



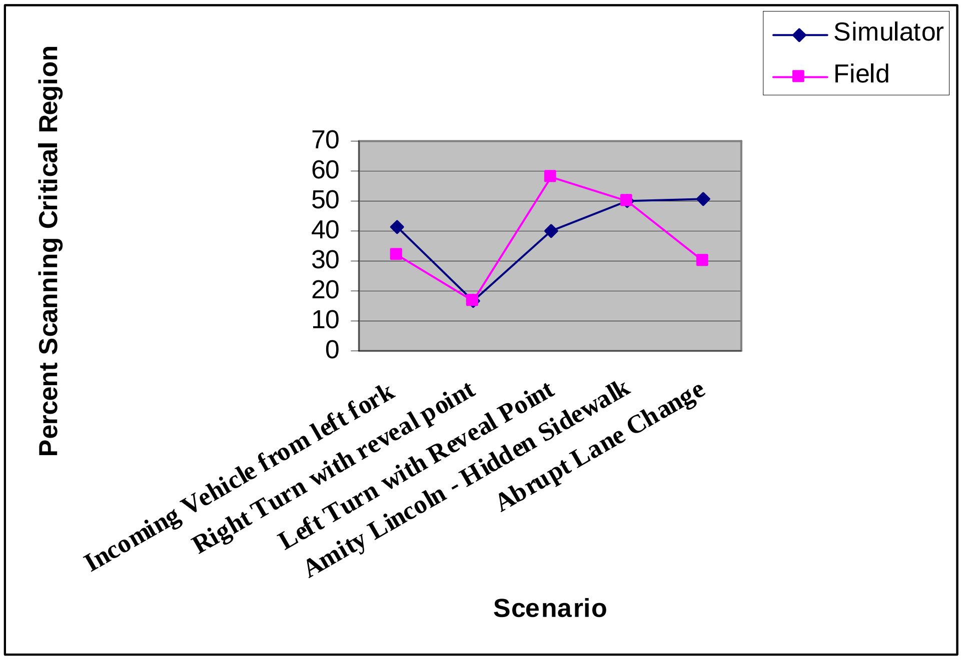
The results of Experiments 2 and 3 appear to be reasonably comparable, although the overall performance appears to be slightly better in the simulator data and the training effect appears to be somewhat larger in the simulator data (Figure 10), especially for the near transfer tests. However, the above comparison is of all 18 scenarios in the simulator study with the 10 scenarios in the field study. Thus, a better comparison would be of the data from the scenarios that the two studies shared and for which the very similar scoring criteria were used. Although we had devised 10 of the scenarios in the simulator study to be similar to the scenarios in the field study, when we were scoring the data, we realized that two of the far transfer studies were really not comparable between the studies.

The pattern of data from this "purified" set is quite similar to that of the overall data above, as the near transfer effect was about the same in the field and simulator studies and the far transfer advantage was somewhat bigger in the simulator study. The near transfer effects averaged over the five scenarios were 37.4 percentage points (71.0% vs. 33.6%) for the field study and 41.3 percentage points (70.6% vs. 29.3%) for the simulator study; the far transfer effects averaged over the three remaining scenarios were 26.5 percentage points (51.7% vs. 25.2%) for the field study and 41.7 percentage points (77.8% vs. 36.1%) for the simulator study. To assess whether any of these differences between the field study and the simulator study were reliable, we did another analysis using the means for individual participants on either: (a) all 8 scenarios (b) the 5 near transfer scenarios or (c) the far transfer scenarios. In these "purified" analyses, the 95% confidence intervals for the differences in the training effect (simulator study minus field study) were: 12.4% ± 25.0% (percentage points) over all eight scenarios, 3.9% ± 26.4% (percentage points) for the near transfer scenarios, and 28.9% ± 36.6% (percentage points) for the far transfer scenarios.

Finally, we made a comparison of the training effects in the field and on the simulator, scenario by scenario, for both the near and far transfer scenarios. (We focused our detailed analyses on just the near transfer scenarios because there were only three far transfer scenarios and as clear from the standard error in the prior paragraph, there was quite a bit of variability.) The training effects corresponded quite well in each scenario (field study vs. simulator study): 31.8% vs. 41.6% (incoming vehicle from left fork), 16.7% vs. 16.7% (right turn with reveal point), 58.3%

vs. 40.2% (left turn with reveal point), 50.0% vs. 50.0% (Amity Lincoln -- hidden sidewalk), and 30.0% vs. 50.8% (abrupt lane change). (The standard error for each of these comparisons is about 16%.) These results are graphed in Figure 11 below to help the reader better visualize the correspondence (also see Table 3 on page 31). (The averages of the individual scenario data are somewhat different from the average near transfer data reported above because the latter were first averaged over participants for each scenario and there is some missing data.)

Figure 11: Percent Scanning Critical Area in Simulator and Field Studies as a Function of Scenario



DISCUSSION

Experiment 3 indicates that, overall, there is a close correspondence between the hazard anticipation behaviors of drivers in the field and on a simulator. This correspondence holds both for young drivers who were not trained to anticipate hazards and young drivers who were trained to anticipate hazards (Figure 10). The correspondence is rather remarkable given the large number of differences between the environment in the laboratory (the driving simulator study) and the environment on the road (the field study), not the least of which is the very real danger present when a driver is actually maneuvering a vehicle on the open road. Not only is there a close similarity overall between the hazard anticipation behavior of trained and untrained novice drivers in the field and on the simulator, but this correspondence extends to individual scenarios.

LIMITATIONS

This study looked at the hazard anticipation behavior of only two groups of young drivers, those who received and did not receive hazard anticipation training. Other groups of drivers may perform differently in the field and on the driving simulator. Similarly, there are many other eye behaviors that one could have measured besides those central to hazard anticipation behavior. Again, these behaviors may differ in the field and on the driving simulator.

Table 3. Comparison of the Trained and Untrained Groups on Individual Scenarios in the Simulator Study[5]

	Scenario	Name	Performance in Trained Group	Performance in Untrained Group	Percentage Point Difference Between Trained and Untrained
Near Transfer	**3**	Left Fork	58.3%	16.7%	41.7%
	5	Right Turn (Reveal)	75.0%	58.3%	16.7%
	8	Left Turn (Reveal)	58.3%	18.1%	40.2%
	17	Abrupt Lane Change	77.7%	20.0%	57.7%
	13	Hidden Sidewalk	83.3%	33.3%	50.0%
Far Transfer	**9**	Blind Drive	91.7%	58.3%	33.3%
	6	Truck Blocking Crosswalk	75.0%	33.3%	41.7%
	16	Hidden Drive	91.7%	50.0%	41.7%
	14	Curve Stop Ahead	91.7%	17.0%	74.7%
	11	Truck Blocking Travel	66.7%	16.7%	50.0%

Of course, while the training programs do provide a clear benefit for young drivers, to the point where they anticipate hazards as well as drivers with on average with 10 years more experience on the road, the young drivers still do not perform as well as one might like on all of the scenarios. Just looking at the results from the simulator, in Experiment 3 (RAPT-3), there were 2 out of 9 of near transfer scenarios in which under 60% of the trained young drivers looked at the critical region. In Experiment 1 (RAPT-2), there were 7 out of 10 of the near transfer scenarios in which under 60% of the trained young drivers looked at the critical region. Perhaps RAPT-3 places some speed stress on the participant since each photo is displayed for only three seconds, and it gives the participant a perspective view as well as a plan view. This suggests that more improvements could be had were the RAPT program to be made even more realistic.

EXPERIMENT 4.[6] EVALUATING SIMRAPT

A new, more realistic training program on risk perception was developed and then evaluated in a driving simulator, a training program that went considerably beyond the first three versions of RAPT. This new training program included two elements. The first element was the PC-based Risk Awareness and Perception Training program (RAPT-1). Plan views of risky scenarios were

[5] Note that the averages of the scenarios are not exactly the same as the participant averages reported in the analyses in the text because of missing data cells.)

[6] Based on a master's thesis submitted by Frank Diete to the Graduate School of the University of Massachusetts at Amherst: *Evaluation of a simulator based, novice driver risk awareness training program*, September 2007.

used to explain to participants the location of potential hazards. The second element of the training (SIMRAPT) was newly developed for this study and used the portable low-cost driving simulator Drive Square Simulation System to train risk perception skills while the participant drove a real car in a virtual environment. A head mounted display presented the virtual world. Feedback was given to participants when they failed to scan appropriately for hazards.

Twelve newly licensed drivers served as the experimental group and were trained with the combined RAPT/SIMRAPT training program on a total of eight scenarios. Twelve other newly licensed drivers were given training not relevant to hazard anticipation and served as the control group. After training, both groups were evaluated on an advanced driving simulator in the Human Performance Laboratory at the University of Massachusetts at Amherst (different from the Drive Square Simulation System used in SIMRAPT training) and the eye movements of both groups of drivers were measured. The drivers' scores were based on whether or not their eye-fixations indicated recognition of potential risks in different driving situations. The simulator evaluation included 8 scenarios used in the RAPT/SIMRAPT training (near transfer scenarios) and 8 scenarios that were not used in the training (far transfer scenarios).

PARTICIPANTS

Twenty-four novice drivers participated in the experiment. Twelve of them were randomly assigned to the experimental group that took the training and the other 12 were assigned to the control group. The participants were recruited from Amherst area driving schools or responded to flyers that were placed in Downtown Amherst. All participants were 16 or 17 years old and either had a learner's permit with at least 5 hours driving experience on the road or a junior operator's license for less than 6 months. Overall, there were 10 participants with a learner's permit and two participants with a junior operator's license in both the experimental and the control group. The ages in the two groups were also very similar: The mean for the trained group was 16.5 years (SD = 0.4 years) and the mean for the untrained group was 16.5 years (SD = 0.5 years). There were 5 women and 7 men in both the trained and the untrained group.

GENERAL PROCEDURE

After having arrived at the Human Performance Lab, the eye-tracker that is used for recording the eye movements during the evaluation on the HPL simulator needed to be evaluated for the particular participant. This evaluation did not take longer than 5 to 10 minutes. Participants whose eyes could not be tracked properly could not participate in the study. There were in total two participants who were sent home after this test. The study consisted of a training part and an evaluation part for both experimental and control groups. The whole experiment took on average about 2 hours for the control group and 2.5 hours for the experimental group.

TRAINING PROGRAM: EXPERIMENTAL PARTICIPANTS

The training session for the experimental participants contained eight scenarios. Participants were trained first in the PC-based Training RAPT-1 and then on the Drive Square Simulator (SIMRAPT). The eight scenarios were represented in both parts of the training.

PC: RAPT TRAINING PROCEDURE AND SCENARIOS

The same training procedure was used in this experiment as was used originally with RAPT-1[7]. The participants had as much time as needed for the training; it took the participants about 40-45 minutes on average to complete the program.

[7] The original version of RAPT-1 was provided for modifications and use in this study.

All training scenarios fell into one of three categories based on the risk that occurred within the scenario. These three categories were defined above in Experiment 1. Plan views of all the 8 training scenarios are presented in Appendix A, Figure 19 - Figure 26[8]. These will be referred to as the *near transfer* scenarios. Each figure both contains (a) a plan view and (b) a perspective view (snapshot from the HPL driving simulator) of the respective scenario. Most of the plan views were taken from the RAPT-1 training program, but they do not always match the scenario presented in the perspective view completely. For example in the Amity Lincoln Scenario (Figure 19, p. 61), the plan view has a stop sign in the training scenario and a traffic signal in the simulation. The basic design of the scenarios is always the same.

SIMULATOR: SIMRAPT TRAINING PROCEDURE AND SCENARIOS

After the PC-Training, the participant who had been trained on RAPT and the instructor walked to the UMass bus garage, where the Drive Square Simulator was connected to a parked car. The Drive Square Simulation System is based on the Drive Square Portable Road Simulator (details on www.drivesquare.com), which emulates real road driving conditions. As opposed to all other simulators in its class, which try to imitate both the vehicle and the road using artificial environments, the Drive Square Portable Road Simulator models the road, while using the actual vehicle. For this experiment, the Drive Square Simulator was connected to a 1992 Toyota Camry. The front wheels of the car were driven onto turntables which allowed the driver of the vehicle freely to turn the wheel (Figure 12a), and sensors were attached to this turntable as well as the accelerator and brake pedal.

The simulated panoramic views of the road were presented to the trainee via a head-mounted display (HMD), which consisted of goggles that created a virtual reality for the driver (see Figure 12b). The HMD included a head-tracker, which means that horizontal movements of the head were recognized by the hardware. The software received data from the wheels and pedals of the vehicle as well as from the HMD. If the car driver turned his or her head horizontally, the environment that could be seen in the goggles moved accordingly, so that the driver had a 360-degree field of view. The resolution of the screen is 800×600 pixels and images are presented at a rate of 70 Hz. The horizontal field-of-view for the generated scenery is 60 degrees. The physical field of view of the HMD is about 45 degrees at any given moment of time, so that the driver has a little bit of field-of-view compression. The participant operated the car as if he or she was driving on the open road and moved through the 8 scenarios in the virtual world accordingly.

During the SIMRAPT training session, the participant drove in a virtual environment through the same eight scenarios with which he or she had practiced in the PC-Training previously. Each drive consisted of only one particular scenario. Therefore the drives were fairly short, about 20 to 40 seconds each. The HMD that displayed the virtual world to the participants contained a head-tracker that recorded their head movements. In order to give participants feedback after each scenario, the instructor needed to see whether the trainee fixated on the risky element in the scenario or not. As the head-mounted display only presented a very small section of the visual scene (the horizontal field-of-view for the virtual environment presented on the head-mounted display subtends 60 degrees horizontally), the driver did not have a large peripheral view beyond a small forward view. Therefore, the driver needed to move his or her head in order to see risky areas that are far into the periphery. Scenarios where chosen that in general required a head movement when fixating on a risky element in the scene since the risky element was itself far to the right or left of the forward roadway. From these head-movements the instructor was able to infer whether or not the participant recognized a risky element in the driving environment. Each

---

[8] The slides for the PowerPoint training had been developed by Anuj Pradhan and Vinod Narayanan at the Human Performance Lab over the last several years.

scenario either required a head turn to the left or to the right. Altogether, there were 5 scenarios requiring a right head turn and 3 scenarios requiring a left head turn (see Table 4).

(a)

(b)

Figure 12. Drive Square Simulator (images retrieved from www.drivesquare.com). (a) Computer-Controlled Road Simulator Ramp. (b) Head-Mounted Display

Table 4. Required head turns in SIMRAPT training.

Nr.	**Name**	**Category**	**Head Turn**	**Required head turn[9] for score 0.5**	**Required head turn[10] for score 1**
1	Amity-Lincoln	Complete Obstruction	Right	20° - 60°	>60°
2	Adjacent Truck Left Turn	Complete Obstruction	Left	8° - 35°	> 35°
3	Truck Crosswalk	Complete Obstruction	Right	15° - 30°	> 30°
4	T – Intersection	No Obstruction	Right	30° - 60°	> 60°
5	Left Fork	Partial Obstruction	Left	8° - 20°	> 20°
6	Opposing Truck Left Turn	Complete Obstruction	Right	20° - 35°	> 35°
7	Blind Drive	Partial Obstruction	Right	10° - 25°	> 25°
8	Pedestrians on Left	No Obstruction	Left	15° - 45°	> 45°

After each drive the instructor provided a printout of the top-down view of the respective scenario to the participant again along with a red and a yellow marker and asked him or her to repeat the task he had to do in the RAPT-1 training, marking potentially risky areas that should be scanned. The participant was then presented the correct solution and given feedback on his or her drive based on the occurrence of a head movement. If a head-turn was made correctly in a scenario, the driver went on to the next scenario. If a head turn was not made correctly in a particular scenario, the instructor explained to the participant why a head-turn is necessary. The procedure was repeated until the participant made the required head-turn, up to a maximum of four times. However, it rarely happened that a scenario needed to be driven more than three times.

In most of the drives the participant was asked to follow a lead vehicle showing the way the driver should go. In both the Adjacent Truck Left Turn scenario and the T-Intersection scenario no lead vehicle was presented due to a restriction of the software, which prevents computer-controlled vehicles from turning at an intersection. Instead, a computer controlled voice told the driver which way to turn at the intersection.

Training Program: Control Participants

In order to create similar conditions for the control and experimental group the participants of the control group received a short combined training program as well. However, this training did not include anything related to hazard anticipation and is therefore referred to as pseudo-training. This pseudo-training program basically consisted of two parts.

[9] Head turn as measured by the Drive Square Head Tracker in degrees. The score 0.5 is given when angle in given range.
[10] Head turn as measured by the Drive Square Head Tracker in degrees. The score 1 is given when angle at least as large defined here.

PC: MASS RMV TRAINING

First, the control participants were presented some reading material that included general information about traffic signs and traffic rules that were taken from the Mass RMV Driver Training Handbook. The participants needed about 10 minutes on average to read the material. After that they were given some multiple choice questions about the material they just read. Questions such as the following were presented:

What does a flashing red traffic light mean?

1. This means to slow down but not to come to a complete stop.
2. This means to stop only if other cars are present.
3. This means stop and not to go until the light is green.
4. This means to come to a complete stop, obey the right-of-way laws, and proceed when it is safe.

SIMULATOR: PSEUDO SIMULATOR TRAINING

After the RMV training, the control participants were taken to the Bus Garage. The general procedure was the same as for the experimental group. After the practice drive, the control participants were told that they would drive 16 scenarios in total and that they should just drive each scenario as well as they could. They then drove the 8 training scenarios one after another without receiving any feedback. After this, they had to drive all 8 scenarios a second time, but in a different order. Again, they were not given any feedback. Therefore, the control participants drove all eight scenarios exactly twice.

HPL SIMULATOR EVALUATION

The major goal of the experiment was to determine whether a combined training program consisting of a PC-based risk awareness and perception training program (RAPT-1 with the modifications as noted above) and a head mounted simulator (SIMRAPT) could lead a larger percentage of novice drivers to recognize risks while driving in the HPL driving simulator than is the case with other training programs which use only more static presentations like RAPT. A secondary goal was to determine whether the training goes beyond the specific scenarios that are presented to the participants in the training. Therefore the evaluation in the driving simulator included both the 8 scenarios on which the experimental participants had been trained in RAPT and SIMRAPT and 8 scenarios that had not been included in the training.

PARTICIPANTS

Altogether 24 subjects were evaluated on the driving simulator. Twelve of them were trained with RAPT-1 and SIMRAPT (experimental group) and 12 were not trained (control group). These were the same participants described above.

EQUIPMENT

The evaluation of the training was done using the same advanced fixed-base driving simulator that was used in the previous experiments (Figure 1) along with the ASL Mobile Eye to track eye fixation locations (Figure 9).

FAR TRANSFER SCENARIOS

As mentioned previously, there were 8 additional scenarios on which the participants had not been trained, but that were included in the simulator evaluation. These scenarios served as the set of far transfer scenarios. They were similar to the training scenarios only in that they contained risky situations of which the driver should be aware. As described above, Figure 27 - Figure 34 (pages 69 - 76) in Appendix A present plan views and screenshots of the 8 far transfer scenarios on the driving simulator. In some cases risks were hidden from the driver's view, but there were also many scenarios that were completely different from the training (near transfer) scenarios, as the potential danger was not caused by an obstruction, but by other elements in the scenario. In fact, there were situations where a head movement was not necessary at all, but where we wanted to test whether the participant focused on elements in the scene that were not hidden, but still required special attention. With the eye tracker the eye fixation point of the driver could be recorded in every situation. With this information it was possible to determine whether or not potentially risky areas (areas where risks might materialize) were fixated on by the participant.

GENERAL PROCEDURE AND DESIGN

All participants were each evaluated on the HPL simulator immediately after coming back from the bus garage, where the participants were driving the Drive Square Simulator.

As mentioned above, each participant had to drive through 16 different scenarios that were designed within the last several years at the Human Performance Lab at the University of Massachusetts as part of several studies evaluating training effects of the different generations of the RAPT program (Pollatsek et al., 2006; Pradhan et al., 2006). These 16 scenarios were divided into four blocks. Each block represented a drive that consisted of fairly neutral portions without any potential risks and four scenarios embedded into the drive. The participants were told to follow a lead vehicle that is controlled by the computer. However, participants could lag behind the lead vehicle at a reasonable distance, as it only served in place of verbal route instructions and, in particular, the lead vehicle indicated to the driver when to turn and in which direction. The orders of the blocks were counterbalanced within each group, which means 12 different block orders were presented to both the experimental and control group. No order was repeated and each block occurred equally often in the first, second, third and fourth drives.

Before the HPL simulator session both the experimental and the control group received written instructions including sentences such as "…as in 'real life' driving, you should obey all traffic laws and posted speed limits to the best of your ability and respect the right-of-way for other vehicles." They also received verbal instructions reiterating that they should drive normally, just as they would do in the real world.

The participants were seated in the car and fitted with the eye tracker (ASL Mobile Eye). After the calibration of the eye tracker, the participants were allowed to spend as much time as they needed getting familiar with the simulator. They drove through an environment similar to the experimental scenarios (similar types of streets, intersections, traffic density, etc.) and had the opportunity to get used to braking, turning, and accelerating in the simulator. They then drove though the four different blocks of scenarios with rest breaks in between.

RESULTS

All participants in the study were scored on the RAPT-1 training, the SIMRAPT training, and the HPL simulator evaluation. For the analysis of the pre-post test gains on the RAPT-1 and SIMRAPT training and the evaluation of the combined effectiveness of the RAPT-1 and SIMRAPT training on the HPL simulator, a total score for each participant was first calculated. This score took a value between 0 and 1 (or 0% and 100%), indicating what percentage of circles and ovals were positioned correctly (in case of the RAPT-1 training), what percentage of head-turns were made correctly (in case of the SIMRAPT training), or what percentage of risks were recognized as indicated by the eye-fixation behavior (in case of the HPL simulator evaluation). In order to compare the overall scores (e.g., a comparison of the pre-test- and post-test-results for the experimental group on RAPT-1, or a comparison of the control and experimental groups on the HPL simulator evaluation), the scores were averaged over all participants in each group.

RESULTS AND DISCUSSION OF PC-TRAINING RAPT

An analysis of the results indicates that the training was successful in getting participants to identify risky parts of a scenario. Participants were much better placing the red circles correctly after the training, scoring 54.5% on average in the pre-test and 74.5% on average in the post-test. The difference of 20.1 percentage points was highly significant, $t(11)=6.1$, $p<.001$. They were also better at placing the yellow ovals after the training, scoring 69.8% in the pre-test and 91.2% in the post-test. The difference of 21.4 percentage points was highly significant, $t(11)=4.4$, $p<.005$. Moreover, the training was similarly successful for all participants.

The above analyses are consistent with previous studies of the effectiveness of RAPT (Pollatsek et al., 2006). In particular, newly licensed drivers can learn what should be continuously monitored and the possible location of potential risks that are hidden from the driver's view. Further, the participants saw the same stimuli both in the pre- and in the post-test.

RESULTS AND DISCUSSION OF THE DRIVE SQUARE SIMULATOR TRAINING

Dependent Variables and Scoring

The recorded data of the Drive Square training session were used for an analysis of the training effect within the trained group. (The *drives* were numbered sequentially, one through eight. Each scenario could occur on any one of the drives. Each drive/scenario could be repeated up to four times. Each repetition within a scenario/drive is referred to as a *trial*.). Both accuracy on the first trial of a scenario/drive was recorded and the total number of trials required to make a correct head turn was recorded. Keep in mind that all trained participants have to repeat each scenario/drive up to four times in the training if they do not make the head-turn correctly. For example, if the Amity Lincoln scenario was the second scenario that a particular participant had to drive, and he or she did not make a correct head turn until the second trial of that drive, then both the Amity Lincoln scenario and drive 2 were scored as incorrect. Further, a total of two trials were recorded for both the Amity Lincoln scenario and drive 2. Or, for example, if the T-Intersection was the fifth scenario, and the participant made the correct head turn on the first trial of the fifth drive, then both the T-Intersection scenario and drive 5 were scored as correct, and a one was recorded for the T-Intersection scenario and for drive 5. If a head turn was recognized at the correct location, but the participant did not turn his or her head far enough in order to really see the whole area that was obstructed by a vehicle or vegetation, the scenario was scored with 0.5, as the behavior suggested that a potentially hidden risk was recognized. However, he or she was asked to repeat the scenario again until a full head turn was done. The values of the head-turns (in degrees, as measured by the head-tracker) that qualified for a score of 0.5 points or 1 point in each scenario are given in Table 4.

SIMRAPT Results of the Experimental Group

There is a clear learning curve for the experimental participants on SIMRAPT. An average score[11] of 0% for all participants in the first drive increases up to an average score of 79% on the eighth drive. This increase was significant, as indicated by a simple two-tailed t-test for paired data, $t(11)=6.92$, $p<.001$. Further, the average number of trials for each participant continuously decreases from 2.58 in the first drive to 1.33 in the eighth drive. These numbers indicate that the feedback given after each drive results in a training effect that generalizes to the other scenarios that are driven later in SIMRAPT. In the eighth drive more than three out of four participants

[11] The term "Score" in connection with the SIMRAPT training refers to percentage of participants recognizing the risk on the first trial in the drive of a given scenario.

were able to identify the risky area in the driving environment and made the head-turn that was necessary to fixate the critical region when driving the scenario the first time.

Of some importance to note is the large initial difference in the difficulty of generalizing what a participant has learned in RAPT to the same scenario in SIMRAPT on the first trial (Figure 13a). Specifically, participants seemed to have problems recognizing the risk and doing the required head-turn especially in the Left Fork scenario (Figure 23b) and in the Opposing Truck Left Turn (Figure 24b) scenario. In both cases the participants had to execute a turn and at the same time look out for a potential risk in the opposite direction. Further it can be seen from Figure 13b that the average number of trials for these two scenarios is much higher than for every other scenario, about 2.4 for both the Left Fork scenario and the Opposing Truck Left Turn scenario, supporting the hypothesis that it might be a problem of multitasking, as the scenarios had to be driven more than two times on average. The charts in Figure 13 a and b also show that the performance is best for the Truck Crosswalk scenario and the Pedestrian on the Left scenario. In both scenarios a crosswalk is obstructed by vehicles, indicating that participants might have been forewarned by the crosswalk and therefore were more likely to watch out for a risk.

Figure 13. SIMRAPT Training Results for Each Scenario.

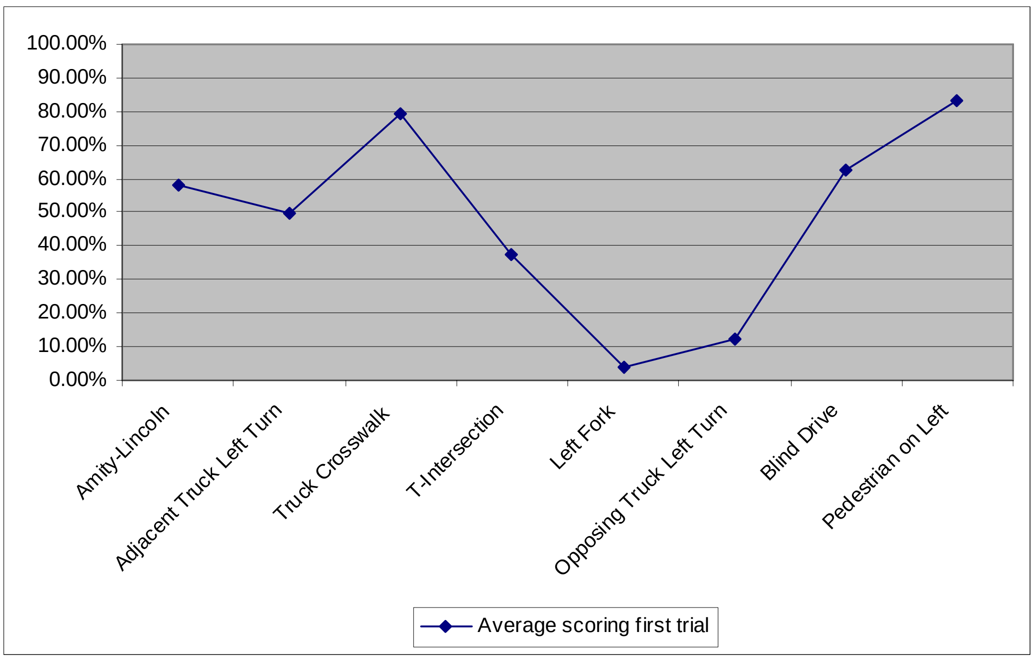


Figure 13a. SIMRAPT Training Results for Each Scenario. (Average score for first trial of first drive in each scenario.)

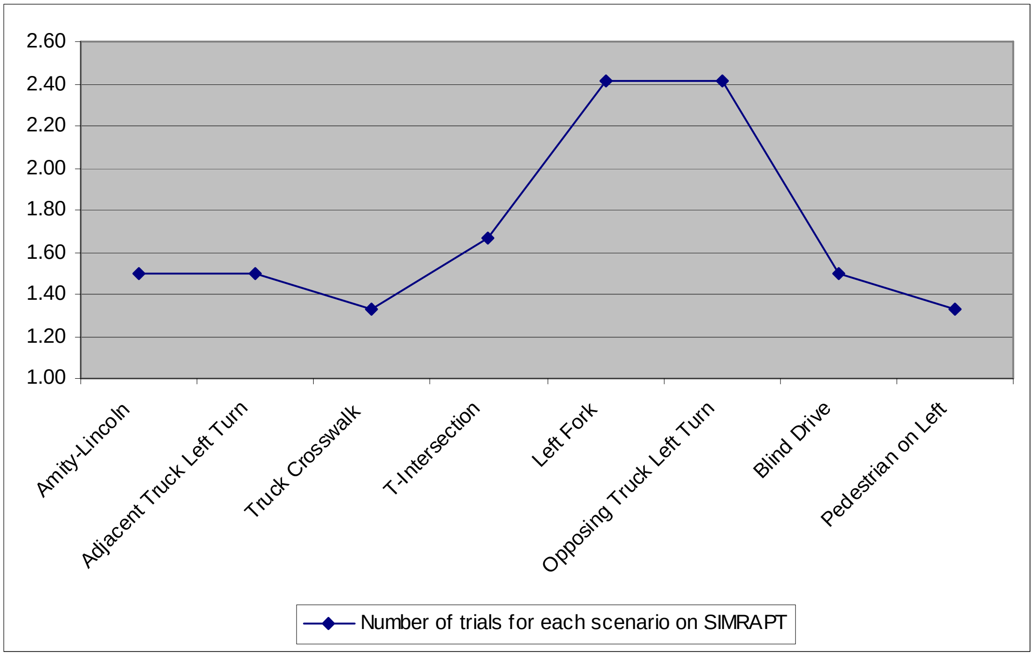


Figure 13b. SIMRAPT Training Results for Each Scenario. (Average number of trials for each scenario.)

Overall, it is clear that participants using SIMRAPT learn where to turn their heads in order to identify potential hazards and that as training progresses they learn to do so in fewer and fewer trials. First, each scenario was shown at most four times. All participants learned where to turn their heads in four trials or fewer. Second, participants were much more likely to turn their heads correctly on the first trial of the last drive (79%) than they were on the first trial of the first drive (0%). Finally, the number of trials that it took participants to turn their head correctly decreased from 2.58 on the first drive to 1.33 on the eighth drive. It is difficult to say whether this represents some more general learning of hazard anticipation skills as training progresses or, instead, a recognition at some point that the hazards they had been asked to anticipate in RAPT were also appearing in SIMRAPT.

Additionally, it is clear that the scenarios varied greatly in their difficulty. In some SIMRAPT scenarios, the hazards were anticipated by few if any participants on the first trial, despite the training that they had already received on RAPT on these very same scenarios (e.g., Left Fork, Opposing Truck Left Turn scenarios). In other scenarios, they were very near ceiling on the first trial (e.g., Truck Crosswalk and Pedestrian on Left). The fact that some scenarios are so difficult suggests these scenarios ought to be over trained, i.e., participants should see the scenarios at multiple points in the training.

Results of the Simulator Session for the Control Group

For the first run through all eight scenarios, the average score over all participants and drives was 0.09, indicating that on average less than one full head turn was made by every participant throughout all eight scenarios. However, this result can not be compared with the experimental group's results, as the control participants did not receive any feedback between their drives. When driving all scenarios a second time, the average score increased from 0.09 to 0.14, suggesting that there might be a small training effect just from driving all scenarios a second time. The difference between the scores in the first and second run is not significant, $t(11)=1.93$, $p>.05$.

Comparison of SIMRAPT Results for Trained and Untrained Participants

As indicated before, one cannot directly compare the results between the trained and untrained group by averaging the score on the first drive over the first 8 scenarios because the trained group had multiple trials in each drive whereas the untrained group had only one trial in each drive. However it is possible to get some meaningful measure of the difference in performance between the control and experimental group by using an approximation in the experimental group to the first eight drives in the control group. In particular, one can compare the average performance of the control group for the second run of all 8 scenarios with the average performance of the last four drives of the experimental group. The idea is that the control group drove all 8 scenarios once and we are measuring their performance on trials 9 to 16. Similarly, since each participant of the experimental group drove his or her first four scenarios on average two times, during the first four scenarios the experimental participants drove on average eight times and so we want to measure their performance on the next 4 scenarios which, again, will consist on average of eight drives. Therefore, both groups have the same driving experience on the Drive Square Simulator. After the first eight drives, the control group has an overall average score of 0.14 for the 2nd run of each scenario, whereas the average score for the experimental group on the last four drives is 0.68. The difference in means of 0.54 is highly significant, $t(14)=6.5$, $p<.001$. This clearly indicates that, even if there is a small training effect for the control group, it is greatly exceeded by the training effect for the experimental group.

RESULTS AND DISCUSSION OF THE HPL SIMULATOR EVALUATION

Comparison of Results for Experimental and Control Participants

In this section, we want to test the first hypothesis that was set forth above. Specifically we want to test if there is a significant training effect of the combined RAPT-1 and SIMRAPT training program. All 16 scenarios which were present in the HPL simulator evaluation, both the 8 near transfer and 8 far transfer scenarios, are used for this analysis. The results for this evaluation of the training are presented in Table 5. In the first case, when near and far transfer scenarios are analyzed together, the total score averaged over all participants is 72.4% for the experimental group and 46.9% for the control group. The difference of 25.5 percentage points between control and experimental groups is highly significant, $t(20)=3.22$, $p<.01$. When the near transfer scenarios are analyzed separately, the novice drivers who were trained with RAPT-1 and SIMRAPT recognized risks 72.2% of the time, the untrained participants recognized only 37.5% of the risks, a difference of 34.7 percentage points that is highly significant, $t(18)=3.1$, $p<.01$. When the far transfer scenarios are analyzed separately, the trained participants recognized 72.5% of the risks; the untrained drivers only recognized 57.3% of the risks. The difference of 15.2 percentage points is not significant when a two-tailed t-test is used, $t(20)=2.06$, $p>0.5$. However, since it was assumed a priori that the trained participants do at least as well as the untrained participants, a one-tailed t-test might be satisfactory. This test would indicate that the difference is significant, $p<.05$. However, a larger sample might be necessary in order to determine whether a significant difference existed using a two-tailed t-test.

Table 5. Results of Driving Simulator Evaluation Including All 16 Scenarios[12].

	Experimental Group	Control Group	Percentage Point Difference
Near Transfer Scenarios:	**72.2%**	**37.5%**	**34.7%**
Far Transfer Scenarios:	**72.5%**	**57.3%**	**15.2%**
Total:	**72.4%**	**46.9%**	**25.5%**

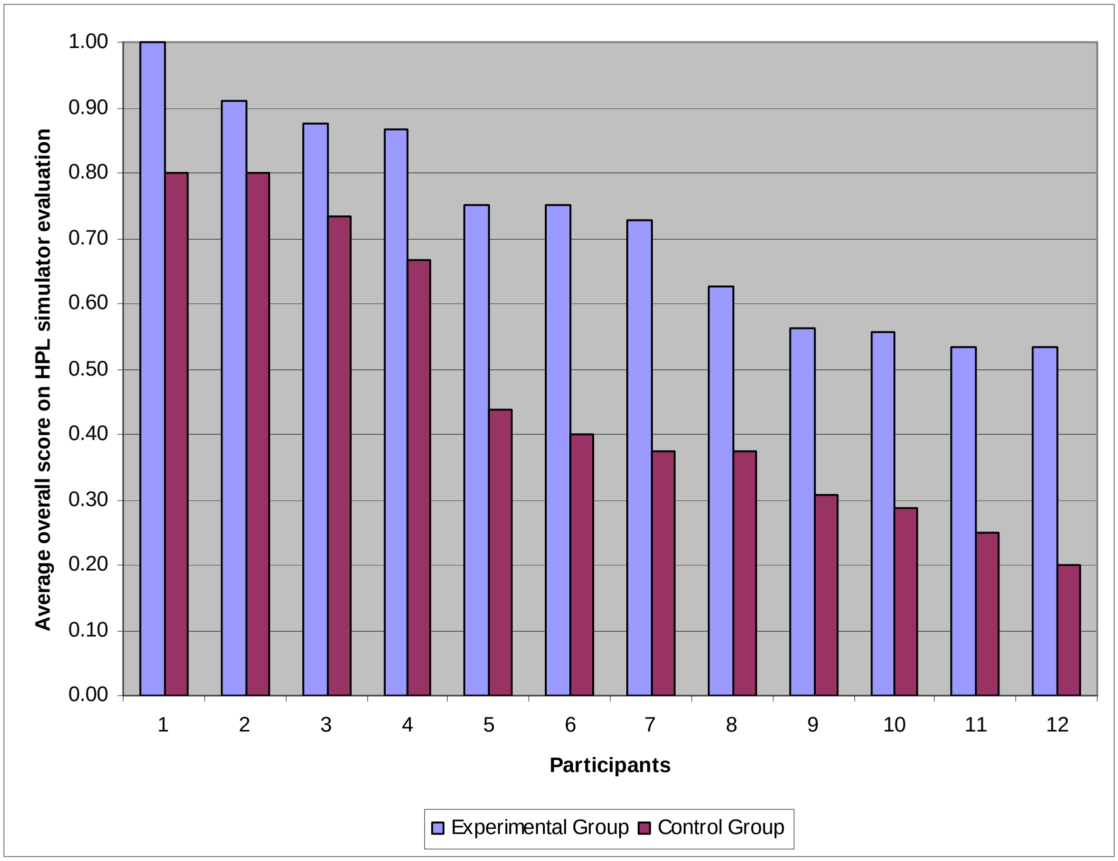
Figure 14 on page 43 presents the total score for each participant of this study. For this chart, the participants in each group were ranked by their scores. It clearly shows that there are large differences between participants within each group. The curves for the control and the experimental group have similar shapes, suggesting that the samples chosen both for the control and experimental group might represent the population pretty well. However, it is especially obvious that there are a few participants in the control group that recognized most of the risks (between 65% and 80%), whereas the majority of the control participants only recognized between 20% and 40% of all risks during the drive. This large difference suggests that some novice drivers might have been taught risk perception skills more than others throughout the driving education process. But this is only a hypothesis, and other explanations might be valid. More generally, clearly this will attenuate the effect of training and suggests that a different measure of training efficacy is required if some proportion of the control participants are already at or near ceiling.

A look at the scoring for each scenario will give more information about the differences in performances of trained and untrained novice drivers. For the near transfer scenarios, the effects of training were very consistent across all scenarios (see Figure 15a on page 44). Interestingly, the difference in performance between control and experimental groups was largest for the scenarios in which a crosswalk is obstructed by vehicles (Pedestrian on the Left and Truck Crosswalk). These are the same scenarios on which the trained participants performed best in the SIMRAPT training.

For the set of far transfer scenarios (see Figure 15b), there are large differences in the effect of training among the different scenarios. There are three scenarios that do not seem to show any effect of training, as the control participants perform better than or as well as the experimental participants. For the Intersection with One-Way Street scenario, there is a clear ceiling effect that makes it impossible to improve the driver's performance; the scores for the Intersection with New Green scenario and the Curved Stop Ahead scenario do not show any benefit of training as well. The clearest training effects can be observed for the Right on Red, Truck Blocking Travel in Lane and Bus Left Turn at Triangle St. scenarios. In all these scenarios, the driver's view of the street is obstructed by a truck for a moment, suggesting that the training generalized to situations in which vehicles obstructed the driver's view.

[12] All results are averaged over participants.

Figure 14. Average Overall Score for Each Participant[13] on the HPL Simulator Evaluation: Control Group and Experimental Group.



The test for differences between near and far transfer scenarios was not significant: t(21)=1.75, p>.05). The training[14]effect was 34.7 percentage points for near transfer and 15.2 percentage points for far transfer.

The difference between men and women was not significant: t(21)=0.64, p>.5. Men scored 62.1% (averaged over all men) and women scored 56.2% (averaged over all women[15]).

There was also the concern that the difference in age could affect the result. However, there was no significant correlation[16] between age and the average simulator score (the correlation was -0.23, t(10)=0.67, p>.5 for the control group and 0.22, t(10)=0.63, p>.5 for the experimental group).

[13] For this chart, the participants in each group were ranked by their scores.
[14] Difference in performance between experimental group and control group
[15] Remember, that there were the same number of females and males both in the control and in the experimental group.
[16] The Pearson product-moment correlation coefficient was used for the calculations and the significance of the coefficient r was tested with a t-test

Figure 15. Driving Simulator Evaluation

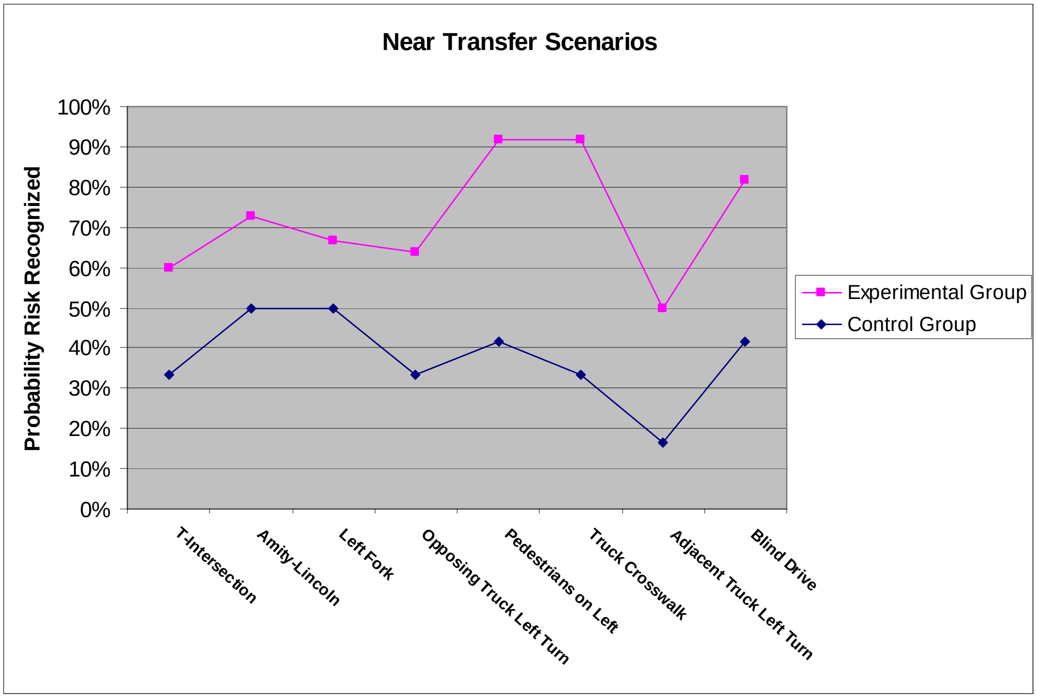


Figure 15a. Driving Simulator Evaluation. (Eight near transfer scenarios.)

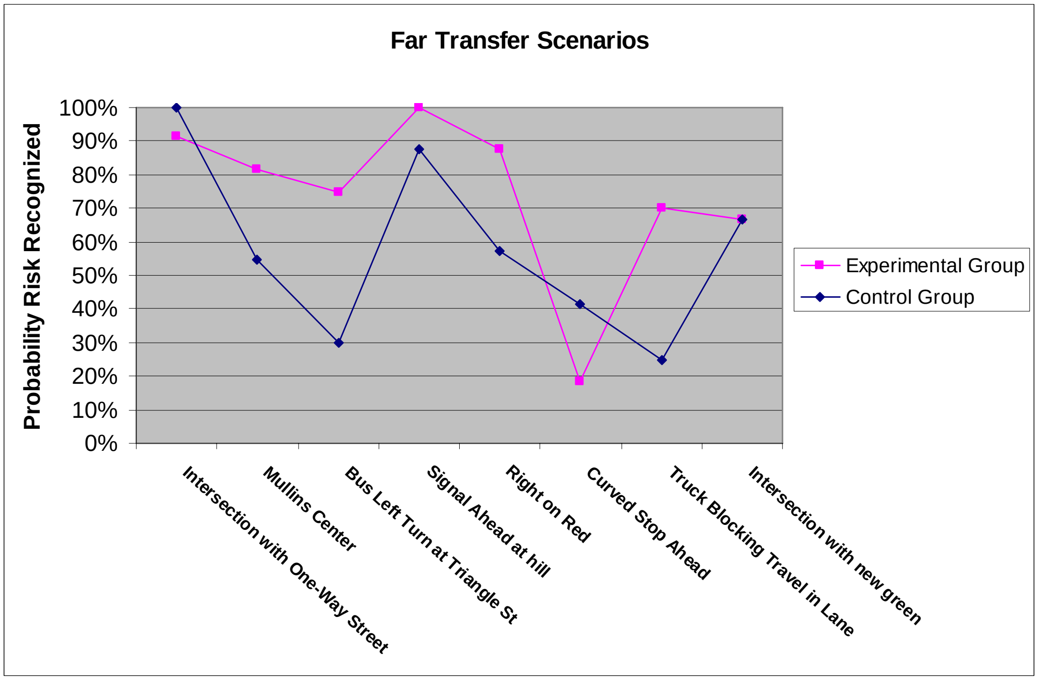


Figure 15b. Driving Simulator Evaluation. (Eight far transfer scenarios.)

Interestingly, three out of the four license holders performed worse than the average of their respective groups, only one license holder in the experimental group performed slightly above average.

It is also of interest to see how well the scores on the training predict the scores on the HPL simulator. Although the sample is very small, we tested different correlations between the individual results on RAPT-1, SIMRAPT and the HPL simulator. For the analysis we used the Pearson product-moment correlation coefficient and tested the significance of the coefficient r with a t-test. First, it is of interest to see if the results of the SIMRAPT training correlate with the scores on the HPL simulator. We especially expected a correlation for the near transfer scenarios. And indeed, the SIMRAPT scores[17] for the trained group correlate 0.51 with the HPL driving simulator scores in the near transfer scenarios; however the correlation was not significant, $t(10)=1.66$, $p < 0.1$. A correlation of -0.56 between the average number of trials on SIMRAPT and the overall HPL simulator score (averaged over near and far transfer scenarios), $t(10)=1.92$, $p < 0.05$, indicates that participants who need fewer trials to make the correct head turn on SIMRAPT perform better on the evaluation on the HPL simulator. Interestingly, there seems to be a clear correlation between the average performance on SIMRAPT and the HPL simulator for the control group. The score on SIMRAPT (averaged over the first and second run on the Drive Square Simulator for each participant) correlates 0.85 with the total score of the HPL driving simulator evaluation, $t(10)=4.52$, $p<.01$.

Overall, we do not want to attach too great an importance to these numbers, as the samples are very small. However, there seems to be a clear trend that performances in the SIMRAPT training and in the HPL evaluation correlate to some degree.

Comparison of Training Results with Prior RAPT Training Evaluations

To test the second hypothesis that was proposed we now compare the training effect of the combined RAPT-1 and SIMRAPT training program with the effect of the RAPT-1 program as presented in Pollatsek et al. (2006). The training in this study did not include exactly the same training scenarios as in the former study. Therefore we only selected scenarios for the comparison that either were far transfer scenarios or near transfer scenarios in both studies and that also had exactly the same scoring criteria in both studies. In total there are six near transfer scenarios and five far transfer scenarios that fulfill these requirements and therefore can be compared.

For this reduced set of scenarios, the trained participants scored 67.5% in the near transfer scenarios averaged over all participants, the control group scored 36.1%. The difference of 31.4 percentage points is significant, $t(21)=2.76$, $p<.05$. The equivalent scores in the far transfer scenarios are 81.3% for the experimental group and 49.0% for the control group. The average difference of 32.3 percentage points is significant, $t(21)=2.94$, $p<.01$. This can be explained by the non-consideration of three original far transfer scenarios (Mullins Center, Intersection with One-Way Street, Curved Stop Ahead) in which the trained participants did not score better than the untrained group.

The scores of the experimental and the control group for the relevant scenarios are also presented in Figure 16, both for the current study and the study presented in Pollatsek et al.(2006). Figure 16a displays the results for the near transfer scenarios; Figure 16b displays the results for the far

[17] The term "Score' in connection with the SIMRAPT training refers to percentage of participants recognizing the risk on the first trial in the drive of a given scenario.

transfer scenarios. Again, the scores in every scenario and the overall scores are averaged over all participants both in this study and in the study of Pollatsek et al. (2006).[18]

Figure 16. HPL Driving Simulator Evaluation Scores For Both This Study Evaluating SIMRAPT ("New") And A Prior Study Evaluating RAPT-1 ("Old") (Pollatsek et al., 2006).

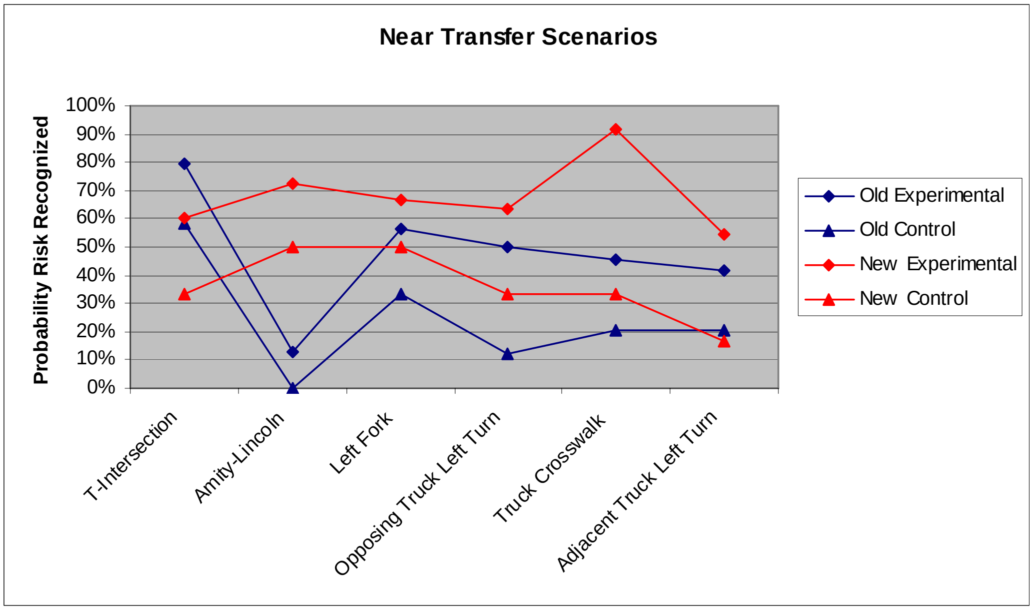


Figure 16a. Comparable Near Transfer Scenarios.

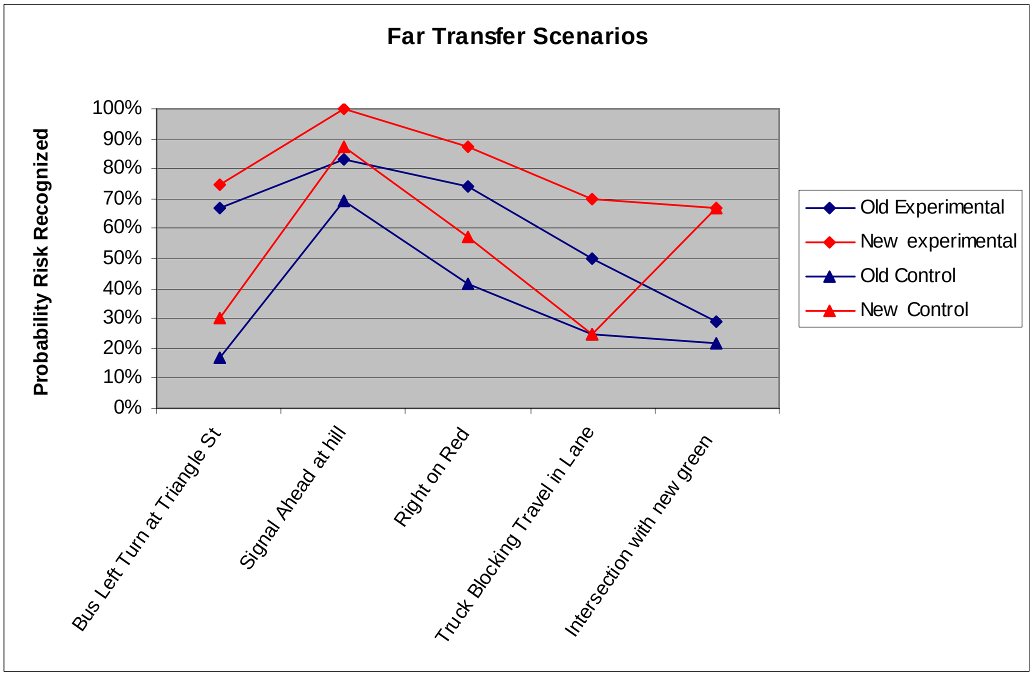


Figure 16b. Comparable Far Transfer Scenarios

[18] The detailed average scores and standard deviations for each participant were provided for the calculations by Anuj Pradhan, who conducted the prior study evaluating RAPT-1.

As can be seen from the two panels in this figure, the scores for the trained participants in this study are noticeably higher than the scores for the trained participants in the prior study. This is pretty consistent over almost all scenarios. However, the participants of the control group also performed better in this study than they did in the comparative study evaluating RAPT-1 (Pollatsek et al., 2006). There is an average difference of almost 12 percentage points between the training effect on near transfer scenarios in this study - as measured by difference between experimental and control participants on the near transfer scenarios – and the training effect on near transfer scenarios in Pollatsek's study. Similar observations can be made for the set of comparable far transfer scenarios.

The above findings indicate that there might be an effect of driving in the Drive Square Simulator for both the experimental and the control group. This is not surprising for the experimental group; however it is for the control group, as the untrained participants did not receive any feedback on their performance on the Drive Square Simulator. We suspect that there is an effect just from already seeing the near transfer scenarios twice on the Drive Square Simulator before driving the HPL simulator. It might be possible that drivers do not recognize a certain risk when driving a scenario the first time because they are not aware of the whole traffic situation. However, when driving a scenario a second or third time, the driver might better be able to sum up the traffic situation, as he or she knows all elements of the situation. This idea is supported by the slight improvement of the control group from the first to the second run on SIMRAPT (about 9% in the first run to 14% in the second run). Furthermore, comparing the results of the control groups for the Amity-Lincoln scenario on the HPL simulator, the percentage of untrained participants recognizing the risk was 0% in Pollatsek et al. (2006) and is 50% in this study. This suggests that the drivers might have benefited from having seen the hedge obstructing the sidewalk on SIMRAPT before. However, this is just a post hoc attempt at explaining the differences between the control group in this and the prior study, and the differences for the far transfer scenarios cannot really be explained by that theory (since such scenarios were not presented on the Dive Square simulator). In order to have evidence for one explanation or the other, a third group of drivers would need to be tested under the same conditions, but without seeing the scenarios on the Drive Square Simulator before being evaluated in the HPL simulator.

It is also obvious that two scenarios are out of line, as both the experimental and the control group seem to perform either much worse or much better than in the prior study. Whereas the differences for the T-Intersection scenario might be explained by chance or different interpretations of the scoring criteria, the difference in the Intersection with new Green scenario cannot really be explained, as it is a far transfer scenario and the scoring criteria is very clear. The results for the control group are especially surprising, as most of the participants made the necessary eye movements to the left and right (about 67%), whereas this was the case for only 22% of the participants in the prior study. The only reasonable explanation we have of this difference in the control groups' performance in the two studies is that both experimental and control participants were asked to practice turning their head to the left and right when waiting at a red traffic light in the SIMRAPT practice drive. This was done to let the driver get a feeling for how far he or she actually have to turn his or her head in order to see the whole intersecting street on the screen of the Drive Square Simulator.

If one compares the absolute training effect (the difference in the scores of the experimental group and control groups averaged over all comparable scenarios) of both studies, the training effect for this study is 30.0 percentage points and it was 20.9 percentage points in the study of Pollatsek et al. (2006). The difference of 9.1 percentage points is not significant, $t(32)=0.88$, $p>.3$. A separate analysis for near and far transfer scenarios shows similar results. Thus, the power of the analysis is just not large enough in order to prove a significantly higher training effect for the combined SIMRAPT/RAPT-1 training over the RAPT-1 training itself. Another factor potentially attenuating the training effect in this experiment is that the control group seems to benefit from the Drive Square Simulator session and performed better in this experiment than they did in the Pollatsek et al. (2006) experiment. Further, for the far transfer scenarios ceiling effects appear, as the control group's score is very high. Therefore the trained participants would have to score almost 100% in order to get significant differences between them and the control participants.

Complicating the picture still more are the results from Experiment 3 above. The control group scored on average 41.1% averaged over all 18 scenarios. This is close to the 46.9% average seen in this experiment for the control group. Moreover, the control group averages in Experiments 3 and 4 are higher than the average of 35.4% obtained in Pollatsek et al. (2006). Of course, the averages are being obtained over sets of scenarios which overlap only in part. Unfortunately, there are too few identical scenarios in Experiment 3, Experiment 4 and Pollatsek et al. (2006) to undertake a comparison of the training effects obtained in these three experiments on the same set of scenarios.

GENERAL DISCUSSION

The major results of this study are very clear. First, the results in the slightly modified RAPT-1 PC-training program reconfirmed what had been found in Pollatsek et al. (2006), that young drivers can be trained to recognize risky situations from just a plan view. Second, it was shown that the SIMRAPT training program led to a clear improvement in the participants' ability to recognize risks within a driving task on the Drive Square Simulation System, as indicated both by the percentage of participants recognizing a risk on the first trial in a scenario and the reduced number of trials to criterion for each scenario. The training generalized over scenarios so that the trained participants reached a level in the end of the SIMRAPT training in which 79% of the risks were recognized on the first trial of a drive and the necessary head-movements were made. The SIMRAPT training effect for the experimental group was much higher than the repetition effect for the control group, who only scored slightly better in the second run on SIMRAPT than on the first run. Third, the combined RAPT/SIMRAPT training also led to a clear improvement in the trained driver's ability to fixate on areas of potential risk in the driving task on the HPL driving simulator. There was a significant improvement for the near transfer scenarios overall and this improvement was reasonably consistent over all near transfer scenarios. The training also seemed to generalize to far transfer scenarios in which a vehicle was obstructing the driver's field of view. However, for far transfer scenarios in which the risk was not necessarily the obstruction of the driver's view by another object, the training did not succeed in generalizing. Fourth, the results suggest that the combined SIMRAPT/RAPT training has a training effect that exceeds the effect that was reached with RAPT training only. The results suggest that control participants also slightly benefit from the simulator session on Drive Square.

This is the first time that the training program RAPT was used in combination with a driving simulator to train young drivers' risk awareness. Unlike prior training attempts using different versions of RAPT, the participants using SIMRAPT practiced hazard anticipation at the same time as they were driving in a virtual environment. The overall training effect in this study was higher than in the past study evaluating RAPT (Pollatsek et al., 2006) both for near transfer and far transfer scenarios, indicating that the idea of learning while driving in a simulated world is a promising approach.

LIMITATIONS

A number of limitations should be discussed. First the SIMRAPT training, which especially focused on head-movements that are necessary to fixate hidden spots in the driving environment, did not generalize for scenarios in which the characteristic of the risk was completely different from the risks presented in the training. Therefore, the design of the training might need to be reconsidered and more risk characteristics included. But the use of the Drive Square Simulator for the training of other risks that do not require a head-movement would have to include another way of evaluating the driver's performance, for example based on the vehicle behavior.

Second, each part of the combined RAPT/SIMRAPT training program took about 45 minutes on average to complete including the time needed to set-up of the computer in the car. This turned out to be too long, as some participants clearly started loosing patience in the end. It is arguably the case that a modified design of the training can lead to significant savings of time while keeping the effectiveness of the training.

Third, this study cannot answer the question whether or not the increase in the size of the training effects observed with the RAPT/SIMRAPT combination in this experiment over prior versions of RAPT is worth the increased effort and investment that are accompanied with the purchase of a low-cost simulator such as the Drive Square Simulation System. The increase itself is not statistically significant. Perhaps SIMRAPT really does not improve hazard anticipation. The two studies that were compared directly, this study and Pollatsek et al. (2006) had a slightly different mix of drivers with a learners permit and intermediate stage license. In addition, the data from the two studies were collected two years apart, and the analyses were completed in a post-hoc manner. Finally, it is not yet clear how one would map between levels of hazard anticipation observed in experiments such as the above and actual crashes, from which one could compute some net economic benefit to society. A more extensive study building on the results of this experiment would be necessary in order to address these problems.

In summary, a series of prior experiments (e.g., Fisher et al., 2002; Pradhan et al., 2006) indicate that hazard anticipation is a problem among young drivers in the field and on a driving simulator. Various ways of training have been explored, including three versions of RAPT and a combined RAPT and SIMRAPT program. All prove beneficial.

EXPERIMENT 5. ATTENTION MAINTENANCE SKILLS OF NOVICE DRIVERS

In addition to failures of a hazard anticipation, failures of attention maintenance (commonly called distraction) are thought to be a major cause of this increased risk. Recent naturalistic and field studies of more experienced, older teen drivers (18 and 19) indicate that they are more likely to glance away from the forward roadway for an extended period of time than more experienced drivers. However, no studies have directly compared the extended glance durations away from the forward roadway of newly licensed and older drivers when performing distracting tasks inside and outside of the vehicle. In order to understand the effect that in-vehicle and outside-the-vehicle distractions have on the glance durations away from the forward roadway of newly licensed drivers, both newly licensed and experienced drivers were asked to navigate a virtual roadway and at various points perform tasks inside and outside the vehicle. All drivers' eye movements were tracked.

METHOD

We asked newly licensed and more experienced drivers to perform various distracting tasks that were located either inside or outside the vehicle while navigating through a virtual world. (Tasks which occur inside the vehicle will be referred to as in-vehicle tasks; tasks which occur outside the vehicle will be referred to henceforth as *external* tasks) The participants' eyes were tracked throughout each drive.

PARTICIPANTS

The 24 participants were recruited from the student body of the University of Massachusetts at Amherst and the town of Amherst. The subjects were divided into two groups; the younger (newly licensed) drivers, between 16 and 18 years old, had a learner's permit or a driving license for less than six months, and the older (more experienced) drivers 21 or older had at least five years of driving experience in the United States. Each group had half men and half women. The mean ages of the older group and the younger group were 23.91 and 16.79 respectively, with standard deviations of 3.83 and 0.59. Due to the difficulties with the eye tracker calibration, it was not possible to recruit participants wearing eye-glasses; thus all participants either had normal vision or vision corrected to normal with contact lenses. All participants were tested for visual acuity prior to the experiment. All participants were screened for 20/20 vision prior to the experiment using a visual acuity test.

EXPERIMENTAL DESIGN

The virtual environment that the participants drove through was a single visual database that included both city sections and rural sections. The city section contained city blocks with four lane city streets and multiple four way signalized intersections. Drivers would travel on average two to three city blocks and then turn, right or left, travel another two to three city blocks, turn, and so on. The rural section contained an extended, slightly curved section of two-lane roadway that occurred at the end of the city section. The urban environment was populated with pseudo randomly occurring traffic including parked vehicles. The overall length of the drive was approximately 5 miles, with 2.7 of the miles being on city streets and 2.3 of the miles being on rural roads.

There were a total of 23 distraction tasks during the experiment: 18 external and 5 in-vehicle tasks. The external distraction was a target search task in which the participant was instructed to search for and indicate the presence or absence of a target letter in a 5 X 5 letter grid that appeared on the side of the road (left or right) roughly in the middle of a city block. The grids were populated with letters that had the same visual shape as the target letters (P, E or X) to reduce the salience of the target letter if it was present in a grid. The target letter was present in 6 grids and absent in the remaining 12. The present and absent trials were intermixed throughout the experiment.

The five in-vehicle tasks consisted of two CD search tasks (present/absent), two map search tasks (present/absent) and one phone-dialing task. The two CD search tasks required the driver to search for a target CD from 12 CDs in a CD case; in one the target CD was present and in the other it was absent. The two map search tasks required the driver to search for a target street name from a map that was provided, and in one the target street name was present and in the other it was absent. The fifth in-vehicle task was a phone-dialing task where the participant was instructed to dial a given number using a cellular phone that was provided in the vehicle on a sheet of paper.

APPARATUS

The same driving simulator was used in this experiment as was used in previous experiments (Figure 1). The eye tracker used in Experiments 2, 3 and 4 was used in this experiment as well (Figure 9).

PROCEDURE

After the initial screening and paperwork the participant was fitted with the head mounted eye tracker which was then calibrated within the simulator. After calibration, participants were given a practice drive to familiarize them with the driving simulator. The practice drive also included four examples of the external distraction tasks. Three letters served as targets in all grids. The participants memorized these targets at the start of the experiment. During the experimental drive the participant followed a lead vehicle and was instructed to maintain a 3-second headway. The speed limit for the city streets was 30 mph and for the rural roads was 55 mph. The grids for the external tasks were sized and positioned such that they would be visible to the participant for approximately 6 seconds when driving at 30 mph. The experimenter verbally indicated the onset of the in-vehicle tasks for each participant at the beginning of a city-block. This was timed such that the participant would get approximately 14 seconds to complete the task before reaching an intersection when driving at the posted speed limit. The experimenter terminated the in-vehicle task just before the driver entered the next intersection. All intersections at which the in-vehicle task was presented had a green signal operating at the time the participant passed through the intersection. In actuality, the drivers had a tendency to drive slower during the tasks and hence the average time that each grid was visible was 8 seconds and the average time that each driver had to complete the in-vehicle task was 16.6 seconds.

RESULTS

Our key data, which we felt best captured inattention to the roadway, was the maximum duration of an *episode* (i.e., the maximum time that the drivers spent continuously looking away from the forward roadway). Perhaps the simplest measure of this inattention was the length of this maximum episode (averaged over the relevant scenarios for each driver). First, consider the in-vehicle task data. There were large differences between the older and younger drivers in the length of the maximum episode in which they failed to monitor the roadway. The average for the older drivers was 1.63 s and for the younger drivers was 2.76 s, $t(22) = 3.57$, $p < .002$. The pattern is the same for a measure that is more comparable to the studies reviewed above: the percent of scenarios in which the maximum duration of such an episode was greater than 2 seconds. The percents were 20% vs. 56.7%, respectively, for the older and younger drivers, $t(22) = 3.87$, $p < .001$. There is the same pattern if one sets the cutoff at 2.5 s (10.0% vs. 45%), $t(22) = 3.72$, $p < .002$, and 3 s (6.7% vs. 33.3%), $t(22) = 3.17$, $p < .005$. The complete pattern is presented in Figure 17.

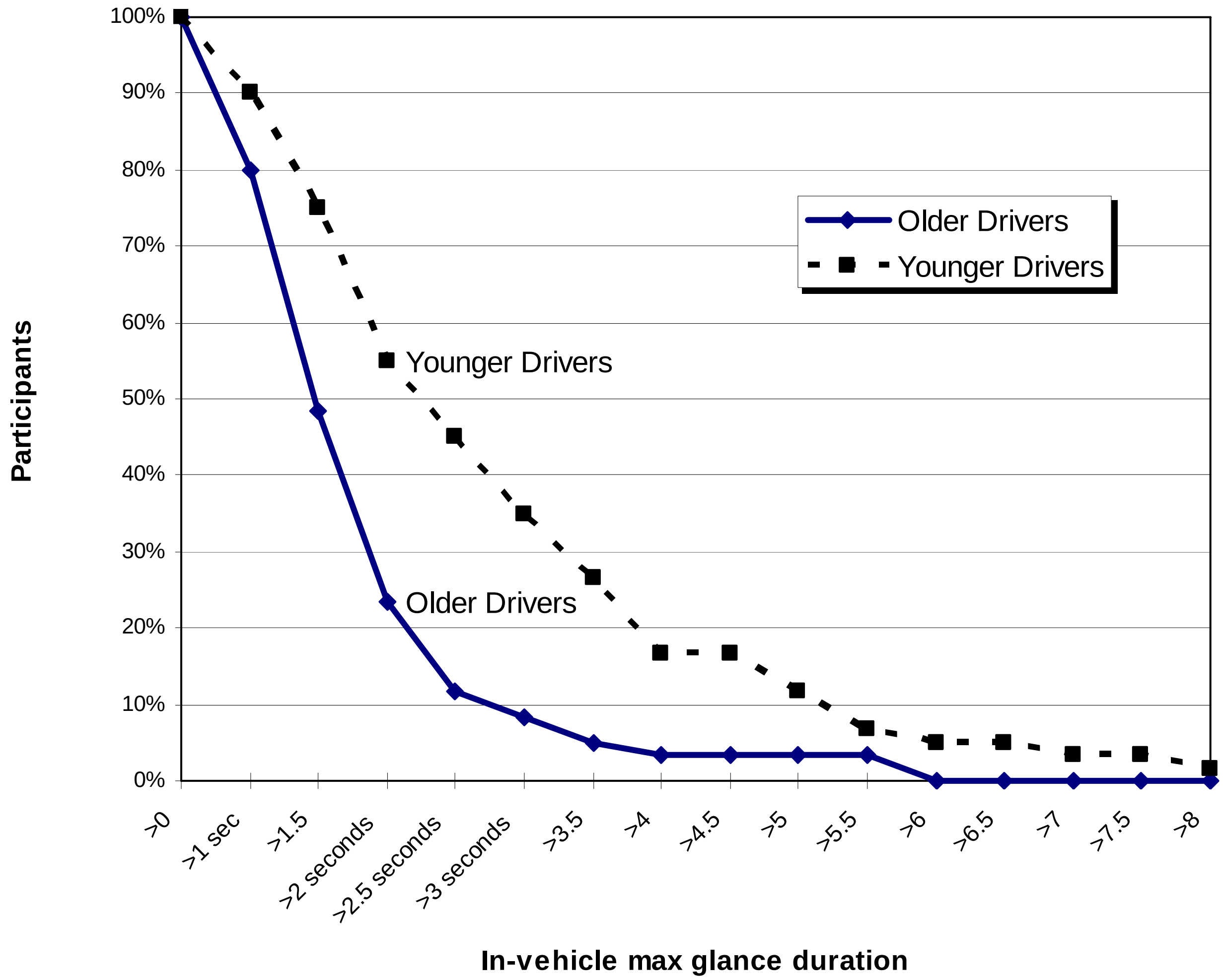


Figure 17. Distribution of In-Vehicle Maximum Glance Durations by Age of Participants

Moreover, as illustrated by the 2 s data in Figure 18, the results for these three measures were quite consistent across scenarios, $t(4) = 6.33$, 5.25, and 3.67, *p*s < .01, .01, and .05, for the percent greater than 2, 2.5, and 3 s data, respectively. Finally, the younger drivers not only had longer maximum episodes than did the experienced drivers, but the total time that the younger drivers spent with their eyes off the road for the in-vehicle tasks (7.36 s) was appreciably longer than for older drivers (5.80 s), however this difference was not significant, $t(22)=1.49$, $p = 0.075$.

In contrast, the data were quite equivocal for the external vehicle tasks. Although the average duration of the maximum episode was slightly greater for the younger drivers than for the older drivers (3.67 vs. 3.41 s), the difference was far from significant, $t < 1$. Consistent with this, there was virtually no difference in the percentage of episodes longer than 2 sec between the two groups: 81.9% for the younger drivers and 81.0% for the older drivers , $t(22) = .18$. For the 3 sec data, the difference was also negligible: younger 58.5%, older 56.9%, $t(22) =.23$ Finally, one might ask how much time in total drivers spent with their eyes off the road in the external tasks. Here we find that, again, there was no difference in the performance of the younger (4.34 s) and older (4.29 s) drivers, $t(22)=0.24$, $p = 0.4$.

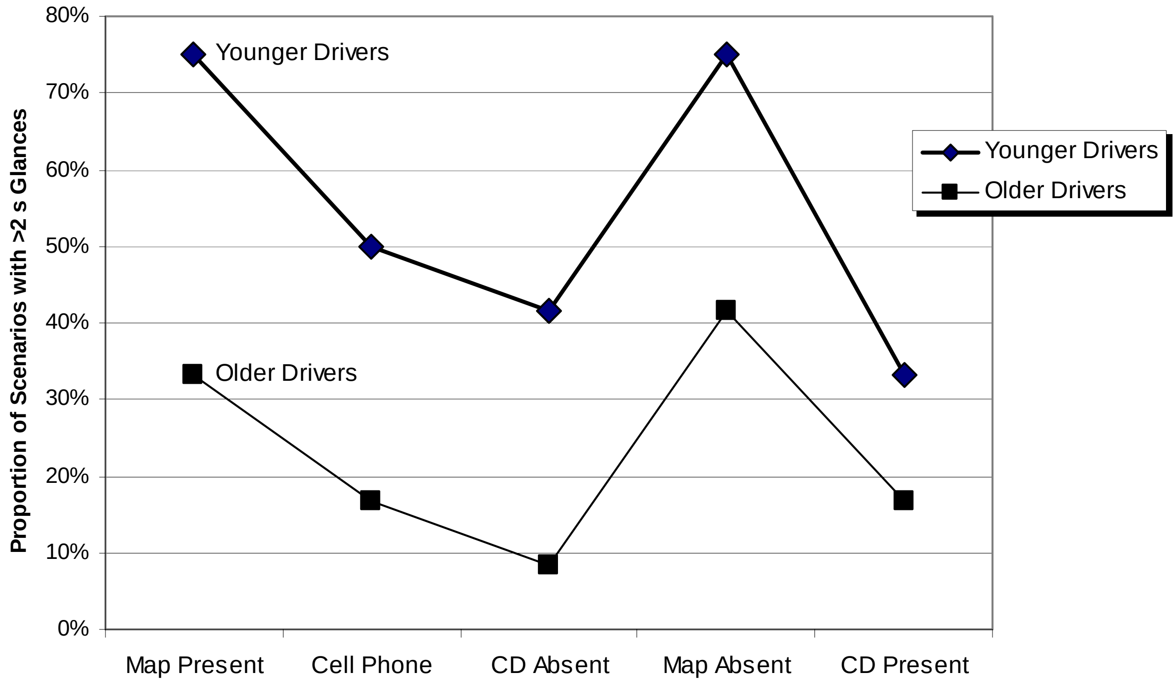


Figure 18. Percentage of Scenarios in which Younger and Older Drivers Glanced at Different In-Vehicle Tasks for Two Seconds or More

DISCUSSION

Distractions are estimated to cause some 20% to 30% of crashes among older teen drivers (McKnight & McKnight, 2003), and to be larger among such drivers than they are among more experienced drivers (Klauer et al., 2006). These studies do not differentiate between external and internal vehicle tasks as causes of the crashes. Nor have these studies looked at younger teen drivers.

First, consider distractions inside the vehicle. Field studies indicate that older teen drivers are more likely to glance continuously at an in-vehicle task for long periods of time than are more experienced drivers (Wikman et al. 1998). Our experiment indicates that this is true not only of older teen drivers, but also of newly licensed drivers. Newly licensed drivers looked for two seconds or longer at more than twice as many in-vehicle tasks as did older drivers. Clearly, in-vehicle tasks pose special problems for newly licensed drivers. It is of interest that the difference between the percentage of younger and older drivers with episodes (sequences of glances) at least two seconds long performing an in-vehicle task does not appear to change greatly from one task to another even though the absolute percentage varies widely from one in-vehicle task to another. Since all our in-vehicle tasks required multiple glances, the differences from task to task in the durations of the maximum episodes cannot be attributable simply to the fact that some tasks were more easily completed in a single episode. Instead, it may be that some tasks were more easily started and stopped (e.g., the CD task) than others (e.g., the map task). Since the difference between the proportion of younger and older drivers remained the same as the proportion of older drivers glancing longer than two seconds at a particular in-vehicle task increased, it appears that roughly the same additional proportion of experienced and inexperienced drivers would decide to throw caution to the wind and glance overly long at an in-vehicle task as it became more difficult to complete in a two second window.

Both findings (in-vehicle and external tasks) suggest that it might be possible to train newly licensed drivers to reduce the time that they spend with their eyes away from the forward roadway and focused on in-vehicle tasks. That is, experienced drivers performed the task correctly even though, on average, their maximum episode duration is much less than inexperienced drivers. We know that older drivers are not processing the information more quickly. Thus, it would seem there is something learned by the older driver which the inexperienced driver could learn in a training program. Moreover, we can hope that if some in-vehicle tasks can be performed correctly and are distracting only a small percentage of the time that other in-vehicle tasks which are distracting a relatively large percentage of the time can perhaps still be performed correctly if drivers could adopt scanning strategies with smaller episode durations.

Second, consider distractions external to the vehicle. We had assumed that experienced drivers would exercise the same caution with distracting external vehicle tasks as they exercised with distracting internal vehicle tasks. Indeed, there is a suggestion in the literature that younger drivers are especially prone to distractions external to the vehicle (Wallace, 2003) Instead, the experienced drivers showed little concern for the effect that diverting their attention to the side of the roadway might have had on their ability to perceive potential risks immediately in front. In fact, in some 81% of the external tasks, older drivers glanced for longer than two seconds away from the forward roadway.

LIMITATIONS

There are several limitations. First, one might argue that the experienced and inexperienced drivers treated the experiment as a game with few consequences. If this were the case, one would have expected no difference between the distribution of the glance durations of the in vehicle and external to vehicle secondary tasks. However, the experienced drivers did show sensitivity to the consequences of the in-vehicle tasks: in only 20% of the internal vehicle scenarios did the experienced driver glance away from the forward roadway for longer than 2 seconds whereas in 80% of the external to vehicle scenarios the experienced drivers glance away for longer than 2 seconds. The inexperienced drivers showed a similar sensitivity to in vehicle and external to vehicle tasks: in 56% of the internal vehicle scenarios the young drivers glanced for longer than 2 seconds away from the forward roadway whereas in 81% of the external to vehicle tasks the young drivers glanced for longer than 2 seconds away from the forward roadway.

Second, with respect to the external to vehicle tasks one might argue that the drivers could pay attention to the road ahead during the external vehicle tasks because they were reasonably able to see the roadway in front of them while performing such tasks, and so these tasks compromised their driving fairly little. There is data, however, that indicates this is unlikely. For example, a recent study on a driving simulator of the use of cell phones in work zones indicated that if a car suddenly stops in front of the driver (the *lead vehicle*) in the work zone, drivers occupied on a cell phone task are just as quick to stop as drivers not so occupied (Muttart et al., in press). However, the results were different if the lead vehicle stopped in response to some event which occurred downstream of the lead vehicle. In this case the driver who was not on the cell phone task was scanning further downstream and so was able to predict the precipitous braking of the lead vehicle in response to the downstream event. Because there is no a priori reason to believe that our external search tasks were less demanding than being involved in a cell phone task, we think that our drivers engaged in the external search task were truly distracted with potential serious consequences. That is, our results suggest, not altogether surprisingly given experienced drivers willingness to use cell phones in their vehicles, that even experienced drivers are willing to scan a sign for extended episodes because they assume, mistakenly, that they can see all that they need to see – the braking of the lead vehicle. Clearly, more research is needed.

In summary, in-vehicle tasks are clearly much more distracting for newly licensed drivers than they are for more experienced drivers. Surprisingly, while external vehicle tasks are even more distracting, they are equally so for both newly licensed and experienced drivers. Training programs can potentially address the risky behaviors of the novice drivers, both with in-vehicle and external vehicle tasks. It remains to be seen whether some education is needed for more experienced drivers when the task is external to the vehicle.

GENERAL DISCUSSION AND FUTURE DIRECTIONS

There is clear evidence that newly licensed drivers are at a greatly inflated risk of crashing (Mayhew et al., 2003; McCartt et al., 2003; Sagberg, 1998). Not surprisingly, they are also at an increased risk of being in a fatal crash (Insurance Institute for Highway Safety, 2005). Until recently, an understanding of why they were at an increased risk of crashing came largely from police accident reports. For example, McKnight and McKnight (2003) determined from such reports that, in order, hazard anticipation, attention maintenance, and speed management were the three leading causes of crashes among younger teen drivers. Earlier studies were consistent with these findings (Treat et al. 1979; Gregersen, 1996). What is not clear from these studies is exactly how the hazard anticipation, attention maintenance and speed management skills of the newly licensed and more experienced drivers differ from one another since no comparisons were made between these two extreme groups.

HAZARD ANTICIPATION

In order to determine more precisely where the hazard anticipation skills of the newly licensed drivers differed from the hazard anticipation skills of more experienced drivers, investigators have turned to driving simulators where it is possible to control rigorously exactly what is being displayed to inexperienced and experienced drivers. It is now clear from such studies precisely how the vehicle (Fisher et al., 2002) and eye (Pradhan et al., 2006) behaviors of the two sets of drivers differ in scenarios which require the anticipation of a hazard that is difficult to identify.

Once it became clear how the hazard anticipation behaviors of inexperienced and experienced drivers differed from one another in particular scenarios, the next obvious question was whether one could train the novice drivers to perform at levels better than the untrained novice drivers. Using a simple PowerPoint training program (RAPT-1), it was shown that novice drivers could be trained to anticipate hazards (Pollatsek et al., 2006) and they did so as well as drivers with on average 10 years of on-road experience (Pradhan et al., 2006).

In this project, our understanding of how to train hazard anticipation skills was extended. First, previously it had been shown that hazard anticipation training was effective immediately after training when evaluated on a driving simulator (Pollatsek et al., 2006). Here we showed that the effects of the training persisted up to a week (Experiment 1). Second, previously it was shown that hazard anticipation skills generalized from PC training program to a driving simulator. Here we showed that the effects of this training generalized to the open road as well (Experiment 2). Third, before this project it was not clear whether what we were learning on the driving simulator at all mirrored what we were learning in the field. Here, we showed that the results of hazard anticipation training are strikingly similar in the field and on a driving simulator (Experiment 3). Finally, before this project no one had studied the benefits that might come from using advanced and relatively inexpensive technologies such as a PC based, head mounted driving simulator for training. Increases in realism in simple PC programs appeared to improve the effectiveness of training. It made sense to take this one step further and use a PC based head-mounted driving simulator. Here, we showed that the drivers trained with the PC based, head-mounted simulator were performing better than the drivers trained with an earlier version of RAPT (comparison of Experiment 4 with Pollatsek et al., 2006). However, drivers who were not trained using the PC-based simulator were also performing better in Experiment 4 than they were in Pollatsek et al. (2006). Thus, it is not clear how much the absolute increase in the trained drivers' performance is due to a general increase in the risk awareness of drivers in the cohort of participants recruited for Experiment 4 and how much this increase is due to the PC-based simulator training.

ATTENTION MAINTENANCE

Consider next the one experiment focused on attention maintenance. Previously it had been determined that older teen drivers made more frequent long glances away from the forward roadway inside the vehicle than did more experienced drivers (Wikman et al., 1998). But, it was not known whether younger, newly licensed teen drivers would perform similarly. If newly licensed drivers are generally risk averse we should find them making relatively few long glances inside the vehicle compared to older teen drivers. In fact, we found just the opposite (Experiment 5). Newly licensed drivers were making many more long glances inside the vehicle than experienced drivers. This is of particular concern since younger drivers are now text messaging and interacting with their iPod inside the vehicle, tasks which definitely require many glances away from the forward roadway.

FUTURE DIRECTIONS

In summary, while it is clear that brief, easy-to-implement training can increase the likelihood that newly licensed will anticipate hazards in a driving simulator and on the road, it is not yet clear whether this will lead to a reduction in crashes. In fact, it is not clear if one would want to evaluate a program that increased hazard anticipation skills, but did nothing to improve attention maintenance and speed management skills. These have been identified as skills clearly deficient in newly licensed drivers, either through police accident reports (McKnight & McKnight, 2003), on road studies (attention maintenance: Wikman et al., 1998), or simulator studies (attention maintenance: Chan et al., 2008; speed management: Fisher et al., 2002).

(1) <u>Further Develop Hazard Anticipation, Attention Maintenance and Speed Management Training Programs</u>. There has been some real success creating a hazard anticipation training program. The training takes at most an hour and could easily be implemented as part of a driver education program. It seems that similar successes could be achieved with programs that trained newly licensed drivers to maintain their attention and manage their speed better. As with the hazard anticipation training programs, future attention maintenance and speed management training programs need to be evaluated on a driving simulator and in the field. Moreover, some effort should go into continuing to improve the current hazard anticipation program. While overall newly licensed drivers perform better, in some scenarios the improvement is much less than one might like. The iterative redesign of hazard anticipation training programs could increase the effectiveness of these programs for those particular scenarios where the effect of training is less than optimal.

(2) <u>Determine Duration of Training Effects and Need for Retraining</u>. It would also appear that more needs to be understood about the duration of the training effects. In order to see a reduction in crashes over the first six months based on only an hour or two of training during the learner's permit stage seems rather idealistic. It may well be that there is a need for retraining during the intermediate license stage. So, for example, one might find that newly licensed drivers maintain their driving skills if they are re-exposed to very brief scenarios for 15 minutes once a week. A priori, it is not clear how much time will be needed in the way of retraining or when that

retraining would be optimally sequenced during the first six months of an intermediate stage license. The logistics of retraining need also to be considered. It seems easy enough to monitor a participant's progress on a web based program, especially were this considered part of standard driver education programs. But this remains to be determined.

(3) Identify Effect of Training on Crashes. Ultimately, of course, one wants to determine whether a comprehensive training program reduces crashes. Assuming one had such a comprehensive program in place and that it improved hazard anticipation, attention maintenance and speed management skills for a period lasting the full six months that a driver held an intermediate stage license on a driving simulator and in the field, the evaluation of the program is relatively straightforward. Perhaps the only qualification should be that the evaluation would occur in a state where the crash data records are linked to the licensing registration records. One needs to know not only how old a driver is when he or she crashes (available from the police accident reports), but also when the driver first obtained an intermediate stage license (available from the registration database). One should also be mindful of the need to consider a broader involvement of individuals in the driver education process, including possibly training parents.

REASONS FOR OPTIMISM

In many ways there would appear to be little reason for optimism that a comprehensive training program would work. After all, driver training programs have been around for some time. The first known driver education program was established in 1916 (National Highway Traffic Safety Administration, 1994, page 3). However, it was not until 1976 that a full-scale, controlled evaluation of driver education was undertaken in a suburb of Atlanta, Georgia. The results were disappointing, both in the short and long term (NHTSA, pp. 7-8). Twenty years later, Mayhew and Simpson (1996) reviewed 30 studies from several different countries that evaluated the effect of driver training programs on crashes. There was very little support for the claim that formal driver education decreased crash involvement. More recently, a number of literature reviews of the effectiveness of standard driver education programs have been conducted. The reviews have spanned the globe, including ones undertaken in Australia (Wooley, 2000), Britain (Roberts & Kwan, 2002), Canada (Mayhew & Simpson, 2002), Sweden (Engstrom, Gregersen, Hernetkoski, Keskinen, & Nyberg, 2003) and the United States (Vernick, Li, Ogaitis, MacKenzie, Baker, & Gielen, 1999). These reviews are uniform in concluding that standard driver education does not reduce the crash rates among newly licensed drivers. In fact, they conclude that standard driver education may increase the crash rates, both by reducing the age at which solo licensing is allowed and by teaching novice drivers skills such as skid control that may increase a novice driver's willingness to take risks (Nichols, 2003).

Despite this rather bleak picture, we remain optimistic about the potential that training programs like the ones we have developed can potentially make a large difference. We start with an initial confidence that the differences we have identified between novice and experienced drivers in the field and on the driving simulator in hazard anticipation, attention maintenance and speed management skills are real ones. We know that current driver education programs are not successfully giving drivers these particular skills because we are evaluating newly licensed drivers who are currently enrolled in driver education programs or have been previously enrolled in such programs. These are the drivers that are showing the large training effects. Furthermore, we know that these skills can be trained (at least hazard anticipations skills can be trained) and that they generalize from the scenarios that are trained to a broader class of scenarios. We have no reason to believe that through a proper program of retraining these skills could not be maintained, both for near and far transfer scenarios. Therefore, we have the very real sense that training programs could be designed which over a period of six months would lead the drivers better to anticipate hazards, maintain their attention, and manage their speed.

REFERENCES

Baker, S. P., Chen, L.-H., & Li, G. (2006). *National Evaluation of Graduated Driver Licensing Programs.* No. DOT HS 810 614. Washington, D. C.: National Highway Traffic Safety Administration.

Boyce, S. J., & Pollatsek, A., 1992, Identification of objects in scenes: The role of scene background in object naming. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **18**, 531-543.

Chan, E., Pradhan, A. K., Knodler, M. A, Pollatsek, A., & Fisher, D. L. (January 2008). *Empirical Evaluation on a Driving Simulator of the Effect of Distractions Inside and Outside the Vehicle on Drivers' Eye Behaviors*. Presentation at the 87th Transportation Research Board Annual Meeting, TRB, National Research Council, Washington, D.C

Chapman, P., Underwood, G., & Roberts, K., 2002, Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F*, **5**, 157 – 167.

Crundall, D., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition in drivers, *Ergonomics, 41*, 448 – 458.

Fisher, D. L., Laurie, N. E., Glaser, R., Connerney, K., Pollatsek, A., Duffy, S. A., & Brock, J. (2002). The use of an advanced driving simulator to evaluate the effects of training and experience on drivers' behavior in risky traffic scenarios. *Human Factors, 44,* pp. 287-302.

Fisher, D. L., Narayanaan, V., Pradhan, A., & Pollatsek, A. (2004). The use of eye movements to evaluate the effect of PC-based risk awareness training on an advanced driving simulator. In *Proceedings of the 48th Human Factors and Ergonomics Society's Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society, p 2266.

Fisher, D. L., Pollatsek, A., & Pradhan, A. (2006). Can novice drivers be trained to scan for information that will reduce their likelihood of a crash? *Injury Prevention, Volume 12, Supplement 1,* i25-i29.

Fisher, D. L., Pradhan, A. K., Pollatsek, A., & Knodler, M. A. Jr. (January 2007). Empirical evaluation of hazard anticipation behaviors in the field and on a driving simulator using an eye tracker. *Proceedings of the 86th Transportation Research Board Annual Meeting* CD-ROM, TRB, National Research Council, Washington, D.C

Gregersen, N. P. (1996). Young drivers' overestimation of their skill: An experiment on the relation between training strategy and skill. *Accident Analysis & Prevention, 28,* 243-250.

Henderson, J. M., & Hollingworth, A., 1999, The role of fixation position in detecting scene changes across saccades. *Psychological Science*, **5**, 438-443.

Hollingworth, A., & Henderson, J. M. (2002). Accurate Visual Memory for Previously Attended Objects in Natural Scenes. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 113-136.

Insurance Institute for Highway Safety (IIHS). 2005. *Fatality facts: teenagers 2005*. Arlington (VA): The Institute; 2006. Accessed December 12, 2007. Available from: www.iihs.org/research/fatality_facts/teenagers.html.

Klauer, S.G., Dingus, T. A., Neale, V. L., Sudweeks, J.D., & Ramsey, D.J. (2006). *The Impact of Driver Inattention On Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data.* Report No. DOT HS 810 594. Washington, D.C.: National Highway Traffic Safety Administration.

Knodler, M. A., & Noyce, D. A. (2005). Tracking driver eye movements at permissive left-turns. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Rockport, ME, pp 134-142.

Mayhew, D. R., & Simpson, H.M. (2002). The Safety Value of Driver Education and Training. *Injury Prevention, 8*,(*Supplement II*):ii3-ii8.

Mayhew, D. R., Simpson, H. M., Williams, A. F., & Desmond, H. (2002). *Specific and long-term effects of Nova Scotia's Graduated Licensing Program*. Arlington, VA: Insurance Institute for Highway Safety.

Mayhew, D. R., Simpson, H. M., & Pak, A. (2003). Changes in collision rates among novice drivers during the first months of driving. *Accident Analysis and Prevention,, 35*, 683-691.

McCartt, A. T., Shabanova, V. I., & Leaf, W. A. (2003). Driving experience, crashes and traffic citations of teenage beginning drivers. *Accident Analysis and Prevention, 35*, 311-320.

McKnight, J. A., & McKnight, S. A. (2003). Young Novice Drivers: Careless or Clueless. *Accident Analysis and Prevention*, 35, 921-925.

McPherson, K., & McKnight, J. A., September 1981, *Automobile driver on-road performance test*, DOT-HS-806-207. Washington, DC: National Highway Traffic Safety Administration.

Mourant, R. R., & Rockwell, T. R. (1972). Strategies of visual search by novice drivers and experienced drivers. *Human Factors, 14*, 325-335.

Muttart, J., Fisher, D. L., & Pollatsek, A. (in press). Driving Simulator Evaluation of Driver Performance during Hands-Free Cell Phone Operation in a Work Zone: Driving without a Clue *Transportation Research Record*.

Narayanan, V.. (February 2005). Evaluation of a PC-based risk recognition training program for novice drivers using an advanced fixed based driving simulator. Master's Thesis, Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA.

Nelson, W.W., & Loftus, G. R. (1980). The Functional Visual Field During Picture Viewing. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 391-399.

Nichols, J. L. (2003). *A review of the history and effectiveness of driver education and training as a traffic safety program*. Washington, D C: National Transportation Safety Board.

Pollatsek, A., Narayanaan, V., Pradhan, A., & Fisher, D. L. (2006). The Use of Eye Movements to Evaluate the Effect of PC-Based Risk Awareness Training on an Advanced Driving Simulator. *Human Factors, 48*, 447-464.

Potter, M.C., Staub, A., Rado, J., & O'Connor, D.H. (2002). Recognition memory for briefly presented pictures: The time course of rapid forgetting. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1163-1175.

Pradhan, A. K., Hammel, K. R., DeRamus, R., Pollatsek, A., Noyce, D. A., & Fisher, D. L (2005). The Use of Eye Movements to Evaluate the Effects of Driver Age on Risk Perception in an Advanced Driving Simulator. *Human Factors, 47,* 840-852.

Pradhan, A. K., Fisher, D. L., & Pollatsek, A. (2006). Risk Perception Training for Novice Drivers: Evaluating Duration of Effects on a Driving Simulator. *Transportation Research Record, 1969*, 58-64.

Raymond, P., Johns, J., Golembiewski, G., Furst Seifert, R., Nichols, N., & Knoblauch, R. (2007). *Evaluation of Oregon's Graduated Driver Licensing Program*. Washington, DC: National Highway Traffic Safety Administration.

Romoser, M., Fisher, D. L., Mourant, R., Wachtel, J., & Sizov, K. (2005). The Use of a Driving Simulator to Assess Senior Driver Performance: Increasing Situational Awareness through Post-Drive One-on-One Advisement. *Driving Assessment 2005 CD-ROM*, Rockport, Maine.

Sagberg, F. (1998). *Month-by-month changes in accident risk among novice drivers*. Oslo, Norway: Institute of Transport Economics, Norwegian Centre for Transport Research.

Sagberg, F., & Bjørnskau, T. (2006). Hazard perception and driving experience among novice drivers. *Accident Analysis and Prevention, 38,* 407–414.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular phone. *Psychological Science, 12*, 462-466.

Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R.L., & Castellan, N. J. (1979). Tri-Level study of the causes of traffic accidents: Final report - Executive summary. Bloomington, IN: Institute for Research in Public Safety. Report No. DOT-HS-034-3-535-79-TAC(S).

Underwood, G., Chapman, P, Brocklehurst, N., Underwood, J., & Crundall, D. (2003). Visual Attention While Driving: Sequences of Eye Fixations By Experienced and Novice Drivers. *Ergonomics, 46*, 629-646.

Victor T. W., Harbluk J. L., & Engström J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research F: Traffic Psychol Behav, 8*, 167-190.

Wallace, B. (2003). External-to-vehicle driver distraction. *Transport Research Series.* Transport Research Planning Group, Social Research. Edinbugh: Scottish Executive Social Researh.

Wikman, A., Nieminen, T., & Summala, H. (1998). Driving experience and time-sharing during in-car tasks on roads of different width. *Ergonomics, 41*, 358-372.

APPENDIX A. EXPERIMENT 4. RAPT TRAINING SCENARIOS

(a)

(b)

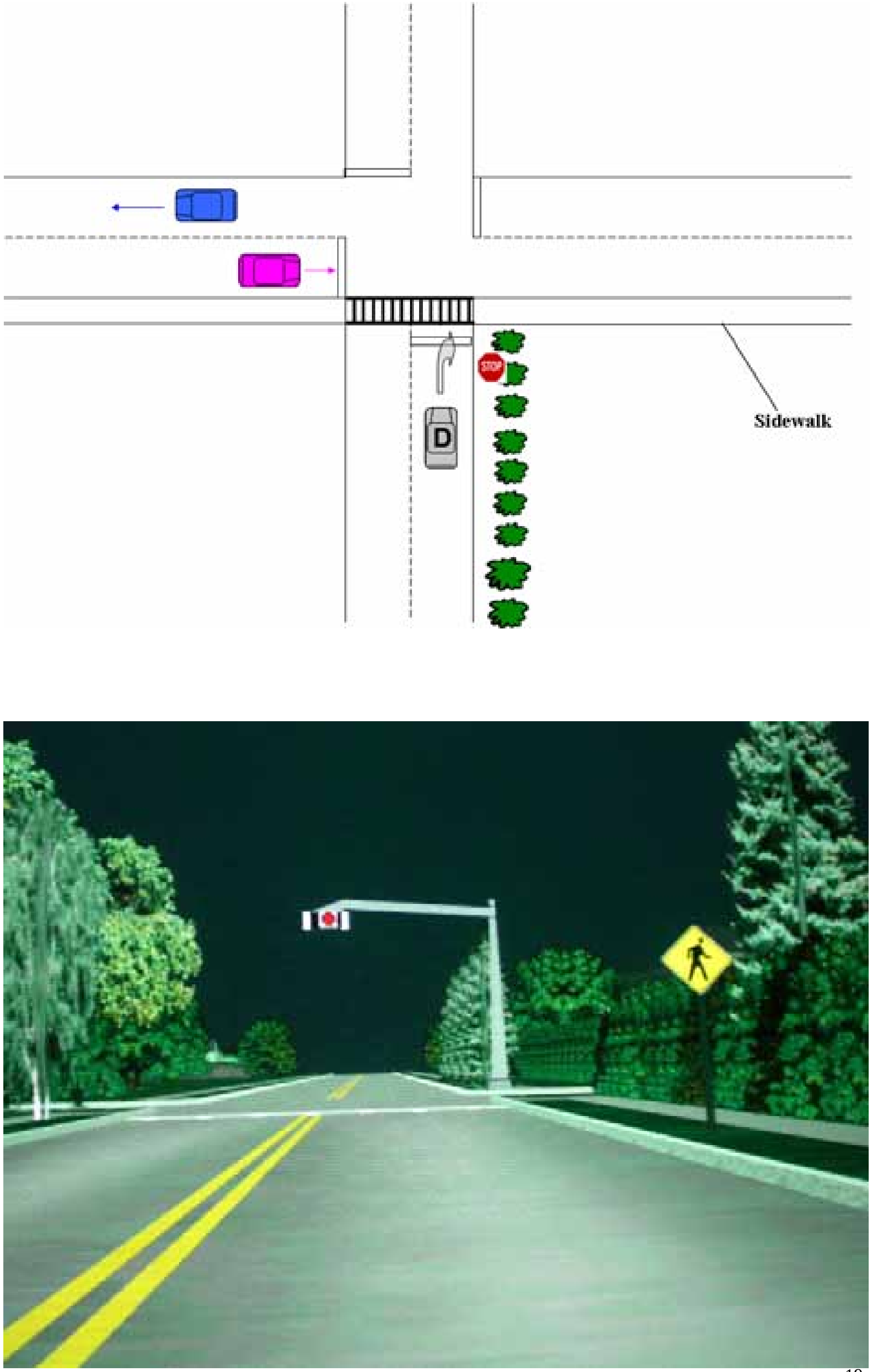
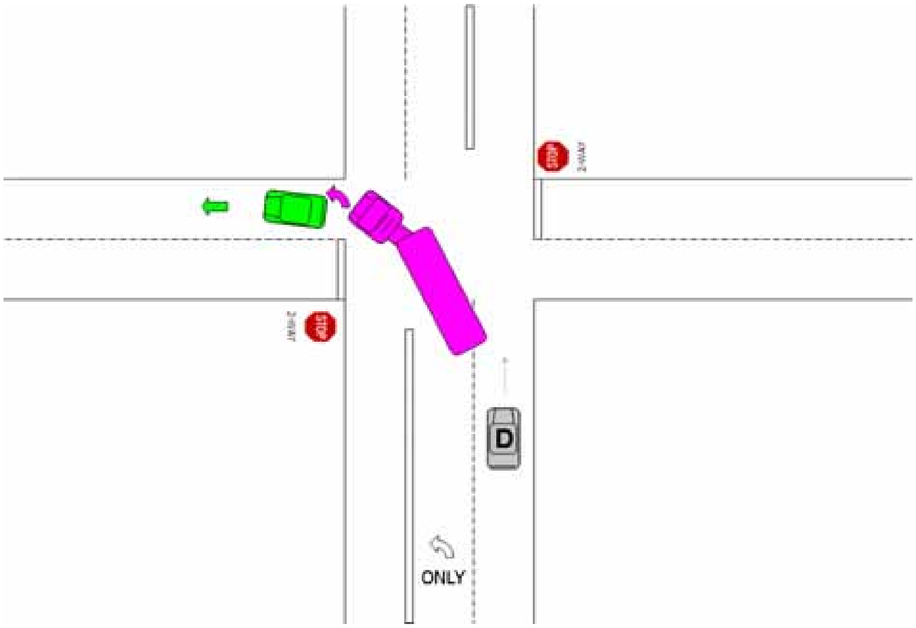


Figure 19. Amity-Lincoln Scenario. (a) Plan View. (b) Perspective View.[19]

[19] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

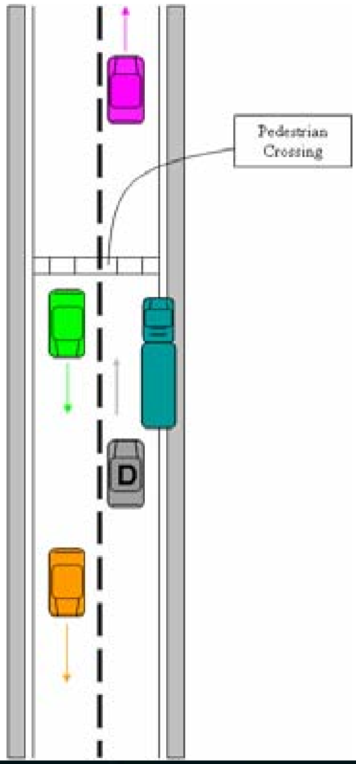


(b)

Figure 20. Adjacent Truck Left Turn Scenario. (a) Plan View. (b) Perspective View.[20]

[20] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

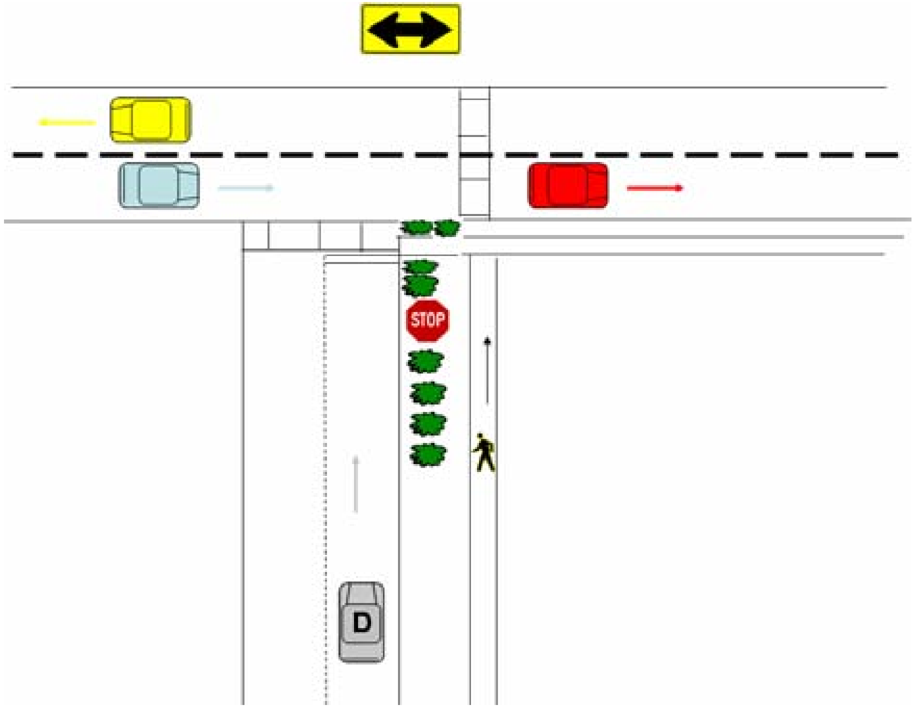


(b)

Figure 21. Truck Crosswalk Scenario. (a) Plan View. (b) Perspective View.[21]

[21] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)



(b)

Figure 22. T-Intersection Scenario. (a) Plan View. (b) Perspective View.[22]

[22] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

(b)

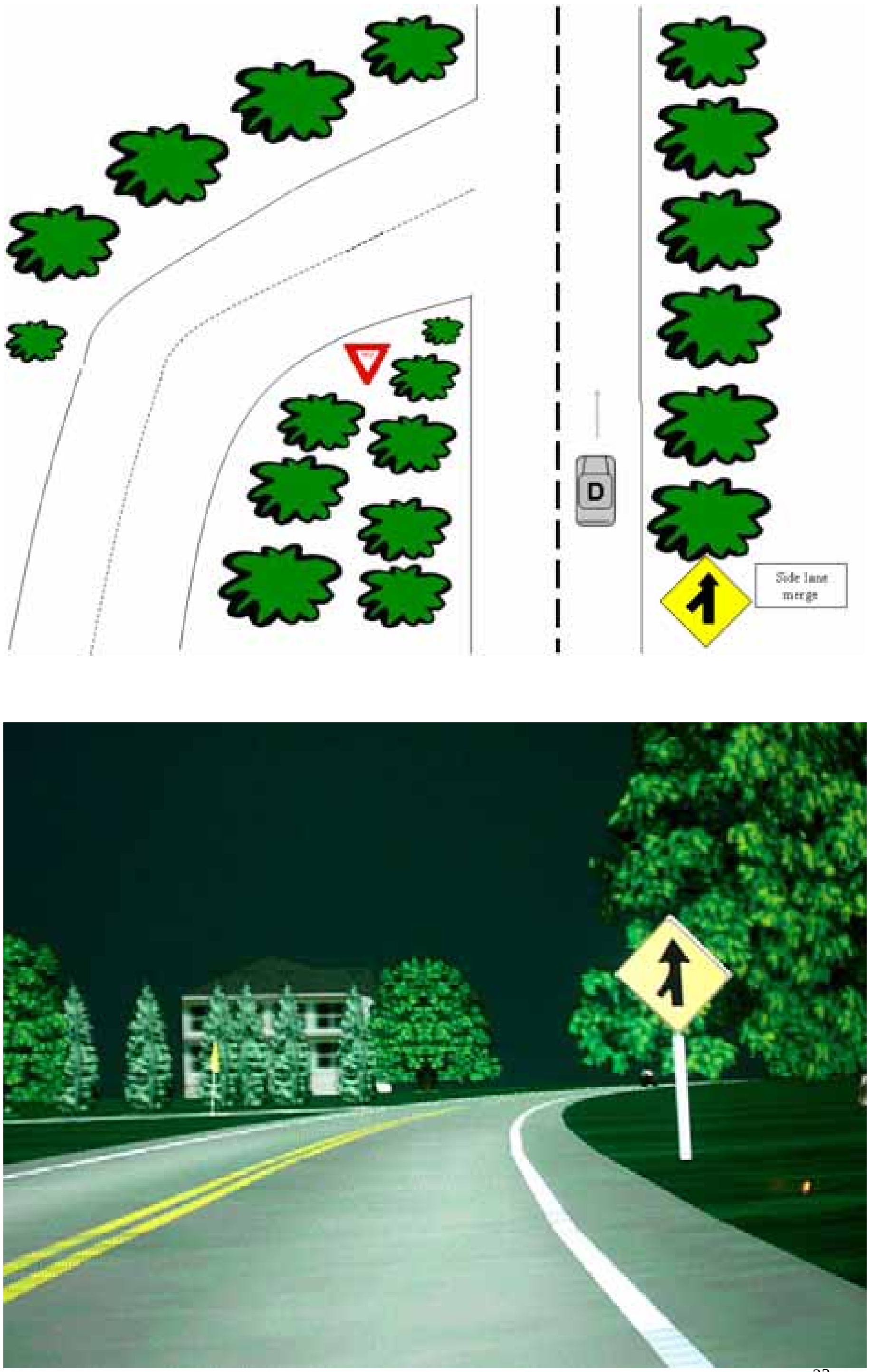


Figure 23. Left Fork Scenario. (a) Plan View. (b) Perspective View.[23]

[23] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

(b)

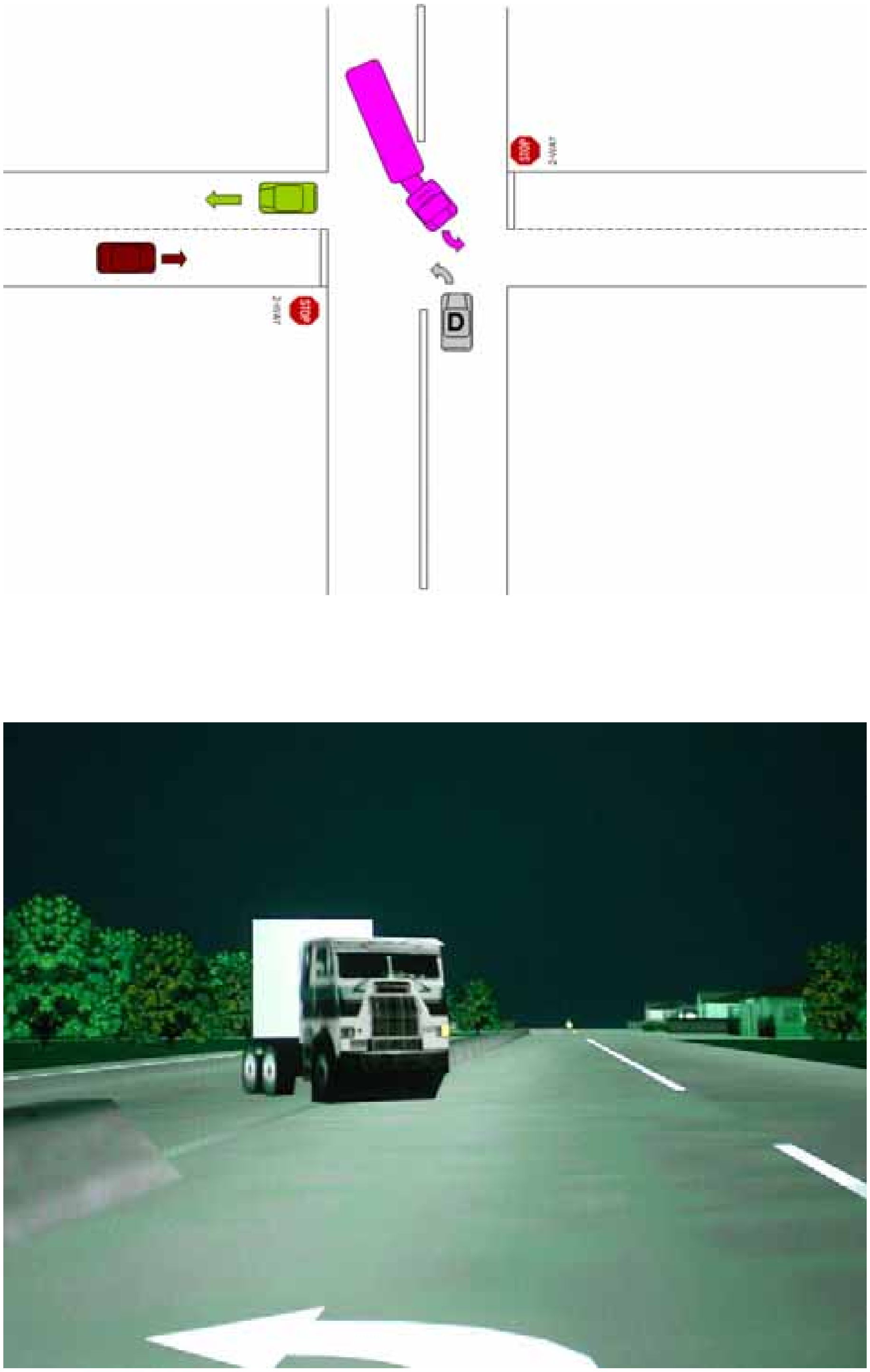
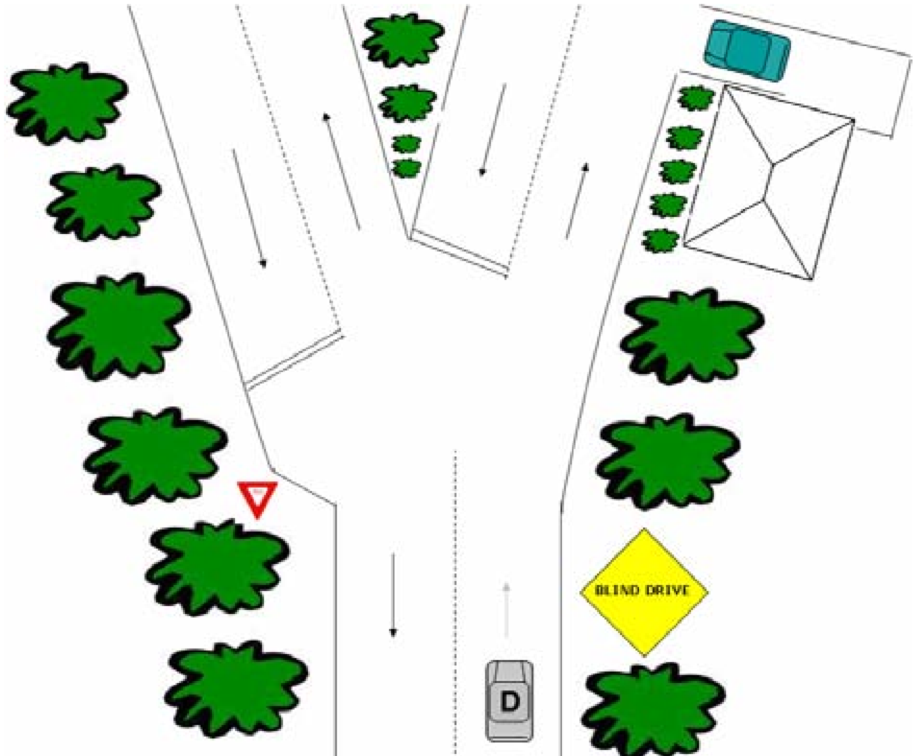


Figure 24. Opposing Truck Left Turn Scenario. (a) Plan View. (b) Perspective View.[24]

[24] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

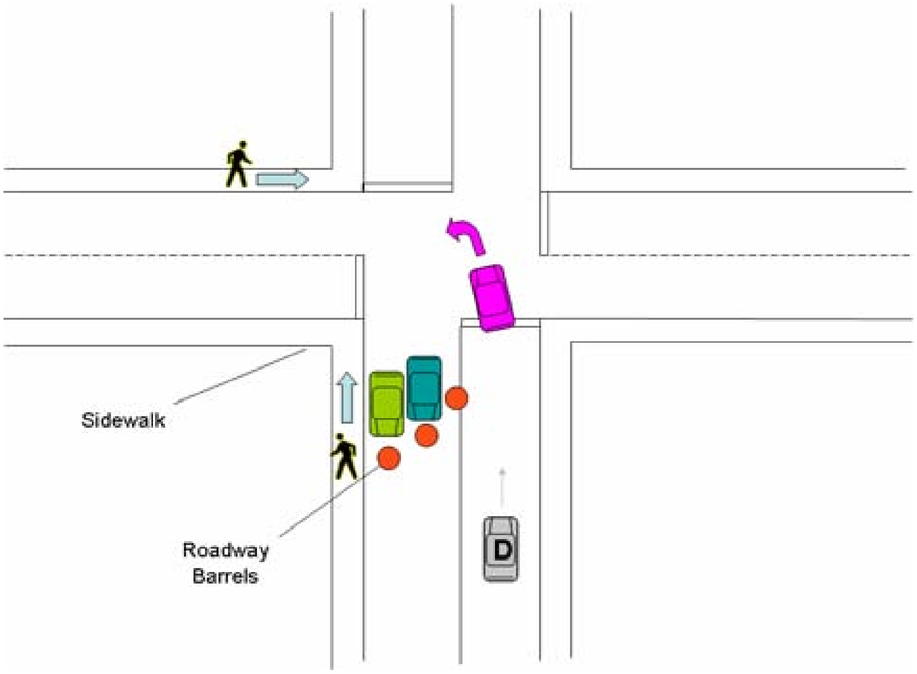


(b)

Figure 25. Blind Drive Scenario. (a) Plan View. (b) Perspective View.[25]

[25] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

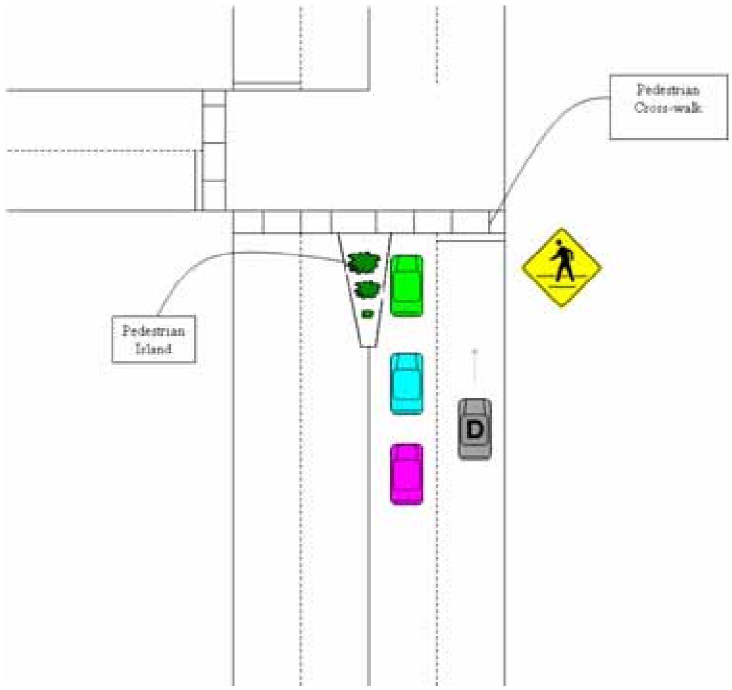


(b)

Figure 26. Pedestrian on Left Scenario. (a) Plan View. (b) Perspective View.[26]

[26] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

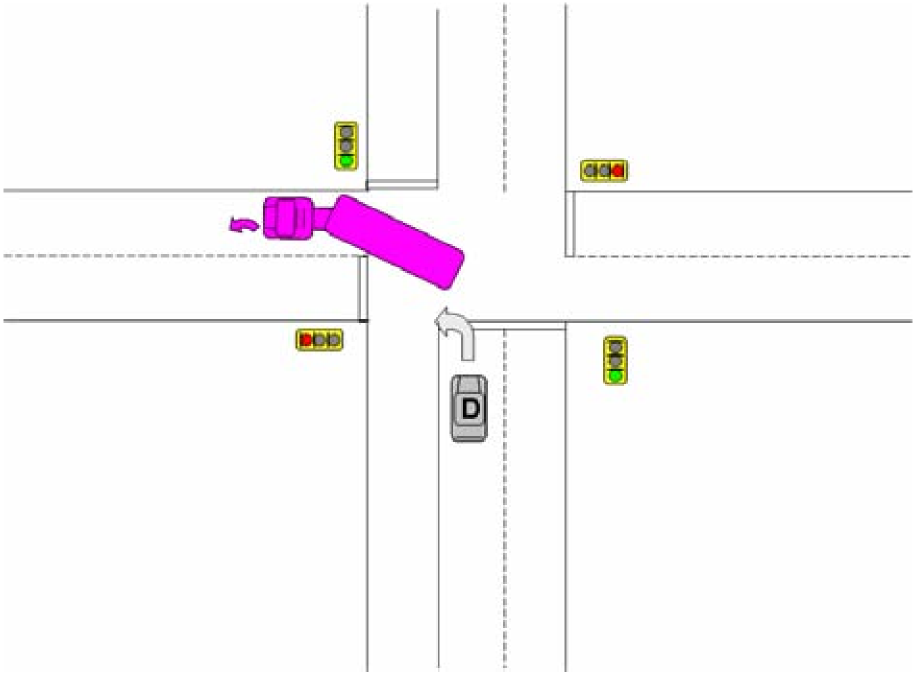


(b)

Figure 27. Mullins Center Scenario. (a) Plan View. (b) Perspective View.[27]

[27] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

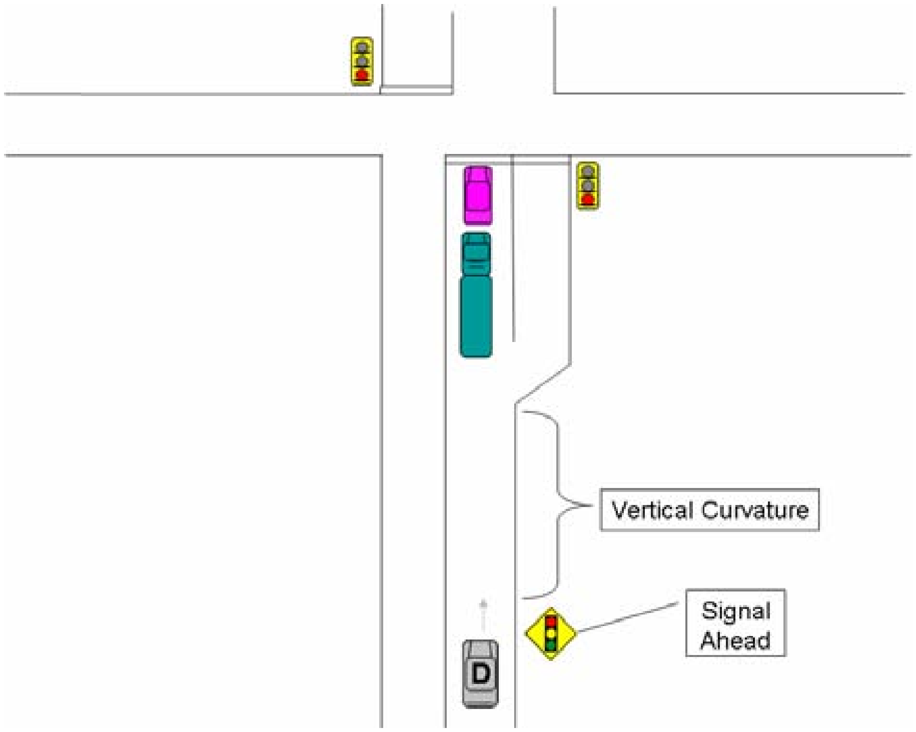


(b)

Figure 28. Bus Left Turn at Triangle St scenario. (a) Plan View. (b) Perspective View.[28]

[28] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

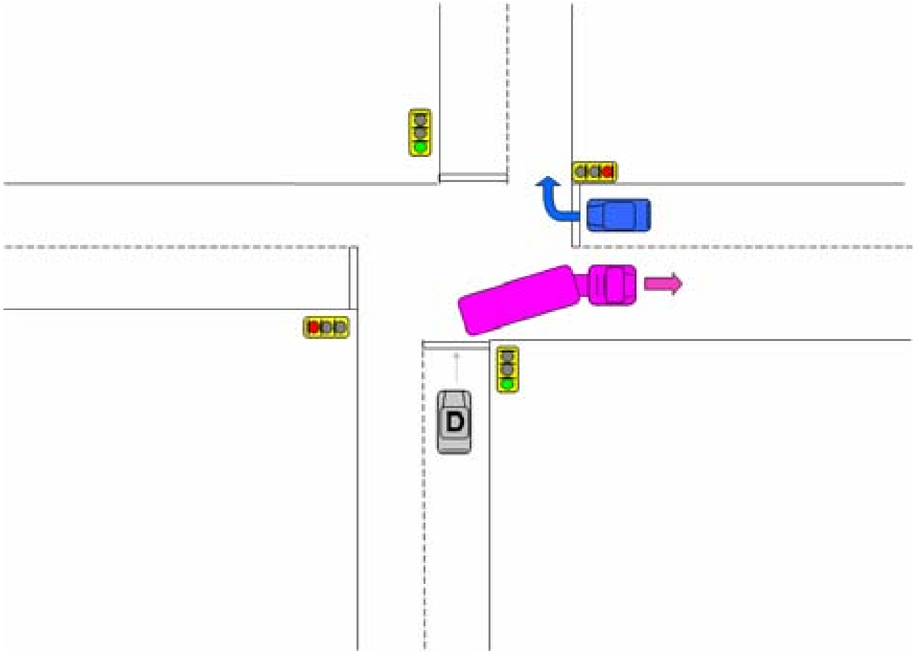


b)

Figure 29. Signal Ahead at Hill Scenario. (a) Plan View. (b) Perspective View.[29]

[29] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)



(b)

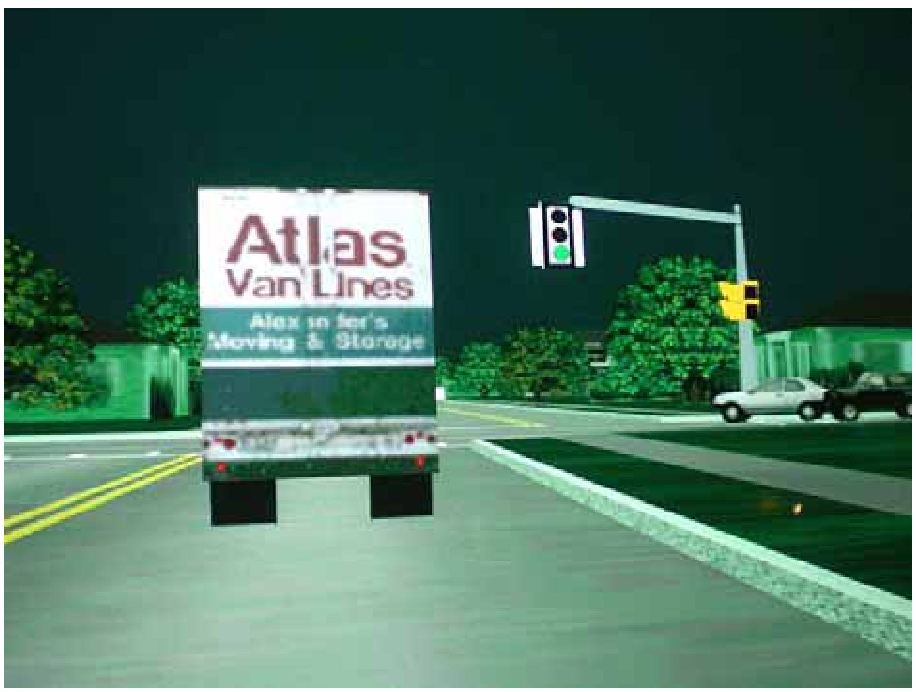


Figure 30. Vehicle on Right at Intersection Scenario. (a) Plan View. (b) Perspective View.[30]

[30] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

(b)

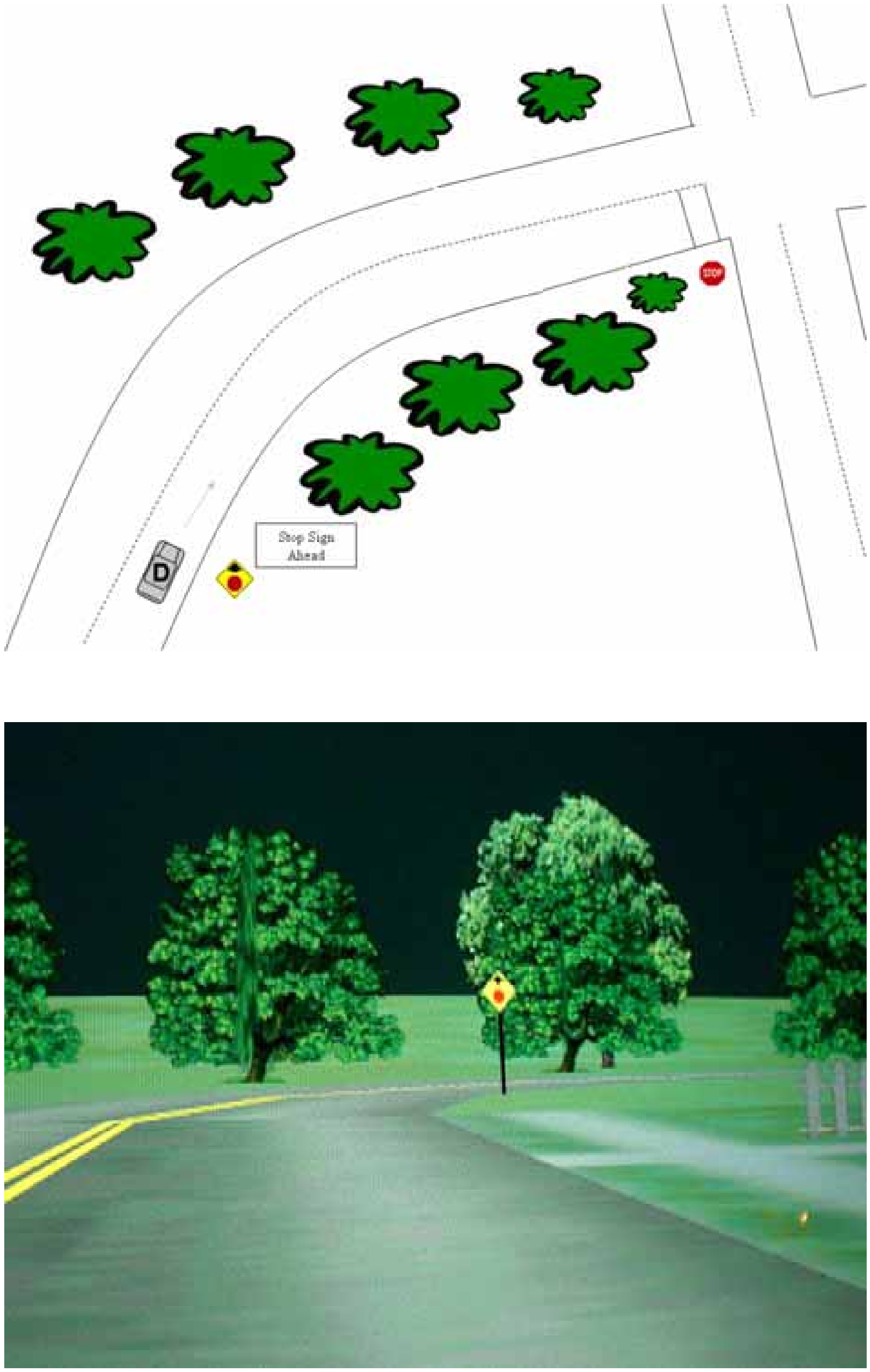
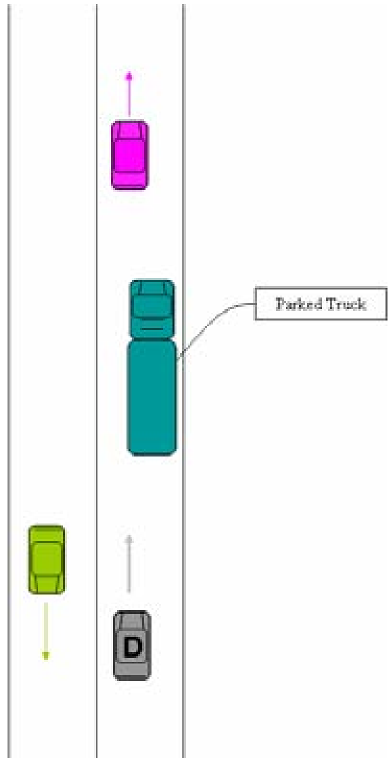


Figure 31. Curved Stop Ahead Scenario. (a) Plan View. (b) Perspective View.[31]

[31] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

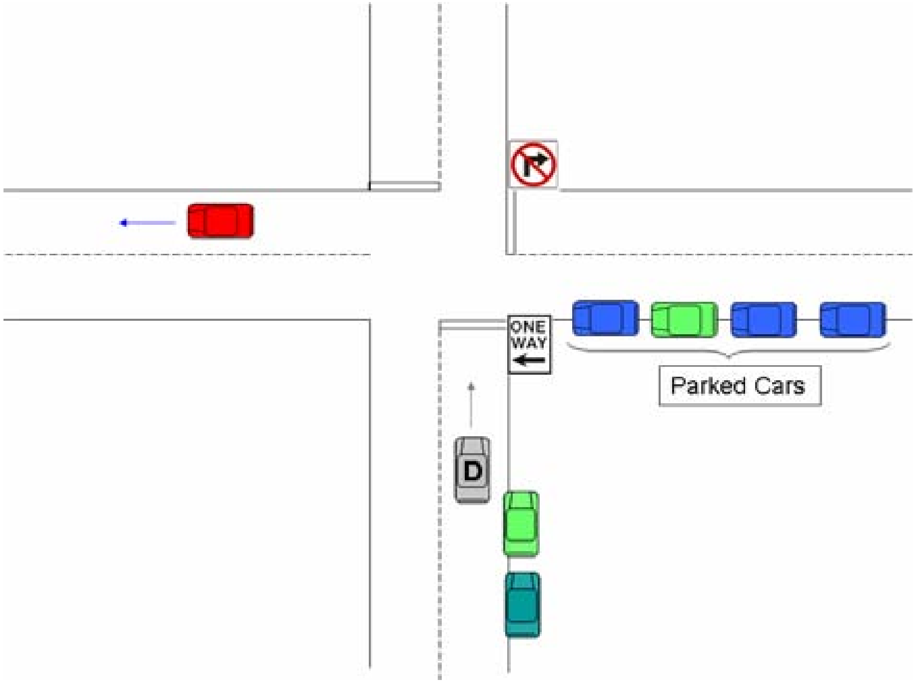


(b)

Figure 32. Truck Blocking Travel in Lane Scenario. (a) Plan View. (b) Perspective View.[32]

[32] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)

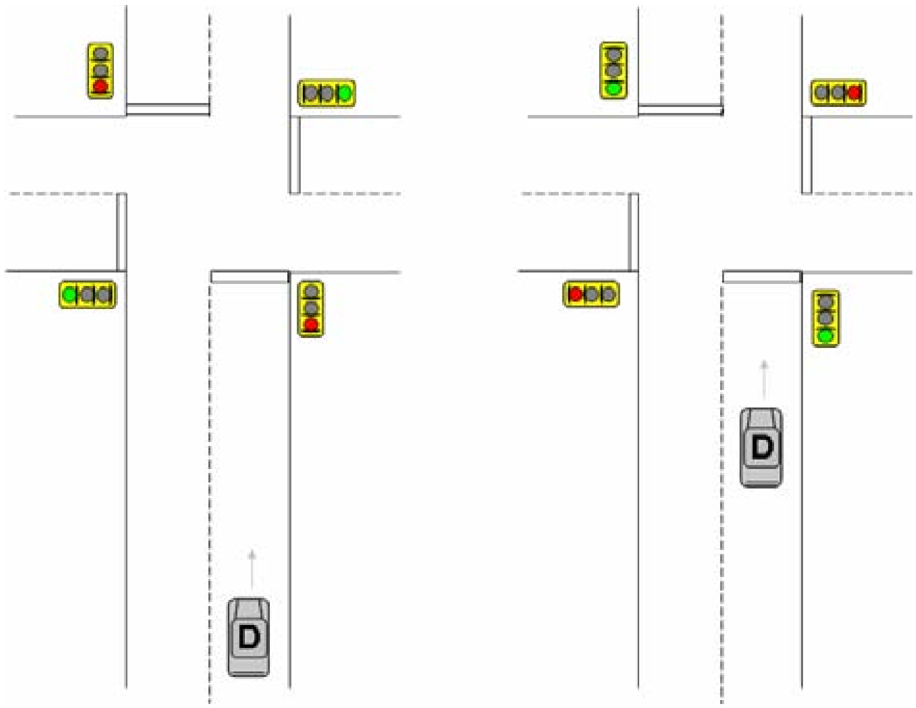


(b)

Figure 33. Intersection with One-Way Street scenario. (a) Plan View. (b) Perspective View.[33]

[33] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a)



(b)

Figure 34. Intersection with New Green Scenario. (a) Plan View. (b) Perspective View.[34]

[34] The scenarios for the HPL driving simulator that are used for this study and the slides for the PowerPoint training had been developed by Anuj Pradhan at the Human Performance Lab within the last year.

(a) (b) (c)

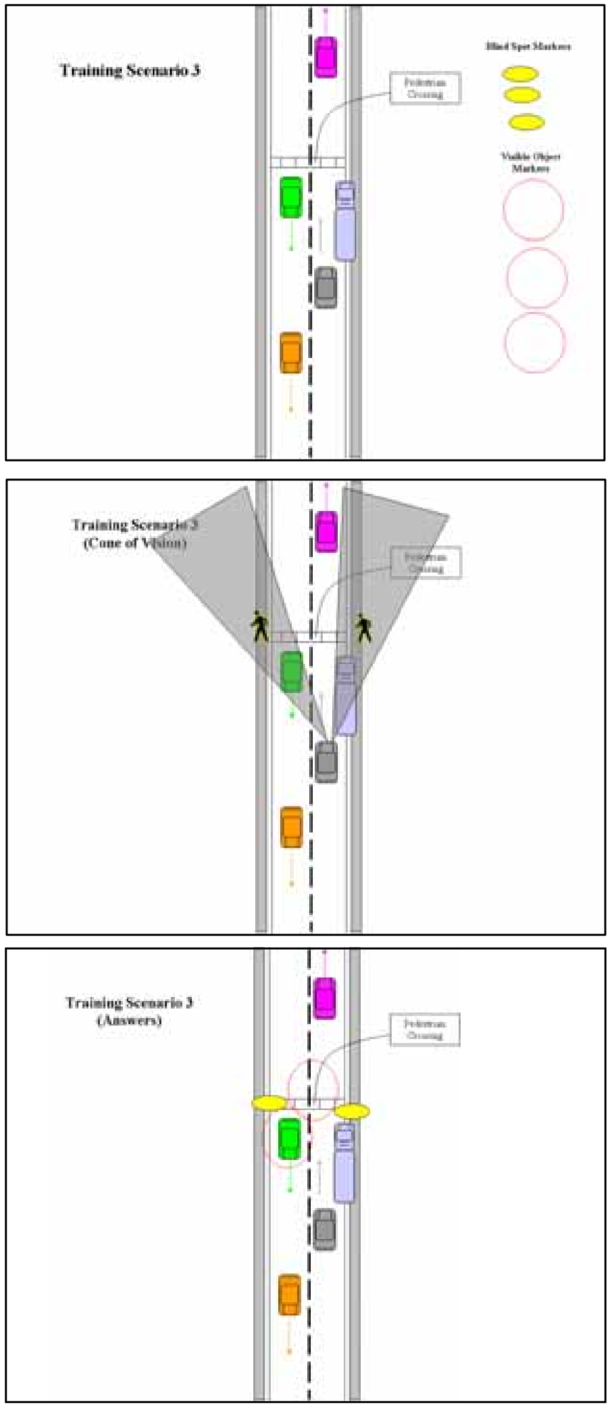


Figure 35. Truck Crosswalk Training Scenario. (a) Participant Response Screen. (b) Vision Obstruction Screen. (c) Answer Explanation Screen.[35]

[35]The slides for the PowerPoint training had been developed by researchers at the Human Performance Lab within the last year.

DOT HS 810 926
April 2008

U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA
www.nhtsa.gov