# Using Eye Movements to Evaluate a PC-Based Risk Awareness and Perception Training Program on a Driving Simulator

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**Objective:** Evaluation of the effects of a PC-based training program on risk perception in a driving simulator. **Background:** Novice drivers have a fatality rate some eight times higher than that of the most experienced group of drivers, primarily because of the novice driver's inability to predict ahead of time the risks that will appear in the roadway. Current driver education programs, at least those in the United States, do not emphasize the teaching of risk awareness skills to novice drivers. **Method:** A PC-based risk awareness and perception training program was developed and evaluated. The training involved using plan (top-down) views of 10 risky scenarios that helped novice drivers identify where potential risks were located and what information should be attended. Both the 24 trained novice drivers and 24 untrained novice drivers were evaluated on an advanced driving simulator. The eye movements of both groups of drivers were measured. The evaluation on the driving simulator included both scenarios used in the training and others not used in training. **Results:** The set of trained novice drivers were almost twice as likely as untrained drivers to fixate appropriately either on the regions where potential risks might appear or on signs that warned of potentially risky situations ahead, both for the scenarios they had encountered in training and for novel scenarios. **Application:** The PC training program developed, which is portable and can be widely used, has great promise in improving risk perception for novice drivers on the road.

## INTRODUCTION

Sixteen-year-old drivers are involved in 10.3 fatal crashes per 100 million vehicle miles, a rate almost double that of 18-year-olds and almost eight times that of 45- to 64-year-olds, who are the safest group of drivers (Insurance Institute for Highway Safety, 2004). In 2004, a total of 2464 16-year-olds died in motor vehicle crashes, of whom 1457 were male and 1007 were female (National Center for Statistics and Analysis, 2004). Not surprisingly, novice drivers are overinvolved in crashes with nonfatal injuries as well. Perhaps of greater concern is the fact that the fatality rate for novice drivers has been increasing at the same time as the fatality rate for experienced drivers has been decreasing. The death rates for 16-year-olds increased from 19 driver deaths per 100,000 licensed 16-year-old drivers to 35 driver deaths per 100,000 licensed 16-year-old drivers from 1975 to 1996, whereas the overall death rate has decreased from 15 driver deaths per 100,000 licensed drivers to 12 driver deaths per 100,000 licensed drivers over the same time period (Insurance Institute for Highway Safety, 1998).

Contrary to popular belief, standard driver education programs in the United States (30 classroom hr, 6 behind-the-wheel hr) and more advanced training courses for novice drivers have failed to decrease novice drivers' fatalities demonstrably. This is as true today (Mayhew & Simpson, 1996, 2002) as it was almost 30 years ago, when the landmark DeKalb County, Georgia, study was undertaken (Stock, Weaver, Ray, Brink, & Sadof, 1983). In fact, there is an indication that there is a greater crash risk for graduates of standard training programs (Boase & Tasca, 1998; Christie, 2000; Mayhew, Simpson, & Williams, 2002),

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perhaps because driver education graduates are licensed earlier than their counterparts are (Robertson, 1980; Stock et al., 1983; Wynne-Jones & Hurst, 1984).

The situation is changing somewhat with the widespread introduction of graduated driver licensing (GDL) programs, in which there are up to three stages in the licensing process. Forty-one North American jurisdictions (35 U.S. states, the District of Columbia, 4 Canadian provinces, and 1 Canadian territory) currently have all three stages, but the systems vary in strength (Insurance Institute for Highway Safety, 2006). Graduated licensing programs typically require that novice drivers spend upwards of 30 hr driving with an adult in a car before obtaining a restricted license, thus increasing the novice driver's experience on the road. The GDL programs have clearly reduced the fatality rate among teens during the learner phase, when the teen driver is supervised by an adult driver (Hartling et al., 2004; Mayhew, Simpson, & Pak, 2003). For example, in Wisconsin the number of crashes among 16-year-olds decreased by 33% the year after the graduated licensing program was put into effect (Wisconsin Department of Transportation, 2004). However, it is not yet clear whether or not many of the crashes are simply shifted to later years (Mayhew et al., 2003), in part because one cannot control the novice driver's exposure to risk during supervised driving or the experienced driver's ability to identify risky scenarios and, as a consequence, make the novice driver aware of the elements in such scenarios.

Many different causes have been proposed for younger drivers' overinvolvment in crashes – both those who have and those who have not received standard driver education. The National Highway Traffic Safety Administration (1994, p. 19) states that younger drivers' lack of experience, increased willingness to take risks, and greater immaturity are the primary reasons for the overinvolvement. Speeding and alcohol are often cited as major factors for teens (National Highway Traffic Safety Administration, 2002), which they are.

There is accumulating evidence, however, that these last two factors are not the major cause of crashes involving novice drivers, the subset of teen drivers who have been on the road for a year or less, and a number of different sources of information lead to the conclusion that it is novice drivers' lack of experience that is at the heart of the problem. One source includes the analysis of police crash reports. For example, a recent review of almost 1000 crashes in which novice drivers were involved pointed to inexperience as the major contributor (McKnight & McKnight, 2003). Examples of behavior attributable to inexperience include failures to search ahead, to the side, and to the rear, a set of factors that taken together was implicated in 42.7% of the crashes. Other examples include the failure to pay attention (23.0%) and the failure to adjust the vehicle's speed appropriately (20.8%). Note in the last category, high speeds (speeds in excess of 70 miles/hr [112.6 km/hr]) accounted for only 1.5% of the crashes. The remaining crashes in this category were attributable to the driver failing to adjust the vehicle's speed to the traffic conditions, weather, or road geometry. These findings are in agreement with an earlier study, reported by Treat et al. (1979), in which visual search, speed adjustment, and attention were implicated as causes of driver crashes, in that order. The findings are also in agreement with a study reported by Gregersen (1996), who estimated that some 70% of the novice driver errors were attributable to inexperience.

Studies on a driving simulator comparing novice drivers' behavior with that of more experienced drivers point to inexperience as a major factor as well, especially failures to search effectively (Fisher et al., 2002; Pradhan et al., 2005). One of the scenarios used in these studies can illustrate the difference in behavior between novice and inexperienced drivers. In this scenario (see Figure 1), a truck is stopped on the side of the road in front of a marked midblock crosswalk in a suburban development (we refer to this as the *truck crosswalk scenario*). The participant driver can not see potential pedestrians crossing in front of the truck and therefore should both look to the right for a pedestrian and steer farther to the left as he or she passes in front of the truck. In fact, experienced drivers were more likely to do both. The results are especially striking when the eye movement analyses are considered (Pradhan et al., 2005). Here it was found that only 9.5% of the novice drivers scanned in front of the stopped truck, as compared with 28.6% of the younger drivers (19–29 years of age) and 57.1% of the older drivers (60 years old and older).

Although training novice drivers to recognize risks is not the total solution to decreasing their accident rates, it is arguably an important component

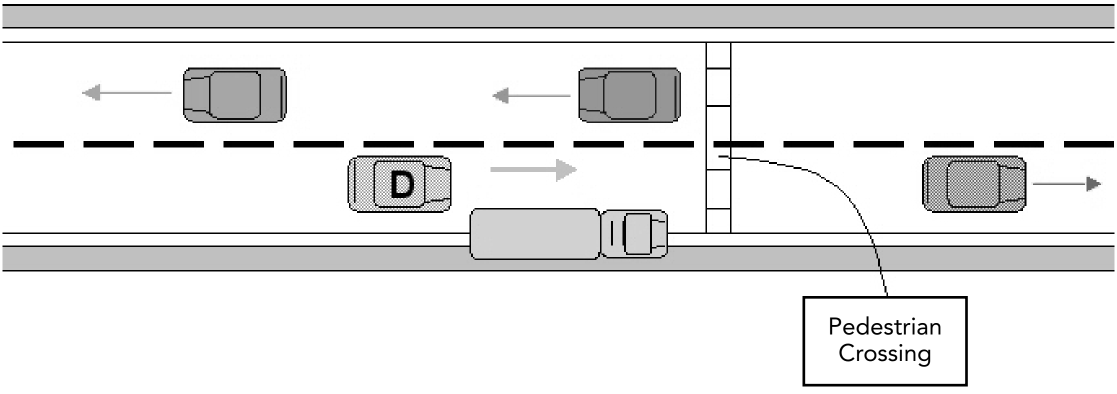



*Figure 1.* Truck crosswalk scenario.

of the solution. In addition, one needs to do this training without endangering either the driver or others on the road. There are many ways one can do this, but given today's technology, perhaps the most affordable one is a widely accessible, PC-based program that can be distributed on a CD or downloaded from the Internet and that requires no or very little additional hardware. A number of such PC-based risk awareness driver training programs have been developed (e.g., Blank & McCord, 1998; Lonero, Clinton, & Douglas, 1998; McKenna & Crick, 1997; Regan, Deery, & Triggs, 1998, 1999; Triggs, 1994; Triggs & Regan, 1998; Triggs & Stanway, 1995; Willis, 1998). However, to date, only three programs have been evaluated, all on a driving simulator: Driver ZED, developed by the AAA Foundation for Traffic Safety (evaluated by Fisher et al., 2002); DriveSmart, developed by the University of Monash Accident Research Center (Regan et al., 1998, 1999; Regan, Triggs, & Godley, 2000), and the Driver Assessment and Training System (DATS), developed by Simulation Technologies, Inc. (Allen et al., 2000, 2003). The Driver ZED program used actual footage of staged risky scenarios on the open road to train drivers. The DriveSmart program also used videotaped real-world driving scenes (as seen through the windshield of a car) in which various traffic scenarios unfolded (Regan, Triggs, & Wallace, 1999). The DATS program, unlike either the Driver ZED or DriveSmart program, used simulations of the scenarios in addition to adding simple game port controls.

All three of these PC-based programs led to significant improvements in drivers' performance. In each case, the driver's awareness of risk was inferred from measures of vehicle behavior (e.g., brake onset time), and in each case the measures were scenario specific. For example, the novice drivers trained on the Driver ZED program were more likely to slow down on the driving simulator in the truck crosswalk scenario (Figure 1) as they passed over the crosswalk than were untrained novice drivers (Fisher et al., 2002). The novice drivers trained on the DriveSmart program were more likely to slow down in fog than were untrained drivers, and the novice drivers trained on the DATS program were less likely to crash into a vehicle that stopped suddenly in front of them after training than they were before training. In fact, their performance after training was indistinguishable from the performance of experienced drivers.

Although these training programs have generally been successful, the use of eye movements of novice drivers to assess their awareness of risk can add important information. This is because there are many situations in which vehicle behaviors by themselves are difficult to interpret directly as an indication that the driver is aware of the risk, and it is this awareness that needs to be trained and assessed. In the truck crosswalk scenario, for example, the trained novice drivers slowed more than did the untrained novice drivers. However, this by itself does not reveal whether or not they actually predicted that a pedestrian might appear from behind the truck. Arguably the connection between eye behaviors and risk perception in such a scenario is much more direct. That is, a driver who looks to the right as he or she is passing in front of the truck is presumably scanning for a pedestrian. Of course, noticing a potential risk does not guarantee that the driver will respond to it appropriately. However, not noticing a potential risk almost certainly guarantees that the driver will not respond to it appropriately.

In this regard, there are studies that have used eye movements of drivers to assess the effects of training on novice drivers' awareness of risks, notably Chapman, Underwood, and Roberts (2002). In their study, the training procedure used videos taken from the driver's perspective with markers (colored ellipses) indicating both what experienced drivers looked at and places where potential hazards were located. The test monitored the eye movements of the drivers while they were actually driving a car, and the chief dependent variable was the percentage of horizontal eye movements. They found that training increased the percentage of horizontal movements, which plausibly represents increased scanning to the side for sources of potential danger. However, this is just a plausible inference, and one would like to know whether a training procedure actually produces increased awareness of and attention to specific risky situations. In contrast, awareness of risk is assessed in the present study by examining whether a key region of a designated part of the drive is fixated; this region is one in which either a risk is reasonably likely to emerge or one that has a message that there is a likely risk ahead.

In addition, all the aforementioned training studies primarily employed perspective views of scenes in the training that were similar to the scenes in which the training was assessed. Although this kind of pattern matching is reasonable as a way of training, we wanted to set up a method of training that went further and that would hopefully generalize beyond such specific training. As a result, plan views (i.e., schematic aerial views) were employed in the training procedure. However, because many of the test scenarios were the same as those involved in training, except for this radical difference in the representation of the information, other scenarios were employed in the test that the participants had not encountered in training. In all of the test scenarios, the participant had to look in a particular area of the roadway in order to anticipate the potential risk, and we hoped to test whether our training succeeded in training such anticipation even in new scenarios. This differs from the tests of generalization to date. For example, after training with the DriveSmart program, drivers become more cautious in scenarios in which they did not specifically receive training (e.g., trained individuals drive more slowly in fog than do untrained individuals; Regan et al., 2000). However, this does not necessarily mean that the drivers will be able to better predict where risks might appear that they had never previously encountered (i.e., the critical moments when they should be cautious). We hoped to test whether our training in fact succeeded in training such prediction in new scenarios.

## EXPERIMENT

The design of the experiment was straightforward. There were two groups of novice drivers. One group was given a training session using a PC-based training program and then evaluated immediately on a driving simulator to determine whether they would attend appropriately to places in their visual world that had elements of potential risk. A second group, untrained novice drivers, was similarly evaluated on the driving simulator. The first part of this section discusses the training session, containing a detailed description of the PC-based risk awareness and perception training (RAPT) program and the performance of the trained group in the training session. The second part discusses the procedure, the methodology used in the assessment, and the performance of both the trained and untrained novice drivers on the driving simulator.

### Method for PC Training

*Participants.* Forty-eight novice drivers participated in the experiment. All were high school students who had had their learner's permit for 1 to 5 months. They were recruited from Amherst Regional High School and from driving schools in the Amherst area. Twenty four were randomly assigned to the trained group and the other 24 to the untrained group. The ages in the groups were quite similar: The mean for trained group was 16.6 years ($SD$ = 0.9 years) and the mean for the untrained group was 16.4 years ($SD$ = 0.6 years). There were 7 women and 17 men in the trained group and 6 women and 18 men in the untrained group.

*General procedure and design for the PC-based RAPT program.* The participants in the trained group were first given three practice scenarios, in which they were shown how to move two different types of symbols (red circles and yellow ovals) using the mouse and, when they had moved them, were instructed on what made an answer correct or incorrect (see the next section for details). They then were given the training portion of the session, which consisted of 10 training scenarios presented in different orders to the different participants in a counterbalanced design. Each training session consisted of two sections; all 10 training scenarios were presented in both sections. In the first section, for each training scenario, the participant saw the participant response, vision obstruction, and answer explanation screens, which will be described in detail. The position of each yellow oval and red circle in the participant response screen was recorded and later scored as correctly or incorrectly placed. These scores counted as the pretest. In the second section, the participant saw the question and feedback screens associated with each scenario. At the end of the training session, the 10 participant response screens in each training scenario were again presented. These scores counted as the posttest. Each participant saw the scenarios in the posttest segments in the same order that they were presented in the training segment. The positions of the ovals and circles were scored in the posttest just as they were in the pretest. Of primary interest was the difference between the pretest and posttest scores. (Again, the details of the procedure for the driving simulator test session will be presented after details of the PC-based training session are presented.)

*Details of the RAPT program.* The training procedure relied on top-down views (plan views) of scenarios. Plan views were used because they should encourage novice drivers to visualize and to reason spatially about a scenario much more actively than they would if they saw perspective drawings or actual videos. In addition, as discussed previously, if novice drivers perform better on a driving simulator after PC-based training, it would be stronger evidence that they had learned the abstract elements of the scenario that made it risky, rather than that they simply recognized the stimulus they had seen in the PC-based training when they were on the driving simulator.

As indicated, the training module was divided into two sections. In the first section, each participant saw three different screens for each of the ten scenarios. An example (the left fork scenario) is presented in Figure 2. The first screen in the mod-

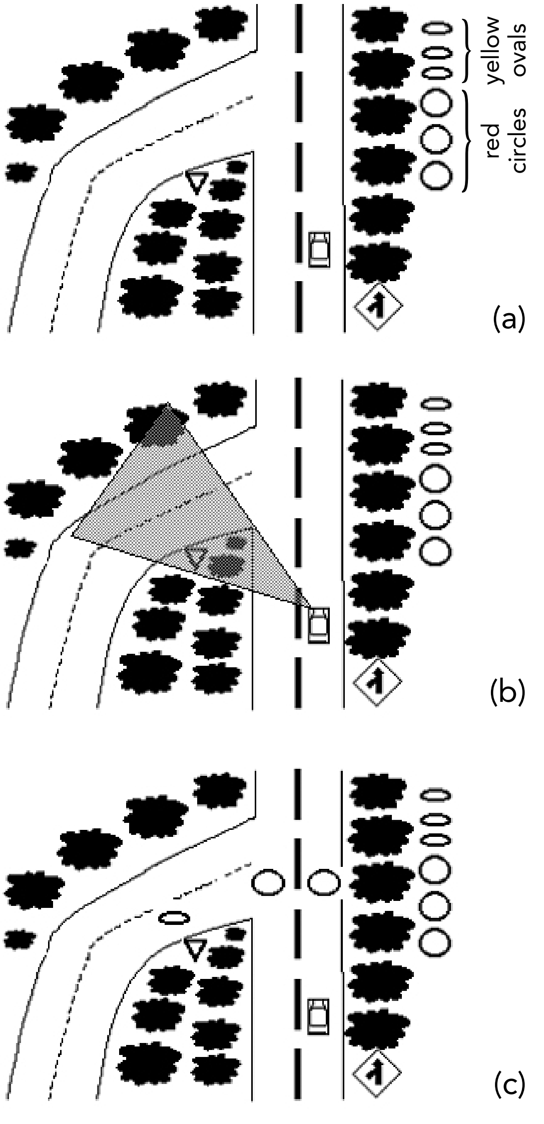



*Figure 2.* Left fork scenario (PC training screens). (a) Participant response screen. (b) Vision obstruction screen. (c) Answer explanation screen.

ule (the participant response screen, top panel) contained a plan view of a scene with vehicles and pedestrians (in some cases), along with the three red circles and the three yellow ovals on the side. The plan view in this example is of a driver approaching an intersection on the left that is obscured by bushes. The traffic sign on the right indicates that the driver should be aware of entering vehicles from the left. The participants were told to imagine that they were driving the car in the plan view and that they had two tasks. The first was to drag a red circle to any area of the scene that they should monitor more or less continuously. In this case, the participant should have dragged a red circle to an area in the opposing lane directly opposite the entering traffic on the left. The second task was to drag a yellow oval to any area of the scene that could contain a vehicle or pedestrian that they could not see from their current position but with which they could be in conflict as they traveled forward. In this case, the participant should have dragged a yellow oval to an area behind the bushes on the left, where a vehicle could appear.

After seeing the participant response screen and responding, the participant then saw the second screen (the vision obstruction demonstration screen, Figure 2, middle panel), in which he or she was given both pictorial and verbal feedback on the areas of the roadway that were obstructed from view and of particular concern. The pictorial feedback most often consisted of a triangle (cone of vision) that extended from the driver's point of view in the direction of the area that was obstructed. In this case, the cone of vision clearly crossed the line of bushes and was therefore obstructed by them.

Finally, after reading the explanations accompanying the vision obstruction demonstration screen, the participant was shown the third screen (the answer explanation screen), which indicated the correct locations of the target objects – the red circles and yellow ovals (see Figure 2, bottom panel) – and explained why they were placed there. For example, the explanation of why the yellow ovals appeared where they did in Figure 2 was "A yellow oval appears across the bushes. This is there to indicate that ideally you would like to be able to see what is beyond the bushes and that the bushes are potentially obstructing critical information to you as the driver specific to this scenario."

In the second section of the training session, the participants were given questions that were designed to reinforce what they had learned previously and then were provided with the answers to those questions. Two screens were used for each of the 10 scenarios, one that posed the questions (the question screen) and one that provided the feedback (the feedback screen). For example, again consider the left fork scenario (Figure 2). The question screen presented the plan view and the following two questions: (a) "Can you see around the bushes?" and (b) "List one reason that you might want to monitor over time the road ahead." The participant typed in a response to each question. The next screen, the feedback screen, provided participants with answers to the questions.

Conceptually, the 10 training scenarios can be grouped into three categories: *obstruction*, *sign ahead*, and *visible pedestrian*. There were five obstruction scenarios. One, the truck crosswalk scenario, is illustrated by the plan view in Figure 1. In the Mullins Center scenario, a line of cars is stopped on the left just before a multilane, marked, midblock crosswalk, obstructing the participant driver's view of a potential pedestrian crossing from the left. (Here, and elsewhere, we refer to the driver of the car that the participant is in, or is supposed to imagine himself or herself in, as the *participant driver.*) In the adjacent truck left turn scenario, a truck in the adjacent left turn lane at a four-way signalized intersection blocks the participant driver's view of cars in the opposing lane that might be turning left in front of the truck and therefore directly into the path of the participant driver. The participant response screen version of the plan view of this scenario is displayed in Figure 3. In the opposing truck left turn scenario, a truck in the opposing lane, again at a four-way signalized intersection, blocks the participant driver's view of oncoming vehicles in the lane adjacent to and to the right of the truck (from the perspective of the truck driver), which is of consequence here because the participant driver is supposed to execute a left turn. Finally, in the Amity-Lincoln scenario, a line of bushes on the right obscures the participant driver's view just before a crosswalk of pedestrians or bicyclists who might emerge suddenly from behind the bushes.

There were three sign ahead scenarios. The left fork scenario is the one displayed in Figure 2 and was already discussed. In the curved stop ahead scenario, the participant driver is warned of a stop sign ahead, but the stop sign would be hidden by bushes until the participant driver was almost next to it. In the blind drive scenario, the participant driver is warned of a blind drive ahead that is obscured, in part, by a hedge. Finally, there were two visible pedestrian scenarios. In the T intersection scenario, a pedestrian would be visible as the participant driver approaches the intersection but then would be obscured by the row of bushes on the right. The participant driver must look out for

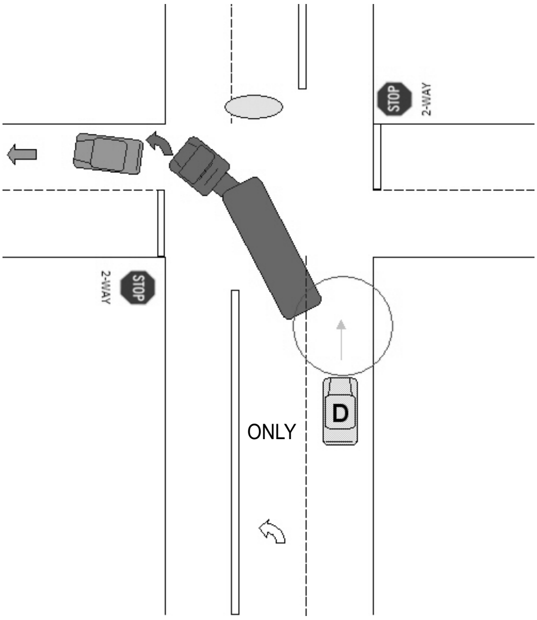



*Figure 3.* Adjacent truck left turn scenario: participant response screen.

the pedestrian after taking a right-hand turn. Because this may be a difficult scenario for the reader to construct from a verbal statement, the vision obstruction screen for this scenario is shown in Figure 4. In the right turn scenario, the car ahead is taking a right turn as pedestrians are crossing, and the participant driver is supposed to proceed straight through the intersection. The participant driver, if not aware that the driver immediately ahead may not be looking at the pedestrians, may need to brake suddenly as the driver ahead brakes to avoid hitting the pedestrians.

## Results and Discussion of Training

An analysis of the results indicates that the training was successful in getting participants to identify those parts of a scenario that they should monitor closely and where in the scenario there were things hidden from view of which they needed to be aware. As indicated, the red circles were used to indicate what should be monitored more or less continually and the yellow ovals were used to indicate areas of importance that would be hidden from the participant driver's view. Participants were almost twice as good at placing the red circles correctly after training, scoring 50% on average in the pretest and 91% on the posttest. The 41% difference was significant, $t(23) = 12.9$, $p < .001$, and, as can be seen in Figure 5a, this improvement was quite consistent across the 10 scenarios. They were about three times as good at placing the yellow ovals after training, scoring 32% on the pretest and 90% on the posttest. The 58% difference was significant, $t(23) = 19.1$, $p < .001$, and, as can be seen in Figure 5b, this improvement was also quite consistent across the 10 scenarios. There was a subsidiary analysis to

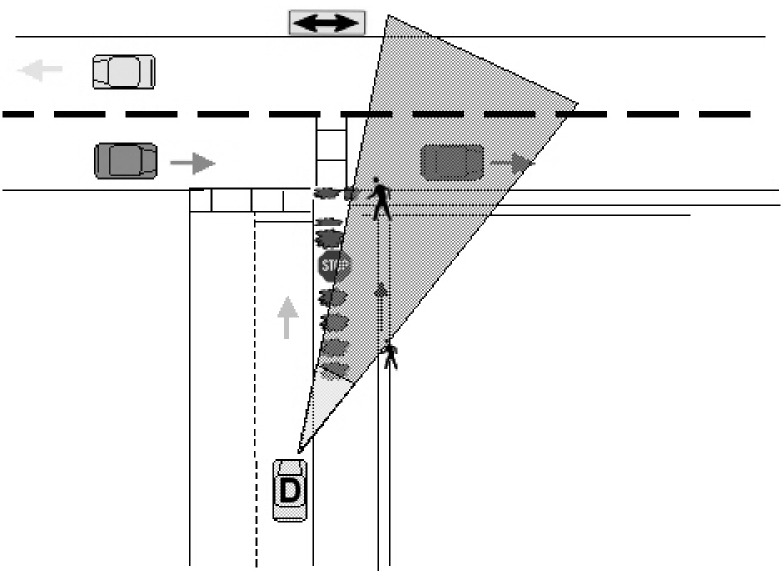



*Figure 4.* T intersection scenario: vision obstruction scene.

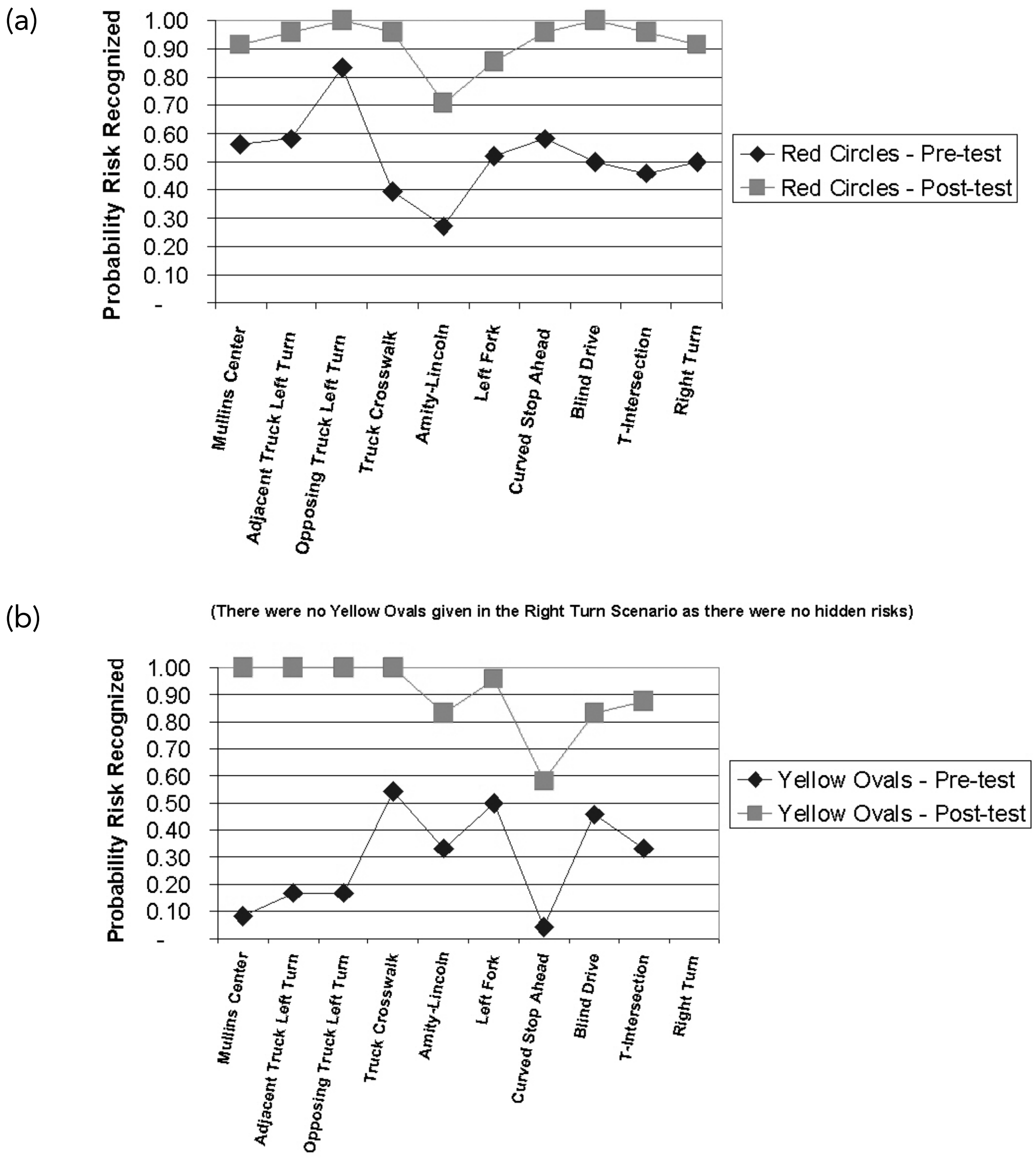



*Figure 5.* PC training program test results. (a) Red circles: pretest and posttest. (b) Yellow ovals: pretest and posttest.

test whether there were any significant differences in the effectiveness of training between the men and women. The difference over training was about 5% bigger for the men than the women, but the gender difference was far from significant, $F(1, 22) = 1.571, p > .20$.

In a prior experiment (Pradhan et al., 2005), novice and experienced drivers were tested in the driving simulator, and the novice drivers performed much worse than the experienced drivers in the first two categories (obstruction, sign ahead) but performed only slightly worse than the experienced drivers in the last category (visible pedestrian). Thus, there was concern about whether the last category was amenable to training, even though the experienced drivers were far from perfect on these scenarios. As can be seen in both panels of Figure 5, however, the effect of the training for this category was not noticeably smaller than that of the other two categories.

The success of the training demonstrated here is clearly just a first step. All that has been shown so far is that the novice drivers could learn what should be continuously monitored and the possible location of other important things that are not visible (such as obscured vehicles, pedestrians, and signs) in an "off-line" task that did not impose upon participants the necessity of making any speeded responses. Moreover, the visual stimuli seen in the pretest (and training) were identical to those in the posttest. What is of much greater interest is whether the effects of this training can be observed in a task (a) that approximates realistic driving and (b) in which the stimuli seen in training are quite different from those seen during the test.

## Method for Simulator Test Session

As indicated, the major focus of the experiment was to determine whether participants who were trained with only a plan view of a scene (one that included no perspective drawings or video animations) could generalize what they had learned to a more realistic environment. Moreover, in order to determine whether training went beyond the specific scenarios that were presented to participants in the training program, the test in the driving simulator included both scenarios that were included in training and scenarios that were not included in training. Specifically, of the 16 test scenarios embedded in the drive they took in the simulator, 10 were the same as those they had been trained on the PC, but 6 were different from any of the training scenarios.

*Participants.* The selection of participants was described above.

*Equipment.* The evaluation of the training program was done using an advanced fixed-base driving simulator. This consists of a fully equipped 1995 Saturn sedan in front of which are three screens positioned to provide a 150° horizontal field of view and 30° vertical field of view (Figure 6). The virtual world is projected onto each of these screens with a resolution of 1024 × 768 pixels. A Silicon Graphics Infinite Reality Engine projects the graphical images at a rate of 60 Hz. The software used to design and develop the virtual databases was Designers' Work Bench (Centric Software) and Real Drive Scenario Builder (Monterey Technologies). A driver can operate the controls of the vehicle just as in a real car on the open road and would thus move through the simulated world accordingly. Each participant was also fitted with an ASL 5000 Series head-mounted eye tracker integrated with a magnetic head tracker. A direct output of the simulated images on the three screens was obtained from a different channel of the graphics engine and was used as the remote scene camera. The eye position of the participant was converted to external point of gaze and superimposed as crosshairs on the output of the remote scene camera at 60 Hz, thus providing a real-time video of the drives with crosshairs superimposed where the driver was fixating at each moment.

The eye tracker was calibrated for the participant at the beginning of the session. This procedure took approximately 5 to 15 min for each

*Figure 6.* University of Massachusetts at Amherst Driving Simulator.

participant. As indicated, the experimenter saw a real-time display of where the eye tracker thought the participant's eyes were fixated. The calibration appeared to remain good in all cases along the horizontal axis throughout the session. That is, the default fixation on a straight portion of roadway was to a point in the center of the lane in which the person was driving. Occasionally, the vertical position appeared to be wrong because of a slight slippage of the helmet, and this was adjusted by the experimenter. However, this was relatively unimportant, as the crucial analyses were almost completely dependent on the position along the horizontal axis. The manufacturer's claimed accuracy of the eye is 0.5° in the horizontal direction. This represents optimal accuracy (i.e., at the midline), and the accuracy is likely to decrease as one moves away from the midline. However, virtually all of the discriminations needed for our scoring were easy and involved far bigger angles than this (to be discussed later).

*General procedure and design.* The participants drove the vehicle through the 16 scenarios described previously, which were embedded into a drive. Most of the drive consisted of fairly neutral portions, which did not contain any potential risks. The participants were instructed that they were to follow a lead vehicle (that was controlled by computer) but that they could lag behind it a reasonable distance. The lead vehicle thus served in place of verbal instructions; the lead vehicle indicated to the participant driver when to turn and in which direction. The trained group went through the simulator test procedure during the same session that they were given the PC-based training session, and the untrained group went through the simulator test procedure after answering some background questions. The written instructions to both groups included "We are interested to know how well you react to real life driving environments" and "...as with 'real life' driving, you should obey all traffic laws and posted speed limits to the best of your ability." The verbal instructions reiterated these points and told the participant to drive as he or she would in the real world.

The 16 scenarios were divided into four blocks of 4 scenarios each, and all 24 different block orders were presented (in a different order for each participant) for both the experimental (trained) and control (untrained groups). After having the eye tracker mounted and calibrated, participants initially were allowed to spend as much time as they needed getting used to braking, turning, and accelerating in the simulator in a virtual environment that was similar to the experimental scenarios (e.g., a similar traffic density, similar speed limits, and similar types of intersections). They then drove the four blocks of scenarios with rest breaks in between.

*Simulator test scenarios and scoring.* A total of 16 scenarios developed for the driving simulator were embedded into the drives that the participants took in the driving simulator and were used as tests for whether training had been effective. Ten of these scenarios were similar to the 10 scenarios that the trained participants had seen. They were used as a test for near transfer of training. Snapshots from the simulation of the 4 training scenarios that were previously presented as plan views are displayed in Figure 7. Figure 7a provides a snapshot of what the driver saw in the simulator in the truck left turn scenario, which was diagrammed in Figure 3. In this case, the truck obscures vehicles in the opposing lane from the participant driver's view, and although no vehicle ever appeared on the left, it would clearly pose a threat if it did. The eye tracker was used to determine whether the driver looked to the left as he or she passed the truck, presumably checking for a vehicle that might be turning. Figures 7b, 7c, and 7d display similar snapshots of the scenarios that were shown as plan views in Figures 1, 2, and 4, respectively. The other 6 near transfer scenarios were patterned closely after the remaining 6 training scenarios.

The other six test scenarios were designed to test for far transfer of training, and they resembled the training scenarios only in that they contained risks that could materialize suddenly, often because the elements that created the risk were hidden from the driver's view. However, they were otherwise very different from the training scenarios in their particulars. Three of the six involved an obstruction, signal ahead, or pedestrian conflict. The truck and driver left turn scenario has the lead vehicle, a truck, and the participant driver, in that order, at a slightly staggered four-way signalized intersection. All three vehicles are in the left-turn lane waiting to make a left turn. After the light turns green, the lead vehicle turns left and the truck follows closely behind. This left-turning truck blocks the participant driver's view of any

(a)
(b)
(c)
(d)

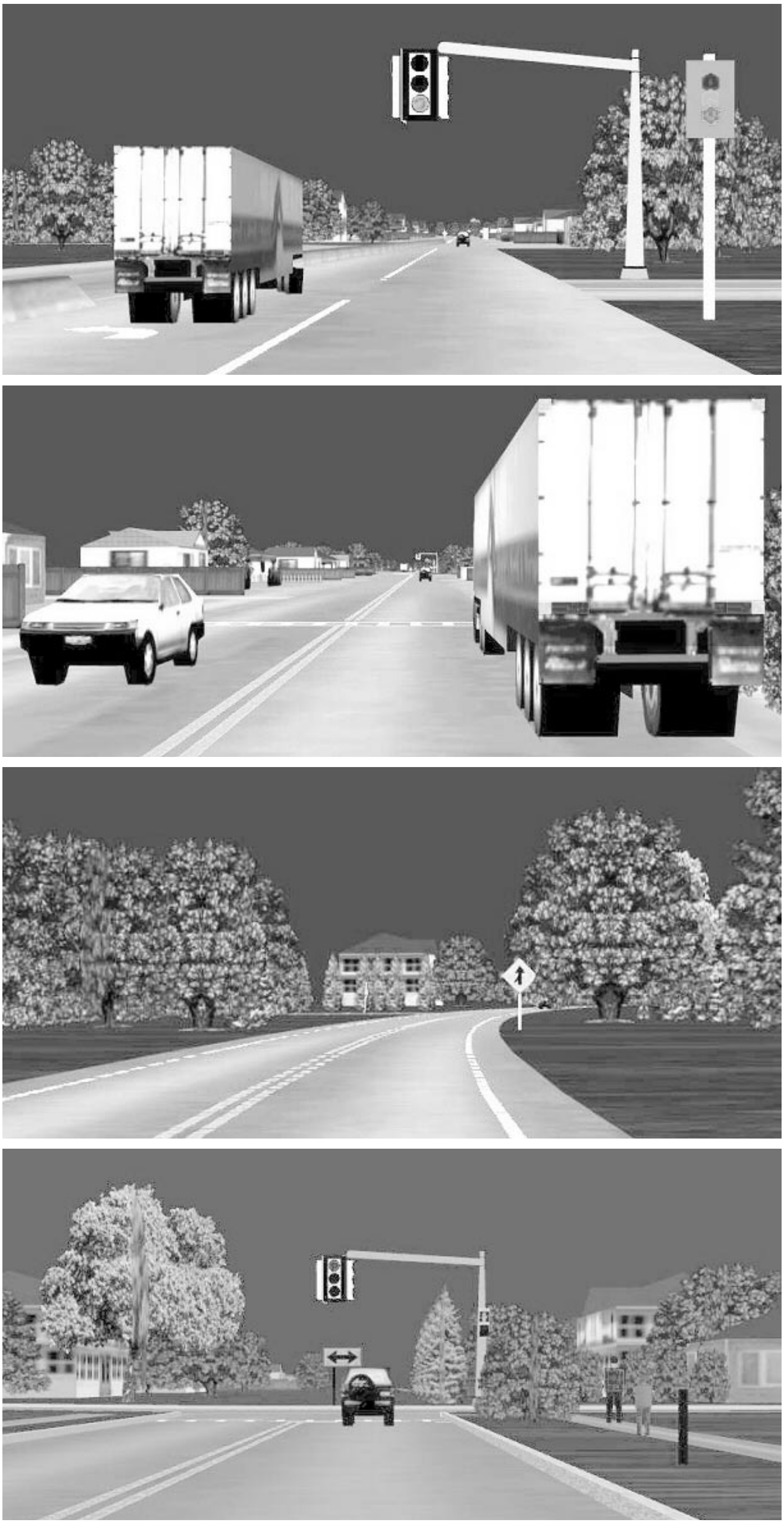


*Figure 7.* Simulator scenarios. (a) Adjacent truck left turn. (b) Truck crosswalk. (c) Left fork scenario. (d) T intersection.

potential vehicles approaching from the opposite lane, and if the participant driver fails to look for this traffic before following the truck and entering the intersection, he or she may move into the path of oncoming vehicles. In the signal ahead at hill scenario, the participant driver approaches a section of the roadway with a rise and a fall. There is a signalized intersection at the bottom of the hill that is hidden from the participant driver because of the vertical curvature of the roadway. A sign indicating the presence of the signal ahead is placed at the beginning of the rise in the roadway to warn drivers of possible traffic backup in case of a red traffic signal. Finally, the pedestrian on left scenario takes place at a four-way nonsignalized intersection with one lane of traffic in each direction. The participant driver is following the lead vehicle, and another vehicle is between them. At the intersection, the lead vehicle proceeds straight whereas the other vehicle signals that it is turning left. There are some visible pedestrians on the left side of the road in front of the pedestrian crosswalks. The risk is that this vehicle might slow down or come to a quick stop if the pedestrians cross the street and the driver has to be aware of this possibility.

In the other three far transfer scenarios, the risk was created by the introduction of new elements into the scenarios (illegal, but not unlikely, maneuvers by vehicles in the first two scenarios; a distraction in the third scenario). In the vehicle on right at intersection scenario, the participant driver is proceeding straight through a jogged intersection with a green signal and is directly behind a truck that is turning right. There is a stopped vehicle on the intersecting road on the right waiting to take a right turn. As a result, the right-turning truck is momentarily blocking the view of the stopped vehicle from the participant driver's vehicle and vice versa. The stopped vehicle on the right may take a right turn on red, ending up in the path of the participant driver, something the stopped driver should and would not have done had he or she looked to the left before and during the turn. In the intersection with new green signal scenario, the participant driver is approaching a four-way signalized intersection with a red signal, with no vehicles between the participant driver's car and the intersection. When the driver reaches a point 100 feet (30.5 m) from the intersection, the light turns green so that the driver can continue straight through the intersection without stopping. The risk in this scenario is that other drivers from the intersecting streets might be running a red light and could be in the intersection when the participant driver is about to cross. Finally, the truck blocking travel in lane scenario is similar to the truck crosswalk scenario except that there is no visible crosswalk in front of the parked truck. Moreover, there is an added distraction: a pickup truck pulling out onto the street from a driveway on the left as the participant driver approaches the parked truck.

Each of the 16 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 had been 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 a potential risk (see Tables 1 and 2 for a fuller description of our criteria for the 16 test scenarios). An example of a risky region is the side of the truck stopped in front of an nonsignalized marked midblock crosswalk (behind which pedestrians might appear; Figure 7b), and an example of an advance signal is a "stop ahead" sign.

As indicated, the discrimination of whether the participant was fixating either the region of potential risk or the region signaling a risk was not a difficult judgment. If the target region was not fixated during the temporal window, fixation was virtually always quite far from the target region at a spatially separate "default region." For most scenarios (such as the one in Figure 7b), the default region was looking straight ahead; however, for a few, such as executing a left turn, the default region was somewhat off to one side (but it was quite similar across participants). The (horizontal) distance between the default region and the target region that would be scored as fixating the risk is indicated in Tables 1 and 2. The values given represent the average distance over the temporal window (as the visual angle between the two changes during the interval). As can be seen, these distances are much bigger than any error that could be attributed to the eye tracker. Moreover, in most cases, as there is a specific target for the participant

**TABLE 1:** Criteria for Scoring Fixation Pattern as Fixating Potential Risk for Near Transfer Scenarios

| Category | Scenario Name | Criterion for Score of 1: Fixated the Potential Risk Appropriately | Visual Angle[a] |
|---|---|---|---|
| Obstruction | Truck crosswalk | Fixated to the right, toward the left edge of truck, while passing it | 11.7 |
| Obstruction | Mullins Center | Fixated to left, beyond stopped or slowing cars, before entering intersection | 16.8 |
| Obstruction | Adjacent truck left turn | Fixated to the left, beyond the right edge of truck, from 50 feet (15.2 m) or less from the intersection | 27.8 |
| Obstruction | Opposing truck left turn | Fixated to right, beyond the truck to the oncoming road, while making left turn | 16.8 |
| Obstruction | Amity-Lincoln | Fixated to right, toward edge of hedges, from 80 feet (24.4 m) or less from crosswalk | 21.6 |
| Sign ahead | Left fork | Fixated on the incoming road from the left after passing the warning sign | 14.8 |
| Sign ahead | Curved stop ahead | Repeated fixations to the right toward vegetation while negotiating the right-hand curve | 15.3 |
| Sign ahead | Blind drive | Repeated fixations to the right toward the vegetation, after passing the sign and while negotiating turn | 17.8 |
| Visible pedestrian | T intersection | Repeated fixations on extreme right edge of screen during right turn | 20.2 |
| Visible pedestrian | Right turn | Fixated on the pedestrian at right when approaching intersection | 5.4 |

[a]Visual angle refers to the angle between the center of area of risk and focus of expansion (in degrees of visual angle).

**TABLE 2:** Criteria for Scoring Fixation Pattern as Fixating Potential Risk for Far Transfer Scenarios

| Scenario Name | Criterion for Score of 1: Fixated the Potential Risk Appropriately | Visual Angle[a] |
|---|---|---|
| Truck and driver left turn | Fixated on lane of oncoming traffic, after truck cleared the view while negotiating left turn | 12.8 |
| Signal ahead at hill | Fixated on “signal ahead” sign from 300 feet (91.4 m) or less from sign | 5.4 |
| Pedestrian on left | Fixated on pedestrians on the left while approaching intersection from 100-foot (30.5-m) distance or less | 9.6 |
| Vehicle on right in intersection | Fixated on the car on right, after the truck cleared intersection and while participant driver is in intersection | 15.8 |
| Intersection with new green signal | Fixation to the left and right of intersection, from a distance of 50 feet (15.2 m) or less from the intersection | 21.6 |
| Truck blocking travel in lane | Fixated to the right, toward the left edge of truck while passing it | 9.1 |

[a]Visual angle refers to the angle between the center of area of risk and focus of expansion (in degrees of visual angle).

(e.g., the side of the truck), the horizontal coordinates of the fixation points were quite similar for the participants who fixated the region containing the risk. In short, the behaviors that were scored as "attending to risk" were quite similar to one another, as were the behaviors that were scored as "not attending to risk"; there were virtually no trials in which the judgment was hard to make.

Each scenario was scored 1 or 0 depending on whether or not the participant's fixation pattern indicated recognition of risk as defined by the scoring criteria. However, there were occasionally missing data in some cells, either because calibration of the eyes was lost (usually attributable to the tracker slipping on the head) or because the participant's driving was nonstandard enough that a scenario did not materialize as intended. For the following analyses, each participant had two scores: the percentage of near transfer scenarios in which he or she scored a 1 and the percentage of far transfer scenarios in which he or she scored a 1.

### Results and Discussion of Test Results

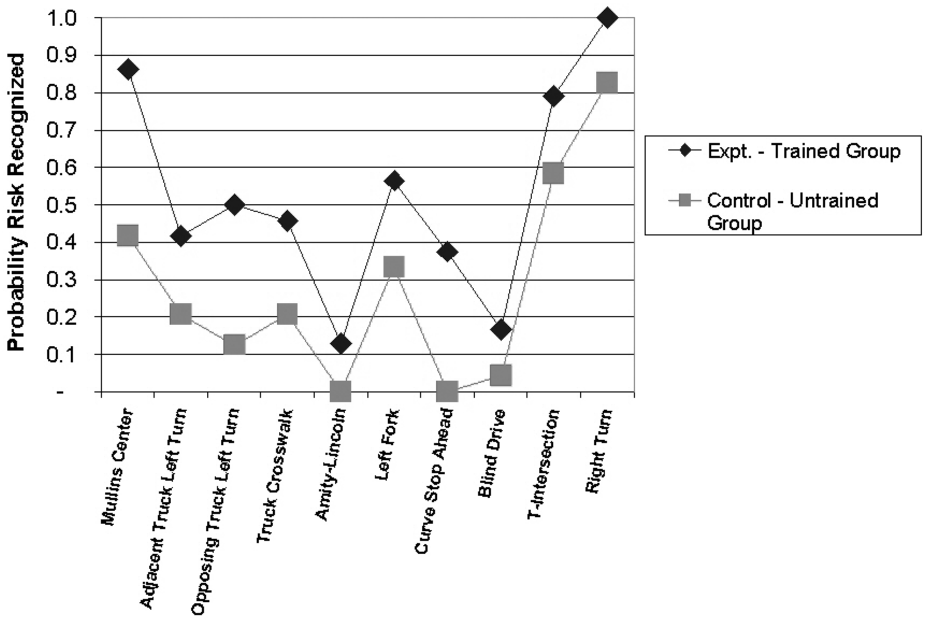
A preliminary analysis of the data made gender an explicit variable to ensure that the slight imbalance of gender in the two groups was not a problem. In this analysis, when the near and far transfer scenarios were analyzed together, there was a significant effect of training, $F(1, 44) = 23.91$, $p < .001$; the effect of training was similar for near and far transfer, $F < 1$, and no effects involving gender were close to significant ($p$s > .10). There was a suggestion that men scored slightly better than women, $F(1, 44) = 1.377$, $p > .20$, and that women benefited slightly more from training than did men, $F(1, 44) = 2.276$, $p > .10$. Because this analysis weights each woman's score more heavily than each man's score, the means in this analysis exaggerate the size of the training effect a bit. Accordingly, in the following analyses, gender was ignored and each participant's score was weighted equally.

When gender was taken out of the analysis, the overall effect of training over the near and far transfer scenarios is still highly significant, $F(1, 46) = 21.2$, $p < .001$, with trained drivers recognizing risks 57.7% of the time and untrained drivers recognizing risks only 35.4% of the time. Again, in this analysis, the interaction of training with near versus far transfer was not close to significant, $F < 1$. It is a bit hard to compare the effectiveness in training between the two sets of scenarios because the absolute level of performance (averaged over trained and untrained drivers) in the far transfer set (53.5%) was substantially higher than in the near transfer set (39.6%), $F(1, 46) = 23.5$, $p < .001$. Nonetheless, it was clear that there was a large effect of training for both sets. When the near transfer set was analyzed separately, the novice drivers who had been trained on the PC recognized 51.9% of the risks, whereas the novice drivers who had not been trained recognized only 27.3% of the risks, a difference of 24.6%, $t(46) = 4.85$, $p < .001$, and when the far transfer set was analyzed separately, the trained group recognized 63.5% of the risks, whereas the untrained group recognized only 43.5% of the risks, a difference of 20.0%, $t(46) = 3.27$, $p < .002$. An analysis of covariance on the data (with age as the covariate) was performed to make sure that the small age difference between the trained and untrained drivers wasn't a significant contributor to the apparent training effect (the trained group was, on average, 0.2 years older than the untrained group); however, the pattern of data was virtually identical to the analysis just given, and again the main effect of training was highly significant, $F(1, 45) = 21.3$, $p < .001$ (this analysis did not use gender as a variable).

Another interesting feature of the data is that the effects of training were pretty consistent across both the near and far transfer scenarios (see Figure 8). In fact, the only scenarios in which the training effect seems noticeably smaller are a few for which there appear to be "floor" or "ceiling" effects. For the latter, it is obvious that it is impossible for training to improve performance a lot. For the former, there is no logical necessity for observing small effects. Interestingly, the three scenarios in which performance was poorest, for both trained and untrained groups, are ones in which vegetation obscures the participant driver's view of pedestrians (Amity-Lincoln), a stop sign (curved stop ahead), or a driveway (blind drive). This suggests deficiencies in the training program that could potentially be remedied in the future.

It was also of interest to see how well individual differences in the scores from the RAPT training session predicted individual differences in the performance on the driving simulator for the

(a)




(b)

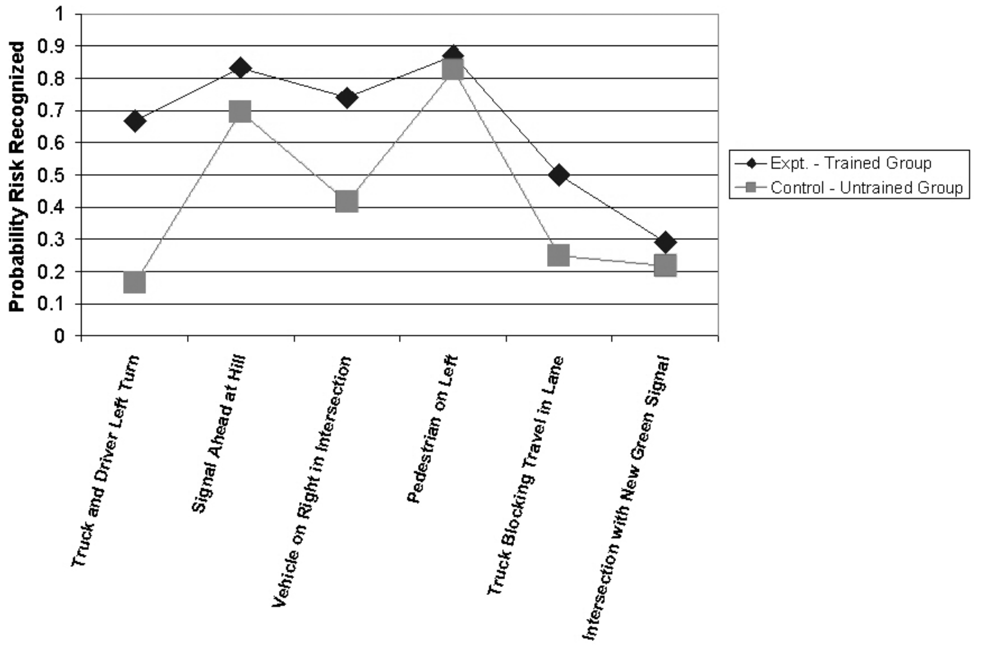



*Figure 8.* Driving simulator evaluation. (a) Ten near transfer scenarios. (b) Six far transfer scenarios.

trained group. The correlations were modest. The correlation between the scores on the pretest in the RAPT training (averaged over the two tasks) correlated .34 with the average driving simulator score (averaged over near and far training), $t(22) = 1.66, p < .20$, and the analogous correlation for the posttest was .23, $t(22) = 1.13, p > .20$. These correlations appear to be low largely because there was little variability in the training scores among the participants either in the pretest or posttest (the standard deviations in the pretest and posttest were 12% and 7%, respectively). Thus, as indicated earlier, all participants improved quite a bit in the training, and it is likely that the remaining individual differences in the training scores may be attributable more to how comfortable participants are in dealing with the plan views and manipulating screen objects with a mouse than to their basic understanding of the risks involved in the scenarios.

## GENERAL DISCUSSION

The major results are quite clear. The PC-based training program first led to a clear improvement in the ability of novice drivers both to recognize and to diagnose risky situations from the plan views. More importantly, it also led to a clear improvement in their ability to fixate on situations of potential risk in the on-line task of driving on the driving simulator. The transfer from the training program is notable because the PC-based training program provided the novice drivers with only top-down views of the scenarios on which they were evaluated in the driving simulator. Thus, in some sense, even the near transfer tests on the driving simulator were not all that "near," as participants had to transfer what they learned from a schematic and static top-down representation presented on a PC to a realistic dynamic representation of the same situation displayed on the driving simulator. The far transfer scenarios, which showed essentially the same gains as the near transfer scenarios, indicated even wider generalization, as the test scenarios were different from the training scenarios in addition to the changed form of the representation and the different environment.

As mentioned earlier, three prior studies have shown that a PC-based training module had a significant impact on the driving behavior of novice drivers (Allen et al., 2000, 2003; Fisher et al., 2002; Regan et al., 2000). This study goes beyond those studies in several ways. First, as mentioned earlier, this is the first time that the effectiveness of training with respect to attending to potential risks has been assessed with eye movements on a driving simulator. Besides providing converging evidence for the effects of training (in addition to driving measures), we feel it may, at least in some cases, be a more interpretable measure of whether the driver is responding appropriately to the risky situation. Consider the truck crosswalk scenario. One way to evaluate driver behavior is to see whether the driver steers the car a bit farther away from the truck. However, many skilled drivers might feel that such a move is unnecessary, and thus whether novice drivers engage in it may be a less valid index of risk avoidance than whether they monitor the side of the truck for hidden pedestrians to emerge. This is essentially what was found in an earlier study from this lab: Skilled drivers do not always steer farther away from the truck (Fisher et al., 2002). In addition, it is our observation that inexperienced drivers often make dangerous exaggerated swerving motions to avoid cyclists on the side of the road. Clearly, such drivers recognized the risk but responded inappropriately. Thus, it may often be quite difficult to assess the driving behavior both with respect to whether the risks were noticed and whether they were responded to appropriately. In contrast, if a driver never monitors the side of the truck, this is almost certainly an index of the driver not noticing risks and thus an index of unsafe driving. Of course, how a driver responds to the presence of risks is important, and we are not arguing that vehicle behaviors have no role to play in the training and evaluation of novice driver training. Future studies are planned that include assessment of driving as well as eye fixations, although this requires considerable thought and additional equipment to do it right.

Second, as previously indicated, the present study appears to assess a wider range of transfer than prior PC training studies have because the stimuli seen in training in our study were only schematic plan views. It is possible that a deeper level of understanding is being tapped than when perspective views are seen. This hypothesis is consistent with the finding that there was almost the same degree of transfer in the far transfer scenarios as in the near transfer scenarios. This is not to say that the training methods in the other PC training studies didn't produce deeper levels of understanding as well; it's just that one can't be sure of this conclusion given the similarity of the stimuli in training and test.

Third, our evaluation of eye movements is perhaps ultimately more diagnostic than are earlier evaluations using eye movements because we specifically looked at moments in the driving scenario when risk assessment was critical. That is, presumably a major part of what one wants to do in novice driver instruction is train behaviors that are likely to be especially relevant at the specific moments in time when risks are likely to develop.

The majority of studies of novice drivers' eye movements have not focused on the eye movements at the exact moment that a risk was appearing. Instead, they have focused on summary measures of eye behavior. For example, in a pair of now-classic studies (Mourant & Rockwell, 1970, 1972), it was found that novice drivers scanned more narrowly than did experienced drivers, that they scanned in the vertical direction more than they did in the horizontal direction, that they tended to focus right in front of their vehicle, and that they used the side mirrors less frequently. Several of these findings have since been replicated (e.g., Renge, 1980) and extended to training, as we mentioned in the Introduction (Chapman et al., 2002). Although such general summary measures may be important, it is not clear that they can be used to determine whether, say, a novice driver will or will not look in front of a truck parked before a crosswalk, anticipating the emergence of a possible pedestrian. In order to determine this, one really needs to look at the eye behaviors in a scenario at the time when the risk might actually materialize.

Our discussion has emphasized the positive aspects of our data and our approach. One negative aspect of our data is that our training didn't produce the desired behavior nearly all the time, especially in the near transfer tests. However, the trained novice drivers did about as well on the scenarios in the driving simulator as the younger experienced drivers (ages 19–29 years) did in the prior study from this lab (Pradhan, et al., 2005). A second negative aspect of the current approach may be that there are significant practical limitations to improving performance without significantly expanding the time and expense of the training procedure beyond an hour's session on a PC. Efforts are underway to improve the training program to try to make it even more effective; however, the current training procedure may be quite close to the attention span of these 16- to 17-year-olds, and thus the current effort may pretty much be the limit of what can be accomplished in a single 1-hr session using an inexpensively produced PC training module. If so, then plausibly the only way to improve training results significantly would be to use some multistage training procedure that would necessitate different types of training, possibly including either seeing video clips about what to look at (Chapman et al., 2002) or training on a driving simulator. It is not clear whether significant numbers of novice drivers can be run through such an elaborate training procedure. However, given the success of the RAPT training program in modifying eye behavior in the simulator and that of Chapman et al. (2002) in modifying eye behavior in actual driving, it is hoped that the research reported herein is moving in the direction of producing a program for training risk awareness that will have a significant impact on the frequency of accidents for novice drivers.

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