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Driving Simulators as Training and Evaluation Tools: Novice Drivers

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Abstract

The Problem. We know that newly licensed 16- and 17-year-old drivers during their first six months on the road with a restricted license are at a greatly inflated risk of crashing. This inflated crash rate has not changed over the last 50 years. ***The Question.*** The question we address is whether there are training techniques that show some promise of reducing these high crash rates. ***Role of Driving Simulators.*** Driving simulators represent an important tool for evaluating the efficacy of training programs in situations that would be too unsafe to study on the open road; they may also be of value in training, although their widespread use may be limited by their cost. ***Key Results of Driving Simulator Studies.*** Studies using driving simulators and the open road have revealed that newly licensed drivers can be trained to anticipate specific hazards, to scan more broadly within the general driving environment, to prioritize their attention, and to maneuver their vehicle more safely, all without becoming overconfident. ***Scenarios and Dependent Variables.*** Examples of the sorts of simulator scenarios that are used to study scanning, attention maintenance, and vehicle management skills are discussed in detail. Difficulties that attend the development of such scenarios are described. Examples of the dependent variables used to differentiate between trained and untrained novice drivers are discussed, as are the procedures that are needed to reduce the data to meaningful summary measures. ***Limitations.*** Although the studies so far have shown that programs that are effective on a driving simulator are also effective on the open road, one cannot assume that this is always true.

30.1 Introduction

The goals of driver education programs have varied over time. In the United States, the very first programs simply attempted to teach the most basic skills of maneuvering a vehicle (Butler, 1982). This has evolved considerably. In 1973 at the Fifth National Conference on Driver Education, the stated purpose of driver education was: "to develop safer and more efficient highway users who understand the essential components of the highway transportation system in a manner that will enhance the effectiveness of such components (Aaron & Strasser, 1977)." Most recently, in a 1994 report to the United States Congress, the National Highway Traffic Safety Administration (NHTSA) defined driver education as follows: "Driver education is a training program of organized learning and practice designed to provide the basic knowledge, attitudes and skills needed to drive safely, and to provide the advanced knowledge and skills needed for safe driving performance under special circumstances" (NHTSA, 1994, p. 1).

If the goals of driver education are to provide the skills, knowledge, and attitudes necessary for safe driving, then one measure of the success of such programs would be a reduction in the crashes of drivers who were exposed to those driver education programs. Although the first known driver education program in the United States was established in 1916 [NHTSA 1994, p. 3], it was not until 1976 that a full-scale controlled evaluation of driver education was undertaken in a suburb of Atlanta, Georgia. Teen drivers were randomly assigned to three groups: one received extensive training, (the Safe Performance Curriculum, SPC) one received more limited training (the Pre-Driver Licensing Curriculum, PDL), and the third group was used as a control. The results were disappointing. The SPC (National Highway Traffic Safety Administration, 1974) contained a component referred to as simulation, but it was a film that was not responsive to any control input and thus different from what we mean by simulation today. Although there was about a 15% reduction in the number of crashes per licensed driver in the groups that received training during the first six months of driving (i.e., the SPC, PDL, and control groups had 0.105, 0.107, and 0.122, crashes per licensed driver; Stock, Weaver, Ray, Brink & Sadoff, 1983), there were no differences between the trained and control groups when evaluated two (Stock et al.) and four years (Smith & Blatt, 1987) after training had ended. Twenty years later, Mayhew and Simpson (1996) reviewed 30 studies from several countries that evaluated the effect of driver training programs on crashes, and found 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 (standard driver education programs typically have 30 hours of classroom instruction and six hours of behind-the-wheel instruction). The reviews have spanned the globe, including ones undertaken in Australia (Woolley, 2000), Britain (Roberts & Kwan, 2002), Canada (Mayhew & Simpson, 2002), Sweden (Engström, Gregersen, Hernetkoski, Keskinen, & Nyberg, 2003) and the United States (Vernick, Li, Ogaitis, MacKenzie, Baker, & Gielen, 1999; Nichols, 2003), and most recently a comprehensive, international review sponsored by the AAA Foundation for Traffic Safety (Clinton & Lonero 2006; also see Lonero, 2007). These reviews are uniform in concluding that in the great majority of experimental evaluations of standard driver education programs, no reduction in the crash rates among newly-licensed drivers is observed. In fact, some reviewers concluded that standard driver education programs may actually increase the crash rates, both by reducing the age at which solo driving 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). Importantly, it is not clear from the reviews whether any of the standard programs required training on a driving simulator where the driver's path through the virtual world was determined by the driver's manipulation of the vehicle controls. However, it seems somewhat doubtful that any did, since fully articulated simulator training programs have not been reported in the published literature until very recently (e.g., Allen, Park, Cook, & Viirre, 2003).

In this context, one can ask three major related questions: (1) What are the behaviors of novice drivers that are causing them to crash? (2) Are standard driver education programs addressing those behaviors? (3) And, if not, are there any existing alternative driver education programs that address these behaviors? The focus here is on the use of driving simulators both to evaluate behaviors that have been inferred to be a contributing cause of crashes and to train drivers to avoid crashes. However, several of these key studies in which simulators were not involved—either in training or in the evaluation—are discussed as well because of their clear relevance to the topic at hand. At the end of the chapter, we discuss more general issues relevant to the evaluation and training of novice drivers on simulators.

30.1.1 Causes of Newly-Licensed Driver Crashes

To the general public, alcohol and high speeds are perhaps thought to be the two major reasons for the high crash rate for newly-licensed drivers. However, during the first six months, the percentage of newly-licensed drivers who crash while under the influence of alcohol (NHTSA, 2006) or while traveling at very high speeds (McKnight & McKnight, 2003) is relatively small. Instead, analyses of police crash reports (McKnight & McKnight) indicate that failures of (a) *visual scanning* (ahead, to the sides, and to the rear), (b) *attention maintenance* (distribution of attention between the forward roadway and other locations inside and outside the automobile cabin), and (c) *speed management*, are responsible, respectively, for 43.6%, 23.0% and 20.8% of the crashes (the causes overlap) among drivers between the ages of 16 and 19 years old. In addition, although the absolute number of crashes decreased as a function of increases in the experience of the young drivers, these three percentages did not change appreciably. Thus, if overall crashes per licensed driver are decreasing rapidly during the first six months, unless there is a not-yet-identified factor causing the decrease, it seems likely that newly-licensed drivers are improving in all three areas. Moreover, there is evidence from laboratory studies and from naturalistic and experimental studies in the field that young drivers do differ considerably from more experienced drivers in all of the three areas identified by McKnight and McKnight as causing problems for teen drivers (2003).

Visual scanning: Hazard anticipation. There is now a large body of literature that indicates that young drivers perform more poorly on hazard anticipation tests that are administered outside of an actual driving situation (Horswill & McKenna, 2004). However, when the hazard is easily detected (e.g., by motion), differences between younger drivers and more experienced drivers are less clear-cut (Sagberg & Bjørnskau, 2006). These differences in hazard anticipation skills also appear when people are on a driving simulator: Young drivers are much less likely than experienced drivers to scan for potential hazards when these hazards are difficult to detect, such as a pedestrian that might emerge suddenly from behind a vehicle stopped in front of a midblock crosswalk (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006). In addition, these differences between groups appear even when the possible risk is "foreshadowed" (e.g., a pedestrian is seen crossing a considerable amount of time before the car enters the area, Garay-Vega, Fisher, & Pollatsek, 2007). The above differences in *tactical hazard anticipation scanning* (i.e., the scanning pattern observed when a feature in the environment suggests that a hidden threat is especially likely to materialize at a particular location and time in a scenario) coexist with differences in *strategic hazard anticipation scanning* (i.e., the scanning pattern observed when there is no such key feature). Specifically, as indicated by studies of strategic scanning on the open road young drivers: a) scan less broadly from side to side, especially when changing lanes (Mourant & Rockwell, 1972); b) have, on average, less widely spaced eye movements as measured along the horizontal axis (Crundall & Underwood, 1998); and c) are less likely to make consecutive fixations on objects in the periphery (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). It is worth mentioning that these differences between age groups in tactical and strategic hazard anticipation scanning in a driving simulator and on the open road appear even though the drivers know they are being tested, and thus are, in some sense, "on their best behavior".

Attention Maintenance. Studies on the open road—both controlled (Wikman, Nieminen, & Summala, 1998) and naturalistic (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006)—and in the laboratory (Chan, Pradhan, Knodler, Pollatsek, & Fisher, 2010) indicate that young drivers are much more likely to gaze continuously for longer than two seconds inside the vehicle when searching for something inside the vehicle (i.e., are more likely not to attend to the roadway). (A common measure employed here is *glance duration*, which is the duration of a period when fixations are in a particular region—in this case, on locations inside the vehicle.) For example, in a controlled study on the open road (Wikman et al., 1998), it was found that only 13% of the experienced drivers had a *glance duration* inside the vehicle of at least 2.5 seconds during an episode of searching for something inside the vehicle whereas 46% of inexperienced drivers had a glance duration of at least this length during such an episode (an *episode* begins when the driver is asked to perform the in-vehicle task and ends when the driver completes the task; there may be several glances inside and outside of the vehicle during any one episode).

Vehicle Management: Hazard Response. Speed management was identified by McKnight and McKnight (2003) as the third most prevalent cause of crashes among young drivers. This included adjusting the speed of the vehicle to traffic/road conditions, slowing on curves, and slowing on slick surfaces. It is clear that speed management is part of a more general category of *vehicle management* which includes behaviors such as maintaining the proper space between vehicles, adjusting the vehicle lane position in response to traffic and road conditions, and responding when a hazard requires an evasive maneuver. *Tactical* vehicle management is particularly important when potential hazards might materialize. A study of the differences in the tactical hazard anticipation vehicle management skills of young and experienced drivers indicates that the differences are pronounced in situations where hazards are difficult to detect (Fisher et al., 2002). So, for example, consider a driver who is approaching an intersection and who intends to drive straight through it (the Truck Left Turn scenario, **Figure 30.1**; for a color version, see the insert pages or Web Figure 30.1 on the *Handbook*

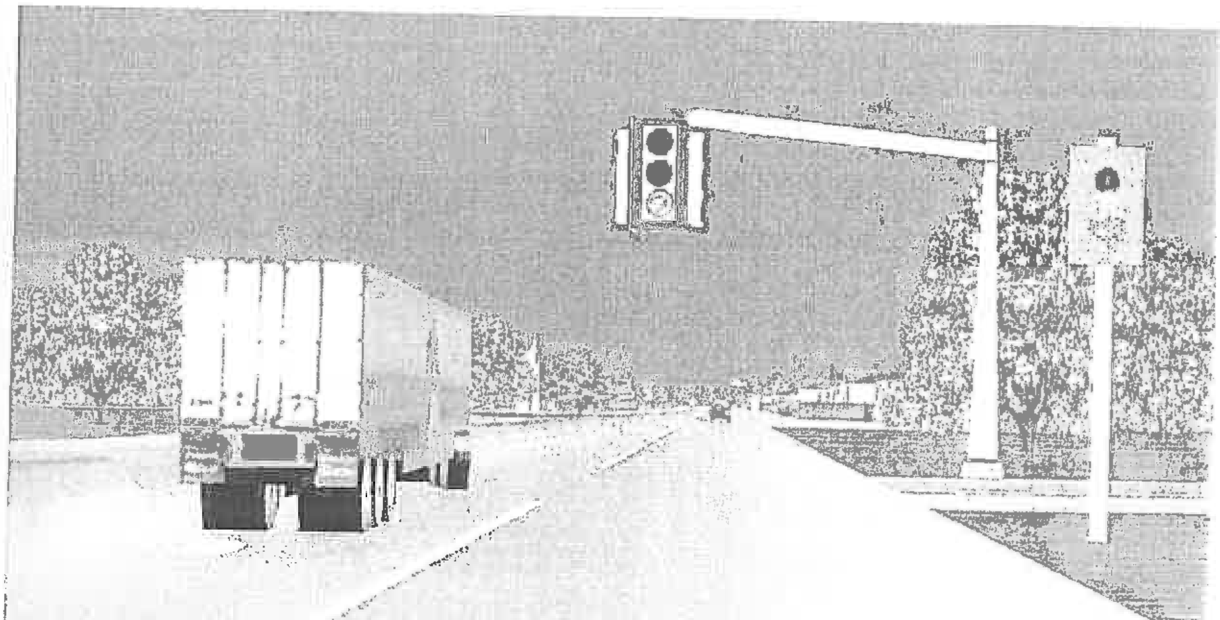


FIGURE 30.1 **(See color insert)** Adjacent truck left turn. (Cars in the opposing lane in front of the truck are obscured from the driver and can turn left into the path of the driver as he or she travels through the intersection.)

web site). Imagine that the driver is passing a truck in a left turn lane that is blocking the driver's view of traffic in the opposing lane which could be taking a left turn across the driver's path. The aware driver should slow down as he or she passes the truck. In fact, experienced drivers are more likely than novice drivers to apply their brakes as they travel past the truck on the left.

30.1.2 Driver Education Programs and Critical Skills

Until recently, there has been little empirical evidence to support the development of a specific content for the training of crash-reduction behaviors in driver education programs. It is true that the recommendation has been made that driver education programs should focus on hazard perception and risk assessment (Mayhew & Simpson, 1995, 1996). But this recommendation is too broad to be of much assistance to driver education instructors, and thus the coverage of the tactical or strategic behaviors in scenarios which would decrease novice drivers' risk has been minimal in driver education (Mayhew & Simpson, 2002). Clearly something is missing from the current driver education programs as a safety countermeasure, since such programs have little impact on crash rates. New driver training programs have been developed which target the critical driving skills to which reference has been made above: Hazard anticipation, attention maintenance, and hazard response. Some of these training programs make use of driving simulators.

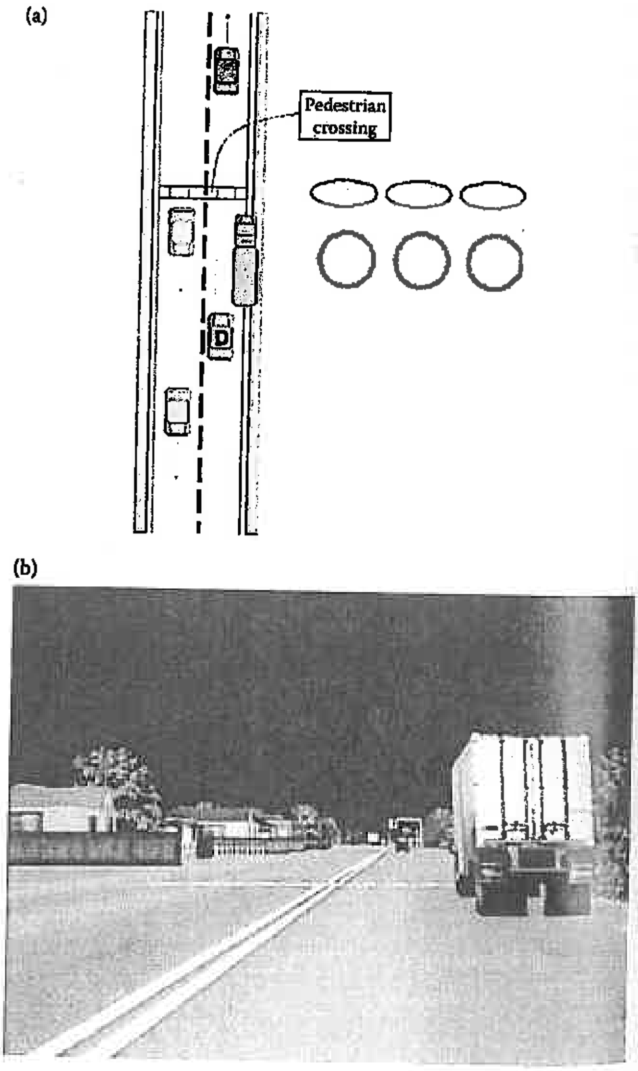
30.1.3 Simulators as Training Devices

Simulators are increasingly being used in driver education programs around the world (Vlakveld, 2006). In the Netherlands alone, there are over 100 simulators in operation in different driving schools (Kappé & van Emmerik, 2005). Despite their increasing use, there has been (and probably will continue to be) vigorous debate about the utility of driving simulators as training devices. Most researchers agree, however, that simulators are the only way in which one can safely learn how to respond in many emergency situations, and most would also agree that simulators are poor substitutes for automobiles for training the psychomotor skills associated with basic driving maneuvers.

In contrast, there is real disagreement about whether simulator-based training programs can be used to train higher-order cognitive skills (e.g., situation awareness, hazard anticipation, attention maintenance) which then transfer to the field. For example, Groeger and Banks (2007) argue that driving simulators are unlikely to have much of a role to play in the training of higher-order cognitive skills because positive transfer of any skills from the simulator would usually require evaluation of a situation that drivers had not experienced before and they would have to apply the skills in less than a second (see also Christie & Harrison, 2003). Those who argue that driving simulators can and should be used to train these higher-order cognitive skills (e.g., Wheeler & Triggs, 1996) note that—unlike more basic psychomotor skills—they do not depend on feedback in a dynamic environment, but are conscious and usually planned (well) ahead of time. A good example is the eye movement that a driver should make in front of the truck stopped before a midblock crosswalk in order to see a pedestrian who might be hidden by the truck (see Figure 30.2). Often, two to three seconds elapse in a situation like this—even for skilled drivers—between the recognition that the situation is one in which a potential hazard can materialize and the resulting response (moving the eyes), but this is still sufficient for the eyes to focus on the potential hazard in time.

Are higher-order skills, such as hazard anticipation, when used on the open road, radically different from these skills when exercised in training? Groeger and Banks (2007), drawing on the work of Barnett and Ceci (2002), have provided a useful framework for discussing the transfer of training. Briefly, transfer is a function of the *content* (of what might transfer from prior experience) and the *circumstances* in which the transfer will occur (the relation

(a)



(b)

FIGURE 30.2 Truck crosswalk scenario. (a) Plan view. (b) Perspective view.

between the context of the prior experience and the context in which the transfer is expected to occur). In terms of content, transfer will occur most easily if the skill is well-practiced, and if the initiation of the skill is prompted externally so that the learner does not have to remember to execute it. In the hazard anticipation scenario discussed above, eye movements are well-practiced, and the speed and accuracy of the eye movements demanded in the field are no different than they would be on a driving simulator. Although a driver on the road is not automatically reminded that a particular hazard must be scanned (and, in fact, this takes some mental effort, Horswill & McKenna, 2004), the recognition of a potential hazard is often simple (e.g., a marked midblock crosswalk signals the driver of a potential hazard each and every time it appears). Thus, from the standpoint of content, it is clear that training of the recognition of this hazard should involve repeated practice of recognizing the hazard; this is easily done with simulators or computer-controlled training programs. However, it would appear that when transfer is at an abstract—conceptual—level, at least when hazard anticipation is involved (Pollatsek, Fisher, & Pradhan, 2006), training is required on only one instance of a scenario in order to achieve generalization, not a large number of instances.

Then there are the "circumstances" of transfer, or the relation between the context of training and the situation to be transferred. Much can be made the same between the simulator and the actual road experience (e.g., cabin noise, sound of traffic, and lighting) but without motion it is difficult to mimic important cues that might help in vehicle management such as cornering (although there is no clear experimental evidence to suggest that motion in training is important). This suggests that only certain types of skills will transfer or will transfer well. In addition, although transfer would likely decline for larger delays between the training and on-road driving, there is little reason to believe that the rate of decline is much different for higher-order driving skills than for other skills. Moreover, because the first couple of months on the road are especially critical, it is not necessary that the effects of training have to last for a long period of time, certainly no more than the first couple of months. Of course, the question of whether some skills can be trained on a driving simulator and then transfer to real driving is ultimately an empirical one, and we turn now to a discussion of the effectiveness of various training programs, some of which use a driving simulator and others do not.

30.2 Alternative Driver Education Programs

30.2.1 Australia

Researchers at the Monash University Accident Research Center (MUARC) have engaged in extensive development (Regan, Triggs, & Wallace, 1999) and evaluation (Regan, Triggs, & Godley, 2000) of a novice driver training program. The program that was eventually developed, DriveSmart, combined CD-ROM and simulator training. A total of 14 different content areas in driving were identified as requiring emphasis (e.g., hazard anticipation, attention maintenance). These content areas were then taught in one of three different driving contexts (rural, freeway, urban) using either digitized real-world videos or a three-dimensional virtual world. The combination of content, context, and instructional modes led to a product with six training modules (Table 30.1). In the Scanning module, video-clips were used to provide the background for the training of hazard anticipation skills. Each of the 67 clips lasted between 20 and 30 seconds. The video was stopped at a given point and the driver was asked, for example, to click on likely risks. In the Keeping Ahead and Playing Safe module, the video was paused and the driver was asked to indicate what the driver should do next. In the Concentration module, three-dimensional virtual words were used to train prioritization of attention. As a drive through a simulated world unfolded, either the participants were asked to keep a constant distance between their car and a car ahead whose velocity varied sinusoidally or they were asked to monitor areas of the periphery in which numbers would suddenly appear and then to perform operations on those numbers. In the fifth and sixth video modules, "On the Road—Urban Driving" and "On the Road—Country Driving", participants were again asked to both scan the roadway and plan ahead. The drives that were presented in these modules exposed the participants a number of times to *near transfer* scenarios (i.e., scenarios similar to ones upon which they would be evaluated after training on a driving simulator) and a limited number of times to *far transfer* scenarios. An example of a near transfer scenario in which novice drivers were trained on the PC and then evaluated on a driving simulator is a right turn at an intersection against opposing traffic (left turn in the United States). An example of a far transfer scenario that was not trained, but which was evaluated, is the driver's behavior in a scenario where it suddenly becomes foggy.

In order to evaluate DriveSmart, 103 learner drivers between the ages of 16 years and 11 months, and 17 years and 10 months were randomly assigned to the treatment (training with DriveSmart) or control (training with a Microsoft flight simulator, which had no obvious relevance) groups. Training was undertaken for both the experimental and control groups in four separate sessions. Immediately after training and then four weeks later, participants were evaluated on a driving simulator in each of four 5-minute *risk perception* drives and three 5-minute

TABLE 30.1 Elements of the DriveSmart Training Program

	Medium	
Module	Digitized Real-World Video	3D Virtual World Simulation
1. Introduction	X	
2. Scanning	X	
3. Keep Ahead and Play Safe	X	
4. Concentration		X (near/far)
5. Urban	X (near/far)	
6. Country	X (near/far)	

attentional control drives. There were a total of four scenarios in each risk perception drive in which it was possible to score vehicle behaviors indicative of what we have defined as tactical hazard perception (and thus a total of 16 scenarios across all four drives). One or more dependent variables were used to index the participant's safe driving performance in each scenario. Two of the scenarios in each drive mirrored what had been trained in DriveSmart (near transfer); two were different (far transfer). Immediately after training, the treatment group was significantly more likely than the control group (at the 10% level) to detect a hazard in four of the near transfer and four of the far transfer scenarios (as indicated by at least one of the measures). There was no statistically significant difference in the remaining eight scenarios. Similar results were observed four weeks later, with the treatment group performing better in three of the eight near transfer, and four of the eight far transfer scenarios. In each of the three attention drives, the speed limit changed in six different places. During each attention drive, the participants had to listen to a series of two-digit numbers (for example, "83"), and then report aloud the absolute value of the difference between the first and last digit, (i.e, "5"). In the evaluation immediately after training the treatment group reached the speed limit more quickly and drove closer to the posted limit than did the control group, all the while performing the arithmetic task equally accurately. In the evaluation undertaken four weeks after training, the treatment group still reached the speed limit more quickly. In part due to this work, passing a hazard perception test is now part of the Victoria, Australia licensing requirement. That test can be downloaded from: http://www.vicroads.vic.gov.au/Home/Licensing/LicenceTests/AboutLicenceTests/HazardPerceptionTest.htm. Unfortunately, the dependent measures were not reported for each scenario so it is difficult to know exactly how large a practical effect training had. Additionally, one cannot know what effect the training might have on actual crash rates.

30.2.2 England

Researchers in England, although not using a driving simulator in the training or evaluation of novice drivers, have focused on a behavior (strategic hazard anticipation) which has been identified as critical to reducing novice driver crashes; thus some discussion is warranted (Chapman, Underwood, & Roberts, 2002). Specifically, hazards were presented in video clips to novice drivers. The training took approximately one hour. No clip that appeared in the training phase appeared later in the evaluation phase. There were five phases in training. In the first, drivers saw four clips, and commented on what they saw and were supposed to press a button whenever they saw a hazard. In the second phase, drivers viewed five clips run at half speed twice; on the first run, they commented on areas that were circled in blue (general areas of interest) and on areas that were circled in red (specific hazards) and then listened to experts' comments on why the different areas were circled. In the third phase, five new clips were played and paused at critical points and the participant's task was to state aloud what will happen next that could pose a threat. The clip was then restarted and an expert explained why there was an impending potential hazard. In the fourth phase, the 10 clips from the two previous phases were played at full speed with the red and blue circles overlaid appropriately. The driver was supposed to comment on the clip and to anticipate the hazards. In the fifth phase, the driver watched four new clips and provided commentary on potential hazards and other driving-relevant information as well as pressing a button at each potential hazard.

The trained group was evaluated three times: three months before training (soon after passing their driving test), immediately after training, and three to six months after training. A control group that was not trained was evaluated at the same times. One evaluation was conducted in the field on a predetermined course on the open road at 18 selected points. The full drive included three different road types (urban, rural, and dual carriageway) and four different speed limits (30, 40, 60 and 70 mph). The eye movements of the participants were evaluated during these drives. Additionally, on each of these testing occasions, after completing the drives the eye movements of the participants were monitored while they watched video clips and pushed a button when they detected a hazard (there were 13 different clips in each phase). In the analyses of the effects of training on driving on the open road course, several different indices of these effects were used—notably time headways, which were computed in situations where a vehicle was directly in front of the driver, and eye movements. For time headway (which was set equal to the distance headway divided by the velocity), there were no differences in the time headways between the untrained and trained novice drivers either immediately after training or three months post-training. However, there were effects of training on the variability of the search; this was computed on three sections of roadway which were selected, one from each roadway type, of roughly 45 seconds in duration that had relatively little traffic and few traffic signals.*

Chapman et al. (2002) concentrated on the variability of fixations along the horizontal axis, which presumably reflects searching areas of potential risk. The standard deviation of the trained drivers increased from 6.18 degree before training to 7.30 degree after training, whereas the standard deviation actually decreased for the untrained drivers from the first to the second test (6.34 degree to 6.08 degree). However, there were no significant effects of training on the third test which occurred three to six months after training. The eye movement patterns from the video clips were similar. The video clips were divided into dangerous sections and not dangerous sections. The horizontal variability of the eye movements was less in all three phases of testing in the dangerous sections. More importantly, the horizontal variability in the dangerous sections was significantly greater for the trained than for the untrained novice drivers both immediately after training (2.34 degree versus 2.05 degree)

* Chapman et al. (2002), reported variances, but we have converted them to standard deviations to simplify exposition.

and three to six months after training (2.28 degree versus 2.00 degree), but not before training (1.93 degree versus 2.08 degree). Finally, it was possible to compare the eye movement behavior of the trained and untrained novice drivers in the video clips in this experiment (Chapman et al., 2002) with experienced and untrained novice drivers seeing the same clips in another experiment (Chapman & Underwood, 1998). In the clips identified as hazardous in both studies, the experienced drivers in the Chapman and Underwood study had a larger search variance than then untrained novice drivers, just as the trained novice drivers in the Chapman, Underwood and Roberts study had a larger search variance than the untrained novice drivers. However, in the scenarios identified as nonhazardous in both studies, the variance of the trained novice drivers' scan continued to be large (Chapman et al. 2002), unlike the experienced drivers (Chapman & Underwood, 1998), suggesting that the training is not helping the newly-licensed driver discriminate hazardous from nonhazardous situations. Note that Chapman et al. did not determine whether the trained drivers were actually looking at areas of the roadway which might reduce their likelihood of a crash; they used only global measures of the amount of eye (and head) scanning behavior. Thus, although the training of Chapman et al., and Underwood and Roberts (2002) focused on knowledge, scanning, and anticipation, rather than on training eye movements per se, without more specific information than the horizontal variance of the search it is difficult to know whether the training is changing much other than the observable scanning patterns.

30.2.3 Sweden

From 2000 to 2004 the European research project TRAINER took place. The aim of this project, which was funded by the European Commission and in which various research institutes participated, was the development of new methods for driver training in which Computer-Based Training (CBT) and simulator training are key elements (TRAINER, 2002). The objectives for the simulator training and CBT were derived from the GDE (Goals of Driver Education) framework, which was the result of a literature review of the causes of the high crash rate of young novice drivers in an earlier European research project called GADGET (Hatakka, Keskinen, Hernetkoski, Gregersen, & Glad, 2003). An abridged version of the GDE-framework is presented in Table 30.2. The last three rows in Table 30.2 are the three levels of skills and control of the driving task which were proposed by Michon (1985): the operational level (vehicle maneuvering), the tactical level (mastery of traffic situations), and the strategic level (driving goals & context). The first row indicates a more global level: "goals for life and the skills for living", which deals with personality, lifestyle and norms and values and how these affect driving behavior. The first column indicates relevant domains of knowledge and skills, the second column indicates the factors that increase risk for young novice drivers, and the third column indicates the required calibration (i.e., balancing task demands and capabilities on the basis of an assessment of the complexity of the task and an assessment of one's own capabilities). As the GADGET project stated that only the lower left boxes are normally addressed in initial driver training, the aim of the TRAINER project was to address all boxes with the aid of simulators and computers.

The CBT that was developed in the TRAINER program differed from DriveSmart (the Australian CBT that is mentioned in Section 2.1) and Driver ZED (the CBT that was developed in the United States, mentioned in Section 2.5.1). In contrast with DriveSmart and Driver ZED, only a small proportion in TRAINER-CBT is about hazard anticipation. This part contains video clips that freeze after about 15 seconds. The learner driver has to click on

TABLE 30.2 Sweden's Goals of Driver Education (GDE) Framework

Essential Contents (Examples)	Knowledge & Skills	Risk-Increasing Factors	Self-Evaluation
Hierarchical levels of behavior			
Goals for life & skills for living (general)	Knowledge about & control over how life goals & personal tendencies affect driving behavior Motivation	Risky tendencies Acceptance of risk Self-enhancement through driving Use of alcohol & drugs	Self-evaluation: Personal skills for impulse control Risky tendencies
Driving goals & context (journey related)	Knowledge & skills concerning: Effects of journey goals on driving Effects of social pressure inside the car	Risks connected with: Driver's condition (mood, blood alcohol concentration, etc.) Driving environment (e.g., urban/rural)	Self-evaluation: Personal planning skills Typical driving goals
Mastery of traffic situations	Knowledge & skills concerning: Traffic regulations Speed adjustment Communication	Risks caused by: Wrong expectations Risk increasing driving style (aggression) Vulnerable road-users	Self-evaluation: Strong & weak points of basic traffic skills Personal driving style
Vehicle maneuvering	Knowledge & skills concerning: Control of direction & position Tire grip & friction	Risks connected with: Insufficient automatism or skills Unsuitable speed adjustment	Awareness of: Strong & weak points of basic maneuvering skills Realistic self-evaluation

the spot in the frozen picture where a potential risk is visible (e.g., a pedestrian in the distance on the sidewalk). All potential risks are explicit and there are no hidden risks. The rest of the CD-ROM contains questions and answers about participant behavior such as drunk-driving, peer group pressure, and fatigue.

The simulator training that was developed had a total of 31 scenarios divided into five training blocks. The blocks were: (1) *basic knowledge* (application of rules of the road and vehicle control), (2) *manoeuvring and safety, divided attention* (car following and overtaking), (3) *manoeuvring and safety, hazard perception* (search strategies, gap acceptance, hazard anticipation), (4) *particular situations with higher risk* (road and weather conditions, darkness) and (5) *particular situations: New technology and personality aspects* (driving with ABS, ecological driving, distraction and attention, motives for driving).

Falkmer and Gregersen (2003) tested whether the hazard perception skills of learner drivers improved when the CBT and the simulator training of the TRAINER project was part of the regular initial driver training in Sweden. Two training simulators, a so-called Low Cost Simulator (LCS) and a so-called Mean Cost Simulator (MCS) were used. The LCS consisted of a driver chair, pedals, a gear lever, a steering wheel, a dashboard, only one monitor (40 degrees field of view horizontally) right in front of the driver, and a sound generator. The pedals and steering wheel had force feedback, but there was no motion system. The MCS had the same configuration but with three monitors (a field of view of about 120 degrees horizontally) and had a simple motion and vibration system. All the participants were learner drivers from a driving school. They had professional driver training (on the road with an instructor) but had not yet taken the driving test. The participants were divided into three groups. The first group initially did CBT and after that received the simulator training on an MCS, the second also did CBT first but received the simulator training on an LCS, and the third (control) group neither did CBT nor simulator training.

To test the acquired hazard perception skills, a high-end research simulator with a moving base was used to present six scenarios to the participants. In the first, the participants drove in an urban environment. At a junction, a bus approached from the right hand side, and according to the rules of the road, the bus has no right-of-way; however, it did not stop. This situation demands early detection and immediate reaction in order to avoid a crash. In the second scenario, the participants drove on a rural road with forest all around. A moose suddenly crossed the road and, after a few seconds, two calves followed. In this condition, situation awareness is required for early detection. In the third scenario, the participant receives an SMS (short message service) on his/her mobile phone when driving on a rural road, and directly after the phone signal, the participant passes a traffic sign indicating a lower speed limit (it was 90 km/h and the sign says 50 km/h). Of key interest is whether participants are distracted by the phone signal or whether they recognize the change in speed limit in time (by reducing speed). Scenarios four to six are actually one long scenario divided into three parts. In the first part, fog gradually reduced the visibility to 100 metres. (Do participants notice gradual decreases in visibility in time and do they adjust their speed?) In the second, the fog disappears and then the driver enters a second fog bank in which a van appears that is driving in the same direction. If the participant is driving too fast, a rear-end collision will occur. In the third, the fog disappears, but then the van (which was directly in front of the participant driver) starts to accelerate (over the speed limit). Will the participant also start to accelerate over the speed limit?

For each scenario, Falkmer and Gregersen (2003) used a different set of dependent variables. All of them dealt with car performance such as speed, onset of braking, following distance, time-to-collision, lateral position, and so forth, so that the drivers' eye behavior was not measured directly (e.g., the scanning behavior was not measured with an eye tracker). There were no significant differences on all dependent variables between the three groups with regard to the bus, moose and the third fog (car following) scenarios. There was a significant difference on one of the dependent variables in the mobile phone scenario and the first fog scenario, and there were significant differences on two dependent variables in the second fog scenario. With regard to the mobile phone scenario, the participants that were trained in the MCS stayed on course better (measured by lateral position) during the secondary task with the mobile phone than either the control group or the group that was trained in the LCS. With regard to the first fog scenario, the average of the speeds of the MCS and LCS groups taken together and the average speed of MCS group by itself were significantly slower than the average speed of the control group when the visibility gradually decreased. In the second fog scenario there was a significantly larger minimum time-to-collision and a larger distance to the van in the MCS group compared to the LCS group, but not compared to the control group.

In summary, the simulator training and the CBT had some positive effects on the driving performance of learner drivers and the group that was trained on the MCS did slightly better than the group that was trained on the LCS. However, there was no improvement when the testing scenarios were considerably different in their appearance from the training scenarios even though there was the same underlying principle in both. That is to say, there was some near transfer but there was no far transfer.

30.2.4 The Netherlands

In the Netherlands, driving simulators are used both for initial and advanced driver training, with more than 100 systems currently in use (Kappé & van Emmerik, 2005). Using driving simulators for driver training requires that cost and effectiveness are carefully balanced. Even though driver training in the Netherlands is relatively expensive (taking about 35–40 hours at €35–40 an hour to pass the practical driving test) driving schools operate a business with small margins. Thus these driving simulators need to be cheap and effective training devices.

The cost-effectiveness of driving simulators was one of the issues in the ELSTAR (European Low-cost Simulators for the Training of ARmed forces) project (see Korteling, Helsdingen,

& von Baeyer, 2000). In this project, aimed at a method for developing cost-effective training simulators, the driving task was dissected into 20 "elementary driving tasks" for each of which the required training cost (in hours) and the required simulator hardware (display, motion base, traffic, etc.) was determined. The resulting cost-effectiveness analysis showed that a cost-effective driver trainer is fixed-base, has a wide field of view (180 degrees horizontal, or wider), a traffic model with a targeted set of traffic scenarios, and a focus on didactics. This allows students to practice a large portion of the curriculum, including procedural aspects of vehicle operation (starting, stopping, changing gears, etc.), and traffic participation (negotiating intersections, roundabouts, etc.) in a relatively cheap simulator. The subtleties of operating the clutch, (hard) braking, curve negotiation and skidding make up only a small portion of the curriculum and rely on motion cues that require an expensive moving base. Those aspects are trained more economically in a real car.

In any training simulator, cost is associated with hardware, software, creating and maintaining the lessons that run on the system, and the instructor operating the system. One of the most important factors in the return on investment is obviously the effectiveness of the training on the simulator. Here the didactical quality of the simulator system, the number of simulators operated by a single instructor and the integration of the simulator in the training curriculum play an important role (Farmer, van Rooij, Riemersma, Jorna, & Moraal, 1999). Since the traffic can be controlled by the simulator system, driving simulators allow an instructive traffic scenario to be presented on demand. Thus, students can, at least in theory, learn faster in the simulator than they can in a practical driving lesson, since they can be programmed to encounter more instructive situations per period of time. Most driving simulators are equipped with a "virtual driving instructor" that guides the student through the lesson, and may provide real-time instruction and feedback as well as briefing and debriefing. With such a system, the role of the human instructor is reduced, allowing multiple simulators to be operated by a single instructor. Some systems claim that they can be used without any human intervention at all, providing "stand-alone" virtual instruction. Even the perfect simulator can fail, however, if its lessons do not fit the training curriculum of the school. Driving schools have to carefully examine how the simulator lessons are embedded in their training. This can be achieved by taking the entire curriculum into account and determining where simulator lessons are best-suited in respect to the other training means (see MASTER, Farmer et al., 1999).

In 2002 ANWB (Algemene Nederlandse Wielrijders Bond; the Dutch Automobile Association) started using simulators in driver training that were developed using ELSTAR and MASTER principles. With a PC-based simulator using a car mock-up, a wide 180-degree three channel projection system, and a sophisticated, scripted, traffic system with virtual instructor, they provided 18 lessons, each of 20 minutes' duration, in which students learned how to master basic vehicle operation and traffic participation. The simulators are located in regional centers, with clusters of two to four simulators operated by a single instructor. Each simulator lesson is focused on a specific topic (e.g. highway driving, negotiating complex intersections, negotiating roundabouts). These specific topics were also treated in the theory book (the homework for that day), in Computer-Based Training (CBT) prior to the simulator lessons, and as the focus of the practical driving lessons that day. An evaluation of the effectiveness of the system showed that practical driving instructors rated the performance of simulator students above average when compared to students that did not receive simulator training. Being freed from explaining and training the relatively boring basic principles of traffic participation, practical driving instructors commented that they had more time to teach students the more cognitive "higher-order" aspects of driving. One ANWB simulator instructor estimated that students learned three times faster in the simulator than in a practical driving course. Based on this evaluation, ANWB driving school decided to proceed with the introduction of the simulator in their curriculum. They now use 30 simulators in their schools, all with a supervising simulator instructor. In 2003, other Dutch driving schools started using driving simulators, but they tended to use simpler driving simulators that were operated in clusters or as stand-alone machines (depending on the size of the school). These simulators did not present specific scenarios to the student, but instead manipulated more general traffic parameters (traffic density, percentage of "aggressive" drivers, etc) to deliver lessons of varying difficulty levels. These schools generally offer the simulator lessons at a reduced cost as an "extra", prior to the start of the regular practical driver training.

Apart from the evaluation that was conducted at ANWB driving schools, the Dutch driving simulators have not been subjected to a classical validation study. Such a study would compare the performance of randomly assigned groups of students trained with the normal practical driving curriculum with that of a group trained with a simulator curriculum. In practice, validation studies are very difficult to perform. They are hampered by their practical setting (at a school, and not in a laboratory) and are sensitive both to differences in the student population (simulators may or may not attract specific subgroups) and to the way the simulator is used (as an "extra to" or as a "replacement for" practical driving lessons). Also, the results of a classical validation study are only valid for a specific simulator in a specific training curriculum, and thus they are difficult to generalize. In addition, the cost and the time involved in a classical validation study have been a hurdle for the Dutch driving schools. They need information on the validity of simulator training at an early stage to help them make a proper decision on the introduction of driving simulators. At that stage, there is often just one prototype driving simulator available with a limited number of students (at best) who can do a small set of lessons that are not fully embedded in the school's curriculum yet. As the effectiveness of training depends primarily on the quality of the simulator lessons and their integration into the curriculum, a classical validation would not be fair at that stage. When the driving simulators are in use, the schools generally have a good sense of the validity of the lessons and are no longer inclined to spend money on a full-blown validation of their system.

Apart from the positive responses of the driving schools, there is some circumstantial evidence that driving simulators like these can be effective trainers. For example, as discussed in more detail in the next section, Allen, Park, Cook and Fiorentino (2007) found that simulator training in the United States can lower novice driver crash rates (compared with the general U.S. novice driver population). In the Netherlands, De Winter, Wieringa, Kuipers, Mulder and Mulder (2007) reported that students that performed well during their driving simulator training have a higher chance of passing their driving test the first time (a correlation of 0.18 in a regression analysis), and that students that required fewer practical driving lessons made fewer errors in the simulator training (predictive correlation 0.45). The curriculum was based on Dutch driver training and consisted of 15 lessons of 27 minutes each. Thus, students that performed well in the simulator also performed well during their subsequent practical driving lessons and on the test, which gives some indication of the validity of the driving simulator that was used.

Although these results indicate that driving simulators can play a role in initial driver training, there are several qualifying observations that can be made (see also, in this book, chap. 5 by Caird & Horrey, "Twelve Practical and Useful Questions About Driving Simulations"). First, simulated environments present a relatively poor abstraction of reality; they display relatively clean, predictable virtual environments with little clutter and without subtle visual cues (e.g., those that signal the characteristics and intentions of other road-users, and potentially hazardous situations). Furthermore, simulated traffic tends to behave very stereotypically, and looks clumsy and erratic from time-to-time (depending on the quality of the simulated traffic). Pedestrians and cyclists also generally look and behave like robots.

An additional concern is the quality of the virtual instruction. Virtual instruction often lacks the subtle student-teacher interactions that characterize practical driver training. This is a relatively minor problem for the first phases of teaching, where instructors guide the student through the "scripts" (i.e., more-or-less standardized patterns) that are required to negotiate different situations in traffic. It is a major problem when attempting to teach higher-order, more cognitive aspects of driving with a virtual instructor. Human instructors tend to know why an error is made (and will ask if they are not sure) and will give appropriate feedback. Virtual instructors generally do not have a clue why an error is made, and will not give the right feedback. Also, virtual instructors cannot measure all the relevant behavior of the student. For example, scanning behavior is difficult and expensive to measure, and there are currently no commercial driving simulators equipped to measure scanning behavior. However, as proper scanning is an important learning goal in driver education, instruction and feedback on scanning behavior need to be provided otherwise. This requires that a human instructor is present to provide instructions and feedback on scanning behavior. Although the driving instructor can not always follow the gaze of the participants, it seems unacceptable to allow a student to learn such aspects in a stand-alone simulator, as they may learn inappropriate scanning motor patterns which would need to be "deprogrammed" in the following practical driving lessons.

As with any driving simulator, the novice driver trainees exhibit some simulator sickness, though with drastically reduced rates compared to experienced drivers. Novice drivers, who have not steered a vehicle, seldom become sick (less than 5%), whereas 50% of the experienced drivers (e.g., driving instructors) experience some symptoms of sickness, in the same simulator driving the same lessons. Reasons for these differences are discussed elsewhere (e.g., see in this book, chap. 14 by Stoner, Fisher & Mollenhauer, "Simulator and Scenario Factors Influencing Simulator Sickness").

All things considered, it seems that driving simulators are best-suited for training the basics of vehicle operation and traffic negotiation. This is exactly how they are used for novice driver training in the Netherlands. However, this does not mean that driving simulators cannot be used to teach expert drivers. The Dutch police driving school has been using six driving simulators for their advanced driving courses. These simulators are used for improving the general driving skills of cadets, as well as for driving in emergency situations. These simulators have the same basic characteristics and shortcomings described above. However, their didactical use is entirely different. Instead of having a single student in the simulator, the students are trained in groups of six. One student is in the simulator, the others are in an adjacent room looking at the performance of their colleague on a separate three-channel display. These students have a response button which they are required to press when an error is made or when there is room for improvement. The teacher uses these responses to trigger discussions on cognitive aspects of the driving task (e.g., What did he or she do wrong? Why? What would you have done?). According to the school's instructors, 60% of the didactical value is in these discussions, and only 40% is in the simulator. (It should be noted that Dutch police always train students in small groups, and that these groups are comfortable in expressing and receiving critique.) This result is in line with Gregersen, Brehmer and Morén (1996) who compared the effectiveness of different types of training on accident involvement rates, and found that having group discussions outperformed books, CBT and skidding courses. It remains to be determined whether these methods for teaching experts might have value for training novice drivers as well.

As with any training medium, it is the didactical setting for simulators that is most relevant in determining its learning value. Driving simulators are well-suited for novice driver training, but may, under the right conditions, be used for experienced drivers too. Given the relatively slow progress in simulator hardware and software, driving schools should have a focus on simulator didactics. That is the single aspect that is most under their control, is most directly related to the validity of simulator training, and is most directly related to making a profit using the simulator.

30.2.5 United States

There have been several attempts in the United States over the past 10 years or so to introduce training that is more focused on hazard anticipation, attention maintenance, and vehicle management. Most evaluations have been conducted only on a driving simulator. One recent evaluation has been carried out both on a driving simulator and in the field.

30.2.5.1 Driver ZED

About 10 years ago, the American Automobile Association (AAA) developed a risk awareness training program called Driver ZED (Zero Errors Driving). Participants sat in front of a PC watching a total of 80 different scenarios filmed in city, town and rural settings (Willis, 1998). The scenarios contained views filmed from the cabin in a moving vehicle—both of the roadway ahead and the roadway as seen in the side- and rear-view mirrors. The participant needed to take one of several actions sometime during or after each scenario, with the action depending on the mode of presentation. There were four modes: scan, spot, act and drive. In the *scan* mode, the driver needed to answer questions at the end of a scenario which assessed how well the driver was paying attention to everything in the scenario (e.g., the driver might be asked whether there was a vehicle approaching in the rear-view mirror). In the *spot* mode, the scenario was stopped at the last frame. The driver was asked to use the mouse to click the cursor on each risky element in the scenario (e.g., a child playing with a ball on the sidewalk). In the *act* mode, the driver was asked what action he or she would take midway through a scenario (e.g., the driver might be asked whether he or she should speed up or slow down at an intersection where the traffic signal was displaying a yellow globe). Finally, in the *drive* mode, the driver needed to click on the mouse at the point in a scenario when they would take an action that could potentially avoid a crash (e.g., the participant might need to brake suddenly when approaching a driveway out of which a car was backing). (Note that Driver ZED has evolved. The most current version, Driver ZED 3.0, can be downloaded at http://www.driverzed.org/home/.) The risky scenarios in Driver ZED were selected specifically because they were ones in which younger drivers frequently crashed (Lonero, Clinton, Black, Brock, & Wilde, 1995).

Fisher et al. (2002) evaluated the effects of Driver ZED training on a driving simulator. Specifically, the vehicle behaviors of three groups of drivers on the driving simulator were recorded: Novice drivers (high school students with a learner's permit) who were trained to recognize risks using Driver ZED; novice drivers who were trained only through standard drivers' education programs; and more experienced drivers (qualified college students who were driving buses for the university in which they were enrolled). Each group drove through a number of potentially risky scenarios on the driving simulator and vehicle behavior was recorded throughout each drive. The 12 scenarios Fisher et al., chose to evaluate on the driving simulator included examples not only from categories of crashes in which younger adults are frequently involved, such as proceeding straight ahead through an intersection, but also examples from categories in which younger adults are only infrequently involved but which are often fatal, such as passing other vehicles (Aizenberg & McKenzie, 1997, p. 53). Fisher et al. (2002) examined the simulator data and found that, overall, there was not a single dependent variable based on vehicle behavior that captured the efficacy of training across all 12 scenarios. However, some clear effects emerged when they evaluated the effect of training on a subset of six of these scenarios using different dependent variables as the outcome measures. Moreover, the behavior of the trained novice drivers closely resembled that of the experienced drivers. For example, in the Truck Left Turn scenario displayed in Figure 30.1, the experienced drivers braked opposite the truck more frequently than the untrained novice drivers, indicating that they recognized the risk that an obscured vehicle in the opposing lane could be in the process of turning across their path; the more frequent braking was also characteristic of the ZED-trained novice drivers. Similar differences in driving behavior between the ZED-trained and untrained novice drivers were reported in other scenarios. However, from these data it could not be determined how much of the differences between the untrained novice drivers on the one hand, and the trained novice and experienced drivers on the other, were due to differences in hazard anticipation skills (predicting that a car might intrude) and a combination of hazard and speed control skills (actually braking). Perhaps all drivers predicted the presence of a potential hazard, but only the trained and experienced drivers were able to act on this information.

30.2.5.2 Driver Assessment and Training System (DATS)

In a recent study, over 500 novice drivers were recruited in the state of California to participate in a study of how effective driving simulators were at reducing crash rates among this population of drivers (Allen et al., 2007). The drivers were assigned to one of three simulator training modes: A single-monitor desktop simulator, a three-monitor desktop simulator, or a wide-screen vehicle cab simulator (135 degrees horizontal). One group of drivers was recruited from the Department of Motor Vehicles and assigned either to the three-monitor desktop or wide-screen vehicle cab simulators. Training occurred in a laboratory setting. A second group of drivers was recruited from high school driver education courses. Training in the high schools was on the single-monitor desktop simulator. Crash data was obtained from the California DMV for up to two years post-training.

In the simulator training that was part of a larger Driver Assessment and Training System (DATS), the students navigated six 12–15 minute drives (Park, Cook, Allen, & Fiorentino, 2006). The temporal and spatial relations between the driver's vehicle and other traffic, traffic signals, and pedestrians were controlled in each of the hazardous situations that a participant encountered in a simulated drive. The scenarios were designed to require and train skills, including situation awareness, hazard perception, and decision-making under time pressure. The order of hazard encounters was varied in the scenarios prepared for training so that students could not anticipate upcoming events. A summary of the critical events that occurred in each scenario is contained in Table 30.3 (Parke et al., 2006). For example, there were six pedestrian events, two coming from the right and four from the left, where the trigger times for pedestrians moving in front of the participants were designed to present the drivers with critical decisions that had to be made in a very short period of time. A participant's performance was scored on each drive, including use of turn signals, time-to-collision, and number of crashes, road edge incursions, traffic signal violations, and posted speeds which were exceeded by the driver. Earlier work suggested that performance on each of these indices reached asymptote after six trials for most participants (e.g., Allen, Park, Cook, & Viirre, 2003). Accordingly, participants could graduate on the sixth trial if they met performance criteria including no crashes, no more than one ticket, nominal values for lane and speed deviations, and reasonable use of the turn signal indicators (Allen et al., 2007; Allen, Park, Cook, Fiorentino, & Viirre, 2003). Otherwise, they were allowed to improve their score on up to another three drives. Almost 80% of the participants graduated.

The crash rates per licensed driver were then computed for each of the three simulator groups over a two-year period. At the end of two years, 17% of the one-monitor desktop simulator participants had a crash, 14% of the three-monitor desktop simulator participants had a crash, but only 7% of the wide-screen vehicle cab simulator participants had a crash (the percentages are estimates because they are taken from a figure). As a control group, the authors compared the cumulative crash rates of drivers in California and Canada over the course of the first two years after obtaining their license. Crash rates were regressed on the time since licensure. The linear increases in cumulative crash rates of drivers in California and Canada were indistinguishable from each other. Both were clearly higher than increases in the cumulative crash rates of the participants in the wide-screen vehicle cab simulator but about the same as the cumulative crash rates of the other two groups. Unfortunately, assignment of the participants to the experimental groups was not random nor, obviously, was assignment of the participants to experimental and control groups, so it is difficult to be certain that the lower crash rates of the wide-screen vehicle cab participants would be replicated in a properly controlled study. Nonetheless, the results are encouraging for the use of the wide-screen vehicle cab simulator (presumably because it mimics what one sees on the road most closely).

TABLE 30.3 Hazardous Events in STI Simulator Drivers

1 head-on collision event
6 pedestrian walkout events:
a) 2 from right
b) 4 from left
10 intersections
a) 1 green signal light event
b) 2 red signal light events
c) 4 yellow light decision making events
d) 2 cross-traffic stop signs – driver did not have to stop at intersection
e) 1 with-traffic stop signs – driver had to stop at intersection
f) 1 right and 1 left turn
2 obscured vehicle pullouts from right
2 overtaking vehicle events
2-lane, dashed line road, vehicle approaches from behind, moves into opposing traffic lane, overtakes driver, returns in front of driver vehicle
1 construction zone environment

30.2.5.3 Risk Awareness and Perception Training (RAPT) Program

A program to train novice drivers to anticipate hazards has been developed and then evaluated; it was motivated by the finding that younger drivers are less likely to anticipate hazards than more experienced drivers (Pradhan et al., 2005). In the simplest version of this Risk Awareness and Perception Training (RAPT) program, participants were presented a plan view of a hazardous situation. For example, imagine a driver is approaching a marked midblock crosswalk. There are two travel lanes in each direction and a parking lane (see Figure 30.2; Web Figure 30.2). A truck or other large vehicle is stopped in front of the crosswalk in the parking lane that (from the perspective of the driver) is potentially obscuring a pedestrian who might enter the crosswalk. (The driver is the gray vehicle labeled with a "D" on the roof). Six markers (three yellow ovals and three red circles) were positioned off to the side. Participants had to drag the yellow ovals to areas on the plan view where a potential threat might be located (in front of the truck) and the red circles to locations on the plan view where they would expect the threat to materialize (to the left and front of the truck). The number of markers needed in each plan view varied between one and three. Participants were then told the correct locations of the ovals and circles (Pollatsek, Narayanaan, et al., 2006). The complete set of plan views used in one of the evaluations of training (Diete, 2007) is presented in Web Figure 30.2 to Web Figure 30.10. (The complete training program can also be seen by going to http://www.ecs.umass.edu/hpl, clicking on "Younger Drivers" and then clicking on "RAPT-2".). In other versions of RAPT, sequences of photographs of hazardous situations were used. The sequence was generated by taking a picture every second or two as one approached and passed beyond an actual hazardous situation. The participant was required to use the mouse to move a cursor to locations in each photograph where a risk might appear but was not visible. Again, feedback was provided. (This sequence is viewable by going to http://www.ecs.umass.edu/hpl, clicking on "Younger Drivers" and then clicking on "RAPT-3").

In a series of studies, it has been shown (principally using eye movement measures) that RAPT increases the likelihood that newly-licensed drivers anticipate hazards, to the point that their performance is not much different than much more experienced drivers. These effects of training were clear both immediately after exposure to the training program (Pollatsek, Narayanaan, et al., 2006) and for up to one week later (Pradhan, Fisher, & Pollatsek, 2006). They were present both on a driving simulator and in the field (Pradhan, Pollatsek, Knodler, & Fisher, 2009), and they were evident both in scenarios which are similar to ones that were trained and ones that were quite dissimilar (Pollatsek, Fisher, et al., 2006). For example, consider one study done on the driving simulator and one in the field where the same version of RAPT was used (Fisher, Pradhan, Pollatsek, & Knodler, 2007). The principal dependent variable was whether participants fixated in a certain region in a certain time window, indicating that they were looking for a specific potential hazard (e.g., fixating around the front of the truck in the example above). There was an overall training effect of 37.4 percentage points on the driving simulator: The trained group fixated the critical region 77.4% of the time, whereas the control group fixated the critical region only 40.0%. The training effect was 41.7 percentage points for the nine near transfer tests (77.4% versus 35.7%) and 32.6 percentage points for the nine far transfer tests (76.8% versus 44.2%). The overall training effects observed on the driving simulator were somewhat larger than the overall averages observed in the field study. In the field study the overall training effect was 27.1 percentage points (64.4% versus 37.3%), 38.8 percentage points (79.2% versus 40.4%) for near transfer and 20.1 percentage points (58.3% versus 38.2%) for far transfer. Videos of trained and untrained drivers scanning behavior in the field and on the driving simulator in the Truck Crosswalk Scenario are available on the *Handbook* web site (Web Videos 30.1–30.4). The three major limitations of this work are that it remains unknown just how long the training effects will last, it remains unclear whether drivers will be motivated to apply what they have learned in training when they are out on the open road by themselves, and it is not certain that there will be a reduction in crashes.

An interesting variation of the training program was recently evaluated. In that variation, a head-mounted driving simulator was used to train tactical hazard anticipation scanning skills (SIMRAPT) in addition to the training they received with RAPT (Diete, 2007). The driver sat in a real car in which inputs from the wheels, brake, and accelerator were sent to a computer which then displayed movements through the virtual world on the head-mounted display consistent with these inputs. Participants who did not make a head movement indicating that they recognized a potential hazard had to repeat the drive. At the end of the combined RAPT and SIMRAPT training, both the trained participants and a group of participants who had not been trained were evaluated on a more advanced driving simulator. The training effect here was no different than the training effect with just RAPT alone. It is not entirely clear why the additional simulator training did not provide a larger benefit, although perhaps the critical hazard anticipation behaviors learned with the head-mounted display (head turns) are sufficiently different from the behaviors that are typically used to anticipate hazards (eye movements and head turns).

30.3 General Discussion

It is clear from the above discussion that training programs for novice drivers are now at the point where novice drivers' hazard anticipation scanning skills, attention prioritization skills, and hazard anticipation vehicle handling skills can all be improved, perhaps even to the point where there is an impact on crash rates. Continued progress in this area will depend on researchers' ability to improve simulation as a tool for both training and evaluation. Above, we have discussed in general terms those aspects of training which are likely to affect the success of training transferring to on-road driving (Groeger & Banks, 2007; Barnett & Ceci, 2002). Below, we discuss what, in general, will be needed to advance our understanding and what limitations there are to using simulation to train and evaluate newly-licensed drivers.

30.3.1 Driving Simulators: Training and Evaluation

Individuals who want to use driving simulators for training and or evaluating novice drivers' scanning, attention maintenance and vehicle management skills need to understand something about the general development of scenarios which have proved to be useful and the equipment (in addition to simulators) and analyses which it is important to be able to undertake.

30.3.1.1 Hazard Anticipation: Scanning and Vehicle Handling

The scenarios that need to be developed in order to evaluate tactical scanning and vehicle management hazard anticipation skills do not generally require the coordination of the movement of other vehicles and pedestrians with the movement of the participant's car. This is because it is not necessary to materialize the potential hazard, as the driver's scanning and vehicle management responses should be the same whether or not the hazard actually appears. This greatly simplifies the construction of the scenarios. There are generally two categories of scenarios used to evaluate scanning and vehicle management hazard anticipation skills. In the first category are scenarios where a threat is obscured by a built object (e.g., a truck in Figure 30.2) or natural object (e.g., a bush in Web Figure 30.3) in the environment. In order for a driver to anticipate the hidden threat, it must be cued in advance, such cues including pavement markings (the crosswalk stripes in Figure 30.2), signs (e.g., the left fork sign in Web Figure 30.6), or the geometry and placement of objects in a given environment (e.g., the truck in the left turn lane of a four-way signalized intersection as shown in Figure 30.1). In the second category are scenarios where the threat is visible, but latent. In this case, the threat is often cued by the geometry and knowledge of other drivers' intentions. For example, a line of cars in the left of two travel lanes waiting to turn left constitutes a potential hazard for a driver in the right travel lane because one or more of the drivers in the left travel lane could pull out suddenly into the right travel lane, perhaps deciding that they actually wanted to go straight. No one currently knows what other categories of scenarios are representative of hazards which need to be anticipated or even how many examples of hazards within each category actually need to be trained in order to get good generalization to the entire category. But, at least currently, it does not seem like there are any issues particular to constructing scenarios used for the simulator training or evaluation of tactical hazard anticipation skills that are holding back progress.

Measures of tactical hazard anticipation skills typically include vehicle parameters (e.g., speed, lane position), information that is collected automatically by all simulators, and eye behavior (e.g., glance locations, range), information which requires specialized eye tracking devices. Analysis of the vehicle information is usually straightforward. Analysis of the eye tracker information can require much more work, especially when the issue is tactical hazard anticipation scanning skills. Here, for each hazardous scenario, a *launch zone* (the location in which the eye movement can be initiated) and *target zone* (the location in which the eye movement must land) must be defined. The eye tracker record must then be analyzed one frame at a time to determine whether there was an eye movement that meets the criteria of fixating appropriately. Fortunately, most scenarios used to evaluate tactical hazard anticipation scanning skills are so constructed that the eccentricity of the eye movements needed to identify the location at which a potential hazard might be, or from which the potential hazard might materialize, is so large that the scoring of the eye tracker videotape is almost always straightforward. Nine out of the 10 near transfer scenarios in the evaluation of RAPT (Pollatsek, Narayanaan, et al., 2006) required eye movements greater than 10 degree in the near transfer scenarios, with the eye movements that were scored as meeting the criteria ranging from as small as 5.4 degree to as large as 27.8 degree (see Web Table 30.1).

30.3.1.2 Attention Maintenance

There has been much less research on programs that deal explicitly with attention maintenance. The one notable exception in this regard is DriveSmart (Regan, Triggs, & Godley, 2000; Regan, Triggs, & Wallace, 1999), where attention prioritization in a combined primary driving and secondary auditory task has been the focus of the training efforts. There is nothing about this training program, or the evaluation of the training program, that could not be implemented on any of the existing simulators. Nor is special equipment required to record the response in these scenarios or advanced algorithms to analyze the data. However, when attention prioritization in a combined primary driving and secondary visual in-vehicle task becomes the focus of a training program, then some type of head and/or eye tracking device will be needed in order to determine how long the continuous glances are in which the driver is not fixating the forward roadway (e.g., when looking for a map on the front seat; see Chan et al., 2008).

30.3.2 Limitations

Newly-licensed drivers, almost to an individual, are not scanning as well as more experienced drivers, are not maintaining attention as well as more experienced drivers, and are not managing their vehicle as well as more experienced drivers. The discussion of the training programs above suggests that notable advances can be made among newly-licensed drivers in each of these skills. However, it would be naïve to assume that skill training alone would be the only influence on newly-licensed drivers' performance. If not motivated to put into practice the skills they have learned, newly-licensed drivers will continue to crash at high rates (Christie, 2001). Moreover, if they actively still choose to behave in a risky fashion, something which is well-documented among teens (Beirness, 1996), the crash rates will remain high. Finally, there is the problem that skills training can sometimes lead to overconfidence, which has a net negative impact on crash rates (Mayhew & Simpson, 1996).

Key Points

- Police crash reports indicate that novice drivers are at a greatly increased risk of crashing during the first six months of solo licensure due to poor hazard anticipation, attention maintenance, and speed management skills.
- Driving simulators have been used to compare novice drivers' eye and vehicle behaviors with those of more experienced drivers in each of the above three skill areas; such comparisons are consistent with the crash reports, showing real deficiencies among novice drivers in their ability to anticipate hazards, maintain attention, and manage speed.
- PC-based programs have been developed that train novice drivers to anticipate hazards and maintain attention.
- The effects of these programs generalize from the PC to both the driving simulator and the open road, from scenarios which are similar to those trained on the PC to those which are far removed, and from evaluations undertaken immediately after training to evaluations taken up to a week after training.
- Although these training programs have been shown to have an effect on driver behavior in fielded observations, it is still not clear that they will reduce crashes.

Keywords: Attention Maintenance, Eye Movements, Hazard Anticipation, Novice Drivers, Simulator Evaluation, Simulator Training

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Glossary

Attention maintenance: There are two varieties of attention maintenance, broadly speaking. First, drivers need to distribute their physical resources (eye movements) appropriately inside and outside the vehicle in order to maintain attention to the roadway. Second, while looking at the forward roadway, drivers still need to concentrate on their driving to the exclusion of talking on the cell phone, interacting with the music retrieval system, or doing anything in general which reduces their capacity to process events in the forward roadway.

Eye behaviors: These typically include only the sequences of fixations, though in some studies they might include pupil diameter and the percentage of eyelid closure.

Tactical and strategic hazard anticipation scanning: *Tactical hazard anticipation scanning* is the scanning pattern observed when a feature in the environment suggests that a hidden threat is especially likely to materialize at a particular location and time in a scenario whereas *strategic hazard anticipation scanning* is the scanning pattern observed when there is no such key feature.

Vehicle behaviors: These include such measures as velocity, acceleration, steering wheel angle and brake pressure.

Web Resources

The *Handbook*'s web site contains supplemental materials for this chapter, including:

Web Table 30.1: Scoring of Near Transfer Scenario in RAPT.

Web Figure 30.1: Adjacent Truck Left Turn scenario (color version of Figure 30.1).

Web Figure 30.2: Truck Crosswalk scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.3: Amity-Lincoln scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.4: Adjacent Truck Left Turn scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.5: T-Intersection scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.6: Left Fork scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.7: Opposing Truck Left Turn scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.8: Blind Drive scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.9: Pedestrian on Left scenario. (a) Plan View. (b) Perspective View.

Web Figure 30.10: Mullins Center scenario. (a) Plan View. (b) Perspective View.

Web Video 30.1: Truck Crosswalk Scenario on Simulator: Untrained.

Web Video 30.2: Truck Crosswalk Scenario on Simulator: Trained.

Web Video 30.3: Truck Crosswalk Scenario on Open Road: Untrained.

Web Video 30.4: Truck Crosswalk Scenario on Open Road: Trained.

Key Readings

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