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Do Crashes and Near Crashes in Simulator-Based Training Enhance Novice Drivers' Visual Search for Latent Hazards?

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Abstract

Young drivers (younger than 25 years of age) are overrepresented in crashes. Research suggests that a relevant cause is inadequate visual search for possible hazards that are hidden from view. The objective of this study was to develop and evaluate a low-cost, fixed-base simulator training program that would address this failure. It was hypothesized that elicited crashes in the simulator training would result in better scanning for latent hazards in scenarios that were similar to the training scenarios but situated in a different environment (near transfer), and, to a lesser degree, would result in better scanning in scenarios that had altogether different latent hazards than those contained in the training scenarios (far transfer). To test the hypotheses, 18 trained and 18 untrained young novice drivers were evaluated on an advanced driving simulator (different from the training simulator). The eye movements of both groups were measured. In near transfer scenarios, trained drivers fixated the hazardous region 84% of the time, compared with only 57% of untrained drivers. In far transfer scenarios, trained drivers fixated the hazardous region 71 % of the time, compared with only 53% of untrained drivers. The differences between trained and untrained drivers in both the near transfer scenarios and the far transfer scenarios were significant, with a large effect size in the near transfer scenarios and a medium effect size in the far transfer scenarios [respectively: $U = 63.00$, $p(2\text{-tailed}) < .01$, $r = -.53$, and $U = 88.00$, $p(2\text{-tailed}) < .05$, $r = -.39$].

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Novice drivers younger than 25 are greatly overrepresented in fatalities (1). The crash rate is the highest directly after licensing. It declines rapidly in the first year, but it takes years before the crash rate doesn't decrease any further (2–6). McKnight & McKnight, after having analyzed more than 2,000 reports of crashes involving 16- to 19-year-old drivers, found that the majority of crashes resulted from errors in visual search, inattention, and driving too fast for the circumstances (7). In 42.7% of cases, inadequate visual search lay at the root of the crash.

Most studies do not differentiate between safety-related scanning inside and outside the vehicle. The relationship between inadequate visual search inside the vehicle and crash risk can be inferred from the 100-car study, although most of the results of this naturalistic driving study were about distracted driving and crash risk. One of the categories was driver-related inattention to the forward roadway (8). These were eye glances away from the forward roadway in the 3 s before the conflict and 1 s after the conflict that were related to safe driving and not related to secondary task distraction. The researchers found that short glances away from the forward roadway for the purpose of scanning the traffic environment, other than straight ahead, reduced near crash and crash risk considerably (9).

This paper focuses only on visual scanning outside the vehicle. Young novice drivers in particular have difficulties in visual search for possible hazards, especially those that are not located straight ahead. Several field studies employing eye-tracking technology have revealed that young novice drivers fail to scan as broadly side to side as do older, more experienced drivers (10–12). In a simulator study, Pradhan et al. found that older, more experienced drivers more often searched for particular possible hazards to the sides of the vehicle than young novice drivers (13).

The purpose of the present study is to evaluate a simulator-based training program for young novice drivers intended to enhance their visual search for potential hazards. These potential hazards were ones that could materialize anywhere in the visual field of the training simulator, which subtended 135 degrees of visual angle, but not ones that could appear in the rearview or side view mirrors, although certainly these latter hazards are important as well.

TYPES OF HAZARDS AND EFFECT OF TRAINING

In this study, a distinction is made between immediate hazards and latent hazards. Immediate hazards are visible threats (e.g., another road user on a collision course with the driver) that require immediate action to avoid a crash. A latent hazard is a possible hazard that will not necessarily develop into an immediate hazard. Three types of latent hazards are distinguished:

1. Possible other road users on a collision course with the driver that are hidden from view by the built and natural environment or vehicles where no sign warns the driver (e.g., a possible but still invisible child that may cross the road from between parked cars). The authors named this type of latent hazard covert hazards.
2. Visible other road users who, because of evolving circumstances in the environment, can act in such a way that they may move into the driver's pathway (e.g., a driver that gets impatient when waiting in a row of cars in a left-turn lane and suddenly pulls out into the travel lane of the participant driver). The authors named these types of latent hazards overt hazards.
3. Possible other road users or situations (e.g., a construction zone) that are hidden from view by the built or natural environment that are potentially hazardous enough to require explicit warning signs. For instance, this includes an intersection

just after a curve in the road with dense vegetation on both sides; the intersection becomes visible only when the intersection is near. A driver that does not notice the warning sign “stop sign ahead” before he or she enters the curve may drive too fast and will detect the intersection too late. These types of latent hazards are called here signed hazards.

The simulator-based training program that was developed and evaluated in this study was designed to enhance the trainee’s ability to detect and recognize latent hazards, and within the domain of latent hazards, the emphasis of the training program was on covert hazards. Covert hazards were emphasized because young novice drivers in particular have difficulty detecting and recognizing these hazards (13–15).

Another distinction that is made in this study is between near transfer and far transfer. Transfer of training is measured by the degree to which trainees apply in reality what they have learned during training. There is near transfer when trainees apply what they have learned in situations that may look different but contain latent hazards conceptually identical to the training situations. There is far transfer when trainees apply what they have learned in situations that conceptually differ from the trained latent hazards.

PERSONAL COMPUTER-BASED HAZARD PERCEPTION TRAINING PROGRAMS

Various computer-based or video-based interactive training programs have been developed for young novice drivers that enhanced drivers’ hazard perception skills (16–20). However, these training programs were only occasionally about latent hazards, and none of them was explicitly about covert hazards. Exceptions are the personal computer (PC)–based risk awareness and perception training programs (RAPT) for novice drivers. Just as in the present simulator-based training program, RAPT was developed by the Human Performance Laboratory of the University of Massachusetts, Amherst. RAPT is currently in its third version. RAPT-1 presented the participant with a plan view of various hazardous scenarios. Participants had to identify areas of the scenario that might contain a possible hazard. These hazards were mostly covert hazards. Plan views were used to allow participants to process more deeply the reason that a particular scenario contained a latent hazard to promote far transfer. RAPT-2, in addition to the plan views, also included a photo of the scenario from the driver’s perspective. This was done to aid the visualization process and to emphasize that the scenarios can happen in real life. In RAPT-3, sequences of photos at a 3-s interval were shot from the driver’s perspective. The hazard never materialized in the sequence of photos. These sequences were presented to participants as a pretest and a posttest. Participants were asked to click with their mouse on the areas of each photo to which they would pay particular attention because of a possible hazard. In the training, the same sequence of photos was used for each scenario (different sequences were used for different scenarios). After each sequence, a plan view of the area where the latent hazard could materialize was presented. On the basis of the plan view, the particular latent hazard that could develop in the scenario was identified. The same sequence of photos was presented again. If on this repetition the mouse clicks were not on areas that allowed the participant to detect hazards, the sequence of snapshots was repeated up to three more times. In posttraining simulator and field evaluations in which participants wore an eye tracker, young novice drivers made significantly more eye glances that allowed for early detection of latent and mostly covert hazards than untrained novice drivers. This result was true in both near transfer scenarios and far transfers scenarios, although the effect size was smaller in the far transfer scenarios. The improvement in anticipatory gaze directions was about the same for RAPT-1, RAPT-2, and RAPT-3 (21–23).

SIMULATOR-BASED HAZARD PERCEPTION TRAINING PROGRAMS

Unlike PC-based hazard perception training programs in which the driving environment as displayed does not change as a function of the participant's inputs, simulator-based programs offer participants the opportunity to experience in real time the consequences of not having detected a potential hazard in time to avoid the risk of physical injury. This didactical advantage of a simulator, (also called error learning) facilitates learning because, among other things, it stimulates active processing.

Error learning was used in a study of driving behavior in a simulator reported by Ivancic and Hesketh (24). Specifically, they developed a training program that contained a cohort of drivers that drove scenarios in which errors were elicited and another cohort that drove scenarios in which errors were not elicited. For the error learning group, no additional feedback was provided about why the crash could have happened and how the crash could be prevented. The researchers then evaluated the participants in the simulator on several near transfer scenarios and one far transfer scenario. The participants in the error learning group had significantly fewer crashes and drove slower in the near transfer scenarios. Participants in the error learning group did not have significantly fewer crashes in the one far transfer scenario, but drove significantly slower in this scenario. Most of the hazardous scenarios in the training were immediate hazards, and the participants could not be considered as pure young novice drivers anymore (mean age 23).

Wang et al. developed a simulator-based training program for novice drivers in which eight critical scenarios were embedded: seven overt hazards and one covert hazard (25). After the training drive, each participant watched the video from the driver's point of view of his own performance in the critical scenarios and then viewed a video in which an experienced driver averted the hazards. To assess training retention, an evaluation drive was arranged 6 weeks after training in the same simulator but with a different scenario. Scores in both the near and far transfer situations were significantly better for the trained group than for untrained drivers in six out of the eight critical scenarios. The effect was greater in the near transfer scenarios than in the far transfer scenarios. Wang et al. did not apply error learning, and little attention was paid to covert hazards (25).

Ideally, training is needed that focuses on latent hazards, especially covert hazards, and that combines error learning with verbal and visual instruction. No one training program developed to date has all these characteristics. Thus, one was developed to incorporate these characteristics. Scenarios for the training were based on those developed for RAPT (21, 23, 26). For this reason, the training was entitled simulator-based risk awareness and perception training (SimRAPT). The hypotheses tested were the following:

1. Trained novice drivers will more often search for latent hazards in near transfer situations than untrained novice drivers, especially when the situation involves a covert hazard, and
2. To a lesser extent, trained novice drivers will more often search for latent hazards in far transfer situations than untrained novice drivers, especially when the situation involves a covert hazard.

METHOD

Participants

Novice drivers with at least 1 year of driving experience were recruited from the student population of the University of Massachusetts, Amherst, and were randomly assigned to one of two cohorts:

- SimRAPT group: [$n = 18$; 53% male; mean age = 19.4, standard deviation (SD) = .7; mean number of months licensed = 28.4, SD = 13.0] and
- Control group that was given placebo pen-and-paper training on traffic signs: ($n = 18$; 47.1% male; mean age = 19.1, SD = .5; mean number of months licensed = 28.3, SD = 6.5).

All participants were naïve to the hypotheses. Each participant was offered a stipend of \$50 upon completion of a 2-h session.

Materials and Apparatus

In this study, a training simulator and a test simulator were used. The SimRAPT training was delivered using the lab's driver training simulator (DTS) (see Figure 1a). The DTS cab consists of an automobile seat in front of a fixture holding a steering and pedal assembly. The cab sits in front of three 5-ft diagonal projection screens subtending approximately 135 degrees of visual angle with the image refreshed at 30 Hz. The simulator runs on a Systems Technology Inc. simulation platform. The posttraining evaluation (see the section about the test) for both groups was performed on the lab's advanced driving simulator (ADS) (see Figure 1b).

The ADS consists of a full cab Saturn sedan positioned in front of three large projection screens each with an 11-ft diagonal, subtending approximately 135 degrees of visual angle. The roadway is virtually projected on the screens and is refreshed at a rate of 30 Hz. The ADS operates on a simulator platform from Realtime Technologies Inc. During the posttraining evaluation drives on the ADS, participants wore a Mobile Eye eye-tracking system from Applied Science Laboratories. The Mobile Eye consists of a pair of lightweight goggles complete with a scene camera and eye camera and allows for full mobility and freedom of movement for the participant. The output from the system includes video with a set of crosshairs (eye position) superimposed upon the scene recorded from a head-mounted scene camera. In a prestudy questionnaire, participants provided demographic data and driving history information. They self-rated their driving skills and ability and they rated their driving style. In the poststudy questionnaire, participants rated their driving skills again and they made prognoses of their future driving style.

Training Intervention

SimRAPT began with a 5-min practice drive, after which the training started. The training contained 10 scenarios: seven hazard anticipation scenarios with common latent hazards and three scenarios with no high-priority hazards. It took about 1 min to drive through each scenario. There were three versions of each hazard anticipation scenario, and participants drove each in succession:

1. Hazard detection drive. In this drive, the possible hazards did not materialize.
2. Error drive. This drive was the same as the hazard detection drive, except that the hazard materialized aggressively.
3. Improvement drive. This drive was the same as the error drive, but the hidden hazard manifested less aggressively.

Directly after a hazard detection drive, the participant was asked, "Did you have a moment where you thought, 'Whew, I hope that something will not happen?' If so, what is it you worried about?" No feedback was provided regardless of the response. Thereafter, participants drove the error drive for that scenario. Whether the error drive ended in a crash or not, an instruction video was provided afterward. In this video, projected on the center screen of the simulator, a plan view of the scenario was presented in which the movements

of road users and fields of view were animated. A voiceover explained what had happened, why it had happened, and in what similar scenarios it could have happened. The next phase in the instruction video was a clip that explained to participants the appropriate gaze directions in the present scenario. After this, the plan view reappeared on the screen and participants had to point with a laser pointer to where the hazard would be located before it became visible, the direction in which the participant should have looked to see the hazard as early as possible, and at which point the participant should have slowed down to enlarge his or her safety margin. After the instruction video, participants drove the improvement drive. Hereafter, the cycle started anew with the next hazard anticipation scenario. To discourage hypervigilance during the training, three scenarios were included in the training that did not contain any high-priority hazard. A summary of scenarios trained in SimRAPT can be found in Table 1. (Because all the near transfer test scenarios are in concept the same as the training scenarios. Table 1 lists the training scenarios as near transfer scenarios to save space.)

Evaluation Drive

After the training session, participants completed an evaluation drive on the ADS to evaluate training transfer. The evaluation drive consisted of three drives of approximately 10 min each while participants wore the Mobile Eye tracking system. Nineteen potential hazardous scenarios were embedded in the three drives, of which seven were near transfer and 12 were far transfer. None of the latent hazards in the evaluation drives actually materialized. The participant's fixations while navigating the scenario were used as an indication of whether the participant successfully anticipated the latent hazard. An overview of the critical near and far scenarios is presented in Table 1.

Procedure

Participants were first provided informed consent forms to sign and were given basic instructions about what they were going to do in the study. Afterward, participants filled out the questionnaires. Participants then were taken to the appropriate locations to complete their training. The length of training ranged from 40 min to approximately 1 h. After training, participants received a short break and then drove the evaluation simulation on the ADS. First they did a familiarization drive and then the three test drives as described. The order in which the three drives were presented was counterbalanced across participants to mitigate learning effects. Finally, participants filled out the posttest questionnaire and were paid for their participation.

Design and Data Analysis

The study employed a between subjects design, comparing the scores on the evaluation drive of the SimRAPT group with a control group. The dependent variable was the number of correctly anticipated latent hazards of the test drives. A latent hazard was assessed as correctly anticipated when two experimenters who were blind to the participant's condition independently scored the gaze directions as such that they allowed for timely detection of the hazard. (When more than one glance was required, the scenario was scored as correctly anticipated only if all necessary glances were made.) Timely detection meant enough time for evasive actions to avert a crash. For each latent hazard, a critical launch zone was determined on the roadway upstream of the potential hazard. The participant had to direct his or her eyes to the target area (the area in which the hazard could materialize) within the launch zone for the latent hazard to be scored as anticipated. A brief description of these critical target areas for each latent hazard and the scanning criteria can be found in the sixth column of Table 1. As an example of how a target area was defined, consider the scenario in which a bus was parked on the near side of a crosswalk (Scenario E in Table 1). Glances that were positioned anywhere between the front left edge of the bus and the crosswalk were

counted as anticipatory. More generally, the definitions of the target area and launch zone were determined by the authors and not by the two experimenters who evaluated the eye movements of the participants. In cases in which the experimenters differed, the experimenters came to consensus after having watched the video of the particular scenario again together. In 2% of all the recordings of the scenarios it was not logically possible to decide whether participants had recognized the latent hazard (e.g., because the participant missed the situation because of a wrong turn during the drive). In the few cases in which a score could not be assigned, the average score across all scenarios was used. All of the participants could be given a score in at least 16 of the 19 scenarios.

In cases in which the assumptions for parametric testing were met, a parametric test was used to test significant differences in scores between the two groups ($\alpha = .05$). In cases in which the assumptions for parametric testing were not met, a nonparametric equivalent test was used ($\alpha = .05$). Besides significance of the results, the effect size (Pearson's correlation coefficient r) was considered with $r = .10$ as small (explaining 1% of the total variance), $r = .30$ as medium (explaining 9% of the total variance), and $r = .50$ as large (explaining 25% of the total variance) (27). To test the internal consistency of the latent hazards in the test drives, Cronbach's α reliability test was applied with $\alpha > .70$ considered as a sufficiently internal consistent scale for hazard anticipation.

RESULTS

Results in Near and Far Transfer Scenarios

The scores of the critical scenarios in the three test drives were internally consistent ($\alpha = .83$). This consistency implies that the 19 potential hazardous scenarios of the transfer test measure one concept. Columns 2 and 3 of Table 2 display the percentage of gazes initiated in the launch zone that were in the direction of the latent hazard in each training group. The distribution of some of the scores were significantly nonnormal. Therefore the Mann-Whitney test was applied instead of the t -test for independent samples.

Compared with the control group, the SimRAPT group anticipated latent hazards significantly more often in the near transfer scenarios, the far transfer scenarios, and in all the scenarios together. The effect size was large in the near transfer scenarios and was medium in the far transfer scenarios and in all the scenarios together. The mean of the standard deviations in the near transfer scenarios was .23 for the SimRAPT group and .43 for the control group. This difference was significant [$t(34) = -2.93$, $p(2\text{-tailed}) < .01$] with a medium effect size ($r = .45$). A reduction in variance and higher scores in the SimRAPT group than in the control group could indicate that both poor performers and relatively good performers before the training (if they would have been tested before the training) rise to more or less the same level because of the training intervention for the near transfer scenarios. The difference between the SimRAPT group and the control group was less for the far transfer scenarios (17.46%) than for the near transfer scenarios (26.7%). In case of far transfer, the mean of the standard deviations was not significantly less for the SimRAPT group than for the control group [$t(34) = -.81$, $p(2\text{-tailed}) = .43$]. These two results indicate that increase in anticipatory gaze directions was less in far transfer situations than in near transfer situations and that poor initial performers will probably profit less from the training intervention with regard to far transfer scenarios than the relatively initial good performers. For the SimRAPT group there was a significant relationship between the scores in the near transfer scenarios and the scores in the far transfer scenarios [$r = .65$, $p(2\text{-tailed}) < .01$]. This result implies that participants with the better hazard anticipation skills after the training in near transfer scenarios also have the better hazard anticipation skills in far transfer scenarios.

Six of the seven near transfer situations contained covert hazards. The difference between the SimRAPT group and the control group for covert hazards only in the near transfer scenarios was highly significant with a large effect size [$U = 48.0, p(2\text{-tailed}) < .001, r = -.61$]. Eight of the 12 far transfer situations contained covert hazards or precursor covert hazards. The difference between the SimRAPT group and the control group in far transfer covert hazard scenarios was significant with a medium effect size [$U = 80.0, p(2\text{-tailed}) < .01, r = -.44$].

The sample was too small to disaggregate by gender. An interesting feature of the data that is not about the effect of the training was the correlation between age and the overall scores on the test drives of the control group. The ages in this group range from 18 and 4 months to 20 and 0 months. The relationship between age and overall scores was marginally significant [$r = .43, p(2\text{-tailed}) = .08$]. This result indicates that hazard anticipation skills may improve with age.

Results per Potential Hazardous Scenario in Test Drives

Table 3 contains the percentage of anticipatory gazes initiated in the launch zone that were in the direction of the latent hazard in the 19 different potentially hazardous scenarios (Table 1). The resulting odds ratios (ORs) are also reported for each scenario. For instance, an OR of 6.25 indicates that it was 6.25 times more likely that a participant who had completed SimRAPT had anticipatory gaze directions in this scenario than a participant who had completed the placebo training. To test if the scores differed significantly between the SimRAPT group and the control group, the χ^2 test was used. For five scenarios the assumptions for the χ^2 test were not met.

In three of the five near transfer scenarios in which tests could be conducted, the difference between the scores of the SimRAPT group and the control group was significant. In the remaining two near transfer scenarios that could be tested, the difference was small but in the expected direction. In one near transfer scenario that could not be tested (Scenario L), the difference between the two groups was also substantial (OR = 7.08). In a second scenario that could not be tested (Scenario N), the difference was small but in the opposite direction. This last scenario [a blind curve with an intersection just after the curve and a warning sign ("stop sign ahead") before the curve] was the only signed hazard scenario in the training. Hazard anticipation in this scenario includes not only visual search (gazes to the right side of the road in search of the expected stop sign), but also speed adaptation (driving into a blind curve). In this study, the dependent variable is gaze direction and not speed adaptation. Further analysis that includes speed adaptation is required.

In two of the 12 far transfer scenarios the difference between the scores of the SimRAPT group and the control group was significant. In one far transfer scenario (Scenario E), the difference between the two groups was also substantial (OR = 10.82), but the assumption of the χ^2 test was not met. In seven far transfer scenarios, the difference was in the expected direction but small, and in two far transfer scenarios, the difference was very small but in the opposite direction. These last two far transfer scenarios were Scenario H (right turn at T-intersection) and Scenario M (right merging fork). In Scenario H, the scores of both groups were relatively high, and in Scenario M, both groups scored relatively low. It could be that Scenario H is too easy to discriminate between the groups. Why Scenario M is in reverse direction is not clear. In the very similar Far Transfer Scenario K (merging fork from the left), the scores of the SimRAPT group were significantly better than the scores of the control group.

Results of Questionnaires

Before SimRAPT on the DTS or the placebo training and after the test drives on the ADS, participants were asked to rate their driving skills and abilities compared with drivers of the same age group on a five-point Likert scale (1 = much worse and 5 = much better). After the training and testing, participants in the SimRAPT group still overestimated their skills (mean = 3.88, SD = .72), but the overestimation was slightly less than before the training (mean = 4.00, SD = .66). For the control group the opposite was the case: before the pen-and-paper training the mean was 3.88 (SD = .93) and after the pen-and-paper training and testing the mean was 4.00 (SD = .69). The interaction effect was not significant [SimRAPT: $T = 9.5$, $p(2\text{-tailed}) = .59$, $r = -.14$; control: $T = 7.0$, $p(2\text{-tailed}) = .69$, $r = -.14$]. Although the overestimation of skills and abilities was not lowered significantly by SimRAPT, the intention to drive more conservatively in the future was [$U = 88.5$, $p(2\text{-tailed}) < .05$, $r = -.38$].

DISCUSSION OF RESULTS

Failing to look in the right direction or at the right objects at the right time and correctly process the significance of the information in the driving environment leads to crashes (8, 9). Visual search for potential hazards is more poorly developed in young novice drivers than in older, more experienced drivers (10, 11, 13). A simulator-based training program for young novice drivers (SimRAPT) of approximately 1 h was developed to improve visual search for latent hazards. The scenarios used in SimRAPT came from the scenarios developed for RAPT (21–23). SimRAPT was based on the principles of active learning from errors (24), inducement of arousal to promote memory consolidation (28), and instruction aimed at the promotion of far transfer (29). SimRAPT had clear influences on the visual search patterns of young novice drivers in quasi (near and far) transfer scenarios. The term quasi is used because the effect of the training was not tested in real-world traffic but on an advanced simulator that differed considerably with regard to the fidelity of the representation of reality from the low-cost training simulator.

With respect to the first hypothesis, the group that received SimRAPT had 46.92% (26.70 percentage points) more proper gaze directions in the near transfer scenarios than the control group. This difference was significant, and the effect size was large. With respect to the second hypothesis, the group that received SimRAPT had 32.64% (17.46 percentage points) more gazes in the correct direction than the control group in far transfer scenarios. This difference was significant with a medium effect size. As expected, because of the emphasis on covert hazards in the training, performance after training was better in the covert hazard situations only than performance in all the latent hazard situations taken together. Similar effects with regard to near transfer and far transfer were found in the simulator-based training programs that were developed by Ivancic and Hesketh and by Wang et al. (24, 25), but the former training program was mostly about immediate hazards and the latter training program was mostly on overt hazards and did not apply error training.

The authors would like to address five additional questions. First, short training programs for novice drivers to enhance their skills (i.e., skid training) tend to have an adverse effect on their crash rate because novice drivers tend to overestimate their abilities after training (30). Did SimRAPT inadvertently stimulate drivers' confidence in their own abilities that could result in more risk taking? Compared with drivers of the same age group, participants in the SimRAPT group rated their abilities as slightly lower after the training than before the training, whereas the control group rated their abilities slightly higher after their placebo training. Although these changes in self-assessment were not significant, participants in the SimRAPT group intended to drive significantly more conservatively in the future than the control group. Because in error training, participants are confronted with their own

limitations, an increase in confidence is not very likely. This result was also found in other studies (20, 24).

Second, would SimRAPT be as effective with novice drivers at 16 years of age as it is with participants in this study, who have held their licenses for approximately 2 years? There are indications from the reduction in variability observed in the trained drivers that, especially for the near transfer scenarios, SimRAPT seems to bring drivers who do relatively poorly and drivers who do relatively well to the same level the hazard anticipation skills. This result implies that SimRAPT could provide effective training earlier in one's driving career than 2 years after full licensing. This is important because the highest crash rate is directly after licensing (2–5).

Third, do simulator-based training programs have value above PC-based training programs? Effective PC-based training programs for enhancement of visual search have been developed (16, 18, 21–23). In this case, a comparison between the PC-based versions of RAPT and SimRAPT is simple enough because the same type of scenarios were used. The difference in percentage of hazards anticipated between the trained group and the untrained group on both near transfer scenarios and far transfer scenarios was about the same for the various versions of RAPT as for SimRAPT. However, the participants in the RAPT studies were younger. Because the effect of training in visual search will probably decrease with the accumulation of experience, no firm conclusions can be made about the different effects of RAPT and SimRAPT.

Fourth, can one expect the effects of training to last for an extended time? A real limitation of the present study is that participants were tested directly after the training. Thus, the effects on long-term retention are not known. Because the experience of crashes or near crashes during the simulator training is presumed to create arousal and moderate levels of arousal enhance memory (28), it could be that retention of skills is better for SimRAPT than for RAPT. Whether SimRAPT has a more lasting effect than RAPT remains to be tested.

Fifth, would the learning that occurs with SimRAPT and generalizes to the advanced simulator actually be found in the real world, and would there be a corresponding reduction in crash rates? What the effect of SimRAPT is for driving behavior in the real world is not known. The effect has been studied for RAPT-3, and significant positive effects of RAPT-3 on driving in the real world could be demonstrated (23). No studies of the effect of simulator-based error training on visual search for latent hazards on crash rates have been conducted. Clearly, more research is required.

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FIGURE 1.
Human performance lab simulators: (a) DTS and (b) ADS.

TABLE 1
Critical Scenarios Embedded in Test Drives (Near Transfer Drives Similar in Concept to Training Drives)

No.	Type	Transfer	Description	Hazard	Target Area and Scanning Criterion
A	O	Far	Straight through at T-intersection; line of cars waiting in lane left of driver	Driver in line of cars may pull out to right into driver's lane.	At least three glances to line of cars when passing
B	C	Near (training)	Straight through at intersection; bushes on right obscure view on left sidewalk of right-hand road.	Hidden pedestrian on sidewalk of right-hand road may cross road of driver.	Glance to far right at sidewalk and second glance in same direction after starting moving again
C	C	Near (training)	Turn left at intersection. Opposing truck waits to turn left. Truck obscures view on lane to right of truck.	Hidden oncoming traffic (in lane to right of truck)	Glance at right side of truck just before turning and second glance in this direction when turning
D	S, C	Far	Straight through, hidden driveway to left: Sign warns of hidden driveway.	Car may pull out from driveway.	Glance to right after warning sign
E	C	Far	Overtake bus at bus stop. Crosswalk is before bus.	Hidden pedestrian may cross road just in front of bus.	Glance toward left edge of bus while passing
F	C	Near (training)	Cross one-way street. Objects obscure view into one-way street.	Traffic from right	Glance to right into one-way street before crossing street
G	S	Far	Traffic light turns green when driver nears.	Traffic from left or right that runs red light (just turned red)	Glances to left and right before crossing intersection
H	C	Far	Turn right at T-intersection. Vegetation obscures view to left.	Possible traffic from left	Glance to far left after glance to right
I	S, C	Far	Straight through at intersection: driver has priority at intersection.	Possible traffic from left or right not obeying rules of road	Glances left and right before crossing intersection
J	C	Far	Footpath to school crosses road. Bushes obscure footpath on left side.	Possible pedestrians (children) who cross road	Glance to left before crossing footpath
K	S, C	Far	Straight through: fork from left is obscured by trees. Sign warns of fork ahead.	Possible traffic merging from left	Glance to left before passing fork
L	C	Near (training)	Overtake parked truck on right. Crosswalk is just in front of truck.	Pedestrian crosses road just in front of truck.	Glance beyond left edge of truck when passing truck
M	S, C	Far	Straight through: fork from right is obscured by trees. Sign warns of fork ahead.	Possible merging traffic from right that is obscured by bushes	Glance to right before passing fork
N	S	Near (training)	Straight through, four-way intersection after blind curve: Stop sign is partly hidden by trees. Before curve is warning sign for stop sign ahead.	Speed that is too high to stop at intersection in time and stop sign that is not noticed	Glance at warning sign "stop sign ahead" and at least two glances to right in search for intersection and stop sign
O	O	Far	Straight through along line of parked cars to right in parking lane	Car may pull out into path of driver.	At least three glances at line of parked cars to right
P	O, C	Far	Straight through: pedestrian walks on driveway on left toward road. Pedestrian disappears behind bushes.	Temporarily hidden pedestrian may cross road.	Glance to left (searching for pedestrian) before passing driveway
Q	C	Near (training)	Straight through at T-junction: line of cars to left of driver obscures view of crosswalk.	Possible pedestrian in crosswalk	Glance to left, beyond right edge of car in front while passing

No.	Type	Transfer	Description	Hazard	Target Area and Scanning Criterion
R	C	Near (training)	Straight on at intersection: truck in adjacent lane to left obscures view of opposing traffic that turns left.	Opposing traffic that turns left	Glance to far left, beyond right edge of truck when passing, looking for turning traffic in opposing lane
S	C	Far	Turn left into driveway. Driveway is just before blind curve (because of trees) to right.	Possible oncoming traffic	Glances at opposing lane as far as possible in distance before and when turning

Note: C = coven hazard; O = overt hazard; S = signed hazard.

TABLE 2

Percentage of Correct Anticipatory Gaze Directions in Latent Hazard Scenarios

	SimRAPT (%)	Control (%)	Mann-Whitney <i>U</i>	Significance <i>P</i> (exact, 2-tailed)	Effect Size <i>r</i>
Near transfer	83.61	56.91	63	<.01	-.53
Far transfer	70.95	53.49	88	<.05	-.39
All	75.60	54.73	74	<.01	-.47

TABLE 3
Percentage of Anticipatory Gaze Directions per Potential Hazardous Scenario in Transfer Test Drives

Scenario	Transfer	SimRAPT (%)	Control (%)	χ^2	P	OR
A	Far	61.1	50.0	.45	.74	1.57
B	Near	88.8	41.2	8.83	.005**	11.43
C	Near	83.3	44.4	5.90	.035*	6.25
D	Far	61.1	16.7	7.48	.015*	7.86
E	Far	94.4	61.1	—	—	10.82
F	Near	77.8	50.0	3.01	.16	3.50
G	Far	77.8	61.1	1.18	.47	2.23
H	Far	77.8	83.3	—	—	.70
I	Far	77.8	66.7	.55	.71	1.75
J	Far	77.8	50.0	3.01	.16	3.50
K	Far	83.3	44.4	5.90	.035*	6.25
L	Near	94.4	70.6	—	—	7.08
M	Far	47.1	50.0	.03	1.00	.89
N	Near	66.7	77.8	.55	.71	.57
O	Far	66.7	44.4	1.80	.315	2.50
P	Far	76.5	72.2	—	—	1.25
Q	Near	88.9	72.2	—	—	3.08
R	Near	88.2	41.2	8.24	.010*	10.71
S	Far	55.6	41.2	.72	.505	1.79

Note: — = not applicable.

* $p < .05$,

** $p < .01$.