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The effects of repetitive presentation of specific hazards on eye movements in hazard perception training, of experienced and young-inexperienced drivers

Naomi Kahana-Levy[a,*], Sara Shavitzky-Golkin[a], Avinoam Borowsky[b], Eli Vakil[a]

[a] Psychology Department, Bar-Ilan University, Ramat-Gan, Israel
[b] Ben-Gurion University of the Negev, Department of Industrial Engineering and Management, Beer-Sheva, Israel

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ABSTRACT

Recent evidence shows that compared to experienced drivers, young-inexperienced drivers are more likely to be involved in a crash mainly due to their poor hazard perception (HP) abilities. This skill develops with experience and may be developed through training. We assumed that as any other skill, HP developed through implicit learning. Nevertheless, current training methods, rely on deliberate learning where young-inexperienced drivers are instructed what hazards that they should seek and where they might be located. In this exploratory study, we investigated the effectiveness of a novel training procedure, in which learners were repeatedly exposed to target video clips of driving scenarios embedded within filler scenarios. Each of the target videos included scenarios of either a visible hazard, a hidden materialized hazard or hidden unmaterialized hazard. Twenty-three young-inexperienced drivers and 35 experienced drivers participated in training session followed by a learning transference testing session and 24 additional young-inexperienced drivers participated only in the transference testing session with no training, during which participants were shown novel hazards video clips. Participants responded by pressing a button when they identified a hazard. Eye movement was also tracked using fixations patterns as a proxy to evaluate HP performance. During training, young-inexperienced drivers gradually increased their focus on visible materialized hazards but exhibited no learning curve with respect to hidden hazards. During the learning transference session, both trained groups focused on hazards earlier compared to untrained drivers. These results imply that repetitive training may facilitate HP acquisition among young-inexperienced drivers. Patterns concerning experienced drivers are also discussed.

1. Introduction

The crash liability of young and inexperienced drivers is greater than that of more experienced drivers. For example, while drivers who are 15 to 20 years of age comprise 6.4% of all drivers, they account for 10.0% of all motor vehicle traffic deaths and 14.0% of all police-reported crashes resulting in injuries (National Highway Traffic Safety Administration, 2012). A fundamental skill that marks the transition from novice to experienced driving is efficient visual search strategy, which develops with accumulated driving experience (Underwood, 2007). Poor visual attention skills are indeed responsible for a high rate of traffic crashes among young-inexperienced drivers (Crundall et al., 2004), compared to experienced drivers who adapt their visual search strategies according to varying demands imposed by different road and traffic conditions (Underwood, 2007; Underwood et al., 2003).

1.1. Hazard HP

Efficient visual search strategy translates into drivers' ability to anticipate hazardous situations, also known as *Hazard HP* (HP; e.g. Horswill and McKenna, 2004). This is among the most safety-critical driving skills, and it relies on drivers attentional and perceptual abilities (Horswill and McKenna, 2004; McKenna and Horswill, 1999; Wetton et al., 2013). HP has received considerable attention over the years, as it is among the few driving skills found to correlate with traffic crashes (Boufous et al., 2011; Congdon, 1999; Horswill et al., 2010, 2015; McKenna and Horswill, 1999; Wells et al., 2008). Drivers who respond early and more efficiently to hazards, that is, they have great HP, are found to be safer drivers than drivers who respond later to the same hazards. HP is often measured through short video-clips of real-world driving situations, filmed from a driver's perspective embedding either genuine or staged hazardous situations. This method allows exposing

* Corresponding author.
E-mail address: naomile11@gmail.com (N. Kahana-Levy).

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drivers to a relatively large number of hazardous situations in a short period (Borowsky et al., 2010). HP scenarios typically develop into imminent situations that require immediate response. Participants are asked to press a response button as quickly as possible once they identify a hazard (e.g. Chapman and Underwood, 1998; McKenna and Crick, 1997; Sagberg and Bjørnskau, 2006; Vlakveld, 2014). Horswill et al. (2015) found that drivers who failed the HP test had 25% more active crashes in the preceding year as well as in the year following the test. Such findings contributed to the integration of the HP test within the UK licensing procedure since 2002 (Crundall, 2016).

1.2. Hazard types

Researches shows that the age factor does not affect the perception of all kinds of hazards. Experienced and young-inexperienced drivers exhibited similar identification accuracy when visual cues (i.e., precursors, Crundall et al., 2012) to the upcoming hazards were directly related to the hazards and visible prior to their materialization (e.g., a pedestrian walking on the pavement and then stepping onto the road), allowing for their prompt detection (Borowsky et al., 2010). Studies have also shown that driving experience is key to identifying visual cues when hazard instigators (e.g., vehicle, pedestrian) are obscured by either natural or built environment or by other road users that are not directly related to the hazard (e.g., a pedestrian obscured by a parked car). In these cases, where the precursors in indirectly related to the actual hazard, experienced drivers anticipate the hazard much sooner compared young-inexperienced drivers (e.g., Crundall, 2016; Crundall et al., 2012; Pradhan et al., 2009; Underwood et al., 2002; Vlakveld et al., 2011).

Researchers have suggested various classifications for hazards based on required anticipation demands. For example, Crundall et al. (2012) suggested the term Behavioral Prediction (BP) hazards when hazards may be identified directly, and Prediction hazards (EP) when hazards are hidden by a precursor in the environment. In the current study, we adopt a HP taxonomy that is also based on prediction demands (high/low) imposed on drivers (Borowsky and Oron-Gilad, 2013; Borowsky et al., 2010). We relate two factors in this taxonomy matrix: whether the hazard has materialized or is yet unmaterialized (i.e., only a potential hazard) and whether it is visible or hidden. A *materialized hazard* is defined as a hazard instigator (e.g., another road user) that is in a colliding course with the driver (e.g., bicyclist on the sidewalk who suddenly burst into the driver's path). This type of hazard calls for the driver's immediate response in order to prevent a crash. *An unmaterialized hazard* is defined as a hazard instigator that may or may not materialize, such as a bicyclist on the sidewalk who remains on the sidewalk throughout the scenario, and who should therefore be monitored. The second factor is whether the hazard instigator is visible or obscured at the onset of the hazardous scenario. *A hidden hazard* is an instigator that is concealed by other road users or environmental factors, such as a pedestrian who is obscured by parked cars. *A visible hazard* is an instigator that is visible to the driver, such as a clearly visible pedestrian who is about to cross the road. Combined, these factors result in four types of hazards (i.e., hidden materialized, hidden unmaterialized, visible unmaterialized, and visible materialized). Anticipation demands are greater for hidden or unmaterialized hazard instigators (Crundall, 2016; Crundall et al., 2012). Thus, Borowsky et al. (2010) reported that experienced drivers detected more unmaterialized hazards than young-inexperienced drivers. Similarly, in a follow-up study, Borowsky and Oron-Gilad (2013) reported that young-inexperienced drivers were particularly challenged when attempting to identify hazards that were obscured by the environment.

1.3. HP training

Not only does HP correlate with traffic crashes, but evidence has been produced that it improves with practice. Thus, researchers invest great effort into developing HP training methodologies targeted at young-inexperienced drivers, who are known to possess poor HP skills (Horswill, 2016). Several methodologies were found effective in improving HP skills among young-inexperienced drivers as measured later in a road-driving test (Pradhan et al., 2009). A growing body of evidence indicates that active engagement in the task during training is crucial for learning transference (Borowsky and Oron-Gilad, 2013; Horswill et al., 2013; Isler et al., 2009; Kahana-Levy et al., 2018; McKenna et al., 2006; Wetton et al., 2013). The effectiveness of a self-instructive training methodology in improving drivers' HP performance has also been shown recently (Horswill et al., 2017; Young et al., 2017). Notably, Young et al. (2017) found no benefit to HP during a commentary training (in which participants listen to and then produce continuous verbal commentary regarding different occurrences while driving) compared to engaged hazard exposure. They concluded that the key factor for improving hazard HP is an engaged observation of the road scene, "whether […] through looking for hazards in silence or listening to a commentary" (p. 9). These conclusions are in line with other research suggesting that training interventions involving only directive features, such as instructing drivers to look or what to do in case of a hazard without including any individual active and practical component have found to be less effective (McKenna and Crick, 1997; Meir et al., 2014).

1.4. Repetitive learning procedure

Non-instructional, active training is a reminiscent of core principles of the implicit nature of skill acquisition, relying on non-declarative learning and memory system (Schacter, 1987; Squire et al., 1993). Skill acquisition was defined by Milner et al. (1998) as: "changes in performance as the result of experience … without providing conscious access to any prior episode" (p. 450). Consequently, skill acquisition has also been termed *implicit learning procedure* (Schacter, 1987; Vakil, 2005; Vakil and Agmon-Ashkenazi, 1997), and it is often studied via tasks where participants are asked to repeat a procedure without being explicitly instructed regarding the repetitive procedure (Vakil and Agmon-Ashkenazi, 1997; Willingham et al., 1989). It has been argued that the automation of a cognitive or motor skill is achieved unconsciously through the repeated practice and active training (Esser and Haider, 2017; Haider et al., 2013). Whether unconscious learning can, in fact, occur has been a long-standing debate that is beyond the scope of the current study (see, for example, Rünger and Frensch, 2010, for a discussion about the adequacy of the different measures for conscious and unconscious knowledge). Nevertheless, researchers show that some degree of explicit instruction is efficient in enhancing skills that involve anticipation demands (Magill, 1998), for example, directing performers' attention to the information-rich regions of the display (Jackson & Farrow, 2005; Magill, 1998). Therefore, for the purpose of the current study, we refer to learning that occurs without explicit intention as a *'repetitive learning without direct instruction'*. A prominent paradigm for studying such learning processes is the Serial Reaction Time Task (SRTT; Nissen and Bullemer, 1987) where participants are asked to press keys in correspondence to a repeated sequence of asterisks appearing on a computer screen. The learning of the sequence, which is evident by the reduction of reaction time achieved by training, is demonstrated even among participants who report no awareness of the repeated sequence (Salas and Cannon-Bowers, 2001; Willingham et al., 1989). The standard approach to measuring the acquisition of a skill involves miscellaneous transfer tests evaluating the extent to which true learning has taken place (Schmidt and Bjork, 1992), that is, whether participant are able to effectively apply the learned skill to contexts that differ from those experienced during the training (Baldwin and Ford, 1988; Schmidt and Bjork, 1992). Vakil et al., 1998 demonstrated that when required to transfer the learned skill to a more difficult task, participants who went through non-instructional active repetitive training benefited more from the training than those who went through passive, instructional training. With regard to visual attention, researchers suggest that being repeatedly exposed to the same scene enhances implicit visual memory of that scene which, in turn, facilitates the efficiency of visual scanning for targets (Brockmole and Henderson, 2006; Kunar et al., 2008; Li et al., 2016; Neider and Zelinsky, 2008; Wolfe et al., 2011). For example, Brockmole and Henderson, 2006 asked participants to search and recognize visual target in a repeatedly presented scene. By the sixth repetition, participants located the target twice as fast compared to the first repetition (2000 ms vs. 4000 ms at the initial stage). Brockmole and Henderson (2006), however, reported that four repetitions were required to reach maximum benefit, and by utilizing an eye tracker, Li et al. (2016) demonstrated that this improvement might occur even faster. In their experiment, participants avoided scanning irrelevant parts of the environment within only three repetitions, reflected by fewer fixations to irrelevant regions within the scene. Related to the latter study, and as discussed below, literature on HP suggests that examining drivers' scanning patterns as they observe driving scenes provides a deep insight into the effect of HP training (e.g., Borowsky et al., 2010; Pollatsek et al., 2006; Pradhan et al., 2009; Vlakveld et al., 2011; Young et al., 2014, 2017).

1.5. Eye movement monitoring during HP tasks

A vast amount of literature is available on drivers' road scanning patterns under different traffic conditions. Underwood (2007), for example, reported that compared to young-inexperienced drivers, experienced drivers, have a broader spread of search along the horizontal axis that is parallel to the road, from where potential hazards are most likely to appear. Young-inexperienced drivers, in contrast, were found to have a greater spread of search along the vertical axis, from where hazards are less likely to appear. Likewise, several studies have found similar patterns that support Underwood's (2007) findings (Chapman et al., 2002; Meir et al., 2014). Furthermore, experienced drivers are able to fixate on some types of hazards sooner than less experienced drivers (e.g., Crundall et al., 2012). Accordingly, a growing body of evidence demonstrates that training improves the scanning behavior of young inexperienced drivers, as reflected in a greater horizontal spread of search, reduced average fixation duration toward hazards (Chapman et al., 2002; Young et al., 2014), and increases likelihood of scanning areas that contain critical information about potential hazardous situations (Pollatsek et al., 2006; Pradhan et al., 2009). The growing body of evidence favoring self-explanatory, active engagement during HP training (Meir et al., 2014; Young et al., 2017) elicits the question of whether training that is based on repetitive learning procedures can be utilized to facilitate scanning patterns among young-inexperienced drivers. Of specific interest is road hazard identification potential, assessed through repeated exposure. Trainees would be exposed to a single hazardous scenario repetitively and the effect of repetition on drivers' HP scanning performance would be measured. The learning curve is expected to be recorded through changes in eye movement measures between repetitions. Additionally, the transferability of HP skill acquisition would be measured in a transfer assessment session where participants are asked to identify a new hazardous situation that they had not encountered in their training. The second goal of the current study was to assess the efficiency of the new repetitive HP training methodology among experienced and inexperienced drivers with respect to different hazardous situations involving varied levels of anticipation requirements.

1.6. Research hypotheses

Leaning on the assumption that HP differences between experienced and young-inexperienced drivers can be measured in terms of different scanning performance (e.g. Underwood et al., 2003), we hypothesized the following:

H1. Prior to training, young-inexperienced drivers will demonstrate less efficient scanning performance compared to experienced drivers while watching hazardous situations. Specifically, untrained young-inexperienced drivers will fixate less often and more slowly on areas from which potential hazards might appear, and they will demonstrate a wider vertical spread of search and more uniform horizontal spread of search while watching hazardous situations (cf. Borowsky and Oron-Gilad, 2013; Borowsky et al., 2010; Underwood, 2007; Vlakveld et al., 2011).

H2. An interaction effect will be found in which the pre-training differences in scanning patterns between young-inexperienced drivers and experienced drivers will be more prominent with respect to unmaterialized and hidden hazards and less so for visible materialized hazards.

H3. Young-inexperienced drivers will benefit from the novel training approach, demonstrating a learning curve over repeated views.

H4. A post-training transfer effect will be found where trained young-inexperienced drivers will scan novel hazardous situations more efficiently than untrained young-inexperienced drivers.

2. Method

2.1. Participants

The study was conducted at two sites in Israel: Ben-Gurion University of the Negev (BGU) or Bar-Ilan University (BIU) in the cities of Beer-Sheva and Ramat-Gan respectively. A total of 82 drivers (57 males, Table 1) participated in this study as paid volunteers. Young-inexperienced drivers were recruited from high schools in these two cities while experienced drivers were students in the two academic institutions. All participants had a visual acuity of 6/9 or better and normal contrast sensitivity. Forty-seven participants were young-inexperienced drivers, 17 to 18 years old (M = 17.44, SD = 0.46), with an average driving experience of 6.45 months (SD = 3.32). Thirty-five participants were experienced drivers, 23 to 40 years-old (M = 31.5, SD = 7.13), with driving experience of at least five years (M = 102.98 months, SD = 27.35). The young-inexperienced drivers were randomly assigned into two conditions: 23 drivers underwent hazard HP training while 24 drivers in the control group did not undergo any training. All experienced drivers underwent the HP training.

2.2. Apparatus

2.2.1. Eye trackers and displays

At BIU we used an SMI iView 125 Hz RED eye tracking portable system installed on a Laptop (17″ LCD) at the resolution of 1360 × 768. At BGU the eye tracker included an ASL D6 remote optics system, and the stimuli during the experiment was presented on a 20″ LCD at the resolution of 1600 × 900. At both sites, gaze coordinates were recorded at a rate of 60 Hz. For analysis of eye movement, we used the dispersion algorithm applied by Gitelman (2002) comprising three parameters: minimum fixation duration (100 ms), minimum dispersion considered a

Table 1
Demographic data.

Characteristics	Young-inexperienced		Experienced and trained
	Untrained (n = 24)	Trained (n = 23)	(n = 35)
Gender	M = 12, F = 12	M = 18, F = 5	M = 27, F = 8
Age (years) ± SD	17.48 ± 0.46	17.42 ± 0.5	31.5 ± 7.13
Driving experience (months) ± SD	7.46 ± 3.44	5.46 ± 3.31	102.98 ± 27.35

fixation (1 visual degree), and maximum consecutive sample loss (infinity). Participants' responses were initiated by pressing the spacebar (BIU) or a designated button (BGU) and recorded by E-PRIME 2.0 software (Psychology Software Tools Inc., Pittsburgh, PA, USA). In both labs participants sat at an average distance of 65 cm from the display.

A computer located vertically behind the participant was used by the experimenter to operate the eye tracking software interface and control the participant's computer. The experimenter was invisible to the participant due to a partition between them. An external data cable was used to synchronize the stimuli (movie frame number and spacebar presses) run on the participant's computer with the eye tracking sampling on the experimenter's computer.

2.2.2. Hazard HP movies

As mentioned earlier, hazards can be classified into four main categories: *visible materialized hazards, visible unmaterialized hazards, hidden materialized hazards, and hidden unmaterialized hazards* (Borowsky and Oron-Gilad, 2013; Vlakveld, 2014). Since our sample of visible materialized hazards each include a section of visible unmaterialized hazard (before the hazard materialized), we opted to exclude explicit allusions to the visible unmaterialized hazard. This decision was taken for two reasons. First, all visible materialized hazards begin with a section in which the visible hazard is yet unmaterialized. Second, increasing the number of filler scenarios between repetitions was thought to reduce potential learning effects (Zang et al., 2018) while also reasonably limiting the duration of the experiment. The scenarios comprised real-world driving, filmed from a driver's perspective. Scenarios were edited into short video clips that were used for both the training and transfer phases. All movies, filmed in a typical Israeli landscape at a rate of 25 frames per seconds and at the resolution of 720 × 576 pixels, were adopted from previous work (Borowsky and Oron-Gilad, 2013; Borowsky et al., 2010). In both the training and the transfer phases, movies included five target scenarios containing the hazards scenarios and fifteen filler scenarios aimed at reducing familiarity effects and maintaining the ecological validity of the repetitive training procedure. To control for a potential effect originating in the movies' presentation order, four different sequences of target movies were generated and were counterbalanced among the participants. All scenarios used in the study are described in Table 2 and Fig. 1.

2.3. Experimental design

Half of the young-inexperienced drivers and all of the experienced drivers underwent two consecutive phases: a HP training phase followed by a HP transfer phase. The other half of the young-inexperienced drivers underwent the transfer phase only. Participants were asked to respond when first noticing a hazard, which was defined as follows: "Any object, situation, occurrence, or combination of these that introduce the possibility of the individual road user experiencing harm. Hazards may be obstructions in the roadway, a slippery road surface, merging traffic, weather conditions, distractions, a defective vehicle, or any number of other circumstances. Harm may include damage to one's vehicle, injury to oneself, damage to another's property, or injury to another person" (Haworth et al., 2000, p. 3; and see also Borowsky et al., 2010). Eye movement data and behavioral data were recorded throughout the study. Analyses were conducted separately for each movie and each phase, as well as for each of the dependent variables.

2.3.1. Training phase

During training, participants observed three target HP movies, each representing one type of hazard, embedded among four filler movies. Each movie was presented three times such that during training each participant was exposed to HP scenarios nine time (3 movies x 3 repetitions) and to filler scenarios twelve times (4 × 3). Two multilevel independent variables comprised a 2 × 3 mixed design. The between-subjects independent variable was driving experience (experienced vs. young-inexperienced drivers). The within-subjects independent variable comprised the three time points (repetitions). The learning curve was measured by changes in measured eye movements along the three repetitions.

2.3.2. Transfer stage

During the transfer phase, participants were exposed to two target HP movies that differed from the ones shows to them during the training phase. These movies showed a two-stage hazardous scenario starting with an unmaterialized hazard instigator, which then became materialized. The hazard was visible in one movie but hidden in the other (see Movies TS-03 and TS-08 in Table 2 above). Additional three filler movies were imbedded between the target movies. Two multilevel independent variables comprised a 2 × 3 mixed design. The between-subjects independent variable was the experimental group: drivers who

Table 2
Description of target hazard HP movies.

Movie ID and name	Hazard type	Exposure duration (ms)	Description
TR-04 lead vehicle	Visible materialized	3420	Participant follows a lead vehicle in a one-way residential street. When the lead vehicle approaches an obscured intersection, a third car bursts into the lead vehicle's path from the right. The lead vehicle stops suddenly directly before the participant.
TR-20, parked truck	Hidden unmaterialized	6520	A truck is parked on the right side of an urban road, a few meters before a zebra crossing at an intersection. The truck obscures a potential pedestrian (hidden hazard) that might burst into the road before the truck.
TR-26, parked bus	Hidden unmaterialized turned to visible materialized	4640	A bus is parked on the right side of a one-way residential street. The bus obscures a possible pedestrian who may burst into the road in front of the driver. The hidden unmaterialized hazard (pedestrian) eventually came out from behind the car and became a visible and materialized hazard.
TS-03, roller- blades skater	Visible unmaterialized turned to visible materialized	5920	Participant drives on a residential road where care are parked on both sides. After a few seconds, a roller blades skater is visibly skating on the right curb, partially obscured by parked cars. Then, when the roller blades skater identifies a gap between parked cars, he bursts into the road directly in front of the participant.
TS-08 Pedestrian crossing	Hidden unmaterialized turned to visible materialized	6040	While driving a one-way pedestrian street, a lead white car, driving on the left lane, and blocking the left field of view, breaks before a zebra-crossing. The lead car is an unmaterialized hazard since there since a hidden pedestrian is likely in front of it. After 2 seconds the hazard becomes materialized when the pedestrian crossing the road becomes visible

Note. TR = training phase, TS = transfer phase. ID numbers correlate to our movie database and have no other meaning.

Fig. 1. Hazards shown in HP movies (TR = training phase, TS = transfer phase movie). TR-04, lead vehicle – materialized visible hazard. TR-20, parked truck – unmaterialized hidden hazard. TR-26, parked bus: TR26a – hidden hazard (frame at 2000 ms from the initial appearance of the hazard); TR26b – visible hazard (frame at 3000 ms from the initial appearance of the hazard). TS-03, roller blades skater: TS-03a – unmaterialized hazard (frame after 2200 ms from the initial appearance of the hazard); TS-03b – materialized hazard (frame after 3000 from the initial appearance of the hazard). TS-08, pedestrian crossing: TS-08a – hidden hazard (frame after 1700 ms from the initial appearance of the hazard); TS-08b – visible hazard (frame after 4600 ms from the appearance of the hazard).

were (a) experienced and trained, (b) young-inexperienced and trained, and (c) young-inexperienced and untrained. Untrained experienced drivers were not included in this study as we were not interested in examining what experienced drivers might learn from the repeated presentation of a hazard compared to experienced drivers who were not exposed to our movies. Our purpose was to test the training effectiveness with respect to young-inexperienced drivers. We achieved this by comparing their performance throughout training to that of trained experienced drivers. In addition, during the testing phase, we compared trained young-inexperienced drivers' performance to that of young-inexperienced drivers who did not undergo any training. The within-subjects variable was the state of the hazard: unmaterialized or materialized. The acquisition of HP ability was measured by comparing measures of trained and untrained groups at the transfer phase.

2.4. Procedure

The ethics committees of BIU and the department of Industrial Engineering and Management at BGU respectively approved the experiments at each institute. Upon their individual arrival at the lab, participants first signed an informed consent and asked about their driving history and demographic background. Participants were then asked to seat approximately 65 cm before the display and read the experimental instructions, including the definition of the hazard. Participants were then told they would be connected to an eye tracker that would record their eye movements throughout the study. After a short calibration process, participants observed several practice movies in order to become familiarized with the experimental setup. Participants were then asked to observe each of the movies as if they were the driver in that scenario and to press the response button or space bar (see above) each time they identified a hazard. When the participant felt comfortable with the experimental task, they were asked to complete either the full program (HP training and the transfer phase) or the transfer phase alone, according to their study group. Participants were debriefed at the end of the experiment. The full procedure took about 40 min without breaks.

2.5. Data analyses

Data had to be prepared before statistical models were applied and various eye movement analyses were conducted. Analyses of the dependent measures between the two eye tracking systems (MSI or ASL) did not yield any significant differences and therefore data from both systems was merged and analyzed as a whole.

Table 3
Description of hazard development over interval subdivisions.

Type of hazard	First section	Second section
Visible materialized	Initial visible unmaterialized stage of hazard development	Requires the driver's immediate response (i.e., breaking the car) in order to prevent a collision
Hidden materialized	The hazards is in its hidden unmaterialized form	The hazards is in its materialized form
Hidden and unmaterialized	Initial hidden unmaterialized stage of hazard development	Interval between when the potential hazardous situation is still unmaterialized and between requiring the driver's immediate response in order to become more alert and cautious (i.e., by slowing down the speed of the driving car)

2.5.1. Data preparation of eye movements

We first extracted eye movements from sections of each movie that related to the critical hazard. These sections were defined as the time interval between the moment the hazard or its preliminary cues first became visible and the moment the participant's vehicle had passed the hazard and responding became irrelevant. These sections were then each subdivided into two subsections representing the phases of hazard development across the scenario (Table 3). We then calculated fixations for each predefined section per hazard per participant. Finally, we define areas of interests (AOIs) for each hazard across sections defined as areas from where the hazard instigator could have appeared in the case of hidden hazards (e.g., the front edge of a truck obscuring a crosswalk) and the area surrounding the hazard instigator (e.g., a pedestrian) where the hazard was visible. AOIs were used to compute the dependent variables.

2.5.2. Dependent variables

Six dependent variables were defined. *Normalized Reaction Time (RT)* was defined as the time interval (in ms) from the beginning of the hazardous event to the first fixation inside the AOI, divided by the overall duration of the hazardous event. In order to analyze this variable using ANOVA we applied a natural logarithmic transformation (LN) on RT. For example, if a certain hazardous event began at 12,000 ms, the overall duration of its time interval was 9000 ms, and the participant made their first fixation within the AOI at 15,000 ms, then the computed normalized RT would yield (15,000 12,000) / 9000 = 0.33, or −1.10 on a logarithmic scale. The variables *Normalized number* and *cumulative duration of fixations* were computed for each participant. These were computed separately for fixations within the AOIs and fixations outside of it. We then normalized the number of fixation within the AOIs by dividing it by overall fixations during the hazardous events. For example, if 20 fixations were recorded for the participant overall throughout the hazardous event, five of which were within AOIs, then the normalized fixation frequency would yield 5 / 20 = 0.25 suggesting that 25% of the participant's fixations were directed toward AOIs. We applied the same calculation method for the *cumulative duration of fixations* measure. The variables *vertical spread of search* and *horizontal spread of search* represent participants' visual spread of search along the vertical and horizontal axes respectively. These variables were computed separately for x and y coordinates as the standard deviation of fixation centers' distance from each axis. The dependent variable *response sensitivity*, derived from the behavioral data, signifies participants' ability to identify the hazard or its precursors correctly and register their response. A response recorded within the hazard segment time window was awarded the score of "1″ while a response outside that time frame (before or after it) or no response was awarded the score of "0″. This binary variable was calculated for each participant and every section of every hazard.

2.5.3. Statistical analyses

All main effects and second order interactions of the fixed effects were included in the model, using SPSS Version 22.0. Participants were included as a random effect. Two-way alpha was set at 5%. We evaluated the fixed and random effects by carrying out a Linear Mixed Model (LMM) with a random intercept. The final model was achieved via a backwards elimination procedure. For significant effects, post hoc pairwise comparisons were applied using Bonferroni correction.

3. Results

3.1. Training (repetition) analyses

3.1.1. Visible materialized hazard (Movie TR-04)

For eye movements measures, we present here only the normalized number of fixations as their patterns were similar to those of the normalized cumulative fixation duration. The interaction between group and repetition (F (3, 2366) = 26.51, $p <$ .01) revealed that at the third repetition, experienced drivers exhibited a lower normalized number of fixations compared to young-inexperienced drivers (see Table 4 Row 6, and Fig. 2a). Consistently, comparing both groups in terms of their normalized RT across repetitions, a significant interaction was found between driver groups and repetitions ($F_{(3,1185)} = 2.56$, $p = .05$), revealing that at the third repetition experienced drivers were slower to respond compared to young-inexperienced drivers (Table 4 Row 11). A significant interaction was also found between driver groups and repetitions ($F_{(7,441)} = 6.20$, $p < .01$) with respect to the spread of search, revealing that at the first repetition experienced drivers showed a tendency ($p =$ 0.06, Table 4 Row 16) towards a narrower horizontal spread of search compared to young-inexperienced drivers. Nevertheless, at the third repetition, experienced drivers exhibited a significantly wider horizontal spread of search compared to young-inexperienced drivers (Fig. 2b). In summary, all dependent variables show that along repetitions, young-inexperienced drivers had increased their focus on the visible materialized hazard compared to experienced drivers who demonstrated an opposite trend, focusing more on items that were unrelated to the hazard. With regard to the response sensitivity measure results in both groups were high across repetitions (0.85–1) without significant differences between groups or across the repetitions.

3.1.1.1. Hidden unmaterialized hazard (Movie TR-20). On average, across all repetitions, experienced drivers exhibited a significantly greater normalized number of fixations on the target ($M = 0.31$, $SD = 0.02$) compared to young-inexperienced drivers ($M = 0.22$, $SD = 0.22$; $F_{(3,4681)} = 117.57$, $p < .01$). The significant interaction between driver groups and repetitions ($F_{(3,4681)} = 29.89$, $p < .01$) reveals that experienced drivers exhibited more fixations on the target in the first and in the third repetition, compared to young-inexperienced drivers (Table 5 Row 6).

3.1.1.2. Scanning behavior during development of hazardous scenarios. Since hazardous scenarios were divided into two segments, we applied the same model with segment as an additional independent variable. The final model revealed a significant interaction between segment, group, and repetition ($F_{(17,3532)} = 5.11$, $p < .01$). During the first and second repetitions, upon the appearance of the hazard (first and second segments, up to 4800 ms), experienced and young-inexperienced drivers had the same normalized number of fixations

Table 4
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TR-04.

Variable	Effect		M1	M2	M3	Post hoc repetitions
Norm. # of fixations on target	Repetition		0.47 (0.03)	0.51 (0.03)	0.54 (0.03)	
	Post-hoc		M3 > M2 > M1, p < .01			
	Group	TYI	0.44 (0.05)	0.52 (0.05)	0.60 (0.05)	
		E	0.50 (0.04)	0.51 (0.04)	0.50 (0.04)	
	Post hoc				TYI > E, p < .05	
Norm. RT	Repetition		0.54 (0.03)	0.57 (0.03)	0.54 (0.03)	
	Post-hoc		N.S			
	Group	TYI	0.54 (0.03)	0.58 (0.03)	0.50 (0.03)	
		E	0.54 (0.02)	0.56 (0.02)	0.58 (0.02)	
	Post hoc				E > TYI, p < .05	
Horizontal spread of search	Repetition		78.77 (6.18)	65.91 (5.95)	52.25 (6.34)	
	Post hoc		M1 > M3, p < .01			
	Group	TYI	90.50 (9.72)	60.00 (9.20)	37.87 (10.1)	M1 > M2 > M3, p < .01
		E	67.06 (7.34)	72.05 (7.58)	66.63 (7.61)	
	Post hoc		TYI > E, p = .06		E > TYI, p < .05	
Vertical spread of search	Repetition		17.53 (2.11)	21.64 (2.03)	23.51 (2.16)	
	Post hoc		M3 > M1, p = .06			
	Group	TYI	13.36 (3.32)	19.90 (3.14)	22.71 (3.46)	
		E	21.70 (2.61)	23.40 (2.60)	24.32 (2.60)	
	Post hoc		E > TYI, p < .05			

Note. M1-M3: mean (SE) of the dependent measure on repetition 1-3. Norm = Normalized. TYI = Trained Young-inexperienced drivers, E = Experienced drivers, UYI = Untrained young-inexperienced drivers.

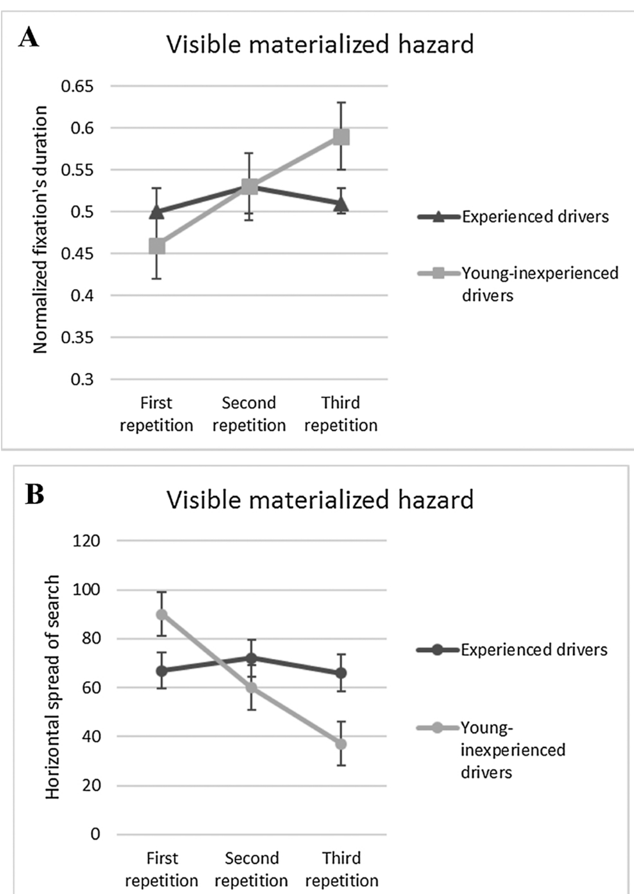

Fig. 2. (a) Experienced and young inexperienced drivers' normalized fixation duration on visible materialized hazard (Movie TR-04) (b) Experienced and young inexperienced drivers' horizontal spread of search on visible materialized hazard (Movie TR-04).

on the target. However, in the third repetition experienced drivers had a higher normalized number of fixations ($M = 0.23$, $SD = 0.03$ and $M = 0.33$, $SD = 0.03$ for segments 1 and 2 respectively) compared to young-inexperienced drivers ($M = 0.09$, $SD = 0.04$ and $M = 0.2$, $SD = 0.03$ for segments 1 and 2 respectively; Fig. 3). Accordingly, with respect to the response sensitivity measure, results of a third order interaction between group, repetitions and segments, showed that during the third repetition experienced drivers were more likely (0.41) to respond to the hidden unmaterialized hazard further away from the hazard compared to young-inexperienced drivers (0.27) (X^2 (2) = 4.43, $p <$ .05).

3.1.1.3. Hidden materialized (Movie TR-26). A significant interaction between repetitions and driver groups ($F_{(3,4681)} = 25.44$, $p<.01$) revealed that while young-inexperienced drivers exhibited a gradual decline along repetitions, (Table 6 Row 4), experienced drivers kept their fixations constant (see Fig. 4). A similar, although insignificant, trend emerged in the response sensitivity measure: Stable response sensitivity results across repetitions among experienced drivers compared to an insignificant increase along the repetitions among young-inexperienced drivers. An additional analysis of the hazard situation across time revealed that at the second repetition, experienced drivers exhibited a greater normalized number of fixations on the target 2200 ms after the hazard appeared compared to young inexperienced drivers (experienced: $M2 = 0.56$, $SE = 0.04$, young-inexperienced: $M2 = 0.40$, $SE = 0.05$, p < .05). At the third repetition. experienced drivers focused more frequently on the target at an earlier stage of the hazard development, that is, during the initial appearance of the hazard, compared to young-inexperienced drivers (experienced: $M2 = 0.31$, $SE = 0.04$, young inexperienced ($M2 = 0.18$, $SD = 0.05$, p < .05).

An interaction effect distinguished between driver groups and repetitions regarding their vertical spread of search. While young-inexperienced drivers exhibited a gradual increase in the vertical spread of search as the number of repetitions increased ($F_{(2,108)} = 4.49$, $p<.01$, Table 6 Row 19), the vertical spread of search of experienced drivers was reduced at the second repetition compared to the first and remained stable at the third repetition (Table 6 Row 20).

In summary, experienced drivers focused better, in terms of fixation frequencies and fixations normalized reaction time on both the unmaterialized and the materialized hidden hazards throughout repetitions compared to young-inexperienced drivers. Experienced drivers also demonstrated a decrease in their vertical spread of search along repetitive viewings of scenarios involving a materialized hidden hazard suggesting that their focus on the hazard increased over repetitions. In

Table 5
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TR-20.

Variable	Effect		M1	M2	M3	Post hoc repetitions
Norm. # of fixations on target	Repetition		0.31 (0.02)	0.28 (0.03)	0.23 (0.02)	
	Post-hoc		M3 > M2 > M1, p < .05			
	Group	TYI	0.25 (0.03)	0.24 (0.03)	0.16 (0.03)	M1 > M2 > M3, p < .01
		E	0.37 (0.02)	0.31 (0.02)	0.30 (0.02)	
	Post hoc		E > TYI, p < .05		E > TYI, p < .01	
Norm. RT	Repetition		0.56 (0.02)	0.58 (0.02)	0.55 (0.02)	
	Post-hoc		N.S			
	Group	TYI	0.56 (0.04)	0.55 (0.04)	0.56 (0.04)	
		E	0.56 (0.03)	0.60 (0.03)	0.53 (0.03)	
	Post hoc					
Horizontal spread of search	Repetition		60.21 (3.00)	55.50 (3.02)	54.20 (3.00)	
	Post hoc		N.S			
	Group	TYI	62.21 (4.63)	52.86 (4.61)	52.00 (4.47)	
		E	58.23 (3.80)	58.12 (3.91)	56.32 (3.94)	
	Post hoc					
Vertical spread of search	Repetition		20.63 (1.56)	20.82 (1.58)	22.65 (1.56)	
	Post hoc		N.S			
	Group	TYI	21.70 (2.42)	20.47 (2.41)	24.32 (2.34)	
		E	19.57 (2.00)	21.18 (2.04)	21.00 (2.06)	
	Post hoc					

Note. M1-M3: mean (SE) of the dependent measure on repetition 1-3. Norm = Normalized. TYI = Trained Young-inexperienced, E = Experienced drivers, UYI = Untrained young-inexperienced drivers.

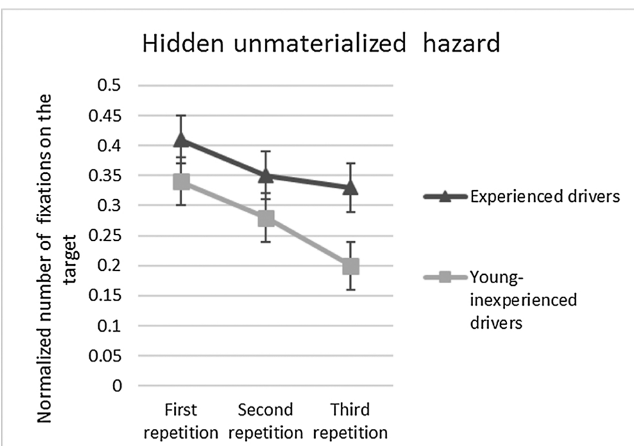

Fig. 3. Experienced and young inexperienced drivers normalized number of fixations on hidden unmaterialized hazard (Movie TR-20) at the second segment.

contrast, young-inexperienced drivers focused less on both materialized and unmaterialized hidden hazards and exhibited a broader vertical spread of search in scenarios involving materialized hidden hazard. Similarly, in the third repetition, during the initial presentation of the hidden unmaterialized hazard we found greater response sensitivity among experienced drivers compared to young-inexperienced drivers. These results imply that young-inexperienced drivers were not aware hidden hazards regardless of the number of exposures to the scenario. Only when the hazard became visible were young-inexperienced drivers able to focus on it.

3.1.2. Transfer (test) phase analyses

The transfer phase aimed at examining how well drivers identify hazards in situations that they had not encountered during the training. We compared performance of trainees (experienced and young-inexperienced drivers) with that of young-inexperienced untrained drivers.

3.1.2.1. Visible unmaterialized and materialized (Movie TS-03). Both experienced drivers and trained young-inexperienced drivers tended to fixate earlier on the hazard during its unmaterialized state (3000 ms after the initial appearance of the hazard) compared to untrained young-inexperienced drivers (Table 5 Row 8). In line with this, the response sensitivity (RS) of both trained groups was greater for unmaterialized hazards (experienced: RS = 0.45, *SE* = 0.02; trained young-inexperienced: RS = 0.37, *SE* = 0.02) compared to the group of untrained young-inexperienced drivers (RS = 0.19, *SE* = 0.02), at a significant level (X^2 (2) = 7.62, $p <$ .05). Throughout both segments of the hazard, untrained young-inexperienced drivers were always slower to fixate on the hazard compared to the other groups. A significant second order interaction was found between driver groups and the phase of the hazard ($F_{(8,1651)} = 7.51$, $p < .01$, Table 5) revealing that during the unmaterialized segment (2200 ms after the initial appearance of the hazard), trained young-inexperienced drivers exhibited a greater normalized number of fixations compared to both untrained young-inexperienced and trained experienced drivers (Table 7 Row 4). At the materialized segment (4280 ms after the initial appearance of the hazard), both groups of trained drivers exhibited greater fixation compared to untrained young-inexperienced drivers (Table 7 Row 5). As shown in Fig. 5 Panels a and b, the normalized number of fixations of the untrained young-inexperienced drivers was smaller than that of both trained young-inexperienced drivers and trained experienced drivers across both stages of the hazard. Finally, a significant main effect of driver groups ($F_{(2,323)} = 5.74$, $p < .01$) revealed that young-inexperienced drivers (both trained and untrained) exhibited a narrower horizontal spread of search compared to trained experienced drivers (Table 7 Row 11).

3.1.2.2. Hidden unmaterialized and materialized Movie TS-08). With respect to the normalized number of fixations on the target, a significant second order interaction was found between drivers groups and the phase of the hazard ($F_{(8,1492)} = 5.78$, $p < .01$, Table 8). During the unmaterialized segment (3920 ms after the initial appearance of the hazard) trained experienced drivers exhibited a greater normalized number of fixations only compared to untrained young-inexperienced drivers (Table 8 Row 4). Young-inexperienced trained drivers exhibited an intermediate normalized number of fixations compared to the high number of trained experienced drivers and the low number of untrained-young-inexperienced drivers (Fig. 5 Panel c). Response sensitivity were higher in both trained groups compared to the untrained young-inexperienced drivers, showing an insignificant tendency of the former to detect the hidden hazard more

Table 6
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TR-26.

Variable	Effect		M1	M2	M3	Post hoc repetitions
Norm. # of fixations on target	Repetition		0.41 (0.03)	0.37 (0.03)	0.35 (0.03)	
	Post-hoc		M1 > M2 > M3, p < .05			
	Group	TYI	0.40 (0.04)	0.32 (0.04)	0.30 (0.04)	M1 > M2, M1 > M3, p < .01
		E	0.42 (0.02)	0.43 (0.02)	0.41 (0.02)	
	Post hoc				E > TYI, p < .01	
Norm. RT	Repetition		0.57 (0.02)	0.60 (0.02)	0.62 (0.02)	
	Post-hoc		M1 < M2, p < .01			
	Group	TYI	0.57 (0.03)	0.55 (0.03)	0.62 (0.03)	
		E	0.57 (0.03)	0.60 (0.03)	0.62 (0.03)	
	Post hoc		N.S.			
Horizontal spread of search	Repetition		51.11 (3.22)	47.91 (3.20)	44.53 (3.21)	
	Post hoc		N.S			
	Group	TYI	50.43 (4.93)	49.66 (4.92)	39.50 (5.05)	
		E	51.80 (4.14)	46.17 (4.10)	49.56 (3.97)	
	Post hoc		N.S.			
Vertical spread of search	Repetition		23.20 (2.07)	21.17 (2.06)	24.22 (2.06)	
	Post hoc		N.S			
	Group	TYI	17.61 (3.17)	24.70 (3.17)	23.07 (3.25)	M1 < M2; p < .01
		E	28.76 (2.67)	17.67 (2.64)	24.74 (2.55)	M1 > M2; p < .01
	Post hoc		E > TYI, p < .01			

Note. M1-M3: mean (SE) of the dependent measure on repetition 1-3. Norm = Normalized. TYI = Trained Young-inexperienced, E = Experienced drivers, UYI = Untrained young-inexperienced drivers.

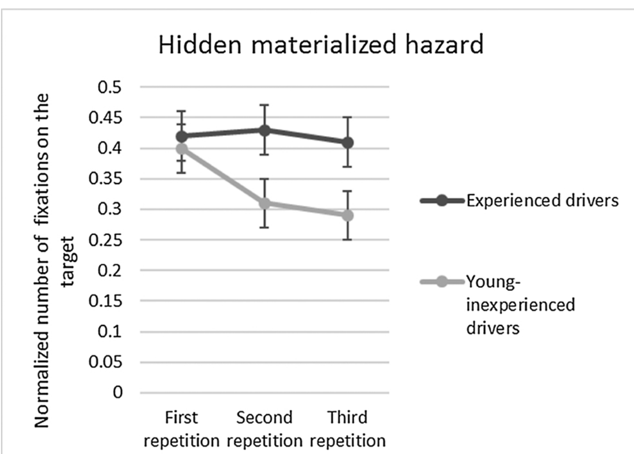

Fig. 4. Experienced and young-inexperienced drivers' normalized number of fixations on hidden materialized hazard (Movie TR-26).

often (Experienced RS: $M = 0.38$, $SE = 0.01$; trained young-inexperienced RS: $M = 0.50$, $SE = 0.01$; untrained young-inexperienced RS: $M = 0.25$, $SE = 0.01$).

Significant group effects were found concerning both the horizontal and vertical spread of search ($F_{(2,307)} = 5.51$, $p < .01$ and $F_{(2,307)} = 7.62$, $p < .01$ respectively). Experienced drivers exhibited narrower horizontal and vertical spreads of search compared to untrained young-inexperienced drivers but only a narrower horizontal spread compared to the trained young-inexperienced, whose vertical spread of search was intermediate (Table 8 Rows 11, 15).

In summary, results from the transfer phase reveal the effectiveness of the repetitive training phase, since compared to the untrained group of young-inexperienced drivers, both trained groups focused on the hazards earlier. This was demonstrated by their greater normalized number of fixations on the target and longer cumulative fixations durations during the early segments of the hazardous situation. Additionally, when the hazard instigator was visible, even in its unmaterialized phase, trained young-inexperienced drivers showed enhanced HP performance compared to untrained young-inexperienced drivers. This was reflected in a greater normalized number of fixations and faster normalized reaction time, accompanied with a greater

Table 7
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TS-03.

Variable	Effect		UYI	TYI	E	Post hoc groups
Norm. # of fixations on target	Group		0.09 (0.02)	0.16 (0.02)	0.14 (0.02)	
	Post-hoc		TYI > UYI, p < .05			
	Segments	UM	0.04 (0.02)	0.13 (0.02)	0.04 (0.02)	TYI > UYI, p < .05; TYI > E, p < .05
		M	0.13 (0.03)	0.26 (0.03)	0.26 (0.03)	TYI > UYI, p < .01; E > UYI, p < .01
Norm. RT	Group		0.63 (0.01)	0.57 (0.02)	0.59 (0.01)	
	Post-hoc		UYI > TYI, p < .05			
	Segments	U	0.61 (0.04)	0.40 (0.08)	0.48 (0.03)	UYI > TYI, p < .05
		M	0.67 (0.04)	0.62 (0.02)	0.60 (0.02)	UYI > E, p < .05
Horizontal spread of search	Group		86.00 (9.67)	95.14 (9.58)	125.50 (7.80)	
	Post-hoc		TYI < E, p < .05, UYI < E, p < .01			
	Segments	U	116.80 (20.12)	120.50 (20.60)	144.58 (16.68)	
		M	51.66 (24.37)	102.14 (23.60)	119.65 (20.60)	
Vertical spread of search	Group		27.58 (2.42)	23.23 (2.40)	28.92 (2.00)	
	Post-hoc		N.S			
	Segments	U	44.72 (5.04)	37.60 (5.16)	43.88 (4.18)	
		M	10.04 (6.11)	16.41 (5.92)	19.20 (5.16)	

Note. M1-M3: mean (SE) of the dependent measure on repetition 1-3. Norm = Normalized. TYI = Trained Young-inexperienced drivers, E = Experienced drivers, YIU = young-inexperienced untrained drivers, UM = Unmaterialized phase, M = Materialized phase.

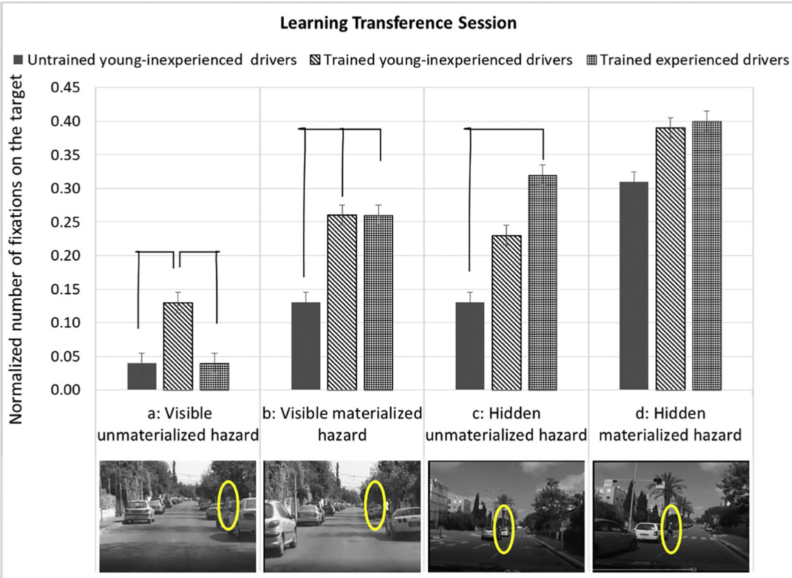

Fig. 5. The normalized number of fixations of drivers during the transfer phase. Panel pictures a–d are representative frames of the two movies. (a–b) Movie TS-03: the hazard (roller blade skater) is visible to the driver; normalized numbers of fixations are shown when (a) the hazard is unmaterialized (still on the sidewalk) and (b) the hazard had materialized (roller blade skater burst onto the road).(c–d) Movie TS-08: the hazard instigator (pedestrian) is obscured but possible materialization can be predicted (crossing the road on a zebra crossing) based on behavior of lead white car on the left lane; normalized numbers of fixations are shown when the hazard (c) is still out of view and unmaterialized and (d) becomes visible and materialized.

response sensitivity. However, when the hazard instigator was hidden, experienced drivers exhibited enhanced HP performance reflected in a greater normalized number of fixations and narrower horizontal and vertical spreads of search. These results imply that the repetitive training was effective in improving young-inexperienced drivers' HP skills especially with regard to visible hazards during their unmaterialized phase and to a lower extent also with regard to hidden hazards. These results also imply a likely ceiling effect regarding the level of expertise that young-inexperienced drivers can achieve during a 40 min training phase.

4. Discussion

This study aimed at evaluating the benefits of using a novel HP training procedure that is based on principles of implicit learning theories. The implicit learning procedure relies on two unique notions. First, it posits that skill acquisition is optimally acquired without the learner's awareness, implying that deliberate instructional methods are usually suboptimal when it comes to skill development (Esser and Haider, 2017; Vakil et al., 1998; Willingham, 1998). Secondly, it involves a repetitive conduction of the same requested behavior (Esser and Haider, 2017; Haider et al., 2013; Salas and Cannon-Bowers, 2001; Willingham et al., 1989) over which the learner is expected to unconsciously self-adapt their behavior to increase precision and speed (Willingham, 1998). Also, it is anticipated that the participant would be able to generalize (or transfer) the acquired skills to a broader range of circumstances, that is, to effectively apply the skill gained via implicit learning to contexts that differ from those experienced during training (Baldwin and Ford, 1988; Rünger and Frensch, 2010; Schmidt and Bjork, 1992). The repetitive HP training without direct instruction method that we developed here included repeated exposure to the same hazardous scenarios. To minimize participants' HP of the repeated stimuli, various filler scenarios were embedded between repetitions. A post-training transfer phase allowed us to assess learning effectiveness as it comprised new hazardous scenarios based on similar principles of the scenarios used during training but applied to different driving contexts. Finally, we compared performance differences between trained and untrained groups in both the training and transfer phases.

Our results suggest that the repetitive training method is effective in facilitating HP in both young-inexperienced and experienced drivers. These results are particularly noteworthy as the training procedure was relatively short (40 min), it involved minimal instructional features, and the participant was not explicitly asked to participate in a training phase. Furthermore, our results are consistent with theories that

Table 8
A summary of the significant effects and post hoc analyses across all dependent variables in M8.

Variable	Effect		UYI	TYI	E	Post hoc groups
Norm. # of fixations on target	Group		0.23 (0.02)	0.27 (0.02)	0.35 (0.02)	
	Post-hoc		N.S			
	Segments	UM	0.13 (0.04)	0.23 (0.04)	0.32 (0.04)	E > UYI, p < .01
		M	0.31 (0.04)	0.40 (0.04)	0.40 (0.04)	
Norm. RT	Group		0.51 (0.01)	0.55 (0.02)	0.59 (0.01)	
	Post-hoc		N.S			
	Segments	UM	0.44 (0.01)	0.48 (0.01)	0.44 (0.01)	
		M	0.64 (0.02)	0.67 (0.01)	0.67 (0.01)	
Horizontal spread of search	Group		59.30 (5.24)	78.40 (5.66)	54.90 (7.80)	
	Post-hoc		TYI > E, p < .01, UYI > E, p < .05			
	Segments	UM	57.95 (12.24)	71.18 (11.92)	54.52 (9.81)	
		M	67.15 (11.92)	67.78 (12.60)	64.84 (10.00)	
Vertical spread of search	Group		29.80 (2.28)	22.52 (2.46)	18.01 (2.00)	
	Post-hoc		UYI > E, p < .01			
	Segments	UM	44.7 (5.04)	37.60 (5.16)	43.88 (4.18)	
		M	10.04 (6.11)	16.41 (5.92)	19.20 (5.16)	

Note. M1-M3: mean (SE) of the dependent measure on repetition 1-3. Norm = Normalized. TYI = Trained Young-inexperienced, E = Experienced drivers, UYI = Untrained young-inexperienced drivers, UM = Unmaterialized phase, M = Materialized phase.

support the implicit nature of skill acquisition in general and of visual search in particular (Wolfe et al., 2011).

4.1. Driving experience and HP skills

The results of this study are in line with the well-established distinction between hazards types based on the predictive demands of preliminary cues (i.e., precursors) that precede the materialization of a hazard (Borowsky et al., 2010; Crundall, 2016). We found that young-inexperienced drivers were unaware of hazardous situations involving potential hazards, especially when the hazard instigator was obscured by elements within the traffic environment. Under such conditions, predictive demands are high since the hidden hazard instigator cannot serve as a salient cue. Thus, drivers are required to decipher the potential appearance of a hazard instigator based on environmental elements that are only indirectly related to the hazard instigator. For example, approaching a curve along the road, the driver is expected to realize that other vehicles might be present further down the road even if none are currently visible due to the structure of the curve (which serves as the preliminary cue in this particular example). In contrast, where the hazardous situations involved a visible hazard instigator that could be easily monitored, young-inexperienced drivers became quickly aware of the hazards and had no trouble identifying them (Borowsky et al., 2010; Chapman and Underwood, 1998; Sagberg and Bjørnskau, 2006).

Using an eye tracker was helpful in eliminating response bias and establishing that young-inexperienced drivers were indeed unaware of hidden hazards (rather than being aware of it but electing not to respond; Crundall, 2016; Horswill, 2016). Interestingly, both experienced and young-inexperienced drivers had the same normalized number of fixation towards hidden hazards at the beginning of the training. With respect to the young-inexperienced drivers, one possible explanation is that some of these early fixations towards the hidden hazard were random rather deliberate. This argument is supported by the fact that over repetitions, young-inexperienced drivers withdrew their focus from these locations (i.e., exhibited a gradual decline in the number of fixations on the hidden hazards) unlike the experienced drivers whose focus remained on the hazards across all repetitions. Thus, our results also support previous finding concerning HP skills being dependent on driving experience (Borowsky and Oron-Gilad, 2013; Crundall, 2016; Horswill, 2016; Pradhan et al., 2009).

Using various measurements of eye movements alongside with the behavioral measure of response sensitivity allowed us to better capture and interpret the effects of driving experience on HP. For example, looking at the third repetition of a visible and materialized hazard, we found that experienced drivers exhibited a broader horizontal spread of search compared to a much narrower spread of search exhibited by the young-inexperienced drivers. This outcome shed light on the apparently surprising outcome of declining fixation's reaction time reflected in the fact that experienced drivers became slower than young-inexperienced drivers during the third repetition of the visible materialized hazard. One can mistakenly assume that a slower reaction time indicates less efficient HP. Nevertheless, by integrating both eye movements measures (spread of search and fixation's response time) alongside with the behavioral response sensitivity measure which showed that experienced drivers kept on responding to the hazard, it seems reasonable to argue that over the course of repetition, experienced drivers intentionally shifted their focus from the visible materialized hazard to other relevant elements within the surrounding environment, while staying aware to presence of the visible materialized hazard. Therefore, this pattern of road scanning exhibited by experienced drivers actually attests to their superior scanning strategy compared to young-inexperienced drivers (Underwood, 2007).

4.2. Repetitive training and HP skills

Over the course of repetitions during training, trained young-inexperienced drivers demonstrated a decline in time intervals between the moment the hazard first appeared and their first fixation on the hazard as well as a narrowing horizontal spread of fixations towards visible materialized hazards. In contrast, these drivers became less focused over repetitions, or they were unable to focus on hidden hazards (both materialized and unmaterialized). These results could imply that the efficiency of the repetitive training procedure depends on the type of hazard to which it is applied, because it seems that young-inexperienced drivers benefited only from the repetitive exposure to visible materialized hazards but did not benefit from the repetitive exposure to hidden hazards. This conclusion might have been valid if at the transfer phase trained young-inexperienced drivers had demonstrated a selective improvement in HP towards visible materialized hazard. These results, however, were only partially confirmed.

As expected, during the transfer phase, trained young-inexperienced drivers tended to fixate on visible hazards in the materialization phase twice as much as their untrained peers and at a rate similar to that of experienced drivers (Fig. 5 Panel b). Surprisingly, however, trained young-inexperienced drivers also demonstrated a greater normalized number of fixations toward unmaterialized visible hazard, accompanied with a higher response sensitivity. These results might reflect a transference effect, in which better HP performance that was achieved with respect to visible materialized hazards during training may lead to subsequent improved HP performance with respect to more challenging situations, such as the unmaterialized visible hazards that were presented during the transfer phase. This transference effect is known as *far transfer* (Pradhan et al., 2009; Vlakveld et al., 2011), indicating that the tested hazardous situations were unlike those to which participants were exposed through in training, as opposed to *near transfer* scenarios, were transference tests are based on similar scenarios as those viewed during training. Our study demonstrates that a repetitive training procedure that fosters greater HP among learners towards apparently salient hazards may also foster greater ability to become aware of less salient potential hazards. In other words, a far transfer effect was indeed achieved through repetitive training procedure, in line with extant literature (e.g., Pradhan et al., 2009; Schacter and Tulving, 1994; Squire et al., 1993; Vlakveld et al., 2011). Notably, during the transfer phase, trained young-inexperienced drivers indeed did not differ significantly from their untrained peers in their scanning behavior of a hidden hazard. We may thus conclude that the transferability of the repetitive training method is limited to visible hazards whether materialized or unmaterialized and does not extend to hidden hazards. We thus suggested that the repetitive training procedure may be effective in increasing HP similarly to other video-based instructional method, such as instructing drivers where should they look or what should they do in case of a hazard (Horswill, 2016; Horswill et al., 2017; McKenna and Crick, 1997; Meir et al., 2014). Nevertheless, other methods have been recorded yielding a greater far transfer effect than found in the current study (Pradhan et al., 2009; Vlakveld et al., 2011). Therefore, further research is necessary in order to compare the transferability effect of deliberate, instructional methods and the suggested repetitive training without instruction method.

4.3. Limitations and further considerations

This work suggests that repetitive HP training can improve drivers' visual scanning of on road hazards. An important issue, of course, is whether the knowledge gained during training can be applied in real-world driving situations. Although HP has been previously found to be associated with safe driving (Horswill et al., 2015), we cannot conclude from the current study that the better visual scanning strategy that was demonstrated in the lab while observing filmed traffic scenarios is directly related to an improvement in scanning during real-world situations and actual driving (Pradhan et al., 2009). Indeed, it is possible that HP skills, which are learned over a PC in laboratory training, would not transfer to the field. Nevertheless, Horswill (2016) demonstrated a correlation between a PC-based HP test and involvement in road crashes a year prior to the HP test and a year after the HP test, thus confirming the connection between laboratory training and improvement in actual driving. To establish transference to field conditions, further studies are necessary that would include real-world or simulated driving methodologies following training. As such, studies similar to Pollatsek et al. (2006) might help in our investigation of the relationship between HP as reflected by visual scanning of filmed driving scenarios and visual scanning during on-road driving.

Additionally, in implicit learning research, extensive effort is invested in answering the question whether the knowledge that is acquired through the so-called implicit procedure indeed reflects unconscious knowledge (Esser and Haider, 2017; Schwager et al., 2012). The principal measure of consciousness is a verbal report (Rünger and Frensch, 2010) indicated by participants' ability to describe their acquired skill. For example, in the SRT task, participants may be required to describe the sequence of target positions after having been informed about the existence of a regular response pattern. Further studies may shed a light on the implicit nature of the current paradigm, by adding a report session once the task has been completed in which participants are asked to describe the hazardous situations to which they were exposed.

Our study was concerned only with immediate effects of the training. It would, however, be prudent to study the duration of the effect found herein. Thus, future studies may be designed to assess retention of the repetitive training effect and determinate what manipulations may yield long-lasting benefits.

While our results are promising, they have a limited statistical power. Ways to enhance statistical power should be considered in order to increase the suggested intervention effect. Greater statistical power might also help reveal additional differences between trained and untrained young-inexperienced drivers and corroborate or refute some of the trends we found. For example, greater statistical power could determine the true nature of the tendency found herein towards more fixations among trained young-inexperienced drivers compared to their untrained peers with regards to an unmaterialized hidden hazard (23% compared to 13% of fixations among trained young inexperienced drivers and untrained peers respectively, Table 6 Row 4), as well as the tendency towards greater response sensitivity at the transfer phase among the trained groups compared to the untrained group regarding hidden materialized hazards. Additionally, the effect size of some results was moderate. For example, while trained drivers showed a greater normalized number of fixations towards visible unmaterialized hazards, both numbers were very low (13% compared to 4% of all fixations on the visible unmaterialized hazard exhibited by trained young-inexperienced drivers and their untrained peers respectively). Similarly, young-inexperienced trained drivers' fixations reaction time towards visible unmaterialized hazards was 20% lower compared to their untrained peer (Table 7 Row 8). Finally, our training methodology was inefficient with regards to the HP of young inexperienced drivers towards hidden hazards. Effect size could possibly be increased by the addition of supplementary training methods during or preceding the suggested repetitive training method. Interestingly, a growing body of research in the field of implicit learning focuses on the potential benefits of integrating both implicit and explicit training in skill acquisition (Esser and Haider, 2017; Haider et al., 2013; Sun et al., 2005; Yordanova et al., 2015). Accordingly, it would be interesting to investigate the combined efficiency of our suggested repetitive training method with more explicit methods were found useful in HP training among young-inexperienced drivers, such as the commentary method suggested by Young et al. (2014), the feedback method suggested recently by Horswill et al. (2017), or the simulator-based training program suggested by Vlakveld et al. (2011).

Furthermore, since the number of scenarios employed in our novel repetitive HP training was small, employment of a greater number of scenarios could strengthen statistical power of the study. Indeed, we are currently working on expanding our database of scenarios. Our results may also be related to the relatively short period of training we introduced. If indeed young-inexperienced drivers benefit from repetitive training procedure, perhaps longer training phase would further increase the training effect with respect to efficient road-scanning patterns. Finally, the generalizability of the current study is somewhat limited due to a significant difference of the gender distribution between the experimental group. That is, due to randomized assignment to the experimental groups, while in the untrained group the gender distribution was even (12:12), in the trained group the males exceeded the females (18:5 in the TYI group, and 27:8 in the E group). Interestingly, although it is unanimously recognized that young people have more risky driving behavior than other age groups, it is unclear whether there are gender differences within this age group (Cordellieri et al., 2016). Therefore, we acknowledge that our results and conclusions should be taken as first, exploratory examination of the efficiency of HP repetitive learning in young inexperienced and experienced drivers. Further research is needed to investigate weather gender differences are exist in HP in general and in repetitive training in particular. Despite the limitation of the sample, and the relatively lower statistical power of our results, our results are consistent with earlier studies in which greater statistical power were reported and which utilized eye trackers to monitor participants' eye movements and assess visual search strategies while observing driving scenarios (Fisher et al., 2007; Pradhan et al., 2009; Vlakveld et al., 2011). For example, Pradhan et al. (2009) reported 25% difference in fixation durations between trained young-inexperienced drivers and untrained peers and 17.9% difference in fixation rates towards "far transfer" objects that are akin to our hidden unmaterialized hazards. Similarly, Vlakveld et al. (2011) reported a difference of about 20% between trained and untrained young-inexperienced drivers with regards to correct anticipatory gaze direction towards latent hazards.

5. Conclusion

The current study serves as a preliminary indication for the efficiency of repetitive training without direct instruction procedure in increasing HP skills. Repetitive exposure to the same hazards resulted in enhanced ability among young-inexperienced drivers to seek and detect hazards in the right location when observing a potentially hazardous situation. Thus, the repetitive training procedure might be utilized as an effective off-road intervention to enhance young-inexperienced drivers' abilities to perceive a wide range of potentially hazardous situations.

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