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Facilitating hazard awareness skills among drivers regardless of age and experience through repetitive exposure to real-life short movies of hazardous driving situations

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1. Introduction

Recent evidence shows that young-inexperienced drivers are more likely to be involved in car crashes than their experienced counterparts, mainly due to their poor hazard anticipation abilities (e.g., Hafetz, Kallan, Winston, & Durbin, 2011; McKnight, & McKnight, 2003). Hazard anticipation, or hazard awareness (HA), may be defined as the ability of drivers to read the road and decipher the location from where a hazard instigator might enter the driver's path (Horswill & McKenna, 2004). HA abilities are often evaluated by visual searching tasks (e.g., Horswill, Garth, Hill, & Watson, 2017). Typically, drivers are exposed to short movies presented on a computer screen of real-world situations taken from the perspective of a driver who is driving along the road. Drivers' HA skills are assessed based on the number of hazards they identify and by their response time in pressing a button indicating that they had indeed identified the hazard (e.g., Borowsky & Oron-Gilad, 2013; Crundall, Andrews, Loon, & Chapman, 2010; Horswill, Hill, & Wetton, 2015; Mills, Parkman, Smith, & Rosendahl, 1999).

Research persistently shows that variance in HA depends not only on driving experience but also on the type of hazard to which drivers are exposed. Young-inexperienced drivers were as successful as experienced drivers in identifying hazard of which visual cues, or *precursors* (Crundall et al., 2012) that are directly related to the hazard and visible before their materialization, allowing for their prompt detection (e.g., a pedestrian walking on the pavement and then stepping onto the road). Driving experience, in contrast, is key to the identification of visual cues when hazard *instigators* (e.g., vehicle, pedestrian) are obscured by either the natural or built environment or by other road users that are not directly related to the hazard (e.g., a

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pedestrian obscured by a parked car). In these cases, where precursors are indirectly related to the actual hazard, experienced drivers anticipate the hazard much sooner than young-inexperienced drivers (e.g., Crundall, 2016; Crundall et al., 2012; Pradhan, Pollatsek, Knodler, & Fisher, 2009; Underwood, Chapman, Bowden, & Crundall, 2002; Vlakveld et al., 2011a).

Recently, based on hazards that best distinguish experienced and young-inexperienced drivers, Borowsky and colleagues proposed a new two-by-two cell taxonomy to describe road hazards (Borowsky & Oron-Gilad, 2013; Borowsky, Shinar, & Oron-Gilad, 2010). In their model, one factor is whether the hazard is materialized (actual) or unmaterialized (potential or latent), and the other is whether the hazard is visible or hidden by other road users or environmental factors. A materialized hazard is defined as a hazard where the source is in a colliding course with the driver, and it therefore calls for the driver's immediate response so as to avoid a crash (such as a bicyclist suddenly bursting from the sidewalk into the driver's travel lane). An unmaterialized hazard is defined as a hazard that should be monitored to determine whether it eventually materializes (e.g., a bicyclist who remains on the sidewalk throughout the scenario). A hidden hazard is a hazard instigator that is not visible at the time at which the hazardous situation begins (e.g., a pedestrian who is obscured by parked cars), whereas a visible hazard is in the driver's view (e.g., a pedestrian who is about to cross the road in plain sight). Combined, these two factors create four types of hazards: hidden materialized, hidden unmaterialized, visible materialized, and visible unmaterialized. A hidden materialized hazard refers to a hazard instigator that is initially obscured and hence is as yet unmaterialized. As the situation evolves, the hazard instigator becomes visible and moves into the driver's path evolving into a materialized hazard and requiring the driver to respond immediately so as to avoid a collision (such as a pedestrian who is first obscured by a parked bus but then walks onto the road).

As HA improves with practice (Horswill et al., 2015), it has often been the target of driving training. Traditionally, training programs are based on explicit, deliberate learning, via which young-inexperienced drivers are explicitly instructed to monitor the type of hazards they should be seeking and where they might be found (e.g., Crundall et al., 2010; Meir, Borowsky, & Oron-Gilad, 2014; Young, Chapman, & Crundall, 2014; Young, Crundall, & Chapman, 2017). Results of these training methods are encouraging, with some studies reporting contribution to HA improvement among young-inexperienced drivers (e.g., Crundall et al., 2010; Horswill et al., 2017, 2015; Pradhan et al., 2009; Thomas et al., 2016). Meir et al. (2014) suggested that the addition of an active engagement might facilitate HA training efficiency. Additionally, it has been shown that the incorporation of explicit components during training, such as asking participants to verbally acknowledge perception and cognitive processes they are experiencing (i.e., commentary training; Young et al., 2014), in parallel to the HA tasks might obscure the process of learning (Young et al.,2017). Interestingly, active training and low – instructional components during the training are both reminiscent of the core principles of skill acquisition (Cleeremans, Destrebecqz, & Boyer, 1998; Jackson & Farrow, 2005). Skill acquisition, also termed as procedural learning (Schacter, 1987) defined as non-deliberate way of learning, often studied via tasks where participants are asked to repeat a procedure without being explicitly instructed regarding the repetitive procedure (Esser & Haider, 2017; Haider, Eberhardt, Kunde, & Rose, 2013). In the case of visual attention and awareness, researchers suggest that memory of past events may guide our expectations, thereby helping us to determine where to look (Goujon, Didierjean, & Thorpe, 2015). Indeed, facilitation of response time is typically observed with respect to repetitive, compared with non-repetitive, configurations (Goujon et al., 2015; Li, Aivar, Kit, Tong, & Hayhoe, 2016; Schlagbauer, Müller, Zehetleitner, & Geyer, 2012; Zang, Zinchenko, Jia, Assumpção, & Li, 2018). Evidence of such a repetition effect on visual attention develops in the face of even a very small number (two to four) of repeated displays (Schlagbauer et al., 2012; Zang et al., 2018).

Considering that HA is a visual attention skill, that improves with the accumulation of driving experience, the aim of the current study was to investigate whether such repetition effect can be achieved in case of HA training. Therefore, the current study is aimed to investigate the effect of a repetitive procedural training method, in which young-inexperienced drivers and experienced drivers will be shown a repetitive presentation of the same hazardous situation, without being explicitly instructed about that. A learning effect supposed to be evident by the reduction of reaction time toward the hazards along the repetitions.

The common approach by which the acquisition of skills is evaluated involves transfer assessment tests aimed at determining the extent to which true learning has occurred (Schmidt & Bjork, 1992). HA training efficiency is also often measured through a transference effect. In a transference effect known as *far transfer* (Pradhan et al., 2009; Vlakveld et al., 2011a), the tested hazardous situations are unlike those to which participants were exposed through training, as opposed to *near transfer* scenarios, in which transference tests are based on similar scenarios as those viewed during training (Pradhan et al., 2009). The transferability of HA skill acquisition would be measured in the current study in a transfer assessment session where participants are asked to identify a new hazardous situation that they had not encountered in their training.

In summary, the novel training methodology used in the current study to assess improvement in the ability of young-inexperienced drivers to anticipate road hazards is based on principles of procedural learning. Learning was expected to occur as each participant individually viewed a series of short movies of various driving situations representing all four types of hazards described earlier. Each movie in the series was presented three times in a randomized order embedded within additional movies representing non-hazardous driving situations. Participants were asked to press a response button each time they identified a hazard. Their eye movement was additionally tracked through an eye tracker to which they were connected. Participants in the experiment group then participated in a post-training session in which the transference effect was assessed. In that session, participants viewed a series of two new movies representing the same types of hazards presented during training, each embedded only once within a series of movies representing non-hazardous situations. Each participant's task was identical to that introduced in the training session. An additional group of untrained young-inexperienced participants who underwent only the transfer assessment session served as the control group.

2. Research hypotheses

H1: *At baseline, before training, experienced drivers will demonstrate superior hazard identification performance compared with young-inexperienced drivers.*

H2: *Trained young-inexperienced drivers will demonstrate gradual improvement during the training session. Training will benefit young-inexperienced drivers more than it will benefit experienced drivers, and at the end of training, performance differences between the two groups will be smaller than differences measured at baseline.* The underlying assumption of this hypothesis is that experienced drivers already possess sufficient driving experience and would therefore benefit only to a small degree from a single training session lasting less than an hour.

H3: *Trained young-inexperienced drivers will benefit more from training on visible hazards compared with training on hidden unmaterialized (i.e., potential, latent) hazards.* We assumed that the identification of hidden unmaterialized hazards relies on substantial driving experience, requiring a higher order of cognitive skills such as anticipation and prediction that could not be fully gained within the short training session.

H4: *During the transfer assessment session, trained young-inexperienced drivers will demonstrate greater hazard detection rates with shorter response latencies compared to untrained young-inexperienced drivers.*

3. Method

Participants were shown a series of short movies as described below and were then asked to respond when identifying a hazard. Recorded responses were then analyzed.

3.1. Participants

Fifty-three drivers (33 men) participated in this study as paid volunteers and were divided into groups on the basis of age and driving experience. The group of young-inexperienced drivers comprised 32 participants (18 men) who were 17–18 years old (M = 17.48, SD = 0.5), with an average driving experience of 6.7 months (SD = 3.5). The group of older, experienced drivers comprised 21 participants (15 men) who were 23–40 years old (M = 31.0, SD = 7.66) with at least 5 years of driving experience (M = 144.50 months, SD = 97.14) The young-inexperienced drivers were randomly and equally assigned to two conditions: half of the group underwent our HA training, whereas the remainder did not participate in any training. All experienced drivers underwent our HA training. Participants in all three groups participated in the transfer skill assessment session.

Participants received monetary compensation of $11 for their participation. Young-inexperienced drivers were recruited from high schools in the cities of Modi'in and Beer-Sheva, and experienced drivers were students at Ben-Gurion University of the Negev (BGU) in Beer-Sheva or at Bar-Ilan University (BIU) in Ramat-Gan. The ethical committees of BIU and the Department of Industrial Engineering and Management at BGU respectively approved the experiments in each institute respectively.

3.2. Apparatus

3.2.1. Environmental settings

Participants at BIU observed all movies on a 17-inch LCD laptop display at a resolution of 1360 × 768 pixels. Participants at BGU observed all movies on a 20-inch LCD desktop display at a resolution of 1600 × 900 pixels. All participants sat at an average distance of 65 cm from the display. In both laboratories, participants' responses (pressing the space bar at BIU or a button at BGU) were recorded upon initiation by E-PRIME 2.0 software (Psychology Software Tools Inc., Pittsburgh, PA, USA). Additionally, participants' eye movements were monitored using eye tracking systems that were installed on a computer in each laboratory. The current study focuses on the analyses of behavioral responses, whereas eye movement variables are reported elsewhere (Kahana-Levy, Shavitzky-Golkin, Borowsky, & Vakil, 2018).

3.2.2. Hazard awareness movies

Participants were shown a series of repeated movies in each study session, all of which included sections of unmaterialized and materialized driving hazards. Each movie comprised real-world driving situations that were filmed from a driver's perspective in a typical Israeli landscape. The video input was filmed at a rate of 25 frames per second and at a resolution of 720 × 576 pixels, and then edited into five short (~40 s long) target movies (Table 1 and Fig. 1) and fifteen filler movies of non-hazardous situation were displayed. The purpose of the filler movies was to reduce any familiarity effects and maintain the ecological validity of the repetitive learning procedure. To control for a potential effect originating in the presentation order of the driving scenarios, four different sequences of target movies were generated and were counterbalanced among participants. All movies were adopted from previous work (Borowsky et al., 2010).

Table 1
Description of target HA movies.

Movie ID and name	Hazard type	Duration (ms)	Description		Responding participants E 21	TYI 16	UYI 16
TR-04, lead vehicle	Visible materialized	3420	The viewer-driver 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 in front of the viewer-driver	R1	19	12	NA
				R2	17	11	NA
				R3	16	13	NA
TR-20, parked truck	Hidden unmaterialized	6520	A truck is parked on the right side of an urban road, a few meters before a crosswalk at an intersection. The truck obscures a potential pedestrian (hidden hazard) that might burst into the road in front the truck	R1	13	7	NA
				R2	13	7	NA
				R3	12	7	NA
TR-26, parked bus	Hidden unmaterialized develops into 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 bursts into the road in front of the bus and develops into a visible materialized hazard	R1	20	14	NA
				R2	20	16	NA
				R3	19	15	NA
TS-03, roller- blades skater	Visible unmaterialized develops into visible materialized	5920	The viewer-driver drives on a residential road where cars are parked on both sides. After a few seconds, a visible roller blades skater appears 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 viewer-driver		20	14	12
TS-08 Pedestrian crossing	Hidden unmaterialized develops into visible materialized	6040	While driving on a two-lane one-way urban street, a vehicle in front of the viewer-driver is driving on the left lane and slows down before coming to a full stop in front of a crosswalk. The lead vehicle obscures the left side of the crosswalk from where a pedestrian might come down to the road (hidden unmaterialized hazard). When the lead vehicle comes to a full stop, the hazard visibly materializes, and a pedestrian indeed enters the road from the left in front of the lead vehicle		17	15	10

Note. TR, training phase; TS, transfer phase; TR and TS ID numbers correlate with our movie database and have no other meaning; E, Experienced drivers; TYI, trained young-inexperienced drivers; UYI, trained young-inexperienced drivers; R1 to R3, repetitions 1–3.

3.3. Experimental design

Half of the young-inexperienced drivers and all the experienced drivers underwent two consecutive sessions: (1) HA training followed by (2) HA skill transfer assessment. The other half of the young-inexperienced drivers participated in the skill transfer assessment only. Data were statistically analyzed separately for each session. Additionally, because each hazard type (visible materialized, hidden unmaterialized and hidden materialized) was represented by only one movie, analyses were conducted on each clip separately for each dependent variable.

3.3.1. Training session

During their training, participants separately observed three target HA movies, each representing one type of hazard (visible materialized hazard, hidden unmaterialized hazard and hidden materialized hazard), embedded among 12 filler movies. Each target movie was presented three times. 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 three reasons. First, all visible materialized hazards begin with a section in which

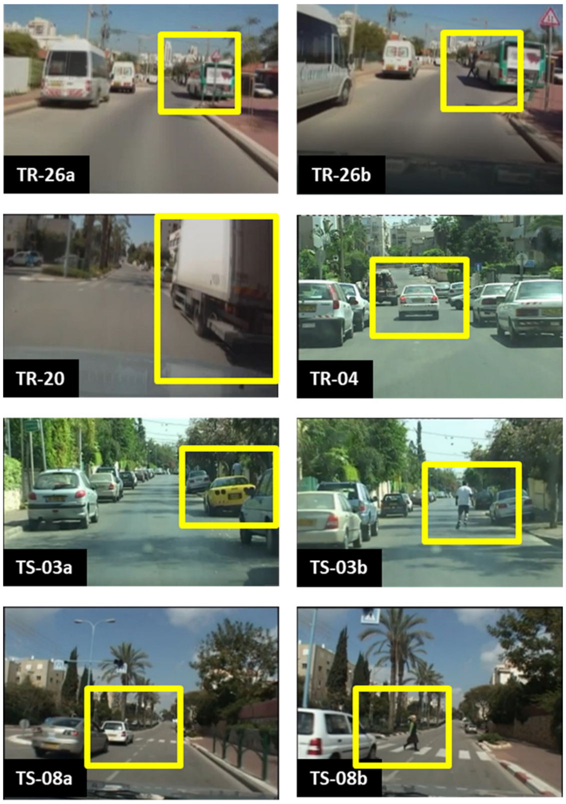


Fig. 1. Hazards shown in HA movies (TR, training phase, TS, transfer phase movie). TR-04, lead vehicle – materialized visible hazard. TR-20, parked truck – unmaterialized hidden hazard. TR-26, parked bus: TR26a – hidden hazard (frame at 2000 ms from the initial appearance of the hazard); TR26b – visible 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).

the visible hazard is yet unmaterialized. Second, we wanted to maintain the lack of awareness of the participants to the repetitive nature of the task, assuming that more repetitions might elicit the awareness of the participants. Third, increasing the number of filler scenarios between repetitions was thought to reduce potential learning effects (Zang et al., 2018). In total then, participants observed nine target movies (3×3 repetitions) embedded among twelve filler movies (4×3 repetitions). In this 2×3 mixed design, the first between-subjects independent variable was driving experience (experienced drivers and young-inexperienced drivers). The within-subjects independent variable included three levels (per each repetition). The learning slope was measured by changes in the dependent variables along the three repetitions.

3.3.2. Skill transfer session

During the skill transfer assessment session, aimed at examining drivers' ability to transfer to novel situations the HA they acquired during training, participants observed an additional set of two new HA movies. Each movie included a two-section hazardous scenario: in the first section, the hazard instigator was unmaterialized, whereas in the second section the hazard instigator became materialized. The hazard was visible in one movie and hidden in the other. In this 3×2 mixed design, the first between-subjects' independent variable was the experimental group (experienced drivers, trained young-inexperienced drivers, and the control group of untrained young-inexperienced drivers). Because our purpose was to assess training effectiveness with young-inexperienced drivers and compare their performance after the training with that of untrained young-inexperienced drivers, we did not include a group of untrained experienced drivers in the skill transfer assessment session. Furthermore, a large body of evidence already shows that untrained experienced drivers possess better HA skills than both trained and untrained young-inexperienced drivers (e.g., Crundall, 2016; Crundall et al., 2012; Pradhan et al., 2009; Underwood et al., 2002; Vlakveld et al., 2011b). The within-subjects' independent variable in the skill transfer assessment session was the state of the hazard: unmaterialized or materialized. The ability of drivers to generalize the knowledge they gained during the training session to novel situations shown in the skill transfer assessment session was measured by comparing performance during the latter session of trained drivers (both experienced and young-inexperienced) with that of untrained young-inexperienced divers.

3.4. Procedure

Upon their individual arrival at the laboratory, participants were asked to sign an informed consent form and fill in details about their driving history and demographic background. Participants were then asked to sit before the display and read the experimental instructions. All participants were given the hazard definition of Haworth, Symmons, and Kowaldo (2000), p. 3, described in Borowsky et al. (2010). Next, participants were told that they would be connected to an eye tracker that records their eye movements throughout the study. After a short calibration process, participant observed several practice movies to help them become familiar with the experimental setup and equipment. Participants were asked to observe each movie as the driver in each situation and to press the response button (in BGU) or the space bar (in BIU) each time they identified a hazard. Participants were explained that the movie will not cease in case of responding and therefore were requested to response only once to each hazard they identify. Once participants felt comfortable with the experimental task, they were asked to complete both the HA training session and skill transfer sessions if they were in the training group, or only the skill transfer session if they were in the control group. Participants were debriefed at the end of the skill transfer assessment session. The full procedure took approximately 40 min without breaks.

3.5. Data preparation of behavioral responses and dependent variables

The first step was to extract participants' behavioral responses from the movie segment during which hazards occurred, that is, from the moment the hazard or its preliminary cues (precursors) first became visible the moment the observer-driver vehicle had passed the hazard and thus responding was no longer relevant. The beginning of a hazard was defined as the minimum of all button presses and the end of the hazard was defined as the last response made by any of the participants that was still relevant for the hazard. To reflect the development of scenarios involving hidden materialized and unmaterialized hazards, continuous time window segments in each scenario were binned into two subsections (Table 2). The next step was to calculate the time of identification and reaction time (RT) for each hazard segment per participant.

Following data preparation, two dependent variables were defined. The first, response sensitivity, was the main dependent variable signifying 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(one), whereas a response outside that time frame (before or after it) or no response was awarded the score of "0″ (zero). This binary variable was calculated for each participant and every segment of every hazard. The percentage of participants who correctly identified the hazard was also calculated for each independent variable. The second dependent variable, *Normalized Reaction Time* (NRT), was defined as the time interval in milliseconds between the beginning of the hazardous event and the first response associated with the hazard, divided by the total duration of the hazardous event. It was calculated only for those responses that scored 1, whereas all other responses were calculated with the value of "no response". To linearly regress this variable, we applied a natural logarithmic transformation (LN) on RT. For example, for a hazardous event beginning at 12,000 ms with a total hazard segment duration of 9000 ms for which the participant's first response was recorded at 15,000 ms, the computed normalized RT amounts to (15,000–12,000)/9000 = 0.33, or −1.10 on a logarithmic scale.

Table 2
Description of hazard development over interval subdivisions.

Type of hazard	First section	Second section
Visible materialized	The hazard is in its visible unmaterialized form	The hazard materializes and 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 become materialized
Hidden and unmaterialized	During the first section of the hazardous situation the AOI is the visible cue which obscures the view of a potential hazard instigator. For example, a parked truck on the right side of the road obscuring a possible pedestrian	The next section begins at the moment when a different cue becomes visible to the driver, 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). For example, when a zebra crossing in front of the truck became visible. This section ended when the participant's vehicle passed away the second cue (e.g., the zebra crossing)

Table 3
A summary of the significant effects and post hoc analyses across dependent variables in Movie TR-04.

	Effect		M1	M2	M3	Post hoc repetitions
Response sensitivity	Repetition		0.84	0.76	0.78	N.S.
	Group	TYI	0.75 (0.01)	0.72 (0.01)	0.81 (0.01)	
		E	0.90 (0.02)	0.80 (0.01)	0.78 (0.01)	
	Post hoc		N.S.			
NRT	Repetition		0.90 (0.02)	0.84 (0.03)	0.77 (0.03)	M1 > M3, $p < .01$
	Group	TYI	0.90 (0.02)	0.83 (0.03)	0.73 (0.05)	
		E	0.91 (0.03)	0.85 (0.04)	0.81 (0.04)	
	Post hoc				TYI < E; $p < .01$	

Note: M1-M3, Estimated means (SE) of the dependent measure on repetitions 1–3; TYI, Trained Young-inexperienced drivers; E, Experienced drivers; UYI = Untrained young-inexperienced drivers; NRT, Normalized reaction time; N.S., Not significant.

3.6. Statistical analyses

All main effects and second-order interactions of the fixed effects were included in the model, using SPSS Version 22.0 (Table 3). Participants were included as a random effect. The two-way α value was set at 5%. To assess whether any differences in the dependent variables were due to group, repetitions, or hazards type, fixed and random effects were evaluated through a mixed-model design analysis. Within this framework, we used a binary logistic regression method to assess *response sensitivity* with a logit link function and a random intercept, whereas NRT was linearly regressed with a random intercept (generalized linear mixed model effect, GLMM). The final model was achieved via a backward elimination procedure starting from the full model. For significant fixed effects, a post hoc pairwise comparisons procedure was applied using the Bonferroni method. Response sensitivity was analyzed through Wald chi-square.

4. Repetitive training results

4.1. Repetition analysis: Visible materialized hazard (Movie TR-04)

No significant differences were found in response sensitivity between groups or across repetitions. In contrast, a significant decrease was found in NRT across repetitions ($F_{2,60} = 9.95$, $p < .01$, Table 2, Row 6). A significant main effect was found for groups ($F_{1,118} = 9.09$, $p < .01$), revealing lower NRT in young-inexperienced drivers compared with experienced drivers. An interaction effect between group and repetition ($F_{6,180} = 3.99$, $p < .05$) revealed that trained young-inexperienced drivers reacted faster than trained experienced drivers during the third repetition (Table 2, Row 9).

4.2. Repetition analysis: Hidden unmaterialized hazard (Movie TR-20)

Analyzing response sensitivity during each scenario as a whole did not yield significant results when analyzed per group by repetition. We therefore reanalyzed the data based on the binned time windows that reflect the hazard's development throughout the scenario. Under such conditions, a significant third-order interaction effect was established for group, repetition, and section at the third repetition. It showed that experienced drivers were more likely (41.4%) to respond to the hidden unmaterialized hazard farther away from the hazard compared with young-inexperienced drivers (27.6%) (X^2 (2) = 4.43, $p < .05$). Additionally, $F_{2,10,333} = 11.27, p = 0.001$) both trained driver groups (experienced and young-inexperienced) showed faster reaction time (gradual decrease in NRT) to unmaterialized hidden hazard across repetitions ($F_{1.45,34.91} = 6.01$, $p < 0.01$, Table 3 Row 6). Comparing the performance of the two groups, trained young-inexperienced drivers exhibited faster NRT (Table 4, row 9) at the beginning of the training phase compared with experienced drivers, but this

Table 4
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TR-20.

	Effect		M1	M2	M3	Post hoc repetitions
Response sensitivity	Repetition		0.54	0.54	0.51	N.S.
	Group	TYI	0.44 (0.01)	0.44 (0.01)	0.44 (0.01)	
		E	0.62 (0.02)	0.62 (0.02)	0.57 (0.02)	
	Post hoc		N.S.			
NRT	Repetition		0.78 (0.07)	0.60 (0.08)	0.53 (0.08)	M1 > M3, $p < .01$
	Group	TYI	0.68 (0.10)	0.61 (0.10)	0.47 (0.10)	M1 > M3, $p < .01$
		E	0.86 (0.06)	0.59 (0.10)	0.57 (0.10)	M1 > M2, M1 > M3, $p < .01$
	Post hoc		TYI < E, $p < .05$			

Table notes as in Table 3.

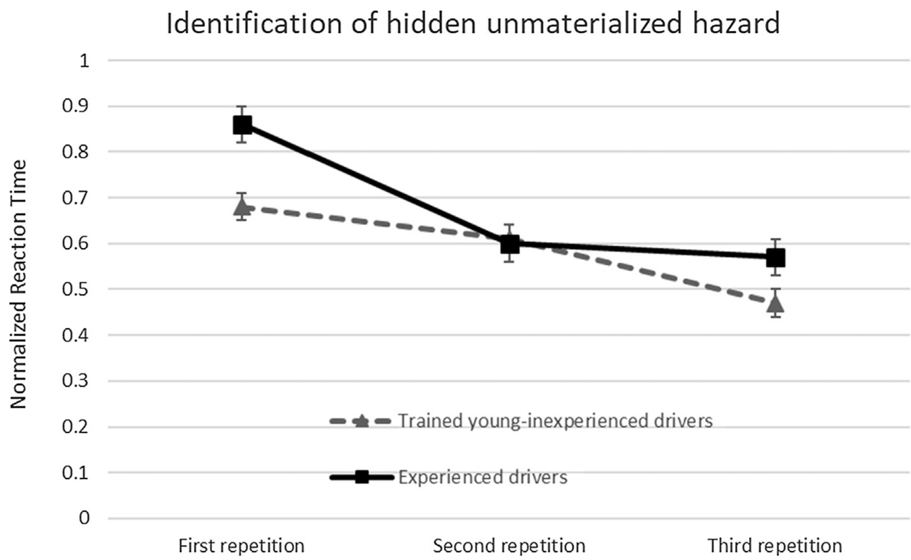


Fig. 2. Normalized reaction time to hidden unmaterialized hazard across repetitions by experienced and young-inexperienced drivers (Movie TR-20).

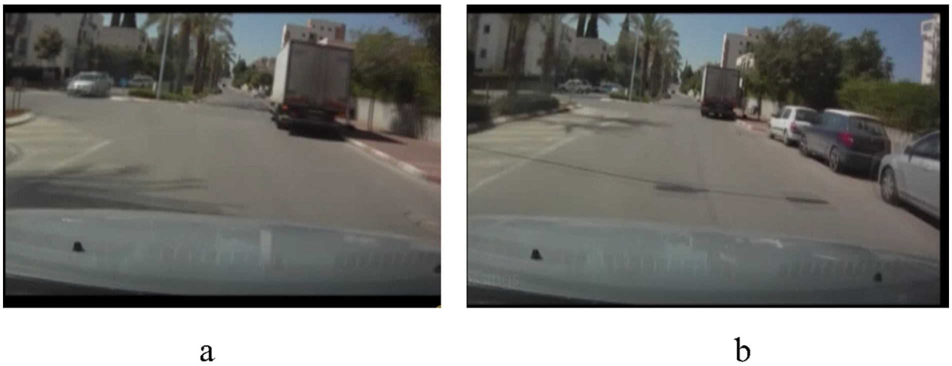


Fig. 3. Improvement in average NRT to the appearance of a hazard precursor (truck blocking the view on the right side of a crosswalk) by young-inexperienced drivers. (a) Identified on first repetition at 4200 ms; (b) Identified on third repetition at 2400 ms, 1800 ms earlier than their NRT on first repetition.

difference became smaller during the second and third repetitions. However, whereas NRT of experienced drivers decreased to an equal level on repetitions two and three compared with repetition one (Table 4, row 9), NRT of young-inexperienced drivers declined more gradually so that only repetition 3 significantly differed from repetition 1 (Table 4, Rows 7–8 and Figs. 2, 3a, and b).

4.3. Repetition analysis: Hidden materialized hazard (Movie TR-26)

Response sensitivity analysis did not yield significant results. In contrast, the NRT of both experienced and young-inexperienced drivers gradually declined in response to a materialized hidden hazard ($F_{2,70} = 5.72$, $p < .01$, Table 5, Row 6). Post hoc comparisons revealed that this gradual decline was significant only for the young-inexperienced drivers (Fig. 4 and Table 5, Row 7).

In summary, significant variability was mostly found for NRT of trained experienced and young-inexperienced drivers. Experienced drivers exhibited reduced NRT only in response to unmaterialized hidden hazards and only between the first and second repetitions. In line with a reduction in NRT toward hidden unmaterialized hazards by experience drivers, these drivers also demonstrated greater response sensitivity than young-inexperienced drivers at the third repetition. Indeed, for hidden unmaterialized hazards, young-inexperienced drivers also showed a learning curve, although less salient, which was reflected in a significant reduction of their NRT only between the first and third repetitions. Furthermore, only young-inexperienced drivers demonstrated reduced NRT in response to the visible materialized hazard across repetitions. These

Table 5
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TR-26.

	Effect		M1	M2	M3	Post hoc repetitions
Response sensitivity	Repetition		0.92	0.97	0.92	N.S.
	Group	TYI	0.87 (0.01)	1 (0.01)	0.94 (0.02)	
		E	0.95 (0.01)	0.95 (0.01)	0.90 (0.01)	
	Post hoc		N.S.			
NRT	Repetition		0.63 (0.03)	0.57 (0.03)	0.54 (0.03)	M1 > M3, $p < .01$
	Group	TYI	0.62 (0.03)	0.58 (0.03)	0.51 (0.05)	M1 > M3, $p < .05$
		E	0.64 (0.04)	0.56 (0.04)	0.57 (0.04)	
	Post hoc		N.S.			

Table notes as in Table 3.

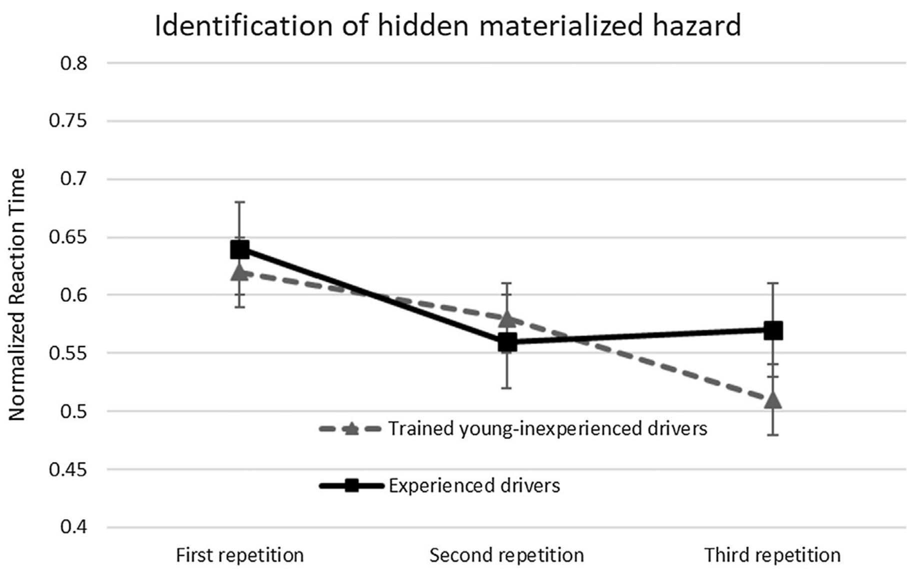


Fig. 4. Reaction time to a hidden materialized hazard across the repetitions by experienced and young-inexperienced drivers (Movie TR-26).

results indicate that both experienced and young-inexperienced drivers had achieved some learning during the training session reflected in their faster responses to hazards across repetitions. While both groups demonstrated a learning slope with respect to the hidden hazard, learning occurred only among young-inexperienced drivers with respect to the materialized visible hazard.

4.4. Skill transfer assessment session

Analyses of the transfer session considered driver groups as a between-subjects independent variable and the bin representative of the hazard scenario development phase (unmaterialized vs. materialized) as the within-subjects independent variable (Tables 6 and 7).

4.5. Visible unmaterialized and materialized hazards (Movie TS-03)

Where the hazard was visible throughout the scenario, response sensitivity of both trained groups was higher than that of the group of untrained drivers, especially within the unmaterialized movie segment (X^2 (2) = 7.62, $p < 0.05$). Similarly, both trained groups responded faster to the hazard during its unmaterialized phase than the untrained young-inexperienced drivers ($F_{3,69} = 6.93$, $p < .01$, Table 6, Row 6). There were, however, no differences in NRT between trained and untrained drivers during the materialized phase of the hazard (Table 6, Row 7).

4.6. Hidden unmaterialized and materialized hazard (Movie TS-08)

Where the hazard was hidden until materialized, although both trained groups tended to detect the hidden hazard more often than the untrained young-inexperienced drivers, these differences in response sensitivity were insignificant. Data

Table 6
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TS-03.

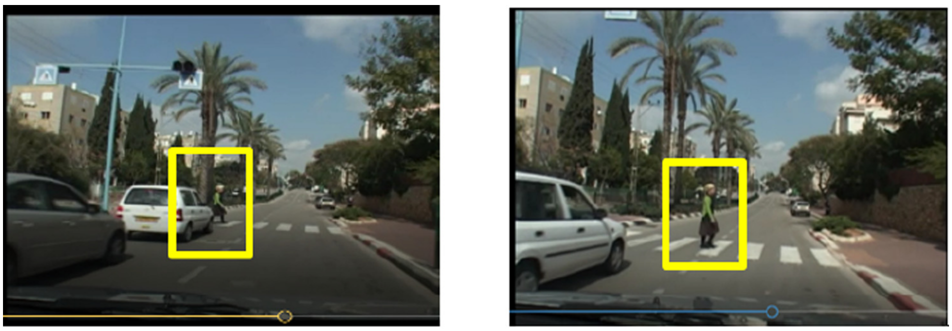
	Effect		UYI	TYI	E	Post hoc
Response sensitivity	Group		0.75 (0.02)	0.87 (0.02)	0.95 (0.02)	UYI < E, p = .09
	Phase	UM	0.19 (0.02)	0.37 (0.02)	0.45 (0.02)	E > UYI, TYI > UYI, p < .05
		M	0.56 (0.02)	0.50 (0.02)	0.52 (0.02)	
NRT	Group		0.83 (0.04)	0.80 (0.05)	0.80 (0.04)	N.S.
	Phase	UM	0.12 (0.05)	0.06 (0.05)	0.08 (0.03)	UYI > TYI, p < .01; UYI > E, p < .05
		M	0.81 (0.04)	0.80 (0.02)	0.80 (0.01)	

Table notes as in Table 3.

Table 7
A summary of the significant effects and post hoc analyses across all dependent variables in Movie TS-08.

	Effect		UYI	TYI	E	Post hoc
Response sensitivity	Group		0.63 (0.01)	0.96 (0.01)	0.81 (0.01)	N.S.
	Phase	UM	0.37 (0.01)	0.46 (0.01)	0.43 (0.01)	
		M	0.25 (0.01)	0.50 (0.01)	0.38 (0.01)	
Norm. RT	Group		0.41 (0.09)	0.26 (0.07)	0.24 (0.06)	UYI > TYI, UYI > E, p = 0.06
	Phase	UM	0.13 (0.03)	0.11 (0.01)	0.10 (0.02)	
		M	0.68 (0.04)	0.41 (0.03)	0.34 (0.04)	UYI > TYI, p < .05; UYI > E, p < .05

Table notes as in Table 3.



a b

Fig. 5. Representative frames of the hazard (pedestrian crossing the road started obscured by a stopping car and eventually becoming full visible) in Movie TR-08, (a) 4700 ms and (b) 6000 ms after the initial appearance of the hazard's precursor, corresponding to the estimated NRT of trained (a) and untrained (b) driver groups.

obtained from drivers in both groups did not significantly differ from that of other groups, and all demonstrated a downward trend in NRT compared with the untrained young-inexperienced drivers ($F_{2,49}$ = 2.92, p = .06, Table 7, Row 5). The interaction effect $F_{7,51} = 61.22, p = 0.00$)between groups and hazard development phases revealed significantly faster NRT at the materialized phase of the hazard among both groups of trained drivers (Fig. 5) compared with the untrained young-inexperienced group ($F_{7,51}$ = 6.22, p < .01; and see Table 7, Row 7).

In summary, in line with our hypothesis, compared with untrained young-inexperienced drivers, trained drivers were faster to respond to both unmaterialized and hidden materialized phases of hazards shown during the skill transfer assessment.

5. Discussion

The hypotheses drawn in this study were partially confirmed. On the coming paragraphs we first refer to conclusions that might address each of the current research hypotheses and then consider broader theoretical implications of our results.

We first hypothesized that under baseline conditions (first presentation of the hazard during the training phase), experienced drivers will better identify hazards compared to young-inexperienced drivers. Both NRT and response sensitivity measurements did not reach significance levels, and we were therefore unable to discriminate between experienced and young-inexperienced drivers based on their response to hazards during the baseline conditions, unlike previous findings (Borowsky & Oron-Gilad, 2013; Crundall, 2016; Vlakveld, 2014). Nevertheless, consistently, experienced drivers tended to respond to hidden materialized hazards more often and sooner than did young-inexperienced drivers. We suggest that methodological limitations of the study, discussed next, might provide insights regarding these discrepancies. The lack of statistical significance may be attributed to insufficient statistical power. We thus suggest future replication of the current methodology on a greater number of participants in each of the groups. In addition, we suspect that unlike the NRT measure, response sensitivity was not sensitive enough to capture the learning effects of our repetitive training methodology. This could be related to the fact that the HA intervention was primarily designed as a response time measure rather than a hit-rate test. The driving scenarios we opted to include in the HA intervention were selected in part because we believed it was likely that most drivers would eventually respond to them (which, indeed, they did). Consequently, the near-ceiling response sensitivity in both groups seems to have obscured the differences between them. Additionally, the advantages in utilizing various training method and the importance of the interaction between them must also be recognized (Sun, Slusarz, & Terry, 2005; Yordanova, Kirov, & Kolev, 2015). We thus also suggest increasing effect size by elaborating our training procedure and including a supplementary explicit component that has already been demonstrated by others and to have improved awareness toward hidden hazards by young-inexperienced drivers (e.g., Horswill, 2016; Horswill et al., 2017; Meir et al., 2014). Finally, these results may be attributed to the relatively short training session in this study. If young-inexperienced drivers indeed benefit from a repetitive training procedure, perhaps longer repetitive training would increase its effect.

The surprising fact that young-inexperienced drivers reacted faster than experienced drivers toward the hidden unmaterialized hazard must be interpreted considering that NRT was calculated selectively only in cases where the hazard was actually detected. In effect, then, the lower NRT represents only 44% of the young-inexperienced drivers in our study.

The second hypothesis was that compare to experienced drivers, young-inexperienced drivers will benefit more from the repetitive training procedure. In our research, however, both types of drivers benefited from the repetitive training procedure. Specifically, during the training phase, both groups showed a gradual reduction in NRT to both materialized and unmaterialized hidden hazards, indicating that both groups improved their HA skills.

We also hypothesized that HA performance differences between experienced and inexperienced drivers during the repetitive training procedure will depend on the type of the hazard. This hypothesis was partially confirmed. We found out that when the hazard developed into a materialized one, regardless of whether it was hidden or visible at the onset, only young-inexperienced drivers benefited from the training. This was reflected in the significant reduction in NRT between the first and third repetitions (Table 5, Row 6) whereas the NRT of experienced drivers remained constant across all three repetitions (Table 2, Row 7; Table 5, Row 7). Moreover, by the third repetition, the NRT of young-inexperienced drivers was significantly lower than that of experienced drivers (Table 3, Row 8). When the hazard was unmaterialized, and its indicators were different from the hazard instigator itself (and therefore it could not have been easily detected), both groups benefited from the training. Notably, experienced drivers demonstrated a greater reduction in RT between the first and second repetitions (27%, Table 4, Row 8) compared with young-inexperienced drivers (7% Table 4, Rows 7). Furthermore, by the third repetition, experienced drivers were more likely (13.8%) to detect the hazard precursor in such complex scenarios compared with young-inexperienced drivers.

The results regarding the second and the third hypotheses might lead to two conclusions. First, young-inexperienced drivers gradually adapted their responses toward various kinds of materialized hazards, slowly becoming better at predicting the hazard as the training progressed. Second, compared with young-inexperienced drivers, experienced drivers adapted their responses selectively, only toward hidden unmaterialized hazards, and not toward more salient materialized hazards. It is possible that training indeed increased HA awareness among young-inexperienced drivers with respect to materialized hazards, whereas experienced drivers were aware of the hazard throughout the scenario but elected to respond to it only when it was in closer proximity to them. Nevertheless, when the hazard was unmaterialized and hidden, and therefore its indicators could not have been easily detected, experienced drivers, similar to young-inexperienced drivers, were less aware of the hazard during their first encounter with it. In this scenario, training would seem to have helped experienced drivers develop their HA because they had indeed adapted their responses and responded faster to the hazard. Our training procedure was less effective for young-inexperienced drivers who demonstrated a slower and less salient learning curve with respect to unmaterialized hidden hazards. Should this be the case, it supports the hypothesis that the predictive demands of the hazard situation serve as a key discriminator between experienced and young-inexperienced drivers (Borowsky & Oron-Gilad, 2013; Crundall et al., 2012; Crundall, 2016; Vlakveld, 2014).

We were also able to confirm our last hypothesis about the transference effect that should appear in the trained groups compare to the untrained group. Indeed, learning through repetitions helps all drivers, whether they are experienced or young-inexperienced, to become more aware of hazard precursors that are different from those to which they were exposed during training. During the skill transfer assessment session, compared with untrained young-inexperienced drivers, both groups of trained drivers showed superior response sensitivity and NRT performance with respect to the identification of hazard precursors. For example, experienced drivers and trained young-inexperienced drivers were both able to detect visible materialized hazard almost twice more frequently than untrained young-inexperienced drivers (37–45% in the trained groups compare to 19% in the untrained group, Table 6, Row 3). One might argue that the use of the transference effect (Pradhan et al., 2009; Vlakveld et al., 2011a) as a means to test the effectiveness of our repetitive learning procedure is less favorable because the movies presented during the skill transfer assessment session differed from those that were presented during the training phase, thus limiting the ability to compare participants' performance between the sessions. Indeed, further investigations can address this concern by apply a different testing method. For instance, measuring responses to the same scenario after a time interval (Tagliabue, Gianfranchi, & Sarlo, 2017) may enable comparisons between participants' responses during the training and skill transfer assessment sessions.

Finally, we will address more theoretical aspects of our results. In the current study, we were able to generalize the benefits of repetitive training to the field of visual attention and awareness in driving. Our results are in line with those from previous studies in the field of visual attention (e.g., Zang et al., 2018). One possible explanation to the learning effect of the repetitive exposure is that single scene enhances implicit visual memory of that scene, which in turn, facilitates efficacy of visual scanning (Brockmole & Henderson, 2006). That is, over the course of repetitive conduct of the same requested behavior (Salas & Cannon-Bowers, 2001; Willingham, Nissen, & Bullemer, 1989), learners are expected to inadvertently self-adapt their behavior to increase precision and rapidness (Willingham, 1999). Behavior is adapted based on previous experience, without outsourcing instructions. Accordingly, in the current study, drivers' improved NRT to repetitive hazards might reflect an implicit memory effect, which is considered to be the first step in learning through appraisal that relies on the memories of our previous experiences in similar situations (Damasio, 1994; Willingham, 1999). Nevertheless, some shortcomings of the current training method limit the compatibility of the suggested implicit learning explanation: During our experiment, we did explicitly direct the participants' attention toward hazards, although we did not supply them any specific rules, cues, or other explicit knowledge. Such an intervention, although it does not trigger a completely incidental learning, it is not as direct as explicit instruction, since performers are guided generally but are left to discover on their own the relationships between cues or movement patterns and behavioral outcomes (Jackson & Farrow, 2005). Furthermore, the repeated exposure to the hazards' evolvements might provide an undeliberate, subtle feedback to the participants. Thus, it seems reasonable to argue that changes that were observed during the repetitive training might results not only from an implicit, self-adaptation procedure but also reflect the effect of a more deliberate intervention and a feedback effect.

An alternative explanation for the RT reduction across repetitions can be viewed as a self-adjustment process that occurs during skill acquisition. According to the 'error learning' theory (Keith & Frese, 2008), errors that inevitably occur during learning methods that rely on active engagement and low-instructional demands, facilitate a better problem solving meta-cognitions such as planning a head and flexible thinking (Ivancic & Hesketh, 2000). Accordingly, the repetitive learning effect in the current study might reflect an error learning. In this view, by becoming more aware of the hazards, participants tried to overcome a previous missing-error of detection of a driving scenario that evolved eventually to hazardous situation, such as the 'hidden materialized' hazard video clip. Further investigation should address the question about the nature of the mechanism that underlies the repetitive training effect.

By applying a repetitive training method, we yielded results similar to those of other training methods that have explicated a causal relationship between cues or response patterns and relevant behavioral outcomes (e.g., Pradhan et al., 2009; Young et al., 2014). For example, the study of Horswill et al. (2017) involved feedback in addition to repetitive scenarios. Having watched driving movies during an HA skill transfer test phase, participants were briefly presented with two alternative types of feedback. All participants were shown a graph-based comparison of HA response times of the participant, the average driver, and an expert driver. One group, however, additionally watched movies from the HA skill transfer test phase for the second time. Both types of feedback led to an improvement of 1–1.5 s in RT among members of both intervention groups compared with the control group that had not received any feedback. In our study, we achieved similar results by extending the repetitive presentation method and providing less salient feedback improved NRT of young-inexperienced at the rate of 0.4–1.8 s between pre-training and post-training and a difference of approximately 1.5 s in NRT of trained and untrained young-inexperienced drivers in one of the movies assessed during the skill transfer assessment session. These results suggest that the repetitive presentation of hazardous scenarios and the feedback methods hold similar learning potential.

To summarize, by adopting skill acquisition theory and methodology, the present study focused on a learning process in which experienced and young-inexperienced drivers adapted responses to repeated hazardous situations. Our limitations notwithstanding, the study's findings confirm the contribution of a repetitive training methodology to the enhancement of HA skills among young-inexperienced drivers and experienced drivers.

Conflict of interest

All authors report no disclosures or conflict of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2018.09.021.

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