Individual differences predict drivers hazard perception skills

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Abstract: Detecting dangerous driving scenarios has been shown to be affected by driving experience, risk-taking or risk perception, and visual search. Given that the results are largely mixed, it is important to understand which individual differences affect drivers' hazard perception abilities. Three hundred ninety-eight drivers recruited throughout the USA participated in an online study by completing a hazard perception video task, two visual perception tasks, and surveys. A latent structural equation model was evaluated finding that visual perception skills and knowledge of traffic laws predicted hazard perception skills. Unlike much of the existing literature, driving experience and risk perception did not predict hazard perception skills. Additionally, the results of a latent structural equation mediation model revealed that driving experience did not mediate the relationship between hazard perception skills and knowledge of traffic laws. These results may prove useful in redesigning training programs and targeting the most susceptible individuals to decrease crash risks.

Keywords: crash risks; driving experience; driving skills; hazard detection; hazard perception; individual differences; SEM; structural equation modelling; traffic laws; USA; visual perception.

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1 Introduction

Drivers differ in their ability to detect and respond to dangerous events while driving – a phenomenon which has been termed hazard perception (Borowsky et al., 2010; Egea-Caparrós et al., 2016; Horswill, 2016; McKenna et al., 2006). More formally, the hazard perception process consists of:

a perceiving a dangerous or potentially dangerous event

b identifying the event using visual selective attention

c comprehending the event

d responding, if necessary, with an adequate manoeuvre to avoid a crash.

Research has shown that automobile crashes resulting from poor hazard perception skills (Egea-Caparrós et al., 2016; Horswill, 2016; Lim et al., 2013; McDonald et al., 2015a) can be prevented through training (Thomas et al., 2016), indicating that such skills are subject to experiential learning and modifiable. Hazard perception skills are affected by driving experience (Borowsky et al., 2010; Huestegge and Böckler, 2006; Lee et al., 2008; McDonald et al., 2015a; McKenna et al., 2006; Pollatsek et al., 2006), risk perception (Elvik, 2010; McDonald et al., 2015a; Pollatsek et al., 2006; Underwood et al., 2005), visual perception (Garay-Vega et al., 2007; Lee et al., 2008; Martens and Fox, 2007; Pollatsek et al., 2006; Trick et al., 2004), and age (Scialfa et al., 2012). Though, much of the current research suggests that the efficacy in detecting and responding to such events is best predicted by driving experience.

It should be noted that there are consistent limitations in interpreting the results from studies measuring the relationship between drivers' hazard perception skills and driving experience. For one, in these studies (e.g., Crundall, 2016; Huestegge and Böckler, 2006; Huestegge et al., 2010; Lim et al., 2013; Parmet et al., 2015; Smith et al., 2009; Underwood et al., 2002; Vensislavova et al., 2016), driving experience is evaluated as a dichotomous variable (i.e., novice, experienced). Categorising drivers in such a way eliminates a large population whereby only drivers with at most three years of experience (novice) and drivers with more than seven years of experience (experienced) are evaluated. In some studies, individuals with only a learner's permit were included in the novice drivers' group (Garay-Vega et al., 2007; Huestegge et al., 2010). There are likely other factors which affect driving experience rather than just the number of years driving such as, average miles driven per week, type of driver's license received, and the state of licensure. It is possible that receiving a driver's license in more than one state could advance drivers' experiential skills in driving in a variety of environments. For instance, drivers need to execute tactic (e.g., interacting with other drivers) and strategic (e.g., route planning) controls when driving in complex or urban environments (Paxion et al., 2014). Likewise, a certain aptitude in vehicle control and manoeuvring is required to safely drive under various adverse weather conditions (Mueller and Trick, 2012) such as snow, rain, high wind gusts, and fog – scenarios that are common in parts of the USA. Knowledge of traffic laws may also influence driving experience and hazard perception skills. In a qualitative study, drivers reported knowledge of traffic laws as being an important factor in successful hazard detection (Barragan and Lee, 2019).

From a methodological standpoint, McDonald et al. (2015a) emphasised the importance for future research to explicitly state the criteria used to categorise drivers into experience-based groups – an important distinction, which currently varies across existing studies. Potential remediations could be to analyse driving experience as a latent or continuous variable. Second, driving experience cannot explain in entirety why drivers; hazard perception skills differ. For example, regardless of driving experience, drivers need to be able to perceive and identify that a scenario may become hazardous – processes which rely heavily on visual perception abilities (Lee et al., 2008; Martens and Fox, 2007; Pollastek et al., 2006; Trick et al., 2004). In support, Borowsky et al. (2016) found that regardless of driving experience, when the visual field was interrupted, drivers perform poorly on hazard tasks. Likewise, Malone and Brünken (2020) found that eye movements (i.e., fixation latency) on a hazard depend on the nature of the hazard response task (e.g., button press, mouse click, verbalise). Though, much of the current literature suggests that regardless of visual attention control, novice drivers are worse at anticipating (McDonald et al., 2015a; McKenna et al., 2006; Pollastek et al., 2006), perceiving (Lee et al., 2008), or responding (Huestegge and Böckler, 2006) to hazards compared to experienced drivers.

Visual perception abilities, in relation to hazard perception may be best understood by the selective attention framework developed by Trick et al. (2004). Of interest to the present study, visual perception involves the processes of orienting and searching for stimuli (Trick et al., 2004). Visual orientation is the process of reorienting attention to stimuli in unpredictable locations (Trick et al., 2004). This process is engaged when detecting abrupt hazards without prior hazard anticipation cues. Similarly, visual search is necessary for hazard identification to locate relevant information (Trick et al., 2004), which may be related to a driver's ability to detect hazard anticipation cues. In support, Martens and Fox (2007) found that when a drive is familiar, hazard anticipation cues are likely to be missed due to errors in visual search. These results suggest that visual search is a key component in the initial hazard perception stage. Alternatively, Lee et al. (2008) suggest that accuracy in visual search is explained by driving experience such that, novice drivers have poor hazard anticipation due to inadequate visual search skills (i.e., not knowing where to search for cues). In addition to driving experience, individual differences in visual perception are affected by other factors such as working memory (Bleckley et al., 2003) and age (Takahashi et al., 2017). Therefore, visual perception, specifically, orienting and searching, is an important aspect in the hazard perception process and deserves further evaluation.

Research has also examined the relationship between risk-taking and hazard perception skills (Elvik, 2010; McDonald et al., 2015a; McKenna et al., 2006; Pollatsek et al., 2006; Underwood et al., 2005). McKenna et al. (2006) explained that novice drivers have poor hazard anticipation (i.e., using cues to predict whether a scenario will become hazardous) skills because they lack risk perception and awareness skills. Alternatively, Elvik (2010) stated that young drivers have an increased crash risk because they deliberately engage in risky behaviour while driving. In this view, the propensity of risk-taking is dependent upon driving experience, but the awareness of consequences associated with risk-taking such as an increased crash risk, may be incidentally related to hazard perception. In other words, the relationship between driving experience and risk-taking as described by McKenna et al. (2006) could suggest that this relationship (rather than each factor individually) may identify which drivers have poor hazard perception skills. However, the relationship between risk-taking and hazard perception irrespective of the underlying cause of the risky behaviour remains largely unknown.

The goal of this study was to determine which factors, either independently or cumulatively best predict hazard perception skills using structural equation modelling. Specifically, the present study evaluated the relationship between hazard perception skills and individual differences in driving experience, risk perception, visual perception abilities, and knowledge of traffic laws. Based on the literature, we hypothesised that visual perception abilities, risk perception, and knowledge of traffic laws would best predict hazard perception skills. It was also hypothesised that the relationship between knowledge of traffic laws and hazard perception would be partially mediated by driving experience.

2 Materials and methods

2.1 Participants

There were 398 participants (263 women, 133 men, 2 other) who completed the study. On average, participants were 26.45 years of age (*SD* = 10.67; min = 18, max = 68) and had 8.99 years of driving experience (*SD* = 10.80; min < 1, max = 51). Participants were eligible to participate in the study if they had a valid US driver's license, self-reported having normal or corrected-to-normal vision, and were at least 18 years of age. There were an additional 138 participants who did not meet the eligibility requirements and 16 participants who did not complete the study and were therefore excluded from data analysis. Participants were recruited from George Mason University, Amazon's Mechanical Turk, and through word of mouth. All participants completed a consent form prior to participating in the study. Individuals recruited from George Mason University were compensated with research credit, individuals recruited from Mechanical Turk received cash compensation, and all other participants did not receive compensation.

2.2 Materials

The materials used in this study included a hazard perception task, two visual perception tasks, and surveys. These materials are described below.

2.2.1 Hazard perception task

Eighteen hazard detection videos were presented on Qualtrics. Each video lasted between 6 and 10 seconds. Seven of the video clips contained one hazardous situation, and the remaining 11 videos did not contain any hazardous events. The hazard scenarios used in this study were challenging traffic situations or interactions with other road users and were previously developed and validated (see Lee et al., 2018; Lee and Winston, 2016; McDonald et al., 2015b for more information). Table 1 provides a description of each hazard. These hazardous scenarios presented latent hazards, some of which were preceded by anticipation cues. These driving scenarios were designed using RealTime Technologies, Inc. SimVista. The scenarios were implemented in SimCreator and a researcher drove through the scenarios in a RealTime Technologies, Inc. high-fidelity driving simulator. While the researcher drove through the simulated scenarios, Fraps software was used to record the center channel display. The videos were then edited using OpenShot Video Editor to have the desired length.

Table 1 Description of hazard events

Clip ID	*Duration (ms)*	*Description*	*Accuracy (%)*
1	9	A vehicle ahead is pulling out of a driveway and the driver must decrease speed to avoid a collision.	63.82%
2	8	A bicyclist appears unexpectedly and driver must decrease speed to avoid a collision.	95.23%
3	8	An oncoming vehicle crossed the center divider. The driver must change speed and direction/lane to avoid a collision.	65.33%
4	10	As the driver approaches, a vehicle is pulling out of a driveway and the driver must increase speed to avoid a collision.	90.20%
5	7	A construction zone ahead blocks the driver's lane. The driver must change speed and direction/lane to avoid a collision.	85.43%
6	6	A vehicle ahead is pulling out of a parking lot and the driver must decrease speed to avoid a collision.	49.25%
7	6	A bicyclist appears ahead and the driver must decrease speed to avoid a collision.	16.83%

Note: Duration refers to the duration of the entire videoclip. Accuracy refers to the percentage of participants who correctly identified a hazard.

A pilot study was conducted with 10 subject matter experts (SMEs) from George Mason University. The SMEs viewed each video and answered, open-endedly, the five questions below (adapted from Vensislavova et al., 2016). Their responses were then used to create multiple-choice options for the hazard perception task questions. The five questions and choice options were:

1 Did you see anything unsafe, strange, or dangerous? [Answer choices: yes, no]

2 What was the unsafe, strange, or dangerous event? [Answer choices varied depending on the video scenario]

3 Why was the event unsafe, strange, or dangerous? [Answer choices varied depending on the video scenario]

4 If you were the driver, how would you feel upon seeing this? [Answer choices: very safe, somewhat safe, neither safe or unsafe, somewhat unsafe, very unsafe]

5 What manoeuvre would you perform if you were the driver of the vehicle? [Answer choices: maintain speed and direction/lane; increase speed; decrease speed; change direction/lane; change speed and direction/lane]

A second pilot study was conducted with three SMEs from the AAA Foundation for Traffic Safety. These SMEs viewed each video and answered the five multiple-choice questions per video. Their responses to questions 1, 2, 3 and 5 were determined to be the gold standard, which was used in analysing participant's responses. In instances of disagreement among the three SME, the answer choice selected by two of the SMEs was used as the correct choice.

For the purpose of the present study, we describe hazard perception skills as consisting of four processes:

1 perception

2 identification

3 comprehension

4 response.

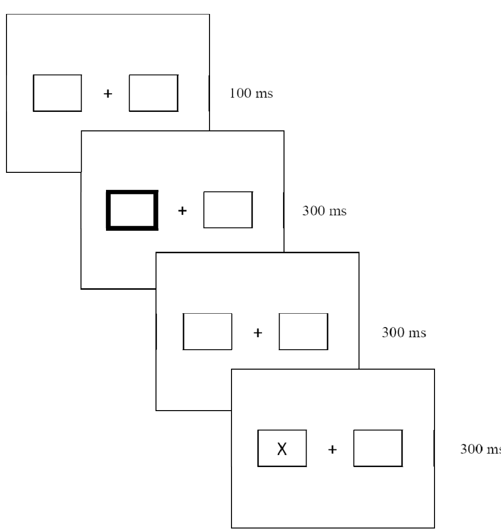
Hazard perception was defined as the accuracy in detecting whether a hazard existed (question 1); hazard identification was defined as the accuracy in detecting what the hazard was (question 2); hazard comprehension was defined as the accuracy in determining why the scenario was hazardous (question 3); and hazard response was defined as the accuracy in selecting the most appropriate manoeuvre to avoid a crash (question 5). The results from question 4 were not analysed in this study.

2.2.2 Selective attention tasks

To evaluate individual differences in visual perception (Trick et al., 2004), two selective attention tasks were included in the study: a visual spatial orientation task and a visual search task. Visual orientation ability was assessed using the Posner Cueing Task (Chica et al., 2014; Posner et al., 1978). Exogenous rather than endogenous cues were used because such cues have shown to capture attention due to saliency using bottom-up processing (Chica et al., 2014). In relation to the hazard perception process, hazards which can be perceived using top-down processing is more likely to be influenced by driving experience. In an effort to eliminate this confound, exogenous cues were used.

The trial sequence is displayed in Figure 1. There were four experimental blocks each with 40 trials for a total of 160 trials. Of the total trials, 50% did not contain a cue (neutral trial), 40% contained a valid cue, and 10% contained an invalid cue.

Figure 1 Example of visual orientation task



Note: This example presents a valid cue trial. The presentation of the duration of each screen is displayed to the right.

A letter discrimination visual search task (Peltier and Becker, 2017) was included to assess drivers' ability to locate relevant information as this may mimic hazard identification. Target (*T*) and distractor (*L*) letters could appear in any of the 25 positions (which formed a rectangle) in any of four rotations: 0 degrees, 90 degrees, 180 degrees, or 270 degrees. A target was present on 20% of the trials. Twenty-four stimuli were presented on each trial for 7,000 milliseconds followed by a 200 millisecond inter-trial interval. There were four experimental blocks, each with 40 trials for a total of 160 trials.

2.2.3 Surveys

Participants completed a demographic and driving history survey, the attention-related driving errors scale (ARDES) (Barragan et al., 2016), the checkpoint risky driving scale (CRDS) (Simons-Morton et al., 2013), and a driving knowledge test. The CRDS was included to measure drivers' state-level risk-taking whereas, the ARDES was included to assess drivers' trait-level propensity of committing driving errors due to inattention. Finally, 13 multiple-choice items were adapted from the California DMV Practice Test (Driver Knowledge, 2018) and used in this study. Participants viewed one question at a time and were allotted 10 seconds (a timer was displayed at the top of each page) to answer each item to discourage cheating.

2.3 Procedure

The study procedures were approved by the George Mason University Institutional Review Board. Participants first consented to participate in the study using an online form on Qualtrics. Then, participants completed the hazard perception task on Qualtrics and then were automatically redirected to Inquisit to complete the visual perception tasks. Finally, participants were again automatically redirected to Qualtrics to complete the surveys.

For the hazard perception task, each video started automatically and participants were unable to control (i.e., pause, rewind, fast-forward, replay) the videos. After each clip ended, participants were directed to a new page asking if they saw anything unsafe, strange, or dangerous in the video clip they just viewed (question 1). If participants responded no, they were directed to the next video clip. If participants responded yes, they were directed to a new page containing the four remaining multiple-choice questions. This task took approximately 10 minutes to complete.

For the visual orientation task, participants first completed practice trials followed by four experimental blocks. Participants were given 20-second break periods between each block. Participants were instructed to keep their eyes on the fixation cross and respond as quickly and accurately as possible using a keyboard as to whether the target was located to the left or right of the fixation cross. Participants were allotted 100 milliseconds to respond, which was then followed by a 100 millisecond inter-trial interval. For the visual search task, participants were instructed to respond as quickly and accurately as possible using a keyboard as to whether the target letter *T* appeared in any orientation. If the target letter was absent, participants indicated this by using a different key on the keyboard. Thus, participants always responded regardless if the target was present. Participants first completed practice trials followed by four experimental blocks. Between each block, participants were given a 20-second break. The visual perception tasks took approximately 20 minutes to complete. Finally, participants completed the surveys, which took approximately 10 minutes to complete. The entire experiment took approximately 40 minutes to complete.

3 Results

All data were analysed using the lavaan package (Rosseel, 2012) in RStudio version 1.1.463.

3.1 Latent structural equation models

A latent structural equation model (SEM) was performed to test the first hypothesis that individual differences including at-risk drivers, visual perception, and knowledge of traffic laws predict hazard perception skills. Additionally, although we did not hypothesise that driving experience would predict hazard perception skills, this construct was included in the latent SEM to verify this prediction. To test the second hypothesis that driving experience would mediate the relationship between hazard perception skills and knowledge of traffic laws, a latent mediation SEM was performed. In evaluating these latent SEMs, four steps were performed including model specification, estimation, evaluation, and modification (Ullman and Bentler, 2013). These steps are described below.

3.1.1 Model specification

Three measurement models were first evaluated followed by a latent SEM and a latent mediation SEM. The first measurement model was a confirmatory factor analysis (CFA) evaluating fit indices for the at-risk drivers' construct, which included four observed variables: scores on the CRDS, scores on the ARDES, the total number of crash involvement, and the number of traffic tickets received within the last two years. The second CFA was performed to evaluate the fit indices for the hazard perception skills construct, which included four observed variables: accuracy on questions 1 (hazard perception), 2 (identification), 3 (comprehension) and 5 (response). CFAs were not performed for the visual perception and driving experience latent factors because these constructs were each predicted by only two observed variables. The observed variables predicted to load onto the driving experience latent factor were years of driving experience and the number of states licensed. Visual perception was indicated by two observed variables: accuracy scores on the visual orientation task and the visual search task.

The first factor loading for each CFA was fixed to 1 and all other paths were freed (Iacobucci, 2009). After verifying acceptable fit of the CFAs, a full measurement model was evaluated in which each latent factor was correlated. In order to estimate factor variances in the full measurement model, the first path loading per latent factor was fixed to 1, observed variances were fixed to 1, and all other parameters were freed (Jarvis et al., 2003). Finally, two structural models were evaluated including a latent SEM and a latent mediation SEM.

3.1.2 Model estimation

The latent SEMs were estimated using maximum likelihood estimates with Satorra-Bentler correction χ^2 and robust standard errors (Satorra and Bentler, 2001).

3.1.3 Model evaluation

The at-risk drivers CFA [$\chi^2(2) = 1.59$, $p = .45$, CFI = 1.00, TLI = 1.00, RMSEA < .001, SRMR = .016] and hazard perception skills CFA [$\chi^2(2) = 1.36$, $p = .51$, CFI = .98, TLI = .98, RMSEA < .001, SRMR = .008] produced acceptable fit indices. Likewise, the full measurement model produced acceptable fit indices, $\chi^2(60) = 68.73$, $p = .21$ (CFI = .99, TLI = .99, RMSEA = .018).

3.1.4 Model modification

Given that the full measurement model produced acceptable fit, no modifications were made to this model. The latent SEM instead included the latent factors, at-risk drivers, driving experience, visual perception, and the observed variable accuracy on the driving knowledge test as predictors of hazard perception skills. Additionally, the first observed variable loading was freed for the hazard perception skills construct and instead the disturbance was fixed to 1 (Iacobucci, 2009). The latent SEM produced acceptable fit, $\chi^2(71) = 81.18$, $p = .19$ (CFI = .99, TLI = .99, RMSEA = .018). The unstandardised and standardised parameter estimates for the latent SEM are reported in Table 2 and Figure 2, respectively.

Table 2 Unstandardised parameter estimates for hazard perception latent structural equation model

Parameter	*B*	*SE*	*p-value*
	At-risk drivers		
Disturbance	.023	.015	.11
CRDS scores	1	-	-
ARDES scores	.86	.11	<.001
Number of crashes	15.51	2.54	<.001
Number of tickets	.57	.54	.29
	Hazard perception		
Disturbance	1	-	-
Perception (question 1)	1.14	.06	<.001
Identification (question 2)	1.11	.054	<.001
Comprehension (question 3)	.93	.045	<.001
Response (question 5)	.47	.039	<.001

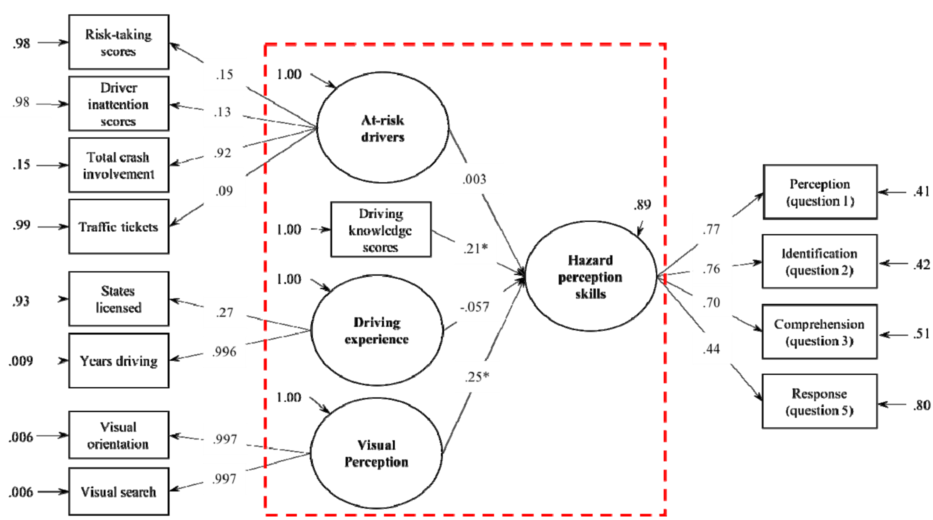
Note: CRDS – checkpoint risky driving scale; ARDES – attention-related driving errors scale; B – unstandardised estimate; SE – standard error.

Table 2 Unstandardised parameter estimates for hazard perception latent structural equation model (continued)

Parameter	*B*	*SE*	*p-value*
	Driving experience		
Disturbance	115.46	12.34	<.001
Years of driving experience	1	-	-
Number of states licensed	.026	.009	.003
	Visual perception		
Disturbance	164.64	27.17	<.001
Visual orientation scores	1	-	-
Visual search scores	1.04	.11	<.001
	Predictors of hazard perception skills		
At-risk drivers	.019	.33	.95
Driving experience	–.006	.005	.28
Visual perception skills	.021	.006	.001
Knowledge of driving laws	.10	.030	.001

Note: CRDS – checkpoint risky driving scale; ARDES – attention-related driving errors scale; B – unstandardised estimate; SE – standard error.

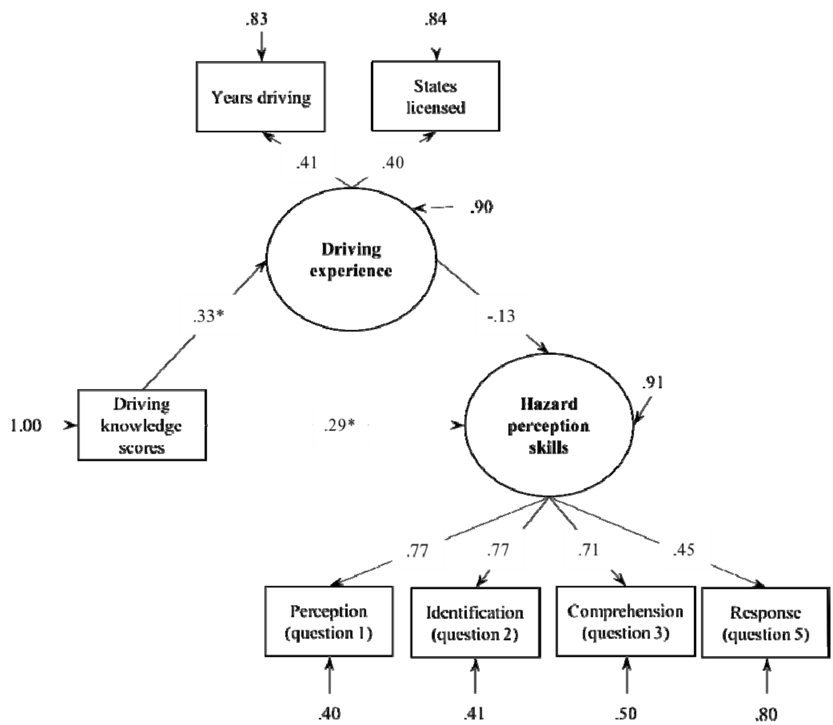
Figure 2 Hazard perception latent structural equation model diagram with standardised (β) parameter estimates (see online version for colours)



Note: The structural model includes the latent and observed variables within the red box. The significant predictors of hazard perception skills are identified with an asterisk (*).

In latent partial mediation SEM, the parameters constraints were the same as the latent SEM. Figure 3 displays the mediation diagram with standardised regression estimates. It was found that for every one-point increase in driving knowledge scores there was .33 (*SE* = .14) increase in driving experience, *p* = .17. When controlling for driving knowledge scores, driving experience was not significantly associated with hazard perception skills, $p = .22$. Additionally, driving knowledge scores were not significantly associated with hazard perception skills indirectly through driving experience, $p = .34$. Finally, driving knowledge scores were significantly associated with hazard perception skills independent of driving experience, $\beta = .29$, $SE = .067$, $p < .001$.

Figure 3 Latent partial mediation structural equation model diagram



Note: Driving experience was evaluated as mediating the relationship between driving knowledge scores and hazard perception skills. The significant paths for this structural model are identified by an asterisk (*). Driving experience was not a significant mediator.

3.2 Years of driving experience

We sought to evaluate our data in terms of results from existing research in two ways. First, driving experience was treated as a categorical variable (i.e., novice, experienced), which has been shown to predict visual scanning abilities (Borowsky et al., 2010; measured as accuracy on the visual search task), hazard identification (Isler et al., 2009; measured as accuracy on question 2), hazard comprehension (Jackson et al., 2009; measured as accuracy on question 3), selecting the appropriate manoeuvre to avoid a collision (Vensislavova et al., 2016; measured as accuracy on question 5), risk-taking (Pradhan et al., 2009; measured as scores on the checkpoint risky driving scale), driver inattention (measured as scores on the ARDES), and knowledge of driving laws. Novice drivers were identified as individuals with less than three years of driving experience

(Crundall, 2016). Experienced drivers were classified as individuals with more than seven years of driving experience (Parmet et al., 2015). Using this categorisation method, there were 137 novice, and 146 experienced drivers. The results from the regression analyses are displayed in Table 3; none of the outcome variables were significantly predicted by the categorial driving experience variable.

Table 3 Regression results for driving experience as a categorical (novice, experienced) predictor

Outcome variable	β	*SE*	*p-value*
Visual scanning	1.96	1.94	.31
Hazard identification (question 2)	.008	.17	.97
Hazard comprehension (question 3)	.12	.15	.42
Hazard response (question 5)	.005	.11	.97
Risk-taking	.09	.07	.18
Driver inattention	.04	.06	.54
Driving knowledge	.06	.27	.83

Note: β = standardised regression coefficient; *SE* = standard error.

Second, as a comparison, driving experience as a continuous variable (i.e., years) was evaluated as a predictor of the same seven variables listed above. When treated as a continuous predictor, driving experience did not significantly predict visual search accuracy (β = .036, *SE* = .07, *p* = .63), accuracy on question 2 (β = .0028, *SE* = .006, *p* = .66), accuracy on question 3 (β = –.003, *SE* = .006, *p* = .63), accuracy on question 5 (β = .002, *SE* = .004, *p* = .69), and driver inattention (β = –.004, *SE* = .002, *p* = .07). Driving experience did significantly predict risk-taking scores such that, as driving experience increased risk-taking decreased, β = –.013, *SE* = .003, $p < .001$. Additionally, driving experience predicted accuracy of knowledge of driving law, β = .029, *SE* = .0099, *p* = .004, which suggests that as driving experience increased knowledge of traffic laws also increased.

4 Discussion

Hazard perception is a skill necessary to maintain safety in everyday driving. It is well established that young and novice drivers have poor hazard perception skills causing them to be at increased crash risk (Egea-Caparrós et al., 2016; Horswill, 2016; Lim et al., 2013; McDonald et al., 2015a). In an attempt to reduce crash risk among this population, training programs have been developed to expedite the acquisition of hazard perception skills (McDonald et al., 2015a). Numerous training programs have been developed to attain this goal, and all but one has failed to successfully show long-term effects. A longitudinal study found that male drivers who completed their hazard perception training program had reduced crash risk (Thomas et al., 2016). Recently, the National Center for Statistics and Analysis (2018) reported that fatal accidents among young drivers aged 16 to 24 years have decreased over the past 10 years whereas; however, there has been an increase for drivers aged 25 years and older. If poor hazard perception skills do increase crash risk then there are likely to be other contributing factors than just years of driving experience. Kahana-Levy et al. (2019) found that, regardless of driving experience, hazard training through repetitive exposure of videos improved hazard perception skills. The goal of this study was to determine which individual differences best predict hazard perception skills. Specifically, we evaluated latent structural equation models to determine whether at-risk drivers, driving experience, visual perception, and knowledge of traffic laws predicted accuracy on a hazard perception video task.

4.1 Visual perception

Visual perception and knowledge of traffic laws significantly predicted hazard perception skills. The former has been supported by prior studies (Lee et al., 2008; Martens and Fox, 2007; Pollastek et al., 2006; Trick et al., 2004) and is in line with Trick et al.'s (2004) selective attention framework. In order to perceive a scenario as potentially hazardous, drivers must first selectively direct their attention to the given situation, which is achieved through orienting and searching (Trick et al., 2004). In support, Huestegge et al. (2010) emphasised the necessity of efficient visual orientation in accurately determining whether a driving scenario contains a hazard (i.e., perception stage). Although not discriminately analysed in this study, these two visual selection processes may best predict performance related to the first two stages of the hazard perception process, perception and identification.

4.2 Knowledge of traffic laws

Knowledge of traffic laws was also found to predict hazard perception skills. This relationship provides empirical support to the goals for driver education framework (Hatakka et al., 2002). Specifically, level 2 in this framework is 'mastery of traffic situations,' which involves knowing how to drive under various scenarios. Proficiency at this level is affected by knowledge of traffic laws, hazard perception skills, and interacting with other drivers. Moreover, Hung and Huyen (2011) suggest that lane misuse, unintentional speeding, following distance along with other traffic violations increases the propensity of crash involvement. Such instances may be unaffected by driving experience, and rather the result of misinformation regarding traffic laws. Though, it is possible that knowledge of traffic laws interacts with driving experience during the execution of compliance. In other words, knowledge must be coupled with operating a vehicle (gaining experiential practice) in obeying traffic laws. In support, we found that as driving experience increased, accuracy in knowledge of traffic laws increased. However, the results of a latent mediation SEM found that the relationship between knowledge of traffic laws and hazard perception skills was not mediated by driving experience. Moreover, driving experience does not directly or indirectly predict hazard perception skills.

4.3 Risk-taking

Although prior studies have found a relationship between hazard perception and risk-taking (McDonald et al., 2015a; McKenna et al., 2006; Pollatsek et al., 2006; Underwood et al., 2005), the at-risk drivers' construct did not predict hazard perception skills in our analysis. One possible explanation is related to how the construct was operationalised. In our study, at-risk drivers were measured by self-report risk-taking surveys, crash involvement, and traffic tickets. In the literature, video-based visual tasks (e.g., identification of hidden and materialised hazards) are commonly used to assess and infer risk perception (Borowsky and Oron-Gilad, 2013; McKenna et al., 2006; Pollatsek et al., 2006). Arguably, these measures and the ones used in this study may be quantifying different aspects of risk-taking. However, consistent with the literature, we did find that as years of driving experience increased, risk-taking decreased. In support, Pradhan et al. (2005) found that older drivers (60–75 years of age) perceived more potential risks than young drivers (19–29 years of age) and novice drivers (16–17 years of age) did. Day et al. (2018) found that in addition to increased risk-taking among novice drivers, this population is at heightened crash risk due to experiential learning of vehicle control and social status – a relationship which may be independent of hazard perception skills.

4.4 Years of driving experience

An important contribution of this study is the methodological concerns raised regarding what constitutes driving experience. Moreover, since existing research operationalise novice and experience drivers differently, care must be taken when combining results across studies. For example, existing hazard perception research categorises drivers as either novice or experienced using various thresholds (Crundall, 2016; Huestegge and Böckler, 2006; Huestegge et al., 2010; Lim et al., 2013; Parmet et al., 2015; Smith et al., 2009; Underwood et al., 2002; Vensislavova et al., 2016). Thus, there is no universal definition of what constitutes a novice driver in terms of years driving despite studies claiming that novice drivers have worse hazard perception. It should be noted that driving experience may likely explain, to some extent why individual differences exist in hazard perception skills, but this relationship cannot be accurately revealed until driving experience is adequately defined. For example, Borowsky and Oron-Gilad (2013) evaluated differences in hazard awareness between discriminate levels of driving experience: professional taxi drivers versus non-professional drivers.

As a first attempt to be able to compare results across studies, we evaluated driving experience as a latent factor consisting of the number of states licensed and the number of years of driving experience (as a continuous variable). Though other factors likely contribute such as miles driven per week, experience driving in various environments (e.g., rural roads, night-time driving, adverse weather conditions), and context of driving (e.g., long-distance travel, commercial truck driver). For example, the National Center for Statistics and Analysis (2018) reported that in 2016 and 2017 there were more fatal crashes in urban compared to rural environments irrespective of the number of years of driving experience.

Another possible explanation for the lack of relationship between driving experience and hazard perception could be due to limitations in this study. For one, this study was conducted online, and there could have been technical errors during the administration of the videos or selective attention tasks. Even though technical errors can also occur in laboratory settings, we could not fix the errors for the online participants. Additionally, there is the possibility of self-reporting errors for demographics and driving history, or deviations in the protocol. Though, procedures were in place to reduce the latter such as, participants could not control the hazard videos. However, it was important to have a large diverse sample of drivers throughout the USA, which was not feasible in a laboratory setting. Future research could evaluate the validity of these results with a smaller sample in a laboratory or field study. Additionally, although the current study did not necessarily evaluate why novice drivers are at increased crash risk, this topic deserves further consideration to determine whether this relationship can be explained by individual differences in hazard perception skills. Specifically, future research should comprehensively evaluate whether differences in driving experience can be revealed by evaluating each of the stages involved in hazard perception skills individually within the sample of participants, as Huestegge et al. (2010) started to compare the differences in driving experience in some of the stages. This relationship is further supported by Ventsislavova et al. (2019) who suggested that driving experience differences are found when measuring hazard prediction skills (such as the hazard comprehension question used in this study) rather than hazard perception skills.

5 Conclusions

The objective of this study was to determine predictors of hazard perception performance on a driving task including risk-taking, driving experience, visual perception, and knowledge of traffic laws. It is imperative for research evaluating individual differences to study a large diverse sample of the target population, which in this instance were licensed US drivers. Therefore, an online study could best meet this requirement. Driver's hazard perception skills were measured as scores on a hazard perception video task, risk-taking was measured through surveys, driving experience was measured as the number of years driving with a valid US driver's license, visual perception was measured as scores on two visual perception tasks, and knowledge of traffic laws was measured as scores on a licensing test. The results of this study provide theoretical contributions to the literature: Drivers who performed best on the hazard perception task had high accuracy scores on the visual perception and the knowledge of traffic laws test. Unlike much of the existing literature, these findings highlight the necessity for researchers to explore factors other than driving experience, which may be more predictive of hazard perception performance. Our results also provide practical contributions to the field of driver training: Training programs can be tailored to target drivers most susceptible to committing hazard perception errors by providing exercise on visual perception and traffic laws during the licensing process. This emphasis may improve their hazard perception skills and ultimately roadway safety.

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References

Barragan, D. and Lee, Y.-C. (2019) 'Drivers' assessment of hazard perception', *Proceedings of the 10th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*.

Barragan, D., Roberts, D.M. and Baldwin, C.L. (2016) 'Validation of the attention-related driving errors scale (ARDES) in an English-speaking sample', *Human Factors*, Vol. 58, No. 8, pp.1262–1274.

Bleckley, M.K., Durso, F.T., Crutchfield, J.M., Engle, R.W. and Khana, M.M. (2003) 'Individual differences in working memory capacity predict visual attention allocation', *Psychonomic Bulletin & Review*, Vol. 10, No. 4, pp.884–889.

Borowsky, A. and Oron-Gilad, T. (2013) 'Exploring the effects of driving experience on hazard awareness and risk perception via real-time hazard identification, hazard classification, and rating tasks', *Accident Analysis and Prevention*, Vol. 59, pp.548–565 [online] https://doi.org/10.1016.j.aap.2013.07.008.

Borowsky, A., Horrey, W.J., Liang, Y., Garabet, A., Simmons, L. and Fisher, D.L. (2016) 'The effects of brief visual interruption tasks on drivers' ability to resume their visual search for a pre-cued hazard', *Accident Analysis and Prevention*, Vol. 93, pp.207–216 [online] https://doi.org/10.1016/j.aap.2016.04.028.

Borowsky, A., Shinar, D. and Oron-Gilad, T. (2010) 'Age, skill, and hazard perception in driving', *Accident Analysis and Prevention*, Vol. 42, pp.1240–1249 [online] https://doi.org/10.1016/j.aap.2010.02.001.

Chica, A.B., Martín-Arévalo, E., Botta, F. and Lupiáñez, J. (2014) 'The spatial orienting paradigm: how to design and interpret spatial attention experiments', *Neuroscience and Behavioral Reviews*, Vol. 40, pp.35–51 [online] https://dx.doi.org/10.1016/j.neubiorev.2014.01.002.

Crundall, D. (2016) 'Hazard prediction discriminates between novice and experienced drivers', *Accident Analysis and Prevention*, Vol. 86, pp.47–58 [online] https://doi.org/10.1016.j.aap.2015.10.006.

Day, M.R., Thompson, A.R., Poulter, D.R., Stride, C.B. and Rowe, R. (2018) 'Why do drivers become safer over the first three months of driving? A longitudinal qualitative study', *Accident Analysis and Prevention*, Vol. 117, pp.225–231 [online] https://doi.org/10.1016/j.aap.2018.04.007.

Driver Knowledge, *California DMV Practice Test* [online] https://www.driverknowledge.com/california-dmv-practice-test/ (accessed 1 October 2018).

Egea-Caparrós, D-A., García-Sevilla, J., Pedraja, M.J., Romero-Medina, A., Marco-Cramer, M. and Pineda-Egea, L. (2016) 'Late detection of hazards in traffic: A matter of response bias?', *Accident Analysis and Prevention*, Vol. 94, pp.188–197 [online] https://dx.doi.org/10.1016/j.aap.2016.06.002.

Elvik, R. (2010) 'Why some road safety problems are more difficult to solve than others', *Accident Analysis and Prevention*, Vol. 42, pp.1089–1096 [online] https://dx.doi.org/10.1016/j.aap.2009.12.020.

Garay-Vega, L., Fisher, D.L. and Pollatsek, A. (2007) 'Hazard anticipation of novice and experienced drivers', *Transportation Research Record: Journal of the Transportation Research Board*, pp.1–7 [online] https://doi.org/10.3141/2009-01.

Hatakka, M., Keskinen, E., Gregersen, N.P., Glad, A. and Hernetkoski, K. (2002) 'From control of the vehicle to personal self-control; broadening the perspectives to driver education', *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 5, No. 3, pp.201–215.

Horswill, M.S. (2016) 'Improving fitness to drive: the case for hazard perception training', *Australian Psychologist*, Vol. 51, pp.173–181 [online] https://doi.org/10.1111/ap.12132.

Huestegge, L. and Böckler, A. (2006) 'Out of the corner of the driver's eye: peripheral processing of hazards in static traffic scenes', *Journal of Vision*, Vol. 16, No. 2, pp.1–15 [online] http://doi.org/10.1167/16.2.11.

Huestegge, L., Skottke, E.M., Anders, S., Müsseler, J. and Debus, G. (2010) 'The development of hazard perception: dissociation of visual orientation and hazard processing', *Transportation Research Part F*, Vol. 13, pp.1–8 [online] https://doi.org/10.1016/j.trf.2009.09.005.

Hung, K.V. and Huyen, L.T. (2011) 'Education influence in traffic safety: a case study in Vietnam', *IATSS Research*, Vol. 34, No. 2, pp.87–93.

Iacobucci, D. (2009) 'Everything you always wanted to know about SEM (structural equations modeling) but were afraid to ask', *Journal of Consumer Psychology*, Vol. 19 No. 4, pp.673–680 [online] https://doi.org/10.1016/j.jcps.2009.09.002.

Isler, R.B., Starkey, N.J. and Williamson, A.R. (2009) 'Video-based road commentary training improves hazard perception of young drivers in a dual task', *Accident Analysis and Prevention*, Vol. 41, pp.445–452 [online] https://doi.org/10.1016/j.aap.2008.12.016.

Jackson, L., Chapman, P. and Crundall, D. (2009) 'What happens next? Predicting other road users' behaviour as a function of driving experience and processing time', *Ergonomics*, Vol. 52, No. 2, pp.154–164.

Jarvis, C.B., MacKenzie, S.B. and Podsakoff, P.M. (2003) 'A critical review of construct indicators and measurement model misspecification in marketing and consumer research', *Journal of Consumer Research*, Vol. 30, No. 2, pp.199–218.

Kahana-Levy, N., Shavitzky-Golkin, S., Borowsky, A. and Vakil, E. (2019) 'Facilitating hazard awareness skills among drivers regardless of age and experience through repetitive exposure to real-life short movies of hazardous driving situations', *Transportation Research Part F*, Vol.60, pp.353–365 [online] https://doi.org/10.1016/j.trf.2018.09.021.

Lee, S.E., Klauer, S.G., Olsen, E.C.B., Simons-Morton, B.G., Dingus, T.A., Ramsey, D.J. and Ouimet, M.C. (2008) 'Detection of road hazards by novice teen and experienced adult drivers', *Journal of the Transportation Research Board*, Vol. 2078, pp.26–32 [online] https://doi.org/10.3141/2078-04.

Lee, Y-C. and Winston, F.K. (2016) 'Stress induction techniques in a driving simulator and reactions from newly licensed drivers', *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 42, Part 1, pp.44–55 [online] https://doi.org/10.1016/j.trf.2016.06.019.

Lee, Y-C., McIntosh, C.W., Winston, F., Power, T., Huang, P., Ontañón, S. and Gonzalez, A. (2018) 'Design of an experimental protocol to examine medication non-adherence among young drivers diagnosed with ADHD: a driving simulator study', *Contemporary Clinical Trials Communications*, Vol. 11, pp.149–155 [online] https://doi.org/10.1016/j.conctc.2018.07.007.

Lim, P.C., Sheppard, E. and Crundall, D. (2013) 'Cross-cultural effects on drivers' hazard perception', *Transportation Research Part F*, Vol. 21, pp.194–206 [online] https://dx.doi.org/10.1016/j.trf.2013.09.016.

Malone, S. and Brünken, R. (2020) 'Studying gaze behavior to compare three different hazard perception tasks', *Human Factors*, Vol. 62, No. 8, pp.1286–1303.

Martens, M.H. and Fox, M.R.J. (2007) 'Do familiarity and expectations change perception? Drivers' glances and response to change', *Transportation Research Part F*, Vol. 10, pp.476–492 [online] https://dx.doi.org/10.1016/j.trf.2007.05.003.

McDonald, C.C., Goodwin, A.H., Pradhan, A.K., Romoser, M.R.E. and Williams, A.F. (2015a) 'A review of hazard anticipation training programs for young drivers', *Journal of Adolescent Health*, Vol. 57, pp.S15–S23 [online] https://dx.doi.org/10.1016/j.jadohealth.2015.02.013.

McDonald, C.C., Kandadai, V., Loeb, H., Seacrist, T.S., Lee, Y-C., Winston, Z. and Winston, F.K. (2015b) 'Simulated driving assessment (SDA) for teen drivers: results from a validation study', *Injury Prevention*, Vol. 21, No. 3, pp.145–152.

McKenna, F.P., Horswill, M.S. and Alexander, J.L. (2006) 'Does anticipation training affect drivers' risk taking?', *Journal of Experimental Psychology: Applied*, Vol. 12, No. 1, pp.1–10.

Mueller, A.S. and Trick, L.M. (2012) 'Driving in fog: the effects of driving experience and visibility on speed compensation and hazard avoidance', *Accident Analysis and Prevention,* Vol. 48, pp.472–479 [online] https://doi.org/10.1016/j.aap.2012.03.003.

National Center for Statistics and Analysis (2018) *2017 Fatal Motor Vehicle Crashes: Overview*, Report No. DOT-HS-812-603, National Highway Traffic Safety Administration, Washington, DC [online] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812603 (accessed 1 October 2018).

Parmet, Y., Borowsky, A., Yona, O. and Oron-Gilad, T. (2015) 'Driving speed of young novice and experienced drivers in simulated hazard anticipation scenes', *Human Factors*, Vol. 57, No. 2, pp.311–328.

Paxion, J., Galy, E. and Berthelon, C. (2014) 'Mental workload and driving', *Frontiers in Psychology*, No. 5, pp.1–11 [online] https://doi.org/10.3389/fpsyg.2014.01344.

Peltier, C. and Becker, M.W. (2017) 'Individual differences predict low prevalence visual search performance', *Cognitive Research: Principles and Implications*, Vol. 2 No. 5 [online] http://doi.org/10.1186/s41235-016-0042-3.

Pollatsek, A., Narayanaan, V., Pradhan, A. and Fisher, D.L. (2006) 'Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator', *Human Factors*, Vol. 48, No. 3, pp.447–464.

Posner, M.I., Nissen, M.J. and Ogden, W.C. (1978) 'Attended and unattended processing modes: The role of set for spatial location', in Pick Jr., H.L. et al. (Eds.): *Modes of Perceiving and Processing Information*, Hillsdale, New Jersey.

Pradhan, A.K., Hammel, K.R., DeRamus, R., Pollatsek, A., Noyce, D.A. and Fisher, D.L. (2005) 'Using eye movements to evaluate effects of driver age on risk perception in a driving simulator', *Human Factors*, Vol. 47, No. 4, pp.840–852.

Pradhan, A.K., Pollatsek, A., Knodler, M. and Fisher, D.L. (2009) 'Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazards?', *Ergonomics*, Vol. 52, No. 6, pp.657–673.

Rosseel, Y. (2012) 'lavaan: an R package for structural equation modeling', *Journal of Statistical Software*, Vol. 48, No. 2, pp.1–36.

Satorra, A. and Bentler, P.M. (2001) 'A scaled difference chi-square test for moment structure analysis', *Psychometrika*, Vol. 66, No. 4, pp.507–514.

Scialfa, C.T., Deschenes, M.C., Ference, J.D., Boone, J., Horswill, M.S. and Wetton, M. (2012) 'Hazard perception in older drivers', *International Journal of Human Factors and Ergonomics*, Vol. 1, No. 3, pp.221–233.

Simons-Morton, B.G., Li, K., Brooks-Russell, A., Ehsani, J., Pradhan, A., Ouimet, M.C. and Klauer, S. (2013) 'Validity of the C-RDS self-reported risky driving measure', *Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, pp.22–28 [online] https://doi.org/10.17077/drivingassessment.1462.

Smith, S.S., Horswill, M.S., Chambers, B. and Wetton, M. (2009) 'Hazard perception in novice and experienced drivers: the effects of sleepiness', *Accident Analysis and Prevention*, Vol. 41, pp.729–733 [online] https://doi.org/10.1016/j.aap.2009.03.016.

Takahashi, R., Kobayashi, M., Sasaki, T., Yokokawa, Y., Momose, H. and Ohhashi, T. (2017) 'Driving simulation test for evaluating hazard perception: elderly driver response characteristics', *Transportation Research Part F*, Vol. 49, pp.257–270 [online] https://dx.doi.org/10.1016/j.trf.2017.07.003.

Thomas, F.D., Rilea, S.L., Blomberg, R.D., Peck, R.C. and Korbelak, K.T. (2016) *Evaluation of the Safety Benefits of the Risk Awareness and Perception Training Program for Novice Teen Drivers*, Report No. DOT-HS-812-235, National Highway Traffic Safety Administration, Washington, DC.

Trick, L.M., Enns, J.T., Mills, J. and Vavrik, J. (2004) 'Paying attention behind the wheel: a framework for studying the role of attention in driving', *Theoretical Issues in Ergonomics Science*, Vol. 5, No. 5, pp.385–424.

Ullman, J.B. and Bentler, P.M. (2013) 'Structural equation modeling', *Handbook of Psychology*, 2nd ed., pp.631–691, John Wiley & Sons, New York [online] https://doi.org/10.1002/9781118133880.hop202023.

Underwood, G., Crundall, D. and Chapman, P. (2002) 'Selective searching while driving: the role of experience in hazard detection and general surveillance', *Ergonomics*, Vol. 45, No. 1, pp.1–12.

Underwood, G., Phelps, N., Wright, C., van Loon, E. and Galpin, A. (2005) 'Eye fixation scanpaths of younger and older drivers in a hazard perception task', *Ophthalmic and Physiological Optics*, Vol. 25 No. 4, pp.346–356.

Vensislavova, P., Gugliotta, A., Peña-Suarez, E., Garcia-Fernandez, P., Eisman, E., Crundall, D. and Castro, C. (2016) 'What happens when drivers face hazards on the road?', *Accident Analysis and Prevention*, Vol. 91, pp.43–54 [online] https://dx.doi.org/10.1016/j.aap.2016.02.013.

Ventsislavova, P., Crundall, D., Baguley, T., Castro, C., Gugliotta, A., Garcia-Fernandez, P., Zhang, W., Ba, Y. and Li Q. (2019) 'A comparison of hazard perception and hazard prediction tests across China, Spain, and the UK', *Accident Analysis and Prevention*, Vol. 122, pp.268–286 [online] https://doi.org/10.1016/j.aap.2018.10.010.