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Consistency between subjectively and objectively measured hazard perception skills among young male drivers

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Abstract

Young male drivers have lower hazard perception skills (HPS) than older and more experienced drivers and a tendency to overestimate their skills in hazardous situations. Both factors contribute to an over-representation in traffic accidents. Based on a sample of 63 drivers aged 18-24, this study compares the consistency of HPS measured by objective and subjective measures and the link between these measures is the key contribution of the study. Both visible and hidden hazards are included. Objective measures of HPS include responsiveness and eye movements while driving in a driving simulator. Subjective measures of HPS include self-reports derived based on the Hazard Perception Questionnaire (HPQ), Driving Skill Questionnaire (DSQ), and Brief Sensation Seeking Scale (BSSS). Results show that drivers who respond to the hazards on time, as compared to drivers who do not respond, have higher scores on subjective measures of HPS and higher driving skills in the visible but not in the hidden condition. Eye movement analysis confirms the difference and shows that response in time to hazards indicate higher HPS and young drivers are poor at detecting hidden hazards. Drivers with a response in time locate the hazard faster, have more fixations, but dwell less on the hazard. At the same time, those who do not respond have a later first fixation and fewer but longer fixations on the hazard. High sensation seeking drivers respond to visible hazards on time, suggesting that sensation seeking does not affect HPS negatively when the hazard is visible. To enhance the HPS among young drivers, the results of this study suggest that specific hazard perception training is relevant, especially for hazards that require more advanced HPS.

Keywords: Young male drivers, Hazard perception skills, Driving simulator, Eye movements

1 Introduction

Road traffic injuries remain the leading cause of death among 15-29 year olds worldwide (World Health Organization, 2015). Young, and in particular male drivers are more prone to engagement in high-risk driving behaviours (Constantinou et al., 2011; Halpern-Felsher et al., 2017) and continue to be over-represented in accident statistics despite general improvements in road safety levels and developments in training and testing (ITF, 2017). Studies show that HPS is a key factor in relation to unsafe driving and accident involvement (e.g. Fisher, Pollatsek and Pradhan, 2006; McKnight and McKnight, 2003; Pollatsek et al., 2006). In line with an established definition (Crundall et al., 2003), we operationalise HPS as a driver's ability to detect and respond in time and appropriately to potentially dangerous events on the road.

HPS are typically measured with direct behaviour methods where participants know that hazards will occur and a quick response to the hazards is requested. Examples of direct measures include response latency assessed by pushing a button (e.g., Borowsky et al., 2010; Underwood et al., 2005), pointing tasks (e.g., Scialfa et al., 2013, 2012, 2011) or mouse clicking tasks (e.g., Smith et al., 2009). Indirect behaviour measures, namely, reactions to hazards when driving in a simulator (e.g., Martinussen et al., 2017; Schall et al., 2013; Young et al., 2017) and eye movements (e.g., Borowsky et al., 2010; Crundall et al., 2012, 2003) are also used. In that case, participants do not know that hazardous situations will occur, which brings participants closer to the naturalistic driving situation. It is argued that, due to the complexity of hazard perception skills, reaction time alone is a too simple measure of HPS (e.g., Huestegge et al., 2010; Sagberg and Bjørnskau, 2006). With indirect measures it is possible to detect driver behaviour before and after the actual hazard is presented. By analysing eye movements it is possible to estimate if a driver has searched and detected the hazard, and by analysing driving behaviour, variations in driving speed, braking, and variations in steering indicates drivers' chosen response to it.

Although young drivers generally have lower HPS compared to more experienced drivers, the level of HPS also differs within sub-groups of young drivers. Moreover, it is unknown whether non-responsive drivers do not interpret hazards as potentially dangerous and therefore do not respond, or if they fail to detect them. Studies have aimed to separate the process of detection and response to the hazards. Young novice and experienced drivers differ in their hazard perception accuracy, when time available for detection is manipulated (Jackson et al., 2009); young drivers still detect fewer hazards when they have more time available. Additionally, novice and experienced drivers have different processing speeds after a hazard is detected, which affects reaction time (Huestegge et al., 2010). Research on eye movements suggests that inexperienced drivers detect fewer hazards (e.g. Fisher et al., 2006; Pradhan et al., 2005), have a narrower horizontal spread of search (Underwood et al., 2003), and fewer (Pradhan et al., 2005) but longer fixation durations (Chapman and Underwood, 1998) indicating a longer processing time. It still remains unclear how young drivers with higher and lower HPS differ when detecting and responding to hazards.

In this study, we measure drivers' response to potential hazards based on changes in driving speed. Additionally, with eye movements, we measure hazard detection to validate the response behaviour (changes in driving speed).

According to Crundall et al. (2012), it is relevant to make a distinction between visible and hidden hazards. Visible hazards have behavioural cues directly related to the hazard. Examples include a blinking turning car starting to drive out of the roadside parking, and a pedestrian standing on the pavement ready to enter the street. Hidden hazards have environmental cues not directly related to the hazard. Examples include a possible but not yet visible road user who may arrive on a collision course, such as a pedestrian behind a bus at a bus stop. Another example of a hidden hazard is a driveway or curve with an object restricting the view of possible traffic approaching from it. Hidden hazards require more advanced HPS than visible hazards. HPS increase with driving experience (e.g. Horswill and McKenna, 2004) and therefore understanding HPS of young, less experienced drivers is of particular interest.

In addition to actual HPS, accurate subjective assessment of one’s own HPS is important, as this provides the basis for relevant behavioural adjustments in challenging traffic situations and the avoidance of unintended risky driving (Deery, 1999). The extent to which drivers assess their HPS accurately can be examined by comparing subjective and objective measures of HPS.

To the best of our knowledge, only two studies have compared the consistency between objective and subjective measures of HPS among young drivers: Farrand and Mckenna (2001) examined the relationship between self-ratings of risk perception and objective HPS assessed by recording response latencies in a video based HP test, while Martinussen et al. (2017) examined the accuracy of self-reported HPS compared to objectively measured driving skills in a driving simulator. Among other driving related skills (overtaking, maintenance of safe gap to car in front) objective hazard prediction and detection was measured as a reduction in driving speed prior to the hazardous event and as a latency to braking after the start of the hazardous event.

While Farrand and Mckenna (2001) found that self-assessments were not related to the objectively measured HPS, Martinussen et al. (2017) found that young drivers overestimated their HPS. Moreover, Martinussen et al. (2017) concluded that sub-groups of young drivers are at a ‘double’ risk because, in addition to inaccurate self-assessments and low objectively measured HPS, they also scored higher in sensation seeking, a factor known to be related to risky driving behaviour (Gregersen, 1996; Schwebel et al., 2006). Sensation seekers have a higher threshold for what they consider risky and even seek out risky situations (Zuckerman, 2007, 1978). They accept higher risks and may thus have a higher threshold for reacting to potential hazards. By contrast, low sensation seekers are more inclined to judge incidents as hazardous (e.g. Horswill and McKenna, 2004). Consequently, sensation seeking may influence hazard perception and is therefore relevant to consider when exploring HPS.

With a focus on young drivers, the purpose of this study is to compare the consistency between self-assessed, and objectively measured HPS in visible and hidden hazard situations, and to examine the possible influence of a sensation seeking propensity. Eye movement analysis is included to determine if participants detected the hazards and thus to assess their HPS in combination with behavioural response measures.

Our hypotheses are as follows:

Hypothesis 1: In line with the findings of Martinussen et al. (2017), we expect that objectively and subjectively measured HPS are inconsistent; drivers with lower objective HPS have higher or the same self-assessed skills than drivers with higher objective HPS.

Hypothesis 2: The possible inconsistency between objective and subjective measures of HPS will be more pronounced in relation to hidden hazards, because hidden hazards require more advanced HPS than visible hazards (Crundall et al., 2012).

Hypothesis 3: Participants who detect potential hazards (measured by eye movements) but do not react to them (measured by changes in driving speed) score higher in self-assessed sensation seeking measures.

Hypothesis 4: Drivers with higher hazard perception skills measured in the driving simulator have more efficient eye movement patterns, meaning they look at the hazard more frequently (Pradhan et al., 2005) but for shorter time intervals (Chapman and Underwood, 1998).

The remainder of this paper is organized as follows: Section 2 describes the applied method and data analysis, Section 3 describes the results, and Section 4 discusses limitations and future work and conclusions of the study.

2 Method

2.1 Participants

Sixty-three young drivers, recruited among university students, participated in this study. The participants were 18 to 24 years old (M = 21.8, SD = 1.4), had normal or corrected to normal vision, and had had a driving licence for 0.5 to 6 years (M = 3.7, SD = 1.3). For 91 % of the participants their annual mileage was less than 10,000 km. They received a gift card (worth about 30 €) or credit points for participation.

2.2 Equipment and materials

2.2.1 Driving simulator and eye tracking equipment

A fixed-base medium-fidelity simulator was used to create the virtual driving environment and conduct the experiment. The simulator is composed of a cockpit equipped with all necessary control systems similar to a real car. The graphics system consists of three 42” plasma displays; the front screen has 1920 x 1080 dpi and the two side screens have 1360 x 768 dpi resolution. Displays are located around the cockpit, providing a 150° horizontal and 40° vertical perspective where scenarios are presented at a rate of 60 frames per second. Speedometer, rear- and side-view mirror information is visible on the centre and side screens. Additionally, the driving simulator has a 5.1-channel 3D sound system providing a rich audio environment with the sound of the engine, wind and tyres (Figure 1) The real-time simulation and modelling are controlled with SCANeR Studio software, developed by OKTAL.

Figure 1 The driving simulator set-up

A Tobii Pro Glasses 2 eye tracker recorded the drivers' eye movements with a sampling frequency of 50 Hz and a Tobii I-VT Fixation Filter (minimum fixation duration = 60 ms, velocity threshold = 30°/s, and max angle between fixations = 0.5°) as a fixation classification algorithm was used to filter out fixations from the raw eye tracking data (Tobii Technology, 2012). Videos were analysed with Tobii Pro Lab software.

2.2.2 Simulated scenarios

Six hazard situations were created and presented to the drivers in two different conditions (visible and hidden) and with two different groups of pedestrians (adult and child), meaning that participants encountered 24 hazard situations. The experiment consisted of three drives, each three kilometres long and the 24 hazards were equally distributed among the drives (8 hazards per drive). The drives were designed in a virtual city with buildings, intersections, parked cars, and street furniture to represent an urban street in Denmark with occasional traffic travelling in both directions and pedestrians walking on the pavement.

The present study analysed the drivers' response in the one of the hazard situations with an adult pedestrian in visible (Figure 2) and hidden (Figure 3) conditions. In both conditions, a pedestrian was standing on the pavement on the left side of the street and as the driver approached, 50 m before the hazard, the hazard window started; the pedestrian began running towards a ball, which was placed on the opposite side of the street. The pedestrian entered the road and stopped after two meters. The ball served as a cue to the driver that the pedestrian could continue crossing the street. In the visible condition, the participant could see the pedestrian during the entire hazard window. In the hidden condition, the pedestrian disappeared behind the parked car, and became partly visible only as the participant passed the parked car. The hazard window ended when the participant had passed the standing pedestrian. The participant had to brake to avoid an accident in case the pedestrian decided to continue crossing the road. This one particular hazard was chosen because that was the only situation where the pedestrian entered the street and the driver had to respond by lowering the speed to avoid the possible accident if the pedestrian continued running. In all other hazard situations pedestrians were on the pavement or were standing on the side of the street and therefore did not require active response from the driver.

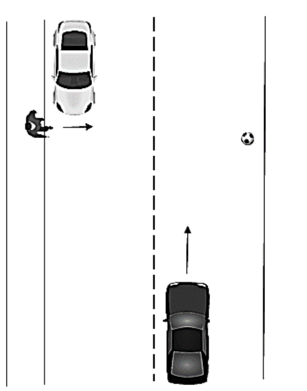

Figure 2 Visible hazard

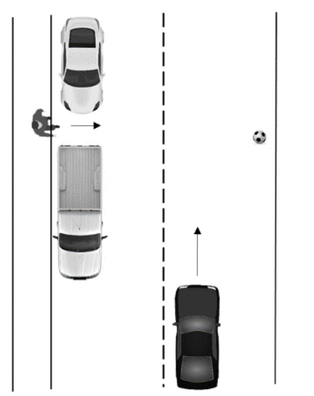

Figure 3 Hidden hazard

2.2.3 Questionnaire

To measure subjective/self-assessed HPS and general driving skills, we used the Hazard Perception Questionnaire (HPQ) (White et al., 2011) and the Driving Skills Questionnaire (DSQ) (McKenna and Myers, 1997). Participants were asked to compare their hazard perception skills (6 items), their overall, (1 item '*Relative to the average driver how skilful do you think you are?*') and specific driving skills (17 items) to the skills of an average driver on a seven-point scale from 1 (much less) to 7 (much more) with a midpoint of 4 (the same).

The Brief Sensation Seeking Scale (BSSS) (Hoyle et al., 2002) was used to measure the participants' sensation seeking propensity. Participants were asked to rate eight sensation seeking propensity statements as true or false for them. The statements regarded adventure seeking, social disinhibition, thrills, susceptibility to boredom, and experience seeking.

Background data included driver's age, years of owning a driver's license, and annual mileage measured in four categories (Table 2).

2.3 Procedure

The experimenter presented the participants with written instructions for the experimental procedure. The participants were informed that the goal of the study was to examine their everyday driving style. Following a demographic questionnaire, the participants undertook a practice drive to get accustomed to the simulator. Next, they were equipped with the eye-tracker and the eye-tracker was calibrated. The experiment continued with three drives presented in a random order (randomized using a Latin Square procedure). After each drive, the participants filled out one of the three questionnaires (HPQ; DSQ; BSS) in a randomized order. The whole experiment lasted about 30-45 minutes.

2.4 Data analysis

This section describes the methods of data analysis applied to the driving simulator data (Section 2.4.1), eye-tracker data (Section 2.4.2) and questionnaire data (Section 2.4.3).

2.4.1 Simulator data analysis

Driving speed was continuously recorded during each drive, but only the data for each hazard window were included in the analysis. A decrease in driving speed within the hazard window indicated that the driver had spotted the hazard and this was interpreted as responsiveness to it.

For each participant, the average speed was calculated and compared in five 10-metre intervals within the hazard window. The first interval with a significant reduction in driving speed (>2S D from average) was identified as the response time. A ‘critical point’ of two seconds before the hazard (the pedestrian) was calculated for each participant to determine the location (based on the individual driving speed of each driver) after which the driver could not avoid the hazard by braking if the pedestrian had continued across the street (e.g., Olson and Sivak, 1986). Based on the changes in average speed, three groups were identified; response in time (if the speed change interval occurred more than two seconds before the hazard), late response (if the speed change interval was closer than two seconds to the hazard), no response (no significant changes in average speed) (Figure 4).

Due to too few participants in the ‘late response’ group (one in hidden condition and one in visible condition), this group was excluded from further analysis.

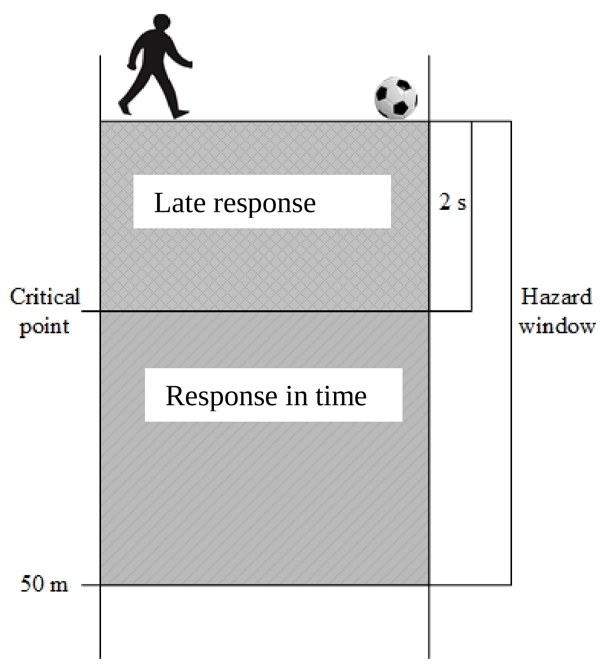

Figure 4 The hazard window

2.4.2 Questionnaire data analysis

To analyse subjective skills, the overall sum-score for HPQ, two sum-scores for DSQ (‘overall driving skills’ and ‘driving skills in specific situations’), and the overall sum-score for BSSS were calculated.

The Cronbach’s Alpha levels indicated an acceptable scale reliability (Peterson, 1994) for both HPQ (α = 0.89) and DSQ (α = 0.87). Mann-Whitney U-tests compared the sum-scores of the questionnaires for the two response groups of drivers in each condition.

2.4.3 Eye movement analysis

Analysis of general eye movements and fixations was based on mean fixation durations, and the standard deviation of fixation in the horizontal plane described the general eye movements of drivers.

Areas of interest (AOI) which covered the pedestrian and followed it during the whole hazard window were created. For each AOI, the number of fixations, dwell time, and meters to the first fixation on it were analysed. Dwell time was defined as the sum of all fixations in the AOI, represented as the percentage of the total length of the hazard window (i.e. the dwell time is 100 if the driver looks at the hazard all the time during the hazard window). To get the location where the hazard was first fixated upon, the participant’s driving speed was combined with the time to the first fixation.

3 Results

The results of this study are presented in three sections. Section 3.1 shows the objective hazard perception skills in hidden and visible conditions, Section 3.2 expands these results by an analysis of eye movements, another objective hazard perception measure. Section 3.2 describes the relation between the objective and the subjective hazard skills.

3.1 Behavioural response to hidden and visible hazards

Two groups of responses to hazards were distinguished: response in time and no response. In the visible condition (N = 62), 49 (79%) participants responded in time to the hazard, while 13 (21 %) did not respond. In the hidden condition (N = 61), 36 (59%) participants did not respond to the hazard, while 25 (41 %) responded in time. Drivers that failed to respond to the visible hazard also failed to respond to the hidden hazard; no drivers responded in time to the hidden hazard and not to the visible hazard. However, almost half (45%) of those who responded in time to the visible hazard did not respond to the hidden hazard (Table 1).

Table 1 *Cross-table of drivers in each group for both hazards*

		Hidden hazard	
		No response	Response in time
Visible hazard	No response	13	0
	Response in time	22	25

Analysis of demographic variables did not show significant differences in age, experience, and mileage between the two groups for both hazards (Table 2).

Table 2 *Groups' mean age, experience and median of category of mileage for both hazards*

		Age (years)	Experience (years)	Mileage¤
Visible	No response (N = 13)	21.85 (1.21)	3.73 (1.23)	1
	Response in time (N = 49)	21.84 (1.45)	3.71 (1.29)	1
Hidden	No response (N = 36)	21.94 (1.12)	3.71 (1.11)	1
	Response in time (N = 25)	21.64 (1.73)	3.76 (1.51)	1

¤ Measured in 4 categories (km/year): 1. ≤ 5000; 2. 5001-10,000; 3. 10,001-15,000; and 4. ≥15,001

Standard deviation shown in brackets.

3.2 Eye movements

To obtain more precise profiles of the drivers in both groups, their eye movements were analysed. Due to calibration problems, the gaze of seven participants in the visible hazard drive, and eight in the hidden hazard drive could not be precisely tracked, thus, the eye movement analysis contains 56 participants (N = 12 for ‘no response’ group, and N = 44 for ‘response in time’ group) in the visible condition and 55 in the hidden condition (N = 33 for ‘no response’ group, and N = 22 for ‘response in time’ group). No significant differences with regard to the average fixation duration and variation of horizontal fixation coordinates were found in visible and hidden condition.

3.2.1 Fixations on the hazard

All participants in both conditions had at least one fixation in the AOI. In the visible condition, the total number of fixations was higher for the ‘response in time’ group (Mdn = 4) compared to the ’no response’ group (Mdn = 2); U = 100.5, p = 0.002, r = 0.4. In the hidden condition, the results were similar: the ‘response in time’ group had more fixations in the AOI (Mdn = 3.5) compared to the ‘no response’ group (Mdn = 2); U = 181.5, p = 0.002, r = 0.4 (Figure 5).

In the visible condition, the dwell time was higher for the ’no response’ group (Mdn = 54.5) compared to the ‘response in time’ group (Mdn = 48.1); U = 149, p = 0.050, r = 0.3. In the hidden condition, the results were similar: dwell time in the AOI was higher for the ‘no response’ group (Mdn = 19.6) than for the ‘response in time’ group (Mdn = 11.4); U = 233, p = 0.036, r = 0.3 (Figure 6).

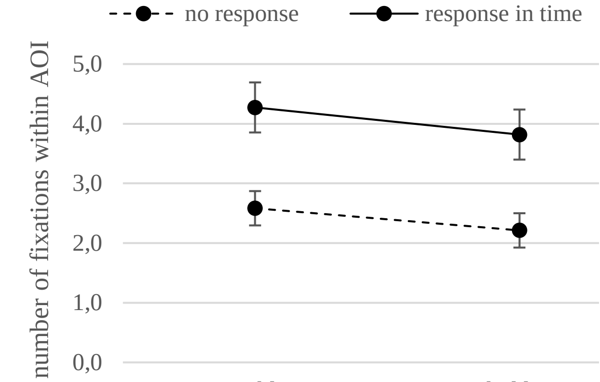

Figure 5 *Mean number of fixations for each response group for each hazard*

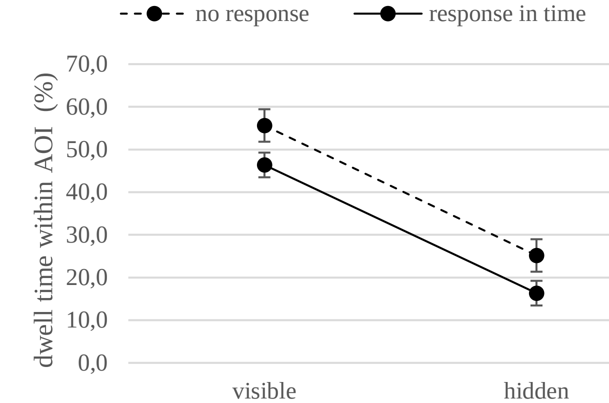

Figure 6 *Mean dwell time for each response group for each condition*

In the visible condition, the distance driven until the first fixation was higher for the 'no response' group (Mdn = 30.7) compared to the 'response in time' group (Mdn = 25.55); U = 99.5, $p = 0.003$, $r = 0.4$. In the hidden condition, the 'no response' group drove further until the hazard was fixated for the first time (Mdn = 30.8) than the 'response in time' group did (Mdn = 23.1); U = 149, $p <0.001$, $r = 0.5$ (Figure 7). The results confirmed our Hypothesis 4.

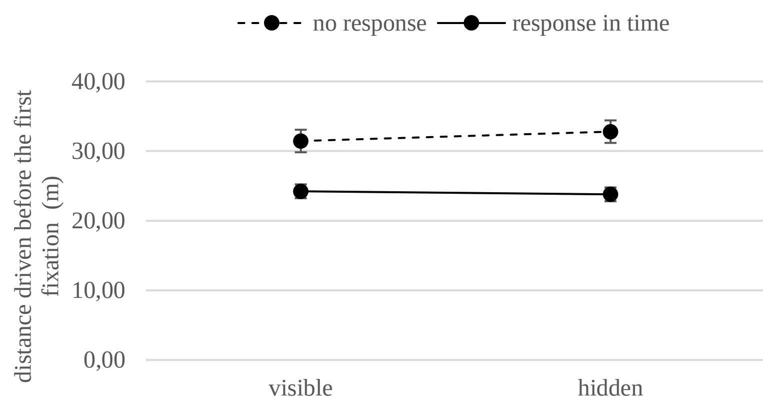

Figure 7 *Mean distance driven from the start of the hazard window to the first fixation for each response group for each hazard*

3.3 Consistency between subjectively and objectively assessed hazard perception skills

In the visible condition, participants with a response in time scored higher on self-assessed HPS than the non-responding participants (Table 3). Also, the scores for self-assessed overall driving skills and driving skills in specific situations were higher for the ‘response in time’ group. Thus, contrary to what we expected in Hypothesis 1, subjective skills were consistent with objective skills. Contrary to what we expected in Hypothesis 3, ‘response in time’ group had higher sensation seeking scores.

Table 3 Visible condition. Comparison of self-assessed measures in ' response in time' and 'no response' groups.

	Response in time N = 49	No response N = 13	Mann-Whitney U-test		
	Mdn	Mdn	U	p	r
Hazard perception skills	26	23	210.5	0.047	0.2
Overall driving skills	5	4	153.5	0.003	0.4
Specific situation skills	77	76	211.0	0.049	0.2
Sensation seeking	5	3	211.5	0.054	0.2

The results of the hidden condition to some degree resemble the results of the visible condition, as the existing differences were less pronounced and not significant (Table 4). Thus, contrary to what we expected in Hypothesis 2, differences between objectively and subjectively HPS were not more pronounced in hidden hazard situations.

Table 4 Hidden condition. Comparison of self-assessed measures in 'response in time' and 'no response' groups.

	Response in time N = 25	No response N = 36	Mann – Whitney test		
	Mdn	Mdn	U	p	r
Hazard perception skills	25	25.5	426.5	0.73	0.0
Overall driving skills	5	5	403.5	0.71	0.1
Specific situation skills	75	76.5	449.0	0.99	0.0
Sensation seeking	5	4	339.5	0.10	0.2

4 Discussion

This study aimed to better understand why drivers of similar experience, age, and same gender differ in their ways to respond to hazards. Objective measures of HPS were assessed when approaching hidden and visible hazards in a driving simulator and used to differentiate between drivers with high and low HPS. This differentiation was validated by eye movement data. Subjective measures of HPS were assessed with questionnaires. In contrast to previous studies (Farrand and Mckenna, 2001; Martinussen et al., 2017), we found that young drivers' objective and subjective HPS were consistent, although only for visible hazards. Drivers who responded in time had significantly higher subjectively assessed hazard perception and driving skills than drivers who did not respond to the hazards.

A potential explanation for the discrepancy of our results to Farrand and Mckenna (2001) can be the differences in the definition and measurement of objective HPS. We separated and compared two groups of drivers based on their responsiveness to hazards measured by decrease in speed in the driving simulator. By contrast, Farrand and Mckenna (2001) used a button pressing task, which measures whether drivers detect the hazard and not whether they also would respond in time to avoid a collision. Consequently, in the study by Farrand and McKenna the link between hazard detection and response to the hazard - an essential part of HPS - remains unidentified. In our results, hazard detection and response is linked, and the results suggest that subjectively measured HPS are indeed a relevant indicator of objectively measured HPS. However, the results also suggest that the HPQ predicts responsiveness to visible hazards, but not to more complex hazards that require anticipation. In addition, it must be noted that the HPQ questionnaire was administered after one of the drives (in randomised order) which may have influenced the results. In future studies counterbalancing the questionnaires with some being filled out before and some after the driving scenarios would be relevant to limit possible response bias created by driving.

Differences to the results of Martinussen et al. (2017) may be related to different methods applied to distinguish between high and low HPS in both studies. While we separated the groups based on response in time or no response specifically to hazards, Martinussen et al. (2017) separated their sub-groups of drivers based on the median of the total score on the behavioural measures across different driving skills such as overtaking, maintenance of safe gap to the car in front, hazard prediction, and hazard detection.

Another explanation for the different results compared to previous studies could be related to the hazards used to assess objective HPS: Martinussen et al. (2017) used hazards without behavioural and/or environmental cues, the situation thus being rather sudden. Studies show that, when testing groups with various driving experience, sudden onset hazards (e.g. a child suddenly running into the road just in front of the driver) are unlikely to be anticipated by any driver (Yeung and Wong, 2015). Farrand and Mckenna (2001) did not specify what kind of hazards were used.

In line with the results of Crundall et al. (2012), our results confirm that hidden hazards with environmental cues are less likely to be identified by young drivers than visible hazards with behavioural cues. The fact that drivers with a response in time had more efficient eye movement patterns and drove longer distances until the first fixation indicates that a lack of response in time is a result of low HPS. However, as the results regarding hidden hazards were not significant, the hypothesis that hidden hazards differentiate better between low and high HPS could not be confirmed. As the ability to anticipate hazards develops slowly with experience (Vlakveld, 2011), the level of experience among this study's participants was probably too similar to detect experience-based differences. Further studies with the possibility of a more detailed categorization of various experience levels are needed to verify this.

Based on driving behaviour, we initially identified three groups of drivers: response in time, no response and late response. As the 'late response group' only consisted of one participant in each condition, it was excluded from further analysis. The size of the remaining two groups varied between the types of hazards. However, none of the non-responding drivers in the visible condition responded to the hidden hazard. This result supports the conclusion that higher levels of HPS are needed to detect hidden hazards, and indicates that the non-responding participants had the lowest HPS among the participants. To confirm this, future studies including additional measures of HPS are relevant, as it is possible that not responding to any hazard is a response pattern rather than an actual behaviour. Additionally, drivers might not have responded to the hazards because they have learned during the experiment that none of the previous hazards materialized. This possible learning effect should be acknowledged as a limitation of this study.

Contrary to what we expected, sensation seeking scores were higher for drivers who responded on time to the visible hazard. This result suggests that a sensation seeking propensity does not influence hazard perception negatively, at least not when the hazard is visible.

All participants in both conditions had at least one fixation on the hazard, suggesting that everyone saw the pedestrian. The response measured in the simulator differentiated between drivers that recognised the pedestrian as a risk, thus having higher HPS. Participants who responded in time fixated on the hazards earlier and more often, but had shorter dwells, suggesting shorter process time indicating higher HPS, which is in line with previous studies (e.g. Crundall et al., 2012). As expected, analysis of eye movements supported the differences between groups in both hazards, contributing to the result that behavioural measures (i.e. changes in approach speed) indeed discriminated between groups of higher and lower HPS.

In conclusion, we found a consistency between subjective and objective HPS, but only for visible hazards. Our results show that the HPS questionnaire applied in this study can be used to predict responsiveness to visible hazards, but not to more complex hazards that require anticipation. However, this result may be different for drivers of varying age and experience levels and should be explored further. Eye movement analysis confirmed the differentiation between drivers with high and low HPS based on the simulator results and provided additional useful information on young drivers' hazard perception.

As HPS develops with driving experience, the results should be taken into consideration when designing the curriculum for new drivers to ensure that a variety of hazards are included in hazard perception training. The results of this study can be used to develop specific training programs by use of the driving simulator with a particular focus not only on detecting, but also adequately responding to hidden hazards that demand more advanced HPS. This could be useful to ensure that new drivers have high HPS when acquiring their licence.

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