What happens when drivers face hazards on the road?

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ABSTRACT

The current study aims to obtain knowledge about the nature of the processes involved in Hazard Perception, using measurement techniques to separate and independently quantify these suspected sub-processes: Sensation, Situation Awareness (recognition, location and projection) and Decision-Making. It applies Signal Detection Theory analysis to Hazard Perception and Prediction Tasks. To enable the calculation of Signal Detection Theory parameters, video-recorded hazardous vs. quasi-hazardous situations were presented to the participants. In the hazardous situations it is necessary to perform an evasive action, for instance, braking or swerving abruptly, while the quasi-hazardous situations do not require the driver to make any evasive manoeuvre, merely to carry on driving at the same speed and following the same trajectory. A first Multiple Choice Hazard Perception and Prediction test was created to measure participants' performance in a What Happens Next? Task. The sample comprised 143 participants, 47 females and 94 males. Groups of non-offender drivers (learner, novice and experienced) and offender drivers (novice and experienced) were recruited. The Multiple Choice Hazard Perception and Prediction test succeeded in finding differences between drivers according to their driving experience. In fact, differences exist with regard to the level of hazard discrimination (d' prime) by drivers with different experience (learner, novice and experienced drivers) and profile (offenders and non-offenders) and these differences emerge from Signal Detection Theory analysis. In addition, it was found that experienced drivers show higher Situation Awareness than learner or novice drivers. On the other hand, although offenders do worse than non-offenders on the hazard identification question, they do just as well when their Situation Awareness is probed (in fact, they are as aware as non-offenders of what the obstacles on the road are, where they are and what will happen next). Nevertheless, when considering the answers participants provided about their degree of cautiousness, experienced drivers were more cautious than novice drivers, and non-offender drivers were more cautious than offender drivers. That is, a greater number of experienced and non-offender drivers chose the answer "I would make an evasive manoeuvre such as braking gradually".

Introduction

Traditional Hazard Perception (HP) tests are used to discriminate between safe and less safe drivers on the basis of their ability to respond quickly to developing hazards in video clips of driving and now form a part of the driver-licensing procedure for the UK and parts of Australia. Many studies have explored the ability of Hazard Perception tests to discriminate between safe and less safe drivers across a wide range of road users, including novice and learner drivers (e.g. Horswill and McKenna, 2004), older drivers (e.g. Horswill et al., 2008), motorcyclists (Crundall et al., 2013; Vidotto et al., 2011), emergency vehicle drivers (Crundall et al., 2003, 2005; Johnston, 2014), driving offenders (Castro et al., 2014; Castro et al., 2016) and even pedestrians (Rosenbloom et al., 2015). Materials have also been developed into training interventions (e.g. Helman et al., 2012; Horswill et al., 2013, 2015; McKenna et al., 2006).

Many studies have demonstrated the ability of hazard perception tests to discriminate safe from unsafe drivers, despite using very different tests created in different laboratories across the world. While there have also been some studies which have failed to replicate these successes (see Horswill and McKenna, 2004 for a review), the body of evidence suggests that Hazard Perception tests do indeed tap into an essential skill for safe driving. One study even found that drivers who performed poorly on an Hazard Perception test were more likely to have died as a result of a traffic collision in the subsequent 12 months (Drummond, 2000). Certainly the introduction of the Hazard Perception test into the UK driver-licensing procedure appears to have had a demonstrable affect upon traffic collisions (Wells et al., 2008). This positive reduction in collisions could be due to two factors: 1) the capacity of this test to filter out "unsafe drivers" before they obtain their driving licenses, and 2) the inclusion of Hazard Perception skills in the training required to obtain a driving license, though in all likelihood, both factors contribute.

However, despite the myriad of studies using hazard perception tests, few studies have attempted to unpack the skill to identify its underlying components (cf. Crundall, 2016). It is important to gain a better understanding of the cognitive processes which underpin HP as this knowledge will allow us to better refine driver education and testing. .

1.1.Sensation and Decision-making: Signal Detection Theory

Brown & Groeger (1988) defined Hazard Perception as the process of identifying hazards and quantifying their potential for danger. However in addition to identifying hazards, the driver also needs to reject possible hazards for continued inspection, so as to better prioritise the most dangerous aspects of the scene. This approach draws parallels with Signal Detection Theory (Green & Swets, 1966; Swets, 1998; Macmillan & Creelman, 2005). Signal Detection Theory (SDT) changed our way of thinking about the performance of sensory tasks by explaining that performance depends not only on sensory information, but also on biases inherent in the decision-making processes.

Signal Detection Theory provides a framework to describe and analyse decisions that are made in uncertain or ambiguous situations (Wickens, 2001). The person must decide whether or not a target is present or a condition is met. For simple tasks such decisions may be easy to make: the alternatives are obvious and the evidence is clear. Other tasks, however, are not so simple. While alternatives may remain distinct, the evidence on which to base the decision may be ambiguous, or the situation presents a high level of noise compared to the target signal. Judging the danger present in a driving situation is one example of a complex task that can be beset by a weak signal-to-noise ratio.

Signal Detection Theory models two important aspects of the decision-making process in such ambiguous scenarios: sensitivity to the signal embedded within the noise, and the bias or criterion that guides one's decisions. The first aspect of the decision-making process is captured in the measure of sensitivity (d-prime), which is essentially the number of hits (correct identifications) minus the number of false alarms (reporting a target when no target is present). This reflects the intensity of the signal in comparison to background 'noise'. A 0 value means an inability to distinguish signal from noise, while increases in d' reflect a greater ability to distinguish signals from noise.

In the second stage, this signal is evaluated and compared to a threshold of evidence above which one accepts the presence of a target. This threshold differs from person to person and across time and tasks. It is often called the response bias of criterion and is represented as β. A low criterion reflects a liberal tendency to always report that the target is present, while a high criterion represents a more conservative stance. Some tasks may even encourage both criteria to be used sequentially. For instance, radiologists can be instructed first to examine all images, using a liberal criterion (tendency to say Yes, there is a tumour), and then to reexamine positive images, using a conservative criterion (tendency to say No). A neutral criterion, $\beta = 1$, is found when participants favour neither the Yes response nor the No response. However, values less than 1 can be interpreted as a bias towards responding YES (liberal criterion), whereas values of β greater than 1 indicate a bias towards the NO response (conservative criterion).

The traditional method of conducting a Signal Detection analysis takes measures of correct hits (when a participant correctly identifies a hazard) and false positives (when a participant incorrectly identifies a non-hazard as being a hazard), which are entered into formulae to determine separate measures of sensitivity (d-prime) and response bias in decision-making (β or criterion) (Stanislaw & Todorov, 1999).

Wallis & Horswill (2007) stated that there are a number of reasons why this approach is both conceptually inappropriate and practically difficult for HP-like tasks. They believe that in the Hazard Perception domain, there is no way to objectively measure whether a scene is "a hazard" or "not a hazard" as it lacks the objectively measurable assessment of a binary true state. They argue that traffic environments can be considered to vary in their potential for hazard with context and over time. Accordingly all traffic situations can be better conceptualised as potentially hazardous *to some degree*. They used ratings of the traffic scenes by driving experts to perform a Fuzzy Signal Detection Theory analysis. They argued that ratings of a domain authority might be appropriate. For example, instructors were used as a benchmark for the level of risk present in a traffic situation (Crundall et al., 2003; McKenna & Crick, 1991; Mills et al., 1999), against which risk judgments by less experienced drivers could be compared.

These fuzzy rates are then used to calculate sensitivity and response bias as in traditional Signal Detection Theory (Parasuraman et al., 2000), for example, a response of 80% 'yes' to an event that is 60% signal-like. The event is somewhat signal-like so warrants a response (hit = 60%), but the individual over-responds so is assigned a proportion of false alarm (20%) and of correct rejections (20%). These fuzzy rates are then used to calculate sensitivity and response bias as in traditional Signal Detection Theory (Parasuraman et al., 2000).

Wallis & Horswill's (2007) results did not identify any sensitivity differences between experienced drivers and novices in the Hazard Perception test (the Signal Detection analysis) or in the hazard-rating task (the Fuzzy Signal Detection analysis). Similarly, the trained and untrained drivers did not differ in sensitivity in either task. Sensitivity in the Hazard Perception test and the hazard-rating task did not correlate with latency in the Hazard Perception test for all groups. However the untrained novice group was significantly more conservative than both the trained novice group and the experienced group in the Hazard Perception test, though these differences did not carry over to the hazard-rating task. Response bias in the Hazard Perception test correlated significantly with latency, so that more liberal responses were associated with faster latencies for trained novices, untrained novices and experienced drivers.

One explanation for these results is that the subjective estimation of a reduced number of experts can contaminate the analysis and bias the results obtained. A similar criticism of the use of expert or experienced drivers' judgments was made by Wetton, Hill & Horswill (2011) of the staged driving situations used to create the Hazard Perception Test. The authors believed that this practice of manoeuvring vehicles in front of a car with a camera so as to deliberately create a dangerous situation from the point of view of expert or experienced drivers (McKenna & Crick, 1991; Catchpole & Leadbeatter, 2000, for instance) could contaminate the criterion. They explained that if expert or experienced drivers inadvertently create scenes that favour individuals who are more like themselves (and not necessarily in terms of Hazard Perception ability alone), then this may explain why those scenes sometimes appear to discriminate between novice and experienced drivers more effectively than scenes featuring unstaged hazards (Crundall et al., 2003).

Recent work published by Sanocki, Islam, Doyon & Lee (2015) also shows that it is possible to study Hazard Perception in terms of the classic Signal Detection Theory (Green & Sweets, 1966), which separates sensitivity, the overall ability to differentiate the presence or absence of vulnerable road users (VRU pedestrians, cyclists, etc.), from bias when interpreting the stimulus information (the amount of perceptual evidence needed for detecting the VRU). They explored how crowded environments decrease sensitivity and thereby increase errors.

An alternative way to apply Signal Detection Theory to hazard perception is to conceptualise the hazard from a functional point of view. If a developing driving situation would cause a collision without an atypical avoidance response (i.e. gradual braking towards traffic lights would not count) then this could be termed a hazard requiring a response. We are still left with the problem of *when* the driving situation is considered to have become hazardous. This is a problem that has taxed all researchers who have attempted to measure response times to hazards. One way to reapply Signal Detection Theory to hazard perception is to remove speeded responses completely, instead adopting a simple binary probe question (e.g. did you see a hazard?). This approach to hazard perception has been the focus of recent research that has attempted to link Hazard Perception with Situation Awareness, but these studies have so far failed to combine this technique with an Signal Detection Theory analysis. The following section will introduce this methodology and discuss its compatibility with Signal Detection Theory.

1.2. Situation Awareness: Hazard Recognition, Hazard Location and Prediction of the Future Situation

Endsley (1987) proposed the Situation Awareness Global Assessment Technique (SAGAT) as a viable method for measuring Situation Awareness. This technique requires the task to be suddenly paused, at which point probe questions are presented to the participant to assess their understanding of the situation at that instant. To have Situation Awareness, one must pass through Endsley's three stages: perception of the environment, comprehension, and finally prediction of future stages. If a driver can correctly perceive, comprehend and predict the environment while driving (and moreover, do this constantly on an iterative basis), then s/he should be less likely to have a collision (though excellent Situation Awareness does not necessarily predict the quality of the ultimate choice of behaviour).

McKenna & Crick (1997) applied the SAGAT technique to hazard perception clips, exploring the training potential of the methodology for improving hazard perception skill. Participants were first given instruction in active search strategies before they were presented with a series of clips that were paused just when a hazard was about to occur. Participants were then asked "what might be about to happen?" The pausing of the video (the paused frame was still available to view on the screen) gave participants more time to process the imminent events. This training significantly reduced response latencies to hazards in a subsequent hazard perception task.

Jackson, Chapman & Crundall (2009) revisited the SAGAT methodology with their ‘What Happens Next?’ task, employing the test for assessment purposes rather than for training. The clips were paused immediately prior to the appearance of a hazard, but crucially, they only discriminated between novice and experienced drivers if the clips were occluded during the pause. Similarly, Castro et al., (2014; 2016) developed a Spanish version of the ‘What Happens Next?’ test. A series of questions probed the participants’ perception, comprehension and prediction abilities during the occluded pauses: *What is the hazard?, Where is the hazard?* and *What happens next?* An adequate response to these questions could be “A pedestrian… on the left sidewalk… is about to step out in front of my car”. Two different driving situations were explored, according to the driver’s experience: hazardous and quasi-hazardous situations. The results demonstrated that learner drivers and re-offenders are less able to identify quasi-hazardous traffic situations than experienced drivers. Regarding hazardous situations, the findings are consistent with previous literature (Jackson et al., 2009 and Crundall et al., 2010, 2012): experienced drivers outperform novice and learner drivers in identifying hazardous situations. This reinforces the finding that experience is an important factor in identifying hazardous situations.

From the current perspective, this type of occluded hazard prediction task lends itself perfectly to a standard, non-fuzzy, Signal Detection Theory analysis. If the findings of Wallis and Horswill are robust, we should be able to replicate them with this simpler approach to analyzing d’ and *β.*

1.3. The Current Study

To measure and quantify different factors to explore the processes involved in Hazard Perception, we built a Multiple Choice Hazard Perception and Prediction Test. It was developed to measure both Sensitivity and Response bias (Signal Detection Theory parameters) and Situational Awareness (Endsley, 1995) through different driving situations, using the following questions: *What is the hazard? Where is the hazard? What happens next?* For this purpose, two types of driving situation are explored: hazardous and quasi-hazardous situations. A hazardous situation was defined as a driving situation that develops into a real hazard that requires the driver to react in order to avoid a collision (for example, by slowing down or by making an evasive manoeuvre). A quasi-hazardous situation was defined as a potentially hazardous situation that does not, in the end, develop into a hazard (i.e. despite the driver changing neither speed nor position).

We also explore the test's capacity to discriminate between drivers with different driving experience (learners, novice and experienced) and according to their offender status (offenders/non-offenders). Psychometric properties, such as reliability measures and evidence of validity are analysed. Finally, we aimed to explore the relationship between Signal Detection Theory parameters, Situation Awareness and Cautiousness in Decision-Making.

1.4. Research Hypothesis

If Hazard Perception skill can be modified and improved by practice (via many hours of real driving), then the current test should discriminate between novice and experienced drivers, and possibly between offender and non-offender drivers. Less clear is the contribution of the different sub-components of hazard perception skill to this potential discrimination. For instance, Wallis and Horswill (2007) might argue that response bias is more important than sensitivity, with less-experienced drivers requiring greater evidence before concluding that a hazard is present. The current study will try to replicate this finding and extend the results to discriminating between drivers on the basis of offender status.

We would like to ascertain whether offender drivers use a more conservative criterion β and show a higher tendency to say No to potentially hazardous situations than non-offender drivers when performing Hazard Perception tasks and whether they make the decision to perform less cautious manoeuvres after seeing a hazardous or quasi-hazardous situation (i.e. making the decision to carry on driving at the same speed and on the same path). If so, new questions could emerge from the results, for instance, it would be possible to further investigate whether offender drivers' assumption of higher risk happens only in the driving context or is more general, a personality trait that may also involve the assumption of higher risk in other facets of their lives.

2. Method

2.1 Participants

One hundred and forty three participants were recruited (47 females and 94 males) with a mean age of 29 years (sd = 11.8), ranging from 18 to 66. These participants were split into three groups: learners (who had yet to pass a driving test but were actively learning to drive), relative novices (within 8 years of passing their driving test) and experienced drivers (8 or more years' experience). These latter two groups could be further classified as offenders and non-offenders. Table 1 provides details on the allocation of drivers to these groupings. Spain applies the following demerit points system to driving licenses: Spanish residents are issued with 12 points initially. If a driving offence is committed, points are deducted from the license according to the severity of the offence. When no points remain, the license is cancelled and the holder must go through a re-education process to have it reissued. All offender participants were attending this compulsory re-education course.

Please insert Table 1 about here

2.2. Materials

2.2.1 Videos

The Multiple Choice Hazard Perception and Prediction Test consisted of twenty-four High Definition (HD) clips, with a resolution of 1920X1080, that were filmed from a Canon HD Legria HF R16 full HD digital camera mounted internally on the windscreen of a moving vehicle. All videos constituted real driving scenarios (none were staged) that included different traffic situations recorded from the driver's perspective. Video scenes were recorded in the metropolitan area of Granada and outside the town, including urban roads, minor roads and highways. All videos were selected from a database that contained more than 300 videos recorded in Granada. Selected clips lasted between 6 and 26 seconds and were edited to occlude immediately prior to the hazard (or quasi-hazard). A description of video content can be seen in Table 2.

Please insert table 2 about here

The 24 clips were split into 18 composed of actual hazardous situations and 6 composed of quasi-hazardous situations. This distinction was based on whether the film-car drivers had to alter their behaviour to avoid a collision (a hazard) or whether they were able to continue without any change (a quasi-hazard). These clips were presented in 3 blocks of 8 (following two practice trials), with a 10-minute break between blocks.

2.2.2 Response booklet

Participant responses following each clip were recorded in a response booklet containing 5 questions per clip. The questions were presented on one page per hazard and asked: (Question 1) “Did you see any hazard at the moment when the video was cut?” (Yes/No); (Question 2) “What manoeuvre would you perform if you were the driver of the vehicle?” (maintain speed and direction/evasive manoeuvre); (Question 3) “Where was the hazard at the moment when the video was cut?” (indicated by participants marking an X to indicate location on a pencil-style drawing of the final video frame, with vehicles, pedestrians and other objects removed); (Question 4) “What is the hazard?” (3 options were given); and (Question 5) “What might happen next in the traffic scene?” (again 3 options were given).

The picture used for Question 3 was created by editing a still shot of the final frame of each video (just before occlusion) in Photoshop, first stylising it into a black and white pencil drawing, then editing out all pedestrians, vehicles and other pertinent objects, while leaving the structure of the road, road markings, road furniture and surrounding buildings. All pictures were formatted to 15 cm by 10 cm. A point was awarded for accuracy if the X was placed within the perimeter of the cause of the hazard (e.g. if participants wished to place an X on a car emerging from a side road, they would score a point if the cross fell within the boundary of where the car would have been in the picture, had it not been removed during editing). They received half a mark if the X was located within 1 cm of the boundary of the cause of the hazard.

The options for Question 4 (what is the hazard?) would provide alternative hazard sources to choose between. For instance: a. The white pickup on the right, b. The car that appears on the left, c. Intersection with poor visibility.

Multiple-choice options for Question 5 (what happens next?) would identify possible outcomes that could occur within the next few seconds of the paused clip. Examples include: a. The car will reverse, b. The white pickup will reverse, c. The car will continue forward.

For these last two questions with three alternative answers, there were two distracting options and one correct option. The items were constructed considering the answers given by the sample of participants recorded in a previous Hazard Perception and Prediction Test, when the same questions were presented in an open format (Castro, et al. 2014). A point was awarded for selecting a correct option.

2.2.4 Demographics questionnaire

A demographics questionnaire collected data from 19 items covering sex, age, education, driving experience (years since a successful driving test), type of license, driving frequency (Km/month and year) and driving history over the preceding 12 months (collisions, near-collisions and fines).

2.3. Procedure

Participants completed the test in group sessions. They were recruited from either the School of Psychology and the School of Sciences of the University of Granada or different collaborating driving schools in Granada: *Autoescuela La Victoria, Luna and Genil*.

First, participants filled in the socio-demographic questionnaire individually. They were then given practice with the question format, using two practice video-samples of the Multiple Choice Hazard Perception and Prediction Test, before the start of the experimental test. The video clips were then presented to participants seated at a distance of between 3 and 5 metres from a projection screen. Each video clip was occluded immediately prior to a hazard (or quasi-hazard). Following occlusion, participants turned to the next page of the response booklet and answered the 5 questions.

2.4. Data analyses

Following item analysis, Levene's homogeneity test, a test for normality (KS test) and reliability checks (using Cronbach's Alpha), a series of Analyses of Variance (ANOVAs) were conducted to explore the processes involved in Hazard Perception and Prediction: Sensation and Decision Making (STD parameters), Situation Awareness (recognition, location and projection) and Cautiousness in Decision-Making. Tukey's test for multiple comparisons, pairwise comparisons using the Bonferroni adjustment and planned comparisons were used to control overall significance while identifying the precise location of main effects and interactions. The level of statistical significance was set at .05. Eta squared (η^2) and partial Eta squared (*$\eta^2 p.$*) were the statistics applied to measure the effect size with values ranging from low (values below or equal to 0.02), moderate (values between 0.03 and 0.14) to high (over 0.14), according to Cohen (1988) and Richardson (2011). All statistical analyses were performed using IBM SPSS Statistics v20 for Windows.

All ethical principles given in the Declaration of Helsinki for research involving human participants were followed in the current study.

3. Results

3.1. Internal Consistency

This test showed good psychometric reliability. Table 3 shows the descriptive statistics and the discrimination indices of the test videos: 20 videos had values of discrimination indices higher than 0.20. Only 4 of the initial videos had discrimination indices outside the established range: 3 hazardous situations and 1 quasi-hazardous situation, and these were removed from the final version of the test analysed. These 20 videos showed a satisfactory reliability and discrimination index. Cronbach's alpha coefficient was found to be acceptable (α =0.770). This value is dependent on the items' sample size, so, in this case, it achieved a reasonable internal consistency with a small sample of video-items.

Please insert table 3 about here

3.2. Analyses of the Signal Detection Theory parameters: d-prime and criterion ***β***

One of the benefits of using a simple accuracy response to detecting a hazard (Question 1: Did you see any hazard at the moment the video was cut?) is that the data can be easily subjected to Signal Detection analysis (Green and Swets, 1966) to assess drivers' sensitivity to hazards (their ability to correctly identify hazards, while avoiding false alarms; *d'*) and their criterion (drivers' general tendency to report everything as either hazardous or non-hazardous; *β*).

Signal Detection Theory (Green & Swets, 1966) was used to analyse data from the first question asked: *Did you see any hazard at the moment when the video was cut?*

The best results were found for Non-Offender Experienced drivers, with 86% of Hits and only 19% of False Alarms (FA), then Experienced Offender drivers, who obtained 73% of Hits and 40% of FA. They were followed by Non-offender Novice drivers, who obtained 64% of Hits and 47% of FA. The worst results were found for Offender Novice drivers, who obtained 56% of Hits and 52% of FA.

Please insert table 4 about here

Taking into account the values of Hits and FA of these groups of participants, the sensitivity and criterion measures were calculated. Following Stanislaw & Todorov (1999), we calculated d' measures for all participants for accuracy in reporting a hazard in Q1. A 2x2 between groups ANOVA was conducted, using d' measures for novice and experienced driver groups, split according to offender status.

Results showed there was a significant effect of both experience [$F(1,108)=16.37$ $p=0.001$ partial $\eta^2=0.13$] and offender-status [$F(1,108)=6.46$ $p=0.012$ partial $\eta^2=0.06$], but the interaction was not significant [$F(1,108)1.84$ $p=0.18$ partial $\eta^2=0.017$]. Experienced drivers (M= 1.60) had greater sensitivity than novices (M=0.35); and non-offenders (M=1.36) had greater sensitivity than offenders (M=0.58), see Figure 2.

A one-factor ANOVA (between subjects) was conducted using d' measures for learner, novice and experienced drivers, all of them non-offender groups. Results showed there was a significant effect of experience [$F(2,94)=21,02$ $p=0.001$ partial $\eta^2=0.309$]. Non-offender experienced drivers (M= 2.19) had greater sensitivity than non-offender novice drivers (M=0.52), $t(61)=-5,51$ $p=0.001$]; and non-offender experienced drivers had a greater sensitivity than learners (M=0.38), $t(58)=-6,57$ $p=0.001$]. But no differences were found between learner and non-offender novice drivers in the d' parameter.

Please insert figure 2 about here

A similar 2x2 ANOVA was carried out to compare drivers' criterion β across the variables of experience and offender status. There was no main effect of experience [$F(1,108)=0.010$] or offender-status [$F(1,108)=0.045$], and the interaction also failed to reach statistical significance [$F(1,108)=2.42$]. All the values obtained were close to 1 (Non-offender experienced drivers=0.92, Non-Offender novice drivers=1.1; Offender experienced drivers=1.09 and Offender Novice Drivers=0.89), suggesting no significant response bias in either direction.

A one factor ANOVA (between subjects) was conducted to compare drivers' criterion β for learner, novice and experienced drivers, all of them non-offender groups. There was no main effect of experience for the criterion β.

3.3. Situation Awareness

3.3.1. Experience X Offenders X Type of Hazard

Questions 3, 4, and 5 probed situation awareness (following Jackson et al., 2009). Response accuracy to these questions was averaged for each participant and a 2×2×2 mixed-model ANOVA compared participant scores across experienced (experienced vs. novice), offender status (offender vs. non-offender), and across the within-groups factor of hazard type (actual hazard vs. quasi-hazard).

No significant main effect of the type of hazard was found [$F(1,105)=2.73$ $p=0.10$ partial $\eta^2=0.02$], nor of offender status [$F(1,105) = 3.91$ $p=0.051$ partial $\eta^2 =0.06$].

The results did, however, reveal a main effect of experience [$F(1,105) = 7.34$ $p=0.01$ partial $\eta^2 =0.06$]. Novices (M=1.06) were less accurate than experienced drivers (M=1.38). None of the interactions reached significance.

3.3.2. Experience X Situation Awareness Questions

A 3×3 mixed-model ANOVA was used to examine the differences between questions of situational awareness (*Where?, What?* and *WHN?*) as repeat measures factor; and driving experience (learner, novice and experienced drivers) as the between-subjects factor. (See Figure 3).

Please insert figure 3 about here

A significant main effect of driving experience was found [$F(2,137)=9.26$ $p=0.001$ partial $\eta^2=0.12$]; learner (M=0.34), novice (M=0.37) and experienced drivers (M=0.45). [The results demonstrate that experienced drivers out-performed learner drivers [$t(137)=-3.82$ $p=0.001$] and experienced drivers out-performed novice drivers $t(137)=-3,24$ $p=0.002$].

Significant differences were found between the situation awareness questions [$F(2,136)=128,66$, $p=0.001$ partial $\eta^2=0.65$]; *What?* (M=0.48) questions were correctly answered significantly more often than *Where?*

(M=0.29) or *WHN?* (M=0.39); though more surprisingly, *Where?* questions were correctly answered significantly less often than *WHN?* questions.

A significant effect of the interaction between experience and questions was also found $F(4,271)=5.17$ $p=0.001$ partial $\eta^2=0.071$].

Planned comparisons located significant differences between learner and experienced drivers for the three questions: *Where?* [$t(94)=-2.96$ $p=0.004$]; *What*?, [$t(94)=-3.67$ $p=0.001$] and *WHN* ? [$t(94)=-4.03$ $p=0.001$]. In addition, the only planned significant comparison between learner and novice was found for the Where question [$t(76)=-2.35$ $p=0.021$]. The results demonstrate that the experienced drivers out-performed the other groups in two of the three questions, while the novices behaved like the learners when answering *What?* and *WHN?* questions, but performed more like the experienced drivers when locating the source of the potential hazard (*Where?*).

3.4. Cautiousness in Decision-making

Another way of analysing the decision-making process was explored with Question 5: "*What manoeuvre would you perform if you were the driver of the vehicle?"* For this question, Cautiousness in decision-making was measured as the number of times a participant marked *"I would make an evasive manoeuvre such as braking gradually"* rather than *"I would carry on driving at the same speed and trajectory"*. This first answer could be considered more cautious and conservative and is recommended by instructors at the driving schools whenever some hazardous or quasi-hazardous situation appears in the driving setting. A cautious answer was given a 1 and a non-cautious answer was scored as zero. These scores were averaged over clips for each participant and then subjected to a 2x2 between-groups ANOVA comparing experience (novice and experienced drivers) and offender status (non-offender and offender drivers) on this question.

A main effect of experience was found [$F(1,105)=13.01$ $p=0.001$ partial $\eta^2=0.11$], with experienced drivers being more likely to make a cautious response to the hazard (novice drivers M=0.61; experienced drivers M=0.75).

A significant main effect of offender status was also found [$F(1,105)=4.14$ $p=0.044$ partial $\eta^2=0.04$], with non-offender drivers. ($M=0.70$) reporting more cautious behaviour than offender drivers ($M=0.67$) (See Figure 4). The interaction was not significant.

Please insert figure 4 about here

3. Discussion

In this work, a pioneering Multiple Choice Hazard Perception and Prediction Test was developed and assessed. The test explored the effects of driving experience and offender-status on the processes involved in Hazard Perception and Prediction: sensitivity, response bias, situation awareness (recognition, location and projection) and decision-making. The psychometric properties of the test appeared to be acceptable. Twenty of the videos that comprise the test showed satisfactory reliability and discrimination indices. Cronbach's Alpha is acceptable ($\alpha=0.77$).

The work adds to Hazard Perception psychological theory because it shows that different processes involved in Hazard Perception and Prediction can be quantified and measured independently (see Flach, 1995, p.155 for an opposite point of view). This type of manipulation has been lacking in previous approaches to HP. Using theories from psychology, such as the Signal Detection Theory for Hazard Perception will help towards an understanding of the processes involved in this task as part of the complexity of driving performance.

To enable calculation of the Signal Detection Theory (detection = sensation + decision-making) parameters, hazardous vs. quasi-hazardous situations were presented to the participants as signal and noise. A hazardous situation was defined as a driving situation that requires the driver to react before the hazard to avoid a collision (for example, by slowing down or by making an evasive manoeuvre). A quasi-hazardous situation was defined as a potentially hazardous situation that then develops without involving any final hazard (i.e. the driver did not actually have to decelerate or make any evasive manoeuvre to avoid a potential collision). Sanocki et al. (2015) showed that it is possible to study Hazard Perception in terms of classic Signal Detection Theory (Green & Swets, 1966) and the current approach offers another useful means of carrying out this analysis. It provides a way to measure objectively whether a scene is "a hazard" or "quasi-hazard" as an objective assessment of a binary true state.

According to the hypothesis devised and the results found, it can be said that:

1). The first hypothesis is confirmed: Hazard Perception skills are less developed in novice drivers than in experienced drivers. Specifically, learner and novice drivers' performance in this test is lower than that of experienced drivers. Different measures taken in the Hazard Perception Test are sensitive to the experience effect: d-prime and Situation Awareness.

2). Unlike Wallis and Horswill (2007), we did note a difference in sensitivity to reporting hazards according to driver experience. A difference was also noted across offender status. While both experienced drivers and non-offenders were more sensitive to the detection of a hazard, these factors did not interact.

3). We did not replicate Wallis and Horswill's (2007) response-bias effect across our different driver groups. Offender drivers do not appear to have a significantly different *β* criterion from non-offender drivers when performing Hazard Perception and Prediction Tasks. However, it was found that experienced offender drivers and novice drivers were less cautious in their decisions about what manoeuvres to make.

Sensation

As was shown, this version of the test proved useful to discriminate between drivers. When we carried out a detailed analysis using the Signal Detection Theory to explore participants' Sensitivity, it was found that d-prime discriminated between learner, novice and experienced drivers. Some traditional measures of hazard perception (mainly response time measures), referred to in various different studies that produced mixed results (Chapman & Underwood, 1998; Crundall et al 1999; Crundall et al., 2002, Sagberg & Bjørnskay, 2006; Borowsky, Shinar & Oron-Gilad, 2010; and Underwood, Ngai & Underwood, 2013), have failed to identify driver group differences. The success of our d' measure opens up the possibility of using Signal Detection Theory analyses to better discriminate between safe and less safe drivers. The simpler approach of combining Signal Detection Theory with an occluded prediction task removes the necessity for a fuzzy analysis and may explain why the current results are opposite to those reported by Wallis and Horswill (2007).

In addition, it was found that not only did the sensitivity of experienced drivers outperform that of novices but also non-offenders showed lower sensitivity scores than offenders.

Situation Awareness

In addition to the sensitivity effects, the test also successfully discriminated between our driver groups on the basis of experience, via the probe questions that were intended to assess situation awareness. The differences in accuracy between groups of different driving experience are consistent with previous literature (Armsby, Boyle & Wright, 1989; Benda & Hoyos, 1983; Brown & Groeger, 1988; Castro et al., 2014; Crundall et al., 2010; Finn & Bragg, 1986; Jackson et al., 2009; Spicer, 1964; Underwood et al., 2013; Crundall, 2016). This suggests that experience can improve Hazard Perception and Prediction when driving and that training in the skill of Hazard Perception and Prediction should be given before acquisition of the driving license; and perhaps post-license too. Although Situation Awareness can be developed during the process of acquiring driving skills, inexperience could make performing the task harder (Logan et al., 1988; Castro et al., 2014; Castro et al., 2016).

Interestingly, although the Situation Awareness probe questions differentiated between drivers of different experience, offender drivers did not demonstrate a significantly worse level of situation awareness. But how can offenders have the same situation awareness as non-offenders yet have a significantly lower sensitivity for detecting the hazards? Are they successfully predicting the situation, but then failing to translate this into the action of reporting a hazard? If this were the case, one might expect their response criterion to be higher, which it was not. Perhaps the questions did not capture the aspects of Situation Awareness that are most important to identifying the hazard? While this is a possibility, these questions have been used successfully in several other studies (e.g. Jackson et al., 2009), and it is hard to imagine finding more relevant questions that lead to the identification of a hazard. A third possibility remains: that the order in which the questions were asked favours non-offenders. Violators, offenders and risk-takers are often characterised by impulsivity (e.g. Moller and Gregersen, 2008), and therefore one could envision a situation where impulsive offenders, when faced with the first questions (did you see a hazard?), report "No". However, the subsequent questions then probe further into the Situation Awareness of the offender, who must then ruminate on what they actually saw and understood of the driving scene. Following adequate probing, they may then realise that they did indeed see a hazard, but this is rarely captured in their first response to Question 1. While the question order was an inevitable consequence of the method employed, it may actually reflect a real mechanism that could mediate violating behaviour on the road. While all the relevant information may be available to the offender, a quick response to a gut feeling may tempt some into an on-road violation.

Decision-making

The Signal Detection Theory also explores the participants' decision-making processes. The measure of the response bias parameter failed to find differences between offender and non-offender drivers and did not succeed in showing up the potential differences between drivers with varying levels of experience or driving profiles.

However, when analysing Cautiousness in decision-making, significant differences were found between experienced and inexperienced drivers. In particular, experienced drivers seem to be more cautious than novices. A greater number of experienced drivers chose the answer "I would make an evasive manoeuvre such as braking gradually" not only for the hazardous video clips but also for the quasi-hazardous ones. In addition, there were differences between non-offender and experienced offender drivers. Non-offenders were more cautious than offenders.

Further research to explain drivers' decision-making should explore other measures that depend on their self-assessment of driving skills and a calibration between the benefits and costs involved in the risk at the time of driving. Offenders are, in fact, aware of what the obstacles on the road are, where they are and what will happen next – at least on reflection. The problem is that drivers fail to separate signal from noise at the point where they need to make an immediate decision about the presence of a hazard.

This knowledge could be useful for several reasons: to better understand the different profiles of vulnerable drivers such as older drivers and offenders; to plan prevention and Hazard Perception training to deal with some hazards that involve specific difficulties, for instance for older drivers; and to establish better intervention strategies and treatment for the specific failings of each group of drivers, for instance, reducing aggressive driving or at least raising drivers' awareness of the problem.

Limitations

Because it is difficult to find women offenders or novice offenders, as offending and loss of driving license are usually related to greater driving experience, the sample employed for this study is not matched for gender). According to Scrimgeour, Szymkowiak, Hardie & Scott-Brown (2011), there were no gender differences in a Hazard Perception task that involved rating a series of traffic still photos as to how hazardous the depicted situations were perceived to be, with males and females rating all scenes similarly. Other sociodemographic variables may play a more important role than gender in Hazard Perception tasks, for instance, drivers' experience, drivers' age or personality traits related to Subjective Risk Estimation, such as sensation seeking, impulsiveness, etc.

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Table 1. A breakdown of participants socio-demographic information by experience and offender-status.

Non offender drivers	**Learner drivers**					**Novice drivers**					**Experienced drivers**				
Socio-demographic information	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
Age	34	18	29	19.31	2.50	43	18	31	21.40	2.86	64	23	66	39.48	10.14
Gender[a] + Gender Percentage	34	1=M 88%	2=F 12%	1.76[a]	0.43	43	1=M 71%	2=F 29%	1.42[a]	0.49	64	1=F 51%	2=F 49%	1.06[a]	0.24
Level of education[b] Mean values between 3 (Secondary) to 4 (Vocational)	34	3	6	4.03[b]	0.38	43	1	5	3.67[b]	0.77	64	1	6	3.75[b]	1.52
Years driving regularly	-	-	-	-	-	36	0	11	3.92	2.82	54	7	54	20.33	10.28
Years since obtaining driving license	-	-	-	-	-	36	0	11	3.92	2.82	54	7	54	20.33	10.28
Driving frequency in the last 12 months[c]	-	-	-	-	-	43	1	5	2.11[c]	0.89	64	1	5	1.23[c]	1.18
Kilometres driven last 12 months	2	0	9999	4999	7070	27	1	175000	13303	34443	40	0	120000	33347	26698
Accidents-material damage last 12 months[d]	-	-	-	-	-	27	0	1	0.22[d]	0.42	40	0	2	0.33[d]	0.52
Accidents with victim last 12 months[d]	-	-	-	-	-	27	0	1	0.04[d]	0.19	40	0	1	0.05[d]	0.22
Quasi-accidents last 12 months[d]	2	0	3	1.50[d]	2.12	27	0	3	1.15[d]	1.06	40	0	3	1.53[d]	1.39
Traffic incidents- Insurance company[d]	-	-	-	-	-	27	0	3	0.41[d]	0.97	40	0	3	0.47[d]	1.32
Nº of times losing driving license[d]	-	-	-	-	-		0	1	0.06[d]	0.23		0	2	0.28[d]	0.52
Traffic tickets received[d]	-	-	-	-	-	27	0	3	0.52[d]	0.52	40	0	3	1.28[d]	1.28
Offender drivers						**Novice drivers**					**Experienced drivers**				
Age	-	-	-	-	-	6	18	31	23.83	5.56	40	26	66	41.88	11.03

Gender[a] Mean values between 3 (Secondary) to 4 (Vocational)	-	-	-	-	-	6	1=M 59%	2=F 41%	1.17[a]	0.40	40	1=M 50%	2=F 50%	1[a]	0
Level of education[b] Mean values between 3 (Secondary) to 4 (Vocational)	-	-	-	-	-	6	1	5	3[b]	1.54	40	1	6	3.78[b]	1.70
Years driving regularly	-	-	-	-	-	4	4	11	7.75	3.77	21	7	54	20.67	11.44
Years since obtaining driving license	-	-	-	-	-	4	4	11	7.75	3.77	21	7	54	20.67	11.44
Driving frequency in the last 12 months[c]	-	-	-	-	-	4	0	1	1[c]	0	21	1	5	1.38[c]	1.20
Kilometres driven last 12 months	-	-	-	-	-	4	5000	60000	22250	26017	21	0	120000	32738	28103
Accidents-material damage last 12 months[d]	-	-	-	-	-	4	0	1	0.50[d]	0.57	21	0	1	0.33[d]	0.48
Accidents with victim last 12 months[d]	-	-	-	-	-	4	0	3	0.60[d]	1.34	21	0	1	0.05[d]	0.21
Quasi-accidents last 12 months[d]	-	-	-	-	-	4	0	3	1.50[d]	1.73	21	0	3	1.38[d]	1.35
Traffic incidents- Insurance company[d]	-	-	-	-	-	4	0	2	0.75[d]	0.95	21	0	3	0.90[d]	1.09
Nº of times losing driving license[d]	-	-	-	-	-	4	0	1	0.50[d]	0.57	21	0	2	0.52[d]	0.60
Traffic tickets received[d]	-	-	-	-	-	4	0	3	2.5[d]	1.11	21	1	3	2.60[d]	0.43

Median valued reported:

(a) 1 = Female. 2 = Male. Median value reported. **(b)** 1 = Primary. 2 = Secondary (compulsory). 3 = Secondary (non-compulsory). 4 = Vocational. 5 = Grade. 6 = Master.

(c) 1 = Every day or almost every day 2 = Once or more than once per week 3 =Once or more than once per month 4= Once or more than once per year 5=Never or almost never Median value reported. **(d)** 0 = 0, 1 = 1, 2 = 2, 3 = 3 or more

Table 2. Descriptions of the videos.

Duration	Potential Hazard	Type of road location	Visiblilty	Content	Type of obstacle	What is the potential Hazard?	What Happens Next?	Manoeuvre already performed
11.90	Car	Urban	Reduced visibility	A car is reversing towards an intersection	Hazard	A car that appears on the left	The car is going to reverse	1). Braking
19.27	Pedestrian	Urban	Hindered by vegetation	A pedestrian is about to cross the street	Hazard	A pedestrian on the left	The pedestrian will try to cross	1). Braking
15.30	Car	Urban	Reduced visibility	A car suddenly joins the lane from the left	Hazard	A car on the left	The car on the left will join the lane	1). Braking
26.27	Pedestrian	Urban	Hindered by vegetation	A pedestrian is approaching a crossroads with the intention to cross	Quasi-Hazard	A pedestrian on the right	The pedestrian approaching the crossroads will stop	2) Keeping
17.23	Motorcycle	Urban	Clear	A motorcycle trying to join the left lane by crossing our lane	Hazard	A motorcycle in the left lane	The motorcycle is going to invade our lane	1). Braking
25.27	Pedestrian	Urban	Hindered by vegetation	A group of pedestrians cross at the crossroads, hidden by the vehicle in front	Quasi-Hazard	The pedestrians on the crossroads	The pedestrian will cross at the crossroads	2). Keeping
12.04	Car	Backroad	Reduced visibility	A car is merging at an intersection	Hazard	A grey car that is joining the road	The grey car will join the opposite lane by crossing our lane	1). Braking
11.27	Car	Dual carriageway	Clear	The red car in the left lane suddenly invades our lane while trying to avoid another vehicle	Hazard	The red car in the right lane	The red car on the right is going to invade our lane	1). Braking
21.97	Pedestrian	Urban	Hindered by urban equipment	A pedestrian is about to cross the street	Quasi-Hazard	A pedestrian on the right sidewalk	The pedestrian will stop	1). Braking
19.63	Car	Urban	Hindered by the other vehicles	A car is trying to join the lane while reversing	Hazard	The dark car parked on the right	The dark car will try to reverse from the parking place	1). Braking
16.17	Car	Dual carriageway	Clear	A car stops in the middle of a junction between two exits and changes direction	Hazard	The grey car in front of us	The car in front of us will reverse, aiming to change its exit	1). Braking
11.27	Pedestrian	Urban	Clear	A pedestrian is about to cross the street	Quasi-Hazard	The pedestrian on the right pavement	The pedestrian will stop	2). Keeping
20.77	Car	Backroad	Clear	A car suddenly crosses our lane, trying to	Hazard	The second car that is	The second car will cross our	1). Braking

				reach the exit of the roundabout		crossing our lane on the roundabout	lane and will invade the right lane	
21.30	Pedestrian	Urban	Hindered by vegetation	A pedestrrian suddenly starts to cross the road	Hazard	The pedestrian on the left	The pedestrian will cross on the left	1). Braking
24.27	Car	Urban	Hindered by other vehicles	A car reversing from a car park near the road, obscured by other vehicles, joins the lane	Hazard	The car reversing on the left	The car on the left will join the lane, while reversing	1). Braking
17.07	Van	Backroad	Clear	A van that has its flashing lights on stops on the hard shoulder	Hazard	The white van in front of us	The white van in front of us will park on the right	1). Braking
18.30	Car	Urban	Clear	A car suddenly stops, trying to park	Hazard	The dark car	The car in front of us will park on the left	1). Braking
19.30	Car	Urban	Clear	A car approaches the intersection on the left	Quasi-Hazard	A car approaching on the left	The car that is joining our lane from the left will brake and give way	2). Keeping
19.27	Pedestrian	Urban	Hindered by vegetation	A pedestrian is approaching a crossroads, trying to cross the street	Hazard	Pedestrian on the left	A pedestrian will try to cross the street	1). Braking
18.57	Motorcycle	Backroad	Hindered by other vehicles	An oncoming motorcycle is about to invade our lane	Hazard	The yellow motorcycle	The motorcycle will invade our lane	1). Braking
20.30	Car	Urban	Hindered by other vehicles	A car appears abruptly on the right, trying to join our lane	Quasi-Hazard	A car coming from the right	The black car will give way to us	2). Keeping
26.53	Car	Dual carriageway	Clear	A car passes us on our left, while another car is trying to join the dual carriageway from the right	Hazard	A red car on the right	A vehicle will pass us on the left	1). Braking
22.70	Truck	Backroad	Clear	An oncoming truck is approaching us	Hazard	An oncoming truck	A truck will invade our lane	1). Braking
12.33	Car	Urban	Clear	A car is trying to change lanes in front of us	Hazard	The car in front of us	The grey car will cross our lane	1). Braking

1.) Braking or performing other avoiding manoeuvre 2.) Keeping the same speed and trajectory

Table 3. *Descriptive statistics of the Multiple Choice-Hazard Perception and Prediction Questionnaire items.*

Videos	Min.	Max.	M	S.D.	Discrimination Index
1*	0.00	3.00	2.13	0.84	0.18
2	0.00	3.00	1.66	0.72	0.20
3	0.00	2.50	1.04	1.08	0.27
4	0.00	3.00	1.11	1.03	0.38
5	0.00	3.00	1.33	1.12	0.44
6*	0.00	3.00	0.40	0.59	-0.02
7	0.00	3.00	1.62	1.23	0.44
8*	0.00	3.00	0.17	0.56	0.17
9	0.00	3.00	0.99	1.11	0.44
10*	0.00	3.00	1.09	0.89	0.09
11	0.00	3.00	1.00	1.05	0.32
12	0.00	3.00	0.81	1.08	0.30
13	0.00	3.00	1.71	0.98	0.42
14	0.00	3.00	1.45	0.99	0.31
15	0.00	3.00	0.35	0.86	0.24
16	0.00	3.00	1.61	1.13	0.31
17	0.00	3.00	1.89	1.09	0.30
18	0.00	3.00	0.94	1.01	0.45
19	0.00	2.50	0.69	0.93	0.26
20	0.00	3.00	1.16	0.73	0.26
21	0.00	3.00	1.59	0.79	0.29
22	0.00	2.50	0.79	0.70	0.20
23	0.00	3.00	1.51	0.82	0.30
24	0.00	3.00	1.07	1.08	0.30

Note. Videos with an asterisk are items removed because they showed values lower than 0.20 in discrimination indices.

Table 4. Hits, False Alarms, d-prime and β criterion, SA (average), What, Where, WHN, Caution DM measures obtained by the groups of participants Non-Offender-Offender (Learner, Novice and Experienced drivers) and Offender (Novice and Experienced).

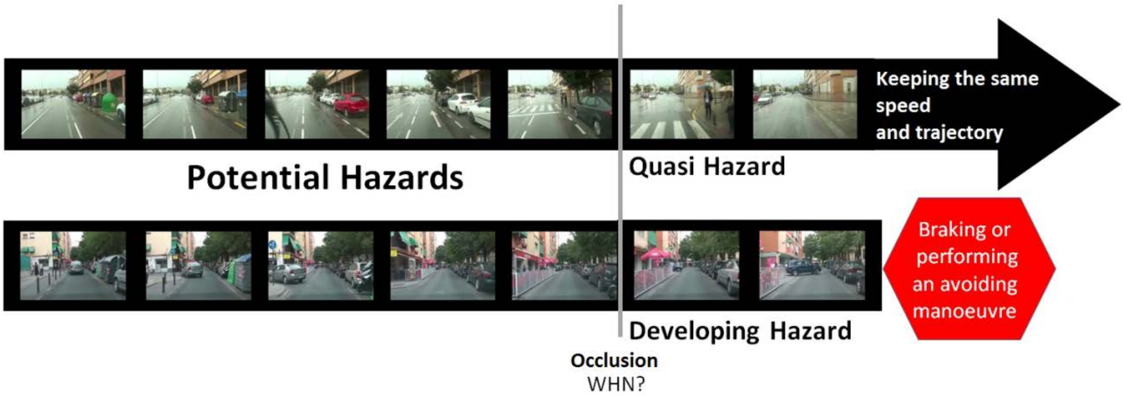
Participants		YES Answers (Mean)											
		Hazards (Max.15)	**Quasi-hazards (Max.5)**	**Total (Max.20)**	**Hits**	**False Alarms**	**d-prime**	***β* Criterion**	**Situation Awareness** Average **(Max. 3)**	**What? (Max. 1)**	**Where? (Max. 1)**	**What Happens Next? (Max. 1)**	**Caution in Decision Making (Max.1)**
Non-offender	**Experienced**	12.9	0.95	13.85	.86	.19	2.2	0.92	1.36	0.32	0.57	0.46	0.835
	Novice	9.6	2.35	11.95	.64	.47	0.53	1.1	1.12	0.30	0.44	0.35	0.614
	Learner	9.75	2.6	12.35	.65	.52	0.38	1.09	1.06	0.24	0.43	0.35	0.607
Offender	**Experienced**	10.9	2	12.9	.73	.40	1.6	1.09	1.25	0.30	0.52	0.43	0.696
	Novice	8.4	2.6	1.1	.56	.52	0.15	0.89	1.06	0.31	0.43	0.27	0.540

Table 5. Main Correlations between the variables studied.

		Average of Situation Awareness	**d-prime**	**β**	**Caution in Decision Making**
Situation Awareness	Correlation Pearson	1			
	Sig. (bilateral)				
d-prime	Correlation Pearson	.849**	1		
	Sig. (bilateral)	.0001			
Β	Correlation Pearson	-.408**	-.412**	1	
	Sig. (bilateral)	.0001	.000		
Caution in Decision Making	Correlation Pearson	.650**	.706**	-.470**	1
	Sig. (bilateral)	.0001	.0001	.0001	

Note. **= Correlation is significant at the .01 level (two-tailed);

Figure 1. Film-strip showing an example of quasi-hazards and hazards. defined by the manoeuvre that the car performed: a. for quasi-hazards keeping the same speed or trajectory; b. For hazards braking or performing an avoiding manoeuvre.



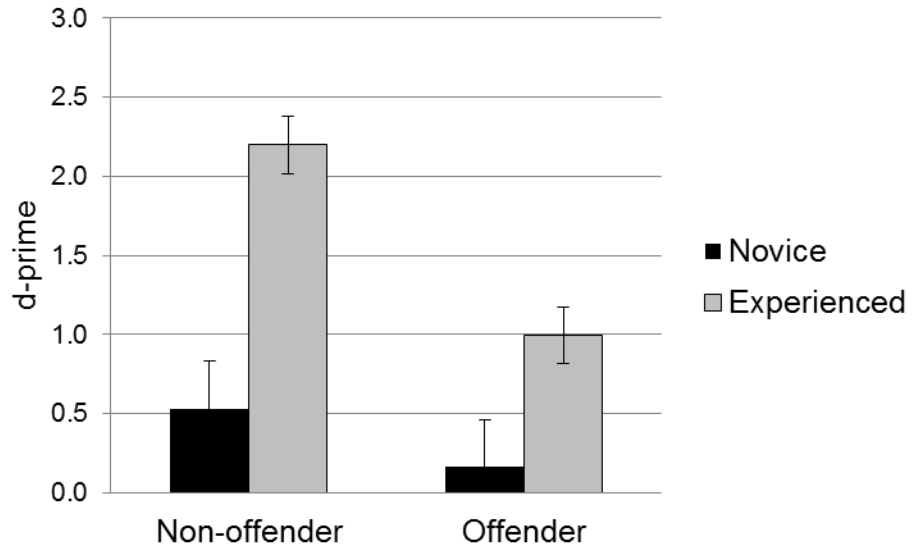


Figure 2. *Mean of d-prime by experience and offender-status.*

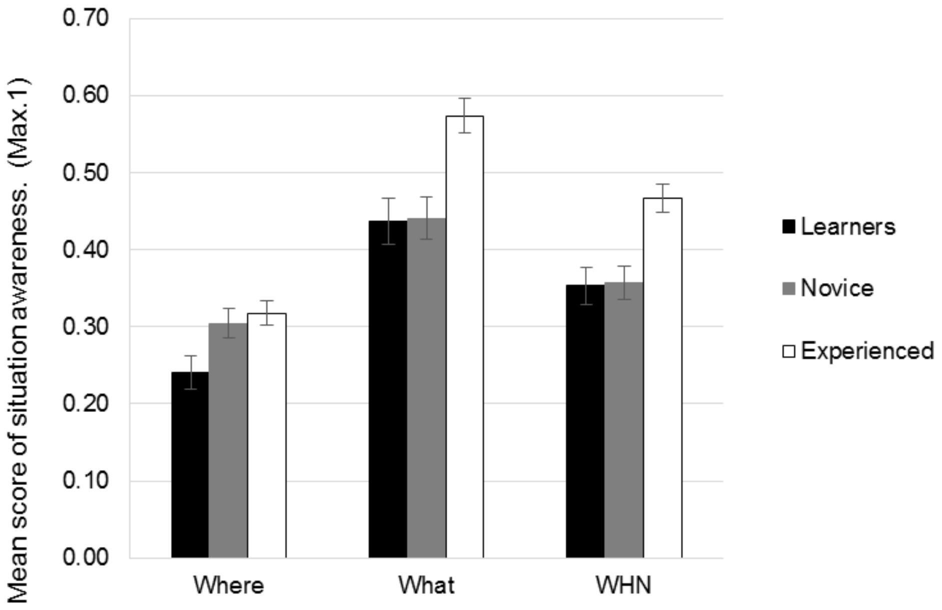


Figure 3. *Mean total scores in the situational awareness questions by experience.*

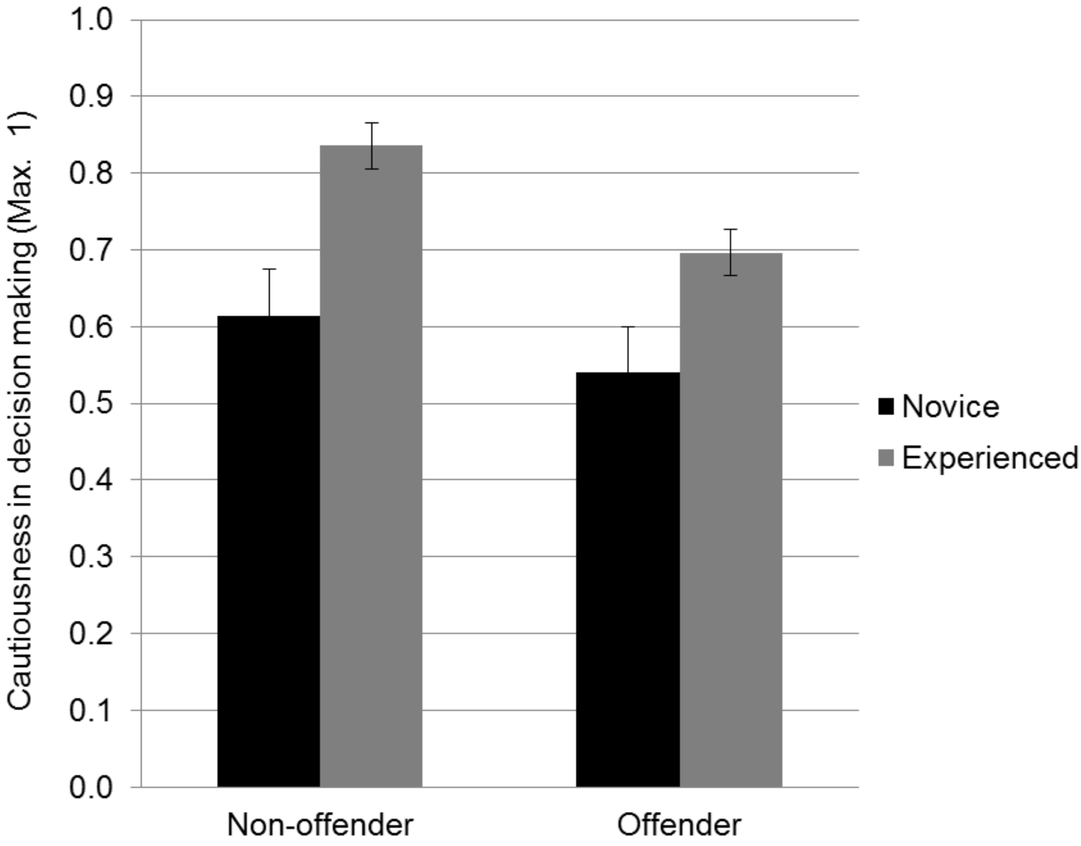


Figure 4. *Cautiousness in Decision-making by experience* and *offender-status.*