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Some hazards are more attractive than others: Drivers of varying experience respond differently to different types of hazard

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ABSTRACT

The ability to detect hazards in video clips of driving has been inconsistently linked to driving experience and skill. One potential reason for the lack of consistency is the failure to understand the structural differences between those hazards that discriminate between safe and unsafe drivers, and those that do not. The current study used a car simulator to test drivers of differing levels of experience on approach to a series of hazards that were categorized *a priori* according to their underlying structure. The results showed that learner drivers took longer to fixate hazards, although they were particularly likely to miss hazards that were obscured by the environment (such as a pedestrian emerging from behind a parked truck). While drivers with a moderate amount of experience were as fast as driving instructors to look at hazards, they spent the greatest amount of time looking at them. Only instructors' ability to detect hazards early in the approach translated into differences in driving speed for certain types of hazard. The results demonstrate that drivers of varying experience respond differently to different hazards, and lay the foundations for a hazard typology.

1. Introduction

Hazard perception (HP) is the process of detecting, evaluating and responding to dangerous events on the road that have a high likelihood of leading to a collision. This has typically been investigated using video clips taken from the driver's perspective (Quimby and Watts, 1981; Olson and Sivak, 1986; McKenna and Crick, 1991, 1994, 1997; Chapman and Underwood, 1998; Crundall et al., 2002; McKenna and Horswill, 1999; Horswill and McKenna, 2004; Sagberg and Bjørnskau, 2006). Each short clip contains one or

strated that HP response times (RTs) are longer for crash-prone drivers (McKenna and Crick, 1991; McKenna and Horswill, 1999; Quimby et al., 1986) and a prospective study linked long HP RTs to the chances of being involved in a fatal accident in the first year of qualified driving (Drummond, 2000). Inexperienced drivers have also been found to have poor HP performance (e.g. Quimby and Watts, 1981; McKenna and Crick, 1991; Renge, 1998; Wallis and Horswill, 2007). Newly qualified drivers are over-represented in the UK and US crash statistics compared to drivers with several years of post-licence experience (Braitman et al., 2008; Maycock et al., 1991; Underwood, 2007), and underdeveloped HP skills have been posited as one contributor to the increased crash risk of novice drivers (Horswill and McKenna, 2004).

The UK Government considered the evidence to be convincing enough to introduce HP testing to the licencing procedure in 2002. The rationale was that learner drivers who do not respond fast enough to video-based hazards might not respond fast enough to on-road hazards, increasing their probability of crashing (cf. Drummond, 2000), and that including HP testing would encour-

... g hazards

... ll learners

Despite the wealth of evidence in favour of hazard perception testing, there have also been a number of studies that fail to find the expected differences in hazard perception ability as a function of age, experience, and accident propensity (e.g. Chapman and Underwood, 1998; Crundall et al., 2002; Sagberg and Bjørnskau, 2006), and an evaluation of the introduction of HP into the British driving test suggests that benefits may be limited to quite specific driving situations (non-low-speed reported public road accidents, especially when the driver accepts some blame; Wells et al., 2008). We suggest that these mixed results derive, at least partly, from a theoretical lacuna at the heart of hazard perception testing. Explanations for why some HP tests discriminate safe and unsafe drivers while others do not have so far been primarily post hoc; this is

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because we lack a theoretical understanding of how safe drivers spot hazards. The current study explores different cues and hazard types in a systematic way in order to begin to build a more general theory of hazard perception.

1.1. Why are some hazards more effective than others?

Only recently have some researchers set about classifying the key components of successful hazards (Garay et al., 2004; Garay-Vega and Fisher, 2005; Borowsky et al., 2007). One of the advances that has made this possible is the use of driving simulators in hazard perception testing. While hazards in a simulator, like those in real driving, do not progress in an identical way for all viewers, they still allow a greater level of experimental control and manipulation than video-based hazards. In a driving simulator the driver also needs to remain in control of the vehicle at all times, thus the resources required to scan for hazards have to be shared with the resources required for normal driving. This means that hazard perception testing in a simulator not only is more realistic than using fixed videos, but also has the potential to uncover performance limitations that would not be present in a traditional test that measures HP skill in isolation.

Garay et al. (2004) tested drivers on a simulated route containing hazards belonging to one of three categories (spotting a pedestrian, noticing a warning traffic sign, and spotting conflicting traffic). Novice drivers performed best on the pedestrian hazards, and Garay et al. (2004) suggested that the novices' experience of being pedestrians may have helped them with such hazards. While Garay et al.'s division of hazards had no theoretical underpinning, the study is a crucial initial example of how some types of hazard might be more likely to discriminate between driver groups.

A more important advance however was their inclusion of a foreshadowing element, which acted as a cue to draw attention to the location of a potential hazard (Garay et al., 2004; Garay-Vega et al., 2007). For instance they theorised that pedestrians in the road ahead might draw the driver's attention to an upcoming pedestrian crossing which is partially obscured by a parked truck. The forewarned driver should therefore be more likely to fixate the obscuring edge of the truck in anticipation of further pedestrians. When tested in the simulator they found that both experienced and inexperienced drivers used the foreshadowing cues to increase attention to the potential hazard location.

While Garay et al.'s conception of foreshadowing did not increase the likelihood of the hazards discriminating good and bad drivers (as all drivers benefited from the cues), our conception of a foreshadowing element (which we term the *precursor*) is more immediate. For instance, a pedestrian on the sidewalk is a precursor to the event of that same pedestrian stepping into the road. The precursor provides a cue to the hazard which might be more apparent to safe drivers with experience of similar situations. The provision of a suitable precursor is no doubt vital to the success of a particular hazard clip. Imagine for instance, a basketball suddenly bouncing into the road from an ostensibly empty drive way. Even experienced drivers are unlikely to anticipate such a random event. In this case, a standard HP test would primarily be recording RTs to a *sudden onset*. When measuring a simple RT to a sudden onset, there is little reason to think that experience and training will be of benefit; indeed, younger, inexperienced drivers may well outperform their older, more experienced counterparts (cf. Gottsdanker, 1982).

For clips to discriminate between driver groups in a safety-relevant manner there must be cues available which safer, experienced drivers either spot more quickly or monitor more intensely. Thus an experienced driver may pay more attention to the pedestrian with the suspicion that they may cross the road, or they may fixate the leading edge of a parked truck because they are aware that an obscured pedestrian might emerge. In both scenarios there are immediate precursors to the potential hazard (the pedestrian in the first example, and the parked truck in the second example). These precursors differ however in their relationship to the hazard. The former has a direct relationship, as the pedestrian is both the precursor and the hazard (dependent on the location of the pedestrian). However the latter example provides an indirect link between precursor and hazard. We suggest that creating a theoretical hazard classification on the basis of the nature of the precursors would identify those hazards that benefit most from experience. For instance, one might suggest that the indirect link between the obscuring van and the pedestrian would make that particular precursor less salient and therefore more likely to discriminate between good and poor drivers.

1.2. The current study

The current study required us to develop a series of hazardous scenarios to be implemented in a simulator which were defined *a priori* according to the relationship between precursor and hazard. Searching the literature for such *a priori* distinctions revealed some consistent suggestions. For instance, Sagberg and Bjørnskau (2006) suggested, *a posteriori*, that *anticipation*, *surprise* and *complexity* were the relevant dimensions of their successful hazard perception clips (i.e. those clips that discriminated between novice and experienced drivers), and they encouraged future research to investigate whether hazard perception skill was differentially related to these dimensions. These concepts map onto three distinct training interventions previously trialled in our laboratory with some short-term success: anticipation, knowledge and scanning (Chapman et al., 2002).

Anticipation has often been referred to in the context of hazard perception (e.g. McKenna and Crick, 1994; McKenna et al., 2006), and while the definitions might be quite nebulous (e.g. "the ability to read the road and anticipate forthcoming events", McKenna et al., 2006, p. 2) the core component appears to require extrapolation from what one can currently see, to what might subsequently happen. This has been equated by some researchers (Jackson et al., 2009; McGowan and Banbury, 2004) to level 3 of Endsley's situational awareness (Endsley, 1995, 2000), where perception (level 1) and comprehension (level 2) of the environment are required for projection of their future status (level 3). Based on the concept of *anticipation* we created three simulated scenarios where the precursor is the same stimulus as the hazard, allowing one to project future behaviour (the hazard) directly from current behaviour (the precursor). One such scenario has a car waiting in a side road (precursor), which then pulls out in front of the participant's car (hazard). We have termed these behavioural prediction (BP) hazards.

Surprise presumably occurs when the driver fails to link precursor and hazard. We suggest that this is more likely to happen when there is an indirect relationship between the two. These scenarios require experience or knowledge of the statistical probabilities of certain stimuli occurring together in the driving scene, such as understanding that a parked van might obscure pedestrians. We therefore created a further three scenarios where the precursor and hazard are indirectly related. For instance, one scenario contains an ice-cream van (precursor) from behind which a child steps into the road (hazard). These are environmental prediction (EP) hazards, and require the driver to consider the probability of two distinct stimuli (van and child) occurring together.

Finally, Sagberg and Bjørnskau's (2006) concept of *complexity* is concerned with the driver's ability to monitor multiple sources of potential threat in a complex and dynamic environment. Certainly many driving experts are aware of the need to maintain a wide scanning strategy. Haley (2006) refers to the "disastrous habit of fixating" (p. 112), while Coyne (1997) and Mills (2005) both emphasise the role of scanning in safe driving. However dividing attention across multiple potential hazards must give way to focussing upon one actual hazard when it occurs. Thus we have termed the third category as dividing and focussing attention (DF) scenarios. These scenarios contain more than one precursor (which can be either a BP or EP precursor). For instance, in one scenario a parked bus provides an EP precursor, while a pedestrian on the other side of the road provides a simultaneous BP precursor. Drivers need to monitor both precursors before focussing on the pedestrian who decides to cross the road to reach the bus. We have previously noted problems in dividing and focussing attention in novice drivers (Crundall, 2009) and predict that these multiple-precursor scenarios may pose specific difficulties for these drivers.

Three groups of drivers drove through these nine simulated hazardous scenarios (learners, experienced drivers and driving instructors) while their eye movements were recorded. Driving experience is often used as a surrogate for driver safety (Crundall, 2009; Crundall et al., 1999, 2002; Horswill and McKenna, 2004; McKenna and Crick, 1991; Quimby and Watts, 1981; Renge, 1998; Wallis and Horswill, 2007) and we predicted that greater driving experience would lead to more hazards being fixated. Experience should also increase the speed with which hazards are spotted, and should affect the processing speed (i.e. fixation duration on hazards), ultimately changing the behaviour of the experienced driver (e.g. a reduction in speed). While it is possible that increased age (which often confounds the measure of experience) can lead to perceptual slowing, potentially counteracting the positive effects of experience, these age-related degradations are most noticeable beyond the age of 70 (Salthouse, 1998), and it is generally accepted that experience has a greater impact on behaviour than age, at least before the age of 50 (Maycock et al., 1991).

In addition to experience leading to faster perceptual processes, we predicted that the benefit of experience would vary across hazard types (cf. Garay et al., 2004), allowing us to identify why some hazards are more dangerous (yet more discriminative) than others (such as the increased psychological distance between the precursors and hazards in the EP scenarios compared to the BP scenarios).

2. Method

2.1. Participants

Forty-nine drivers formed three groups: a learner group ($N = 14$, with a mean of 7.5 months since beginning to learn; and a mean age of 20.3 years), an experienced group ($N = 17$, with a mean of 16.4 years since gaining a licence; mean age of 33.0 years); and a driving instructor group ($N = 18$; mean driving experience of 30 years, and instructing experience of 13 years; mean age of 48.5 years). All instructors had passed the UK Driving Standards Agency exam for instructors (eight at Grade 4, five at Grade 5 and six at Grade 6).

2.2. Apparatus and stimuli

The hazards were presented in a Faros GB3 driving simulator, with a visual display of approximately $90^\circ \times 21^\circ$ presented across three 19 in. LCD monitors (380 mm × 300 mm). Door mirror and rear view mirror information is visible in the display, while driving speed was presented via a dashboard-mounted speedometer (Fig. 1; see Konstantopoulos et al., 2010, for further details). All car controls (steering wheel, handbrake, lights, indicators, and windscreen wiper switches, gear box and gear stick) were modelled on a right-hand drive Vauxhall Corsa (a GM sub-compact).

Fig. 1. The simulator used in the current study. The top panel shows a participant sat in the cab wearing a head-mounted eye tracker. The middle panel shows the three-screen display with steering wheel and dashboard. The bottom panel shows the centre screen containing a behavioural prediction precursor: a small child waits between parked cars on the left to cross the road.

Eye movements were recorded using a SMI HED 50 Hz eye tracker. Frame-by-frame video analysis of eye movements required Noldus' Observer software.

The test route was planned through a virtual city with buildings, junctions, traffic, and road-side furniture including signs and traffic lights. Automated verbal directions (supported by an on-screen arrow just above the dashboard) guided participants through the route. The route contained nine hazards which were triggered when the driver approached (see Table 1 for a list of hazards and their precursors). These hazards fell into three categories. A behavioural prediction event could be avoided by anticipating the behaviour of a visible stimulus before it becomes hazardous. An environmental prediction event differs from a BP event in that the source of the hazard is not visible prior to the hazard triggering. EP precursors are parts of the environment which obscure the hazard

Table 1
All hazards and their precursors according to hazard classification.

	The critical stimuli	
	Precursor	Hazard
Behavioural prediction hazards (BP)	Child visible at roadside between parked cars	Child steps into road
	Car waiting at nearside side road	Car pull into driver's path
	Approaching motorcycle in contra flow lane stops and waits to turn into nearside side road	Motorcycle turns in front of driver
Environmental prediction hazards (EP)	Near side parked ice-cream van	Child steps out from behind van into driver's path
	Offside parked truck (with flashing hazard warning lights)	Man with box steps out from behind truck into drivers path
	Blind bend	Nearside truck, broken down with hazard warning lights
Dividing and focussing attention hazards (DF)	Parked bus on near side, plus pedestrian on central reservation (offside)	Pedestrian steps off central reservation into driver's path
	Empty side roads to left and right at crossroad junction	Car from offside side road fails to give way
	Two pedestrians, one on the nearside pavement waving to an offside pedestrian	The offside pedestrian steps into the road in front of the driver

source (such as the blind bend or the ice-cream van). The final category is the dividing and focussing attention events which require multiple precursors to be monitored before selecting one source as the actual hazard. These events contained both BP and EP precursors, with the important distinction that there must be more than one available to view at the point at which the hazard triggers.

2.3. Design

The study employed a 3 × 3 × 2 mixed design. The between-groups factor was experience (learners, experienced drivers and instructors). It was predicted that the instructors would perform most appropriately, followed by the experienced drivers, and finally the learner drivers. The second factor was within-groups and was termed *hazard type*. There were three categories: behavioural prediction, environmental prediction and dividing and focussing attention. The final factor distinguished between two levels of *critical stimuli* – the approach to the hazard (before it had triggered) and the period of time immediately following the hazard being triggered. The approach was termed the *precursor window*. It started from when the precursor to the hazard was first visible (i.e. when the precursor could first be spotted by the experimenter in a frame-by-frame analysis of the resultant eye tracking video) and ended when the hazard was triggered. The *hazard window* started from when the hazard was triggered and finished when the participants' car either crashed into or successfully navigated past the hazard. In addition to eye movement measures the simulator recorded speed at 10 m intervals for the 100 m approach to each hazard.

2.4. Procedure

Following a demographic questionnaire, participants undertook a supervised practice drive. They were then fitted with the eye tracking equipment and calibrated, before driving the experimental route through the simulated city. At various points in the route nine pre-programmed hazards, three of each of the hazard types described above, were triggered. Each hazard always appeared in the same location for each participant, although hazard types were pseudo-randomly assigned to this order such that the hazard types did not cluster together sequentially.

3. Results

The results are presented in four sections. The first section simply asks whether drivers looked at the critical stimuli (both precursors and hazards). The second section is concerned with how quickly drivers spot the critical stimuli, while the third section compares how long they fixate or dwell upon them. The final section reports measures of speed recorded by the simulator. In all analyses, wherever planned contrasts were used to further investigate hazard type, we compared DF events to the mean of the BP and EP events (as the DF events contained a mixture of BP and EP precursors), and then compared the BP and EP events to each other directly. Tukey HSD post hoc tests were used to investigate any effect of experience.

3.1. Did participants look at the critical stimuli?

The small amount of previous research on eye movements to simulated hazards has primarily been concerned with the binary measure of whether or not participants look at the critical stimuli (e.g. Pradhan et al., 2005, 2009; Fisher et al., 2006; Pollatsek et al., 2006). To allow comparison with previous studies we conducted the same analysis, although it should be noted that, as in many of the aforementioned studies a hazard never materialised, the most direct comparison between the current study and the previous literature would use only glances to our precursors. In the current analysis precursors and hazards are two levels of a single factor. This allows both the direct comparison across studies of glances to precursors, while allowing us to also assess glance probability to hazards that actually materialised. In a small number of cases (<2.5%) hazards did not trigger appropriately due to the behaviour of the participant or other computer controlled vehicles. These events were removed from analysis.

A 2 × 3 analysis of variance (ANOVA) compared the percentage of critical stimuli that were fixated (both precursors and hazards) across driver groups. More hazards were fixated than precursors (86% versus 61%; $F(1,46) = 97.9$, $MSe = 138$, Cohen's $f = 1.46$, $p < 0.001$). A main effect of group ($F(2,46) = 6.4$, $MSe = 157$, $f = 0.52$, $p < 0.05$) found instructors ($p < 0.005$) and experienced drivers ($p < 0.05$) to fixate more critical stimuli than learners (with no difference between instructors and experienced drivers). There was no interaction. One addition that can be made to this analysis, extending that of Pradhan et al. (2005, 2009), is to include our factor of hazard type. When the three hazard categories are included, a three-way interaction emerges ($F(4,92) = 4.3$, $MSe = 347$, $f = 0.43$, $p < 0.005$; Fig. 2). Tukey tests did not suggest any group differences for fixations on DF critical stimuli. In BP scenarios however, learners fixated fewer precursors than both experienced drivers ($p < 0.001$) and instructors ($p < 0.001$), but there were no group differences in the percentage of BP hazards that were fixated. Conversely, there was no difference between groups in the likelihood of fixating EP precursors, but learners looked at fewer EP hazards than both experienced drivers ($p < 0.01$) and instructors ($p < 0.005$).

In summary, it appears that while learners fixate fewer critical stimuli than more experienced drivers (cf. Pradhan et al., 2005),

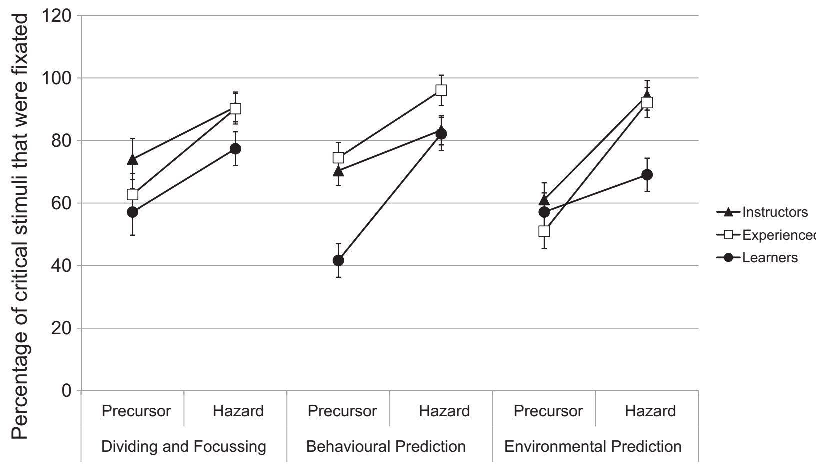

Fig. 2. The percentage of hazard scenarios on which participants fixated the precursors and the hazards according to hazard type.

the type of event determines whether it is the precursor or the hazard that is missed. Specifically they are more likely to miss BP precursors and EP hazards, when compared to more experienced drivers. While this analysis already extends our understanding of what types of event might be missed, this binary measure may mask group differences in how quickly critical stimuli are spotted and processed.

3.2. How quickly do participants fixate the critical stimuli after onset?

A 2 × 3 × 3 ANOVA (precursor/hazard × driver group × hazard type) compared the speed with which participants first fixated the critical stimuli. To allow comparisons across different precursors and hazards with varying time courses, the time taken to first fixate critical stimuli is expressed as a percentage of the time that they were available for inspection. Thus a low number reflects an early fixation upon a stimulus, and a higher number represents a later fixation. Cases where no fixation was made during the window were awarded the maximum score of 100% (i.e. the window had fully elapsed without a fixation). Where a participant failed to fixate all precursors or hazards of a particular type, this could result in a cell mean of 100%, but this only occurred in 5.6% of cells. All three main effects were significant. The effect of hazard type ($F(2,92) = 12.3$, $MSe = 0.02$, $f = 0.52$, $p < 0.001$) revealed that the BP critical stimuli (fixated after 40% of the relevant window had elapsed on average) were fixated sooner than EP critical stimuli (50%; $F(1,46) = 20.1$, $MSe = 0.05$, $f = 0.66$, $p < 0.001$). DF critical stimuli were fixated at roughly the same time as EP stimuli (48%).

A second main effect saw hazards fixated relatively sooner than precursors ($F(1,46) = 160.3$, $MSe = 0.04$, $f = 1.87$, $p < 0.001$). On average hazards were fixated 32% into the hazard window, whereas precursors were only fixated after 61% of the precursor window.

The main effect of experience ($F(2,46) = 16.3$, $MSe = 0.03$, $f = 0.84$, $p < 0.001$) was explored with Tukey HSD tests. Instructors and experienced drivers (both 39%) were faster than learners (60.2%) to first fixate the critical stimuli (both at $p < 0.001$).

Three interactions were significant. The first was an interaction between hazard type and the critical stimulus ($F(2,92) = 4.9$, $MSe = 0.02$, $f = 0.33$, $p < 0.01$). Planned contrasts revealed that while participants were equally quick to fixate EP and BP hazards (32% and 29%), EP precursors were fixated later than BP precursors (69% versus 52%). The second interaction, between experience and hazard type ($F(4,92) = 6.2$, $MSe = 0.02$, $f = 0.52$, $p < 0.001$), is subsumed by the three-way interaction across all factors ($F(4,92) = 3.1$, $MSe = 0.02$, $f = 0.37$ $p < 0.05$; Fig. 3). Tukey tests compared the driver groups across hazard type for both the precursor and hazard windows. For DF events both instructors ($p < 0.001$) and experienced drivers ($p < 0.01$) were faster to fixate the hazards than learners. There was also a suggestion that instructors might fixate DF precursors faster than learners ($p = 0.065$). For BP events, both instructors and experienced drivers fixated precursors sooner than learners (both at $p < 0.001$), and were also faster to fixate the hazards than learners ($p < 0.05$ and $p < 0.005$, respectively). Experienced drivers were even faster than instructors when fixating the precursor however ($p < 0.01$). For the EP events there were no differences between the three groups in the time taken to fixate the precursors, although both instructors ($p < 0.001$) and experienced drivers ($p < 0.005$) fixated the EP hazards sooner than the learners.

In summary of the three-way interaction it appears that instructors and experienced drivers are faster to fixate all types of hazard compared to learners, but they were only faster to fixate the BP precursors than learners (although there was marginal evidence for instructors fixating DF precursors sooner than learners as well). The experienced and instructor groups only differed in that experienced drivers were the fastest to fixate BP precursors. Overall EP precursors take the longest time to fixate, and experience does not appear to give an advantage in prioritising these precursors for fixation.

3.3. Amount of attention devoted to the critical stimuli

A second 2 × 3 × 3 ANOVA (precursor/hazard × driver group × hazard type) examined dwell time upon the critical stimuli, represented as a percentage of the time that they were available for inspection (where a score of 100 would represent the participant fixating upon the critical stimulus for the full time that it was available on screen). All three main effects were significant. Planned contrasts on the main effect of hazard type ($F(2,92) = 11.0$, $MSe = 0.02$, $f = 0.49$, $p < 0.001$) revealed BP critical stimuli (32.0%) received more attention than EP critical stimuli (23.5%; $F(1,46) = 25.0$, $MSe = 0.01$, $f = 0.73$, $p < 0.001$). Percentage dwell on DF critical stimuli fell in-between (27.9%).

A second main effect ($F(1,46) = 160.7$, $MSe = 0.02$, $f = 1.87$, $p < 0.001$) found more attention was given to the hazard (38.4%) than the precursor (17.2%). Tukey tests on the main effect of experience ($F(2,46) = 21.7$, $MSe = 0.01$, $f = 0.97$, $p < 0.001$) revealed that while instructors fixated critical stimuli for longer than learners ($p < 0.001$), the experienced drivers fixated for longer than the instructors ($p < 0.05$).

Two interactions were also significant. Experience interacted with both hazard type ($F(4,92) = 3.9$, $MSe = 0.02$, $f = 0.41$, $p < 0.01$) and with the type of critical stimuli (precursor or hazard;

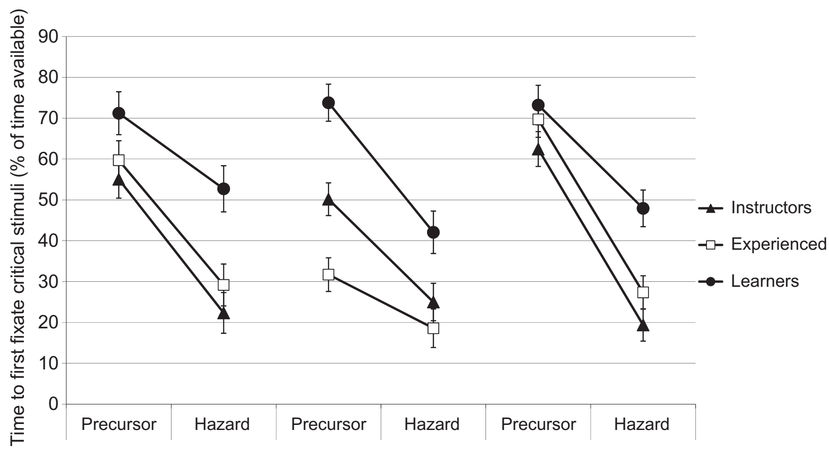

Fig. 3. The average time taken to first fixate a critical stimulus (precursor or hazard) across event type for all driver groups.

$F(2,46) = 7.1$, $MSe = 0.02$, $f = 0.56$, $p < 0.005$). In regard to the first interaction (Fig. 4) Tukey tests compared the three groups of drivers for each scenario type. For all hazard types instructors and experienced drivers devoted more attention to the critical stimuli than learners (at least $p < 0.05$). For BP events however experienced drivers fixated critical stimuli for longer than the instructors as well ($p < 0.005$).

The second interaction, between experience and type of critical stimuli (Fig. 5), showed both instructors and experienced drivers dwelled longer on precursors than learners (Tukey tests both at $p < 0.001$). While there was also marginal evidence that instructors dwelled longer on hazards than learners ($p = 0.054$), experienced drivers gave more attention to hazards than both of the other groups (both at $p < 0.001$).

There are several parallels between the analyses of dwell time and the speed with which critical stimuli are fixated. For instance, the experienced drivers fixated the BP critical stimuli sooner than the other two groups, and then spent longer fixating these critical stimuli than the other two groups. Obviously the amount of time that one can spend looking at a critical stimulus (as a percentage of its availability) depends on how quickly one first fixates it. It is possible to assess the impact of this contingency by repeating the dwell analysis with the time spent looking at the critical stimuli expressed as a percentage of the remaining window length following first fixation of the critical stimuli.

A further $2 \times 3 \times 3$ ANOVA was therefore undertaken on the percentage of time spent looking at critical stimuli contingent upon when they were first fixated. As some participants did not fixate some stimuli at all, these participants had to be removed from this analysis leaving 18 instructors, 14 experienced drivers, and 8 learners.

The main effect of hazard type was not significant [$F(2,76) = 1.2$, $MSe = 0.06$] suggesting that the effect of increased dwell on the BP hazards noted in the non-contingent dwell analysis was due to the faster fixation of BP critical stimuli reported earlier. The other main effects were still significant however. More attention was again devoted to the hazard (55%) than to the precursor (44%; $F(1,38) = 25.0$, $MSe = 0.03$, $f = 0.81$, $p < 0.001$) suggesting that this effect is independent of when the critical stimulus is first fixated. The effect of experience ($F(2,38) = 5.1$, $MSe = 0.01$, $f = 0.51$, $p < 0.05$) was subjected to Tukey tests. In the non-contingent analysis experienced drivers devoted more attention than both other driver groups. In the contingent analysis experienced drivers (57.9%) still had greater dwell times than learners (43.1%; $p < 0.05$) but only marginally greater dwell than instructors (48.0%; $p = 0.05$). While instructors had a greater dwell time than learners in the non-contingent analysis, their contingent dwell time on critical stimuli was not greater than that of learners, suggesting that their faster times to fixate the critical stimuli were responsible for the effect found in the non-contingent dwell analysis.

An interaction between experience and type of critical stimuli ($F(2,38) = 10.6$, $MSe = 0.03$, $p < 0.001$) was due to experienced drivers again dwelling longer on hazards (72%) than both the instructors

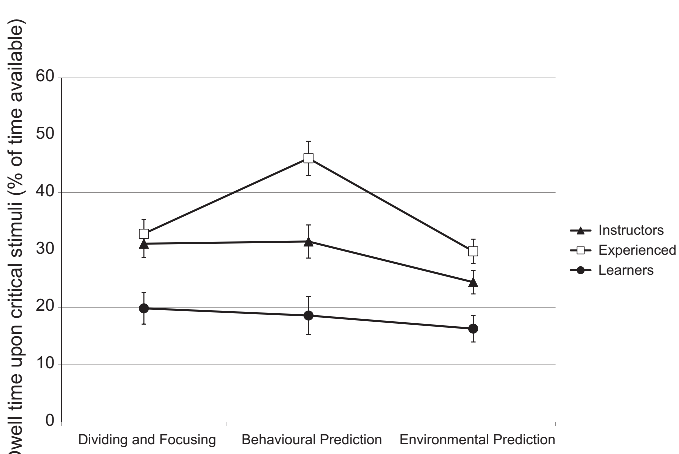

Fig. 4. The average total dwell time upon a critical stimulus, expressed as a percentage of the time window within which each stimulus was available for inspection, across event type and driver groups.

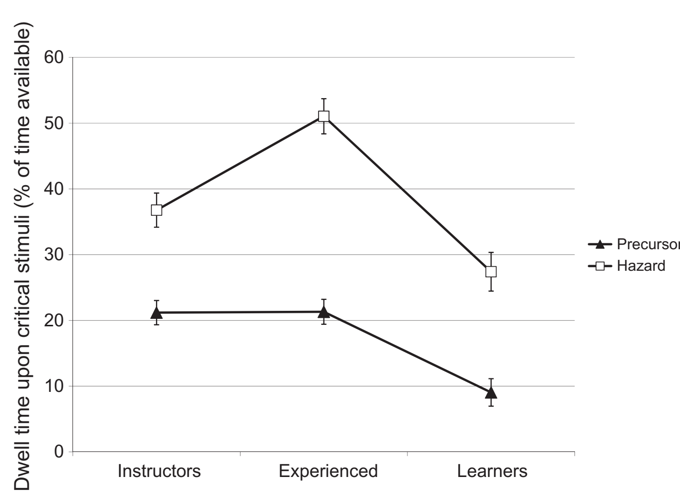

Fig. 5. Total dwell time upon precursors and hazards across driver groups.

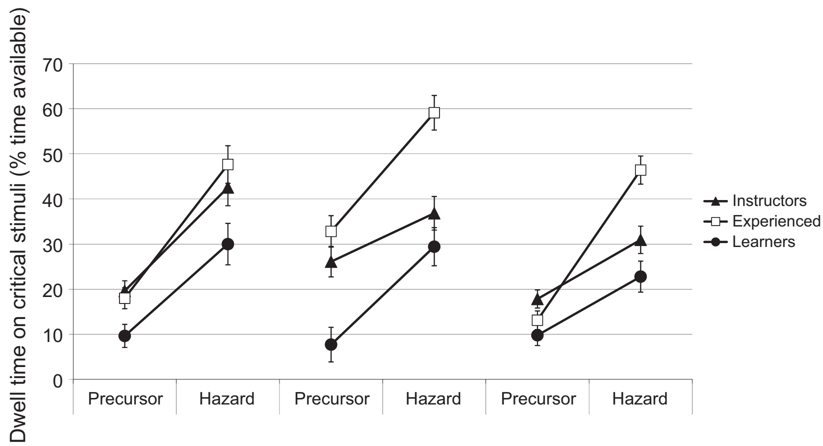

Fig. 6. The mean dwell time on critical stimuli (contingent on when participants fixated the stimuli) across hazard type, window and group.

and learners (48% and 51%; both at $p < 0.001$), while there was no difference in dwell upon the precursors across the groups.

A second interaction was noted between hazard type and type of critical stimuli ($F(2,76) = 4.5$, $MSe = 0.03$, $f = 0.34$, $p < 0.05$). Planned contrasts revealed the interaction to lie mainly in the BP and EP comparison ($F(1,38) = 4.9$, $MSe = 0.11$, $f = 0.36$, $p < 0.05$). This result suggested that while BP hazards (59%) receive more attention than precursors (46%); the amount of contingent attention given to EP precursors and hazards is the same (45% and 47%, respectively).

Both of these interactions contributed to the third interaction between all three factors ($F(4,76) = 2.7$, $MSe = 0.03$, $f = 0.37$ $p < 0.05$; Fig. 6). Tukey tests compared the driver groups across hazard type for both the precursor and hazard windows. For both BP and EP hazards (but not the precursors), experienced drivers had a greater mean dwell time than both learners and instructors ($p < 0.005$ for all comparisons).

3.4. Analysis of simulator data

Participants safely negotiated 89% of hazards (s.d. 10.4%), with no particular hazard being more problematic than any other. There were no differences across hazard type or driver group, although any underlying differences may be masked by ceiling effects.

Participants' speed (km/h) was sampled at 10 m intervals starting 100 m before the hazard (this included both the precursor and hazard windows used in the eye tracking analyses). Responsiveness to the hazard was assumed to be reflected in the relative variability of approach speed across these samples. Accordingly the standard deviations of all samples for each participant were analysed in a 3×3 ANOVA across driver group and hazard type. Initial data collection used less precise speed sampling intervals. This was modified after preliminary analysis of the early participants' data. The following analyses are based on all participants' data collected after this point (17 instructors, 8 experienced drivers and 14 learners).

Main effects were found for both hazard type ($F(2,72) = 4.8$, $MSe = 1.9$, $f = 0.37$, $p < 0.05$) and experience ($F(2,36) = 4.9$, $MSe = 1.2$, $f = 0.52$, $p < 0.05$), although both are subsumed by a two-way interaction ($F(4,72) = 4.6$, $MSe = 1.9$, $f = 0.51$, $p < 0$ .005). Further Tukey tests found that instructors had greater speed variation than experienced drivers ($p < 0.05$) and learners ($p < 0.001$) in the DF events, but not in the BP and EP events.

Average speeds for each group on approach to the hazards were also compared (independently for each hazard type) across the ten 10 m intervals. Nine planned interaction contrasts were conducted for each hazardous event type, comparing mean group speeds at 100 m to those at 90 m, then comparing 90 m to 80 m, and so on. Each analysis is essentially a 3×10 mixed ANOVA with the three driver groups providing an average speed for each distance from the hazard (the means of which can be viewed in Fig. 7 as a series of *speed signatures*, following the method first reported by Crundall et al., 2010). As the repeated contrasts are planned in advance, we do not need to be concerned with the omnibus interaction term, which we thought unlikely to be sensitive enough to reveal anything across 10 levels of a factor.

The analysis of speed for the driver groups across the 10 distance intervals for DF events did however produce a significant omnibus *F* interaction ($F(18,324) = 4.5$, $MSe = 9.3$, $f = 0.5$, $p < 0.001$). The contrasts revealed this to lie between 30 and 20 m from the hazard ($F(2,36) = 5.1$, $MSe = 12.3$, $p < 0.05$). As shown in Fig. 7a, the instructors' speed signature diverges significantly from the other groups, decreasing more rapidly as they get nearer to the hazard. This presumably reflects a greater responsiveness to DF events.

Planned contrasts for BP events revealed a group × hazard type interaction between 50 and 40 m before the hazard ($F(2,36) = 6.6$, $MSe = 2.3$, $f = 0.61$, $p < 0.005$). From Fig. 7b it can be seen that this corresponds with a crossover in speeds for learners and instructors, with a greater decrease in speed from the instructors. There was also a main omnibus effect of driver group ($F(2,36) = 3.8$, $MSe = 17.0$, $f = 0.46$, $p < 0.05$) with a greater overall speed for experienced drivers than for both instructors ($p < 0.05$) and learners ($p = 0.05$).

The EP events did not show any interactions in the contrasts, although there was a main omnibus effect of driver group ($F(2, 36) = 3.6$, $MSe = 13.5$, $f = 0.45$, $p < 0.05$), due to the greater speed of the experienced drivers compared to the instructors ($p < 0.05$).

4. Discussion

This study was an attempt to identify underlying reasons for why some hazardous scenarios discriminate between safe and unsafe drivers, yet others do not. We predicted that the distinction between precursor and hazard, and the relationship between the two, was important to the success of the scenario. We manipulated this relationship through the use of three hazard types: dividing and focussing scenarios, behavioural prediction scenarios, and environmental prediction scenarios.

Simply analysing whether drivers looked at the critical stimuli produced results in accordance with the limited literature. Pradhan et al. (2005) found inexperienced drivers were less likely to fixate potential hazards than more experienced drivers. While they made no distinction between precursors and actual hazards (although their 'potential' hazards are more akin to our precursors), we found that our learner drivers were equally poor in fixating both types of

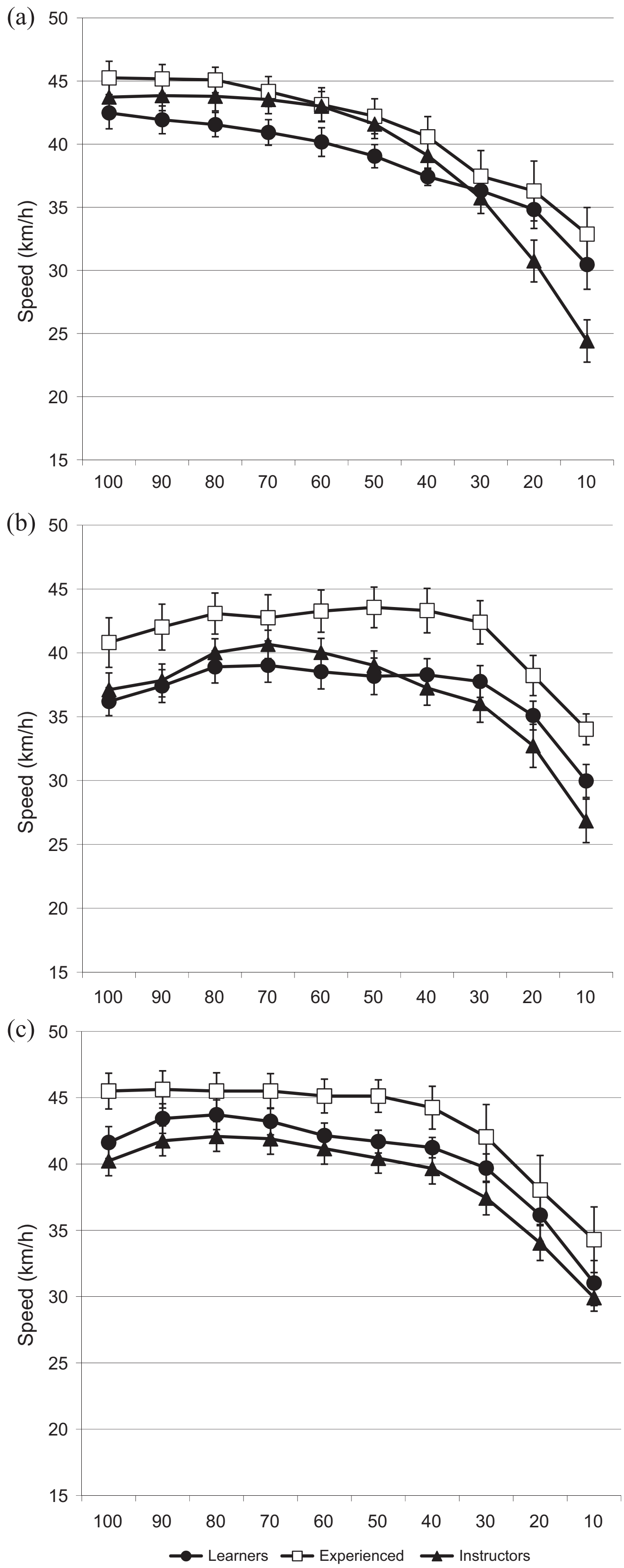

Fig. 7. Graphs depicting the speed in kilometres per hour across the 100 m prior top a hazard (in 10 m intervals) for learners (filled circles), experienced (empty squares) and instructors (filled triangles) for (a) DF hazardous events, (b) BP hazardous events and (c) EP hazardous events (with standard error bars).

critical stimuli compared to experienced drivers and instructors. It was also noted that hazards are fixated more often than their less-salient precursors, suggesting that drivers are not using all the available information to help them predict a hazard. This relates to the findings of Borowsky et al. (2007) who, using a video-based presentation method, found that those precursors which did not actually materialise into hazards were more discriminative than actual hazards. While we have supported Borowsky et al.'s finding that glances to precursors can discriminate driver groups, we have also demonstrated that this effect can transfer to actual hazards in a simulator.

When we included hazard type as a factor in this analysis however, it was clear that different types of hazardous scenario had varying effects on spotting the precursors and the hazards. Learners tended to miss more BP precursors than the other drivers, but spot the same number of BP hazards. However EP precursors were fixated with the same probability as other drivers, yet learners tended to miss more EP hazards. This simple expansion to the methodology of Pradhan et al. (2005) has demonstrated the heterogeny of our hazard types.

One can imagine that the direct link between BP precursors and their hazards should increase the likelihood that drivers would fixate BP precursors compared to EP precursors (which only have an indirect link to the hazard). Indeed this result can be seen in Fig. 2, with instructors and experienced drivers fixating BP precursors more so than EP precursors. The learner drivers do not benefit from the more direct link between BP precursors and hazards however. Despite this, they still manage to spot the actual BP hazard with a level of probability equal to other groups. Does this suggest that attention to BP precursors is not required to successfully spot a BP hazard? On the basis of this binary measure, we might suspect so. However the more sensitive analysis of the time taken to first spot the critical stimuli shows that although learners might spot BP hazards as often as other drivers, it takes them longer to do so. It is highly probable that the greater likelihood of experienced drivers and instructors fixating the BP precursors has a role in reducing the time taken to first fixate the BP hazards.

The analysis of the probability of fixating the critical stimuli also provided an interesting result in regard to EP precursors and hazards. While all drivers fixated the precursors with equal probability (although relatively infrequently compared to other precursors) the learners missed more EP hazards. Similarly, when learners did fixate EP hazards they were typically slower to do so than instructors and experienced drivers. If a driver does not use an EP precursor to help predict an EP hazard, then the hazard is simply an abrupt onset (akin to the unpredictable basketball bouncing into the road). With an abrupt onset one might expect that younger (and inexperienced) drivers might respond to the hazard fastest and most frequently. This was not the case; therefore the experienced drivers and instructors must be obtaining some predictive information about the upcoming EP hazard.

One possibility is that the effectiveness of a fixation made by an experienced driver is greater than that of a learner driver (e.g. Chapman and Underwood, 1998). Thus a short fixation on a parked car might provide the experienced driver with information concerning a potential hazard, whereas the same fixation for a learner driver may not allow such deep levels of processing.

In addition, it is possible that the experienced drivers and instructors monitor the EP precursors peripherally until they draw near to them. While EP precursors have an indirect link with the hazard, they have more temporal accuracy in their predictive information. It could be argued that one only needs to be concerned about pedestrians behind a parked truck when one is close to passing it. Thus EP precursors may be fixated later than BP precursors because there is no advantage to fixating them earlier. The lower probability of fixating EP precursors may reflect some occasions where the precursor is monitored solely through peripheral vision, or when the driver has left it too late to fixate the precursor before the hazard triggers. This explanation fits with data we have previously reported which suggest that experienced drivers can withhold attention from critical stimuli until such a time as they feel it is optimal to devote attentional resources foveally (Crundall et al., 2002).

The general pattern of results regarding the speed with which critical stimuli are first fixated also accords well with those studies which have identified RT differences between safe and unsafe drivers while responding to hazards on video clips (see Horswill and McKenna, 2004). While the results were mixed regarding the speed to fixate the precursors, learners were slower to spot all types of actual hazard compared to instructors and experienced drivers. Slower fixations to hazards are likely to be a key component in slower RTs on video-based hazard perception tests.

One other reason that learners might respond more slowly to hazards in a video-based test is that it may take them longer to process the hazard (i.e. longer to comprehend the fact that a particular stimulus poses a hazard). Previous research on eye movements to hazard video clips has suggested that while hazards evoke longer fixations than safe driving conditions, inexperienced drivers are disproportionally affected, with much longer fixations on hazards than might otherwise be expected (e.g. Chapman and Underwood, 1998). Chapman and Underwood (1998) were referring however to individual fixations (i.e. a driver's sampling strategy) rather the amount of attention devoted to a hazard reflected in the current analyses of dwell time. While the current analyses reinforce the suggestion that hazardous stimuli will capture more attention than non-hazardous stimuli (even if such non-hazardous stimuli are still precursors to hazards), the analyses do not provide a straightforward replication of the experiential effect. The least experienced group actually gave the least attention to the critical stimuli. Even when the results were contingent on when the critical stimuli were spotted, learners had shorter dwells than experienced drivers, and were at least equal with the instructors. Does this mean that the learners were as able to process the hazard as quickly and as efficiently as the instructors? One might expect them to be especially sensitive to hazards as their driver training will include preparation for the official video-based hazard perception test that forms part of the UK driving test. Indeed the difference between the findings of Chapman and Underwood (1998) and the current study, might reflect a change in UK learner drivers brought about by the inception of the official UK hazard perception test in 2002. Alternatively, their relatively short dwell times may reflect failures to process. If a fixation is too short it may have been terminated because the viewer failed to realise that the object of fixation was important enough to require further attention (see Crundall et al., 2012, for an application of this idea to Look But Fail to See collisions). This possibility underlines the importance in not relying simply upon the probability that drivers might fixate a certain stimulus without considering the length of time they fixate for. Certainly, the similar amounts of attention that learners and instructors give to the hazards, do not result in similar speed signatures. The instructors' speed signatures clearly diverge from the other groups in DF and BP hazards, suggesting that their relatively short dwell time upon the critical stimuli has been put to good use. The failure of learners' speed signatures to show dips similar to that of the instructors suggests that they have not extracted sufficient information from their relatively short dwell time upon the critical stimuli, or at least do not know how to translate the information into behavioural requirements.

It is interesting to note however that the experienced drivers have longer dwells than the instructors, suggesting that they are processing the hazards for longer (or suffering from attentional capture). Combined with the analysis of the speed with which drivers fixate the critical stimuli it is clear to see that the learners and experienced drivers differ from the instructors in different ways. While the learners are failing to identify important stimuli early enough, the experienced drivers fail to disengage from the hazards (specifically in BP and EP hazards).

To summarise, it appears that the distinction between precursor and hazard, and the relationship between them, is important. Typical video-based hazard perception tests monitor responses to actual hazards (Horswill and McKenna, 2004), while some simulator studies have been more interested in potential hazard sources (i.e. precursors; Pradhan et al., 2005). It might be argued that the materialisation of multiple hazards in typical video HP tests, and in the current simulator test, sensitises drivers to possibility of hazards occurring. If this is the case, then the levels of discrimination that we have identified in the current study are all the more remarkable. The results here have shown that different types of precursor and hazard are especially susceptible to being missed or fixated late. This difference between potential hazards and actual hazards may account for some of the inconsistencies in the literature. It is also possible that the role of the precursor is important in inducing a change in driving behaviour. Speed signatures for instructors showed considerable slowing compared to other groups in both the DF and BP scenarios; the same scenarios which saw the instructors fixate the precursors faster than the learners. The advanced warning of the potential hazard via fixating the precursor is likely to have prompted an early decrease in instructor speed. Instructors did not fixate EP precursors faster than other groups however, and therefore may not have had any more evidence than the learners and experienced drivers to prompt a greater reduction in speed during the 100 m approach.

The experienced drivers had the same exposure to the precursors however, yet they did not slow as much as the instructors. Again this suggests that experienced drivers and learners differ from the instructors in different ways: while the learners are slow to spot important stimuli, the experienced drivers spot them earlier but do not translate the information into appropriate behaviour.

The results offer tentative suggestions for future training. If the early fixation and processing of the BP precursor are important to the instructors' decision to reduce speed, training drivers to recognise, monitor and process these precursors may improve hazard responsiveness. Conversely increasing foveal attention to EP precursors appears unnecessary and could be potentially detrimental (needlessly reallocating attentional resources away from other vital visual tasks). Instead the role of these environmental precursors in peripheral vision should be investigated, possibly through the application of gaze-contingent methodologies in a driving simulator.

In conclusion, the current results further support the hypothesis that hazard perception is dependent on how quickly drivers spot relevant hazards. Furthermore the distinction between hazard types suggests that the underlying structure of a hazard will determine what is fixated and how quickly it is processed. EP hazards appear to be the most difficult to process for all drivers, although learners show specific problems with BP precursors (perhaps, as one reviewer suggested, because these BP precursors might themselves have an EP precursor). These findings pave the way for further distinctions between hazards on the basis of their deep structure.

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