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Hazard perception as a function of target location and the field of view

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ABSTRACT

A typical hazard perception test presents participants with a single-screen view of the road ahead. This study assessed how increasing this field of view would affect hazard perception abilities. Drivers were shown video clips of driving situations containing at least one hazard either on a single screen, or with the addition of side views on two separate but adjacent screens that extended the perceived worldview to approximately 180°. Mirror information was also included to allow information from behind the vehicle to be attended. Participants were instructed to press a button as soon as they saw a hazard. Faster response times were found for hazards that appeared in the centre of the central screen, than in the periphery of the central screen, with hazards that first appeared in the lateral screens responded to slowest. Additionally, responses to the hazards were faster and were more likely to occur in the three-, as compared to the single-screen condition. These results suggest that providing participants with a wider field of view, which includes more environmental cues that are related to the relevant hazardous situation increases their ability to detect hazards, and some limited support to that providing them with a wider view increases this ability even when all hazard-relevant information appear only in the central screen. A number of reasons for the three-screen advantage are discussed. This study suggests that even responses to central hazards may be under-estimated in a typical single-screen hazard perception test, and that improvements can be made for new hazard perception tests, by including visual information from the side and from behind the driver. This new methodology not only allows testing hazard perception skills in a potentially more immersive and realistic environment, but also enables to create hazard perception clips that cannot be realised in a typical single-screen test.

1. Introduction

With most crashes occurring due to human error (Lewin, 1982; West et al., 1993), drivers' abilities, to anticipate road events, to detect hazardous traffic situations and to respond to them appropriately are considered to be substantial characteristics of cautious driving and major contributors to traffic safety. These abilities are often termed hazard perception (HP). Although definitions for HP vary, researchers have usually focused on either the above-mentioned components (i.e., the abilities to anticipate road events etc.; e.g., Deery, 1999; Elander et al., 1993; Horswill and McKenna, 2004; Jackson et al., 2008; Sagberg and Bjørnskau, 2006), or on the subjective experience of risk in potential traffic hazards (Adams-Guppy and Guppy, 1995; Brown and Groeger, 1988; DeJoy, 1989; Finn and Bragg, 1986; Gregersen, 1996; Harre, 2000; Jessor, 1987; Matthews and Moran, 1986; Rosenbloom et al., 2008). Studies focusing on the subjective experience of risk in potential traffic hazards, namely risk perception, typically concentrate on an expected negative correlation between risk perception and risky behaviour. In other words, the general notion pointed out in these studies is that in a given situation, perceiving low crash risk would lead to less cautious driving.

In fact, it has been argued that HP more than any other driving component has been found to predict accident involvement (Horswill and McKenna, 2004). Studies showing a relationship between HP performance and accident involvement typically demonstrate that drivers who have not had an accident respond more quickly to hazards than drivers who have (e.g., McGowan and Banbury, 2004; McKenna et al., 2006; Wallis and Horswill, 2007). In addition, a number of studies have found experiential differences in HP performances. These include studies which discriminated between learner drivers and novices (Sexton, 2000), novices and experienced drivers (e.g., Jackson et al., 2008; McKenna and Crick, 1991, 1994; Sexton, 2000; Wallis and Horswill, 2007) as well as between experienced and expert drivers (McKenna and Crick, 1994). Apparently, such differences between novice and experienced drivers are related to the fact that novices are less willing to classify situations as hazardous and require higher thresholds of risks to be present before doing so (Wallis and Horswill, 2007), hence they are related to lower risk perception. Experienced drivers

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seem to perceive more – and generally be more sensitive to – potential hazards than novice drivers, and therefore they recognize elements missed by novices (Borowsky et al., 2009).

Among the different methods used to assess detection and response to hazards, the presentation of short video clips is probably the most common. In a typical video-based HP test participants are asked to watch clips taken from a driver's perspective through the windscreen of a moving vehicle, and to respond by pressing a button or a foot pedal to the appearance of hazards. Hit rates and response times are normally recorded and these measures are used to reflect HP skill. Based on such evidence and on the related assumption that with practice individuals learn to correctly identify hazards, the HP test has been incorporated into the UK driving test since 2002.

In spite of the evidence presented above for both accident liability related HP differences and experiential related HP differences, there have also been failures to replicate both types of findings. Specifically, some studies have failed to discriminate between experienced and inexperienced drivers (e.g., Crundall et al., 1999; Groeger et al., 1998), and between accident-involved and accident-free drivers (e.g., Groeger et al., 1998). These failures to demonstrate the expected negative correlation between HP performance and accident involvement and the expected positive correlation between HP performance and driving experience raise some questions about the validity of HP tests (for a review see Horswill and McKenna, 2004; Groeger, 2000). Briefly, poor face validity (button presses in response to filmed hazards may be considered quite different than real driving; Groeger, 2000), low internal consistency, and different thresholds to defining hazards (Horswill and McKenna, 2004) are all potential factors in limiting the consistency of HP tests. It has also been argued that the complexity of hazard perception skill may not be reflected by the most commonly used push-button measure of reaction times (Jackson et al., 2008). Also as noted previously (e.g., Sagberg and Bjørnskau, 2006; Sexton, 2000), not all clips are capable of demonstrating experiential differences.

The current study dealt with yet another characteristic, which we believe reflects a substantial drawback inherent to the typical HP test. While the standard HP test is presented on a single screen, presenting *only* the front view from a driver's perspective (approximately 60–80° of visual angle depending on which camera the clips were filmed with, and where the camera was mounted on the car), real driving involves detecting and processing information from the sides as well as from behind the vehicle. Pedestrians who intend to cross the road, overtaking and undertaking vehicles, and vehicles which do not maintain a safe distance are just few examples of the many occurrences of potential hazards outside the frontal view of a driver, with substantial implications to safety of road users. With respect to McKenna and Crick's (1991) argument that the most important aspect of the hazard perception test was viewing the visual scene (and that it therefore was not necessary to simulate being in a car to watch the clips), we suggest that the typical HP test lacks not only the interactivity found in a driving simulator (which we agree is not necessarily required for assessing some types of hazard perception), but also the full range of visual cues that compete for attention when actually driving a car in the real world. As the side views and mirror information, which in real driving often provide information which can be critical to preventing accidents, are not present in the typical HP tests, we may be underestimating or overestimating drivers' HP skill.

For instance, by adding mirror and side view information we may increase the likelihood that drivers are looking in the wrong place when the hazard appears, thus decreasing hazard perception (suggesting that typical single-screen tests overestimate real HP skill). In this sense the additional information from the sides and from behind the vehicle also builds up additional mental load. Decremental effects of increased mental load upon driving performance have been demonstrated, often with respect to use of mobile phones (Alm and Nilsson, 1994; Consiglio et al., 2003; McKnight and McKnight, 1993; Patten et al., 2004; Strayer and Drews, 2004), but also with other, both visual and non-visual related tasks (Recarte and Nunes, 2000, 2003). However while increases in localised visual demand tends to narrow the attentional focus, prolonging fixations (Chapman and Underwood, 1998) and impairing peripheral processing (Miura, 1990; Crundall et al., 1999; Crundall et al., 2002), increased visual complexity instead tends to increase the sampling rate of a search strategy, resulting in a greater number of shorter fixations (e.g., Crundall and Underwood, 1998). Such short fixations are likely to occur with a wider field of view, and may therefore reduce the processing power of any individual fixation, potentially increasing the possibility of Look But Failed To See errors (Brown, 2002). This is encapsulated in Findlay and Walker (1999) model of saccade generation which describes a reciprocal inhibitory relationship between the urge to fixate and the urge to move the point of gaze. With more stimuli in the visual field, the urge to move the eyes may be increased, thus reducing the time spent at any particular fixation point, which in turn increases the possibility that the eyes move away from their current location before they have fully processed whatever they were looking at.

This explanation assumes however that a decrease in fixation durations would reduce the level of attention at the point of regard to below that which is required for an optimum level of processing (thereby interfering with hazard perception skills). By encouraging wider scanning of the visual scene and a higher sampling rate with shorter fixations without reducing fixations to below that required for successful processing, the provision of a wider visual field could in fact lead to improved hazard detection. There are a number of other possible reasons why a wider available visual field would result in better hazard detection.

One might argue that a wider field of view could provide a more immersive experience (Allen et al., 2005). This may encourage more realistic scanning of the scene (a more realistic search pattern), focusing the participants in the most vital areas and directing them to the most relevant sources of information thus improving HP scores (suggesting that that the typical single-screen test underestimates HP skill). Allen et al. (2005) undertook studies of novice drivers across three simulator platforms; a single-screen, three-screens and a large three-screen display with participants sat inside an instrumented car cabin. One of the findings they reported was that the novice drivers tended to behave differently in the single-screen simulator to the other two platforms, with more aggressive behaviour (faster speeds, harsher braking), reduced time-to-collision estimates and more accidents. Allen et al. (2005) put these differences down to the greater information provided across three screens which may have increased the immersive qualities of the simulator, encouraging more realistic behaviour. If this is indeed the case then it is also possible that the greater immersion with the three-screen platforms encouraged different scanning patterns. This is potentially of great importance to the hazard perception literature, especially if a wider field of view induces a more realistic scan pattern. If scanning a single-screen HP test is not a reflection of visual behaviour during real driving, then not only can we suggest that this might lead to single-screens over-estimating HP skill, but also the alternative argument could be made for an underestimation: a narrow field of view might be so far removed from real driving that participants would view it without feeling immersed in the driving situation, resulting in greater temptation to look at objects in the scene that are less relevant (e.g., searching shop fronts for emerging customers), and spending much of their time not inspecting relevant aspects of the scene. Even if drivers are consciously searching for hazards, the lack of realism in a single-screen study might encourage them to seek hazards in unlikely places.

A different potential mechanism could be the level of arousal and general alertness that a wider field of view could induce. This could potentially lead participants to respond faster due to either lower criterion thresholds for whatever targets they are instructed to search for (in this case hazards), or due to increased sensitivity. In terms of signal detection theory, this would mean that variations in either beta (criterion) or d prime (sensitivity) could both lead to faster responses.

Finally, while all of the above-mentioned explanations are capable of accounting for HP differences between a narrow and a wide visual field, where the additional information in the wide field is not directly relevant to the hazardous event, a wider field of view may have more environmental cues that *are* related to the relevant hazardous situation, providing participants with a better situation awareness (e.g., Endsley, 1995; Borowsky et al., 2009) thereby affecting directly their responses to the hazards.

In order to assess the impact of a wider field of view in a hazard perception test, we developed a three-screen test which allows a more realistic experience than the typical HP methodology by including information from the front, side, and back views of the driver, with three sources of mirror information inset into the screens (a rear-view mirror in the top centre of the central screen and two side mirrors in the bottom right and bottom left corners of the left and right-hand screen, respectively). We then assessed the HP performance of drivers presented with all three screens compared to a second group of drivers who only saw information from the central screen (with only the rear-view mirror inset). It was anticipated that drivers presented with the full field of view would respond differently to the hazards. While based on the discussion above there are many reasons to expect improved HP (reflected by greater accuracy and faster response times) in the three-screen condition (as well as some reasons to expect the opposite pattern), the present experiment did not monitor eye movements and therefore cannot confirm or dismiss any of the above hypotheses.

2. Method

2.1. Participants

Forty participants volunteered to take part in the experiment. The data of one participant were excluded from the analyses (see results). From the remaining participants (mean age = 24.56; SD = 4.79), 12 females and 8 males composed the single-screen condition (mean age = 25.9, SD = 5.13; mean license seniority = 6.5, SD = 5.97) and 10 females and 9 males composed the three-screen condition (mean age = 23.16, SD = 4.08; mean license seniority = 5, SD = 4.44). Participants were offered an inconvenience allowance of £3 for their time. All of them had normal or corrected-to-normal vision.

2.2. Apparatus and stimuli

2.2.1. Filming

All clips were filmed around Nottingham over a three-week period in August 2008. We were assisted in the filming and editing of the clips by a film company (Cantab Films). Six digital video cameras were mounted externally to a film car using suction mounts to allow the positioning of the cameras to match the required view as closely as possible. Three forward facing cameras, positioned on bonnet of the car, recorded the front and side views, while three rear-facing cameras, positioned on the side mirrors and on the roof of the car, recorded the view that one would see in the three mirrors (side-view mirror and wing mirrors). The main forward-looking camera was a Sony HVR-V1E camcorder recording in DV format in 16:9 ratio. The remaining five cameras were Sony CVX-3P mini cameras, recording in DV format in 4:3.

While most of the clips filmed were aimed to allow specific hypotheses regarding car–motorcycle interactions to be investigated (which will not be discussed here), an additional set of about 20 HP scenarios were filmed, each containing one hazardous event (e.g., a parked car suddenly pulls in front of the film car and blocks the way; a pedestrian, hidden from view by a parked van enters the road; a parked car suddenly reverses out of a parking driveway invading the lane). While some of the hazardous events arose from opportunistic on-road filming, most of them were staged. All staged clips involved stooge vehicles or pedestrians and were approved by an accompanying police escort who remained with the film crew throughout the three weeks it took to gather enough footage.

2.2.2. Editing and clip selection

Following the filming the footage was edited into short clips lasting up to 30 s by Cantab Films to the specification of the authors. The three forward views were synchronized and the three sources of mirror information were inserted in the forward views. The rear-view mirror information was placed at a top central location on the centre screen. The left mirror was placed in the right-hand corner of the left screen, and the right mirror was placed in the left-hand corner of the right screen. Editing and synchronization of the clips were carried out using Adobe Premiere CS4 software. They were encoded into Mpeg 2 format with a bit rate of 8 MBit. The movies were synchronized by marking when the car moved off on each clip and again when it stopped at the junction. The clips were then precisely aligned before being split into the separate feeds for the monitors. Each camera was independently recorded on tape with unsynchronized time-code. Three separate files are used for playback, one for each screen. These files are then converted to WMV format for playback in the custom software. It uses windows media player as the playback engine together with custom logic to enable the synchronized streams to be shown on the three monitors. Once the clips had been filmed and edited, 14 HP clips were selected on the basis of pilot work for presentation in the experiment. However, after data collection the response times of one clip, in which the hazard appeared on one of the side screens prior to appearing on the central screen, were removed (for more details, see Section 2.3). Detailed descriptions of the 13 hazard clips analyzed are given in Table 1.

2.2.3. Three-screen playback system and experimental set-up

The horizontal visual angle of the central screen was approximately 42° wide at a distance of 115 cm, though this extended to 112° when the side screens were included. The actual view from the three forward cameras on the film car was however closer to 180° though the experimental set-up required this real world angle to be condensed into a narrower angle for the laboratory. This was achieved through angling the side screens relative to the central screen such that drivers could see the whole view within the 112° subtended by the laboratory image. Though this required some distortion of the visual scene three driving experts were consulted and found to be happy with the display. Only one participant commented on this, while the remainder seemed either unaware or unperturbed.

A push button was provided for participants to record their responses to a hazard. The playback system consisted of a PC workstation running Windows XP with the ability to have three DVI digital outputs. These outputs are converted to HDMI for connection to the 40 inch displays via an adaptor. The displays were Toshiba 40XF355D televisions (i.e., 40 inch). The central screen displayed the front view while the two further screens positioned to the left and right of the central screen at a set angle of 120°, dis-

Table 1
Detailed descriptions of the hazard perception clips, including means (SD) response times, *t*-tests performed on these means, number of participants who responded to each hazard, and average response times without assigning maximum response times (given in curly brackets), for the single-screen and three-screen conditions.

	Hazard	Description	Hazard onset	Single screen (mean seconds (SD); correct responses to hazards)	Three screens (mean seconds (SD); correct responses to hazards)	*t*-Value
1	Bicycle enters the road	The film car is travelling on a 30 mph suburban road. Ahead, a bicycle appears on the pavement from behind a fence. The bicycle then enters the road in front of the film car	When the front wheel of the bicycle reaches the edge of the pavement	2.05 (1.16) 16 {1.66}	1.84 (0.94) 17 {1.56}	0.61
2	Car invading the lane	The film car is travelling on a 30 mph suburban road, approaching a t-junction. A car approaches from the left-hand side and turns right into the road cutting the corner in front of the film car	When the car begins to turn	1.12 (1.01) 18 {0.87}	0.91 (0.90) 17 {0.63}	0.66
3	Pulling out lorry	The film car is travelling on the central lane of a 30 mph three-lane urban carriageway. A lorry, ahead in the left lane suddenly signals and immediately turns right, entering the lane in front of the film car	When the lorry's signal onsets	4.03 (2.71) 15 {3.01}	2.55 (1.63) 18 {2.24}	2.08*
4	Pedestrian enters the road 1	The film car is travelling on the 30 mph urban one-way road. A pedestrian, hidden from view by a parked car enters the road from the left-hand side and crosses in front of the car	When the pedestrian steps out from behind the car	1.76 (0.59) 20 {1.76}	1.88 (0.86) 18 {1.70}	−4.9
5	Car reversing into lane	The film car is travelling on a one way 30 mph suburban road. A parked car suddenly reverses out of a parking driveway from the left-hand side, invading the lane	When the car starts reversing	3.34 (0.64) 20 {3.34}	3.29 (0.41) 19 {3.29}	0.27
6	Car pulls out	The film car is travelling on a 30 mph suburban single lane one-way road, approaching a right turn. A car is driving in front of the film car. It stops on the left-hand side and suddenly pulls out again and turns right in front of the film car	When the braking lights of the vehicle ahead offsets	3.00 (1.16) 13 {2.68}	2.25 (0.97) 18 {2.11}	2.17*
7	Opening door	The film car is travelling on a 30 mph suburban road. A van is parked ahead on the left-hand side. The door of the van suddenly opens and the driver steps out	When the door begins to open	1.95 (1.01) 14 {1.62}	1.75 (0.94) 15 {1.35}	0.64
8	Car reversing into lane	The film car is travelling on a 30 mph suburban road. At a crossroads ahead a car is reversing, invading into the lane	When the car starts reversing	2.74 (1.26) 19 {2.56}	2.73 (0.78) 19 {2.73}	0.03
9	Pedestrian enters the road 2	The film car is travelling on a 30 mph suburban road. A pedestrian, hidden from view by a van parked on the left-hand side of the road, enters the road and crosses in front of the film car	When the pedestrian steps out from behind the van	1.43 (0.21) 20 {1.43}	1.43 (0.15) 19 {1.43}	−0.06
10	Right of way violation at crossroads	The film car is travelling on a 30 mph suburban road, approaching a crossroads. A car enters the crossroads from the right, violating the right of way of the film car	When the car crosses the give way line onto the main carriageway	2.62 (1.35) 20 {2.62}	2.62 (1.22) 18 {2.41}	0.01
11	Motorbike undertaking	The film car is travelling on a 40 mph suburban road. As the road opens to become a dual carriageway a following motorcycle undertakes the film car. The motorcycle can be seen simultaneously in both the rear-view mirror and left side mirror, before entering the left lateral screen and then the central screen	When the motorcycle speeds up to undertake	7.10 1 {6.60}	6.70 (1.60) 3 {5.46}	0.84
12	Car approaches from slip road and undertakes	The film car is travelling on the right-hand lane of a 40 mph dual carriageway road. A car in the left-hand lane speeds up to undertake the film car and then moves into the right-hand lane without due warning or headway. The car can be seen in both the rear-view mirror and the left-view mirrors, before entering the left lateral screen and then the central screen	When the car speeds up to undertake	4.51 (1.44) 3 {3.95}	3.19 (1.65) 9 {2.76}	2.66**
13	Pedestrian enters the road – reversing	The film car reverses on a 30 mph urban one-way road. A pedestrian, hidden from view by a van parked on the left-hand side of the road, suddenly enters the road behind the reversing car. The pedestrian can be seen in the left and rear-view mirrors at the same time	When the pedestrian steps out from behind the van	1.70 (0.63) 18 {1.69}	1.63 (0.41) 19 {1.63}	0.41

[*] Significant at 0.05.
[**] Significant at 0.01.

Fig. 1. Multi-screen set-up for the three-screen hazard perception test.

played the side views. A screen resolution of 1280 × 720 was used. The front view was displayed in 16:9 aspect ratio on the central screen. The lateral views covered most of the lateral screen length and had a 4:3 display aspect ratio. The frame rates of the videos were 25 Hz. Fig. 1 displays the multi-screen set-up.

2.3. Design

The study employed a mixed 2 (×3) design, comparing a group of drivers who saw the clips presented solely on the central screen with a group of drivers who saw all three screens for each clip. The within subject factor was the initial location of the object (i.e., the other road user) that caused the hazard. The 13 clips were categorized into three groups: (a) clips in which the hazardous situation (onset) occurs in the central 50% of the central screen (measured horizontally; the *central* condition); (b) clips in which the hazardous situation initially appears in either the left 25% or right 25% of the central screen (either solely, or in addition to in the centre of the central screen), but there is no available information about it in either of the lateral screens (termed the *peripheral* condition); and (c) clips in which information about the hazardous situation is also available (in addition to the central screen through the rear-view mirror) through either one of the lateral screens (the *lateral* condition).

There were seven clips in the central condition (hazards 1–5, 7, 9, in Table 1), three in the peripheral condition (hazards 6, 8, 10) and three clips in the lateral condition (hazards 11–13). Critically, in none of the lateral clips did the hazard appear on one of the lateral screens *prior* to it appearing on the central screen (the data of the only clip excluded from the analysis were removed on this basis: faster RTs to such hazards in the three-, as compared to the single-screen condition, would reflect the fact that the onset time is calculated from a point at which the hazard was not even visible on the central screen).

The dependent variable included response times (RTs) to detect hazards in seconds. RTs were calculated as the time of response minus the hazard onset time. Hazard onsets were determined a priori by two driving experts, and these were later revised on the basis of the distribution of the response times backwards in time by 500 ms to allow for genuine anticipations of the hazard. All clips were presented randomly. Failures to respond to a hazard were assigned a maximum RT (following McKenna et al., 2006), which was either an a priori offset based on time-to-contact, or the latest correct response given by a participant, whichever was longer.

2.4. Procedure

Participants were seated approximately 115 cm from the central screen. They were told that they were about to watch video clips taken from a car driver's viewpoint. In the three-screen condition participants were told that the central screen would display the front view from a moving vehicle, while the two screens, positioned to the left and right of the central screen would display the side views. They also were told that rear- and side-mirror images would allow them to see information from behind the vehicle. Participants were asked to view each clip as if they were the driver, keeping an eye out for any hazardous events. The instructions further explained that hazardous events included any situations where the driver should change his or her driving behaviour to avoid danger (i.e., braking, swerving, etc.).

Participants were instructed to press a push button as soon as possible once they saw a hazard and following this response to then say out loud what the hazard was. Each clip played to the end. The screen then went black for 3 s before the next clip was presented. Button responses were recorded and participants were informed on-screen that they had pressed a button. If participants did not press a button they were informed on-screen that they had not pressed a button.

The instructions for the single-screen condition were identical, with the exception that there were no references to either the side screens or the side mirrors. After the participants had read the instructions, the experimenter started the session.

3. Results and discussion

Participants' RTs were averaged across the hazards within each condition to give an overall measure for that condition. The data of one participant, who pressed excessively (over 4.6 clicks per clip), were removed from the analyses. The remaining participants pressed 1.2 times per clip on average, with a mean accuracy of 86% (calculated as the percentage of times that the participants reported the correct hazard verbally after pressing the button). The difference in the number of button presses between the single-screen (mean = 1.16; SD = 0.27) and three-screen (mean = 1.23; SD = 0.42) conditions was not significant [$p > 0.10$]. Generally, these patterns, particularly the high percentages of responses to hazards, with the relatively low number of false alarms (as indicated by the average of 1.2 presses per clip) suggests that the hazardous events depicted in the clips were perceived as hazardous by the participants, and that they could distinguish these events from the non-hazardous situations in the same clips.

A 2 × 3 ANOVA (screens × location) was performed on the RT data. A main effect was found according to the number of screens that participants watched, $F(1,37) = 4.10$; $p = 0.05$, indicating faster RTs with three-screens (mean = 2.87 s; SE = 0.15) compared to the single-screen condition (mean = 3.29 s; SE = 0.15). A main effect of location, $F(2,74) = 265.87$; $p < 0.001$, was also found to be significant. Planned contrasts comparing the three locations for the within factor revealed that RTs were faster when the hazard appeared in the centre of the central screen, than in the periphery of the central screen, ($F(1,37) = 280.11$; $p < 0.001$), which in turn was faster than the lateral condition (i.e., when information about the hazardous situation was available through either of the lateral screens in addition to the main screen; $F(1,37) = 257.01$; $p < 0.001$). Thus, participants' response speed increased as a positive function of the centrality of the hazards, within the visual field. The interaction was not significant [$F(2,74) < 1$].

Finally, *t*-tests (performed on RT data; see Table 1) and two-tailed Fisher's exact test (using number of participants that responded to each of the hazards) were used to assess group differences in each of the clips. As shown in Table 1, although for nine out of the 13 clips means RTs were indeed smaller in the three-screen condition, whereas only in one clip, mean RTs was smaller in the single-screen condition, *significant* group differences (*t*-tests) were found only for three of these clips (3, 6 and 12). Two of those clips (3 and 6) however were non-lateral clips, and just one was a lateral-condition clip. The differences between the numbers of participants who responded to the hazards in the single-screen condition compared to the three-screen condition (see Table 1) were significant for hazards 6 and 12 ($p < 0.05$, Fisher's exact test).

As mentioned in Section 2.3, following McKenna et al. (2006) failures to respond to a hazard were assigned a maximum RT. Our RT measure was therefore a composite measure of whether participants spotted the hazard and how quickly they responded. This composite relies on the assumption that everyone spots the hazard eventually though their responses may not be recorded because they are too late (i.e., the hazard has already occurred) or because the participants decide not to respond because it is obvious to themselves that it is too late to gain credit for responding. This assumption is only breached if a predetermined hazard actually turns out to be so unhazardous that practically no one responds to it. Indeed, only four participants responded to hazard 11 raising the possibility that the hazard was simply not hazardous enough. In addition to this problem, assigning maximum RTs decreases the variance of the analysis affecting particularly hazard 11 to which so few participants had responded. We have therefore undertaken the analysis both with and without hazard 11 (while relatively few participants responded also to hazard 12 this event was kept to allow that the lateral category would contain more than one event). The pattern of significant results remained the same.

Finally, while one might argue that assigning a maximum RT to lack of response cannot be accepted to represent response time measurement particularly due to those instances where participants may have noticed the hazard perhaps even at an early stage, but made a conscious decision not to respond, this problem would have had little effect on the current data where absence of responses were the exception rather than the rule. Moreover, as can be seen in Table 1 the pattern of the data appears to remain the same with or without assigning maximum RT. Only in 3 of the 13 events (4, 8, and 10), the pattern changes: for event 4 slower mean RTs and for event 10 the same average RTs are indicated in the three-screen condition as compared to the single-screen condition when maximum RTs are assigned, though when maximum RTs are *not* assigned the opposite pattern is indicated (faster RTs in the three-screen condition than in the single-screen condition). Only for event 8, slower RTs in the three-screen condition than in the single-screen condition are indicated when maximum RTs are not assigned. To some extent those averages produced without assigning maximum RTs validate both the maximum RTs measure with which they highly correlate and the finding of faster RTs in the three-screen condition.

While the results suggest that the wider field of view improves hazard detection times, lateral information contributed substantially to the improved HP performance in the three-screen condition. Specifically, in clips 3 and 6, although most of the vehicle (the lorry and car in front, respectively for clips 3 and 6) appeared on the central screen, the rear end of these vehicles appeared in the left screen. Although neither of these clips had on the lateral screens typical cues revealing the driver's intentions (in clips 3, the lorry *does* indicate but this can be seen primarily in the central screen and only at the very end of the clip it can be seen slightly in the left screen. In clip 6, the driver does not signal. In both clips, the rear wheel cannot be seen in the lateral screen), in both clips the gradual disappearance of the rear of the vehicle from the left screen's view could have provided motion and speed cues that were only available to participants in the three-screen conditions. Importantly, while this can be interpreted as an artefact of the laboratory conditions, specifically of the fact that the lateral and front views appeared on different screens, the blind areas in the visual world as it appears in our rig highly corresponded to the blind areas created by the doors' frames in real vehicles. Finally, in hazard 12, although the undertaking car is visible in both the left- and the rear-view mirrors, it disappears from view in the rear-view mirror as it accelerates but is still available for view on the left screen. This was also the case for the undertaking motorbike clip (clip 11).

In sum, while the difference between the single- and three-screen conditions does not appear to reflect only lateral hazards, lateral information seems to have contributed substantially to the improved HP performance in the three-screen condition. It should be noted however that the differences between the single and three-screen conditions are not due to hazard-relevant information appearing in the side screens *prior* to it appearing on the central screen (the data of the only clip which had such *prior* information were excluded). Thus, any differences between the single and three-screen conditions are either due to: (1) a greater amount of hazard-relevant information (i.e., for those clips where hazard information in the lateral screens is presented in addition to information in the central screen) being available only to participants in the three-screen condition, as the greater visual evidence for an impending hazard must surely provide participants with a better situation awareness (e.g., Endsley, 1995; Borowsky et al., 2009) increasing the chance of spotting it, or (2) one or more than one of the possible reasons why a wider field of view may lead to improved hazard detection, as discussed in Section 1. Briefly, it was suggested that improved HP with a wide visual field may reflect (a) wider scanning of the visual scene, and a higher sampling rate with shorter fixations, (b) a more immersive experience (Allen et al., 2005), which may induce a more realistic search pattern, directing participants to the most relevant sources of information, and (c) either lower criterion thresholds for identifying hazards or increased sensitivity in detecting them, due higher levels of arousal and general alertness that the additional screens could induce. These explanations, which suggest that the wider field of view (in this study, the three-screen condition) may affect hazard detection independently of the hazard location and of the availability of additional hazard-relevant information, receive some support from the main effect of screens and from the fact that most of the hazards had no hazard-relevant information in the side screens. In spite of this, it is possible that even where no hazard-relevant information whatsoever was available in the lateral screens, participants in the three-screen condition perceived higher speeds compared to participants in the single-screen condition (e.g., Alfano and Michel, 1990; Jamson, 2000; Pretto et al., 2009; Toet et al., 2007), resulting in higher levels of subjective risk perception in the same scenarios amongst participants in the three-screen condition. It is actually quite difficult to evaluate the extent to which the latter explanation could account for the group differences in this study. Specifically, distortions in speed perception (typically decrements in speed estimations as a negative function of the size of visual field; Toet et al., 2007) appear to be restricted to (or at least more likely to occur in) relatively narrow visual angles (lower than 60°; Alfano and Michel, 1990; Pretto et al., 2009). In this study however, while the horizontal visual angle of the central screen was approximately 42° wide (hence, a visual angle of less than 60° for the single-screen condition), and this extended to 112° when the side screens were included, the actual view of the forward cameras on the film car was however closer to 180°, with the central 90° within these 180° displayed on the central screen (hence, a visual angle greater than 60° for the single-screen condition).

Finally, the second main effect of hazard location most likely reflects the typical distribution of attention in driving scenes. Drivers tend to look predominantly at the road ahead and then distribute their attention along the horizon (e.g., Chapman and Underwood, 1998; Crundall et al., 2006). Thus central hazards receive faster response times than peripheral hazards, presumably because the majority of attention is devoted to this location. Peripheral hazards also receive more attention than lateral hazards, again because attention is less likely to be given to locations that are so eccentric from the line of travel. However one should bear in mind that the lateral hazards were initially placed behind the film car as there are very few situations that can be manufactured where a hazard appears in front of the film car yet outside the central screen. While all hazard onsets were chosen from when the other road user began to engage in a hazardous behaviour, this may still have less personal relevance to the participant until the other vehicle has reached a point at which it will intersect with the film car's trajectory. As all lateral hazards appear behind the film car in the first instance, this may have the effect of inflating response times compared to peripheral and central hazards.

In conclusion the results suggest that the provision of a wider field of view can have an impact upon the responses (accuracy and times) of participants to hazards. Although this effect which appears across the hazards as a whole suggests that even responses to central hazards may be under-estimated in a typical single-screen hazard perception test, the better hazard perception performance in the three-screen condition in this study was at least mediated by more environmental cues that were related to the relevant hazardous situation, providing them with better situation awareness (e.g., Endsley, 1995; Borowsky et al., 2009). This study mainly indicates that due to the absence of the side views and mirror information in these typical HP tests (which in real driving often provide information which can be critical to preventing accidents), those tests underestimate drivers' HP skill. Although it is not unlikely that different scanning patterns, higher perceived speeds, or greater alertness, in the three-screen condition contributed to this effect (the absence of significant differences between the single-screen and three-screen conditions in the number of button presses suggests that there were no different response criteria for the two groups, implying that any arousal effect would be mediated by sensitivity rather than by response bias), the current data do not allow us to draw direct conclusions about participants' arousal, speed perception or eye movements. While this line of research is at an early stage, there are many insights to be gained from this methodology, especially with the inclusion of eye tracking technology. In addition, we were able to create some hazard perception clips that could not be realised in a typical single-screen test. Using three screens and mirror information opens up new opportunities for testing hazard perception skills in a potentially more immersive and realistic environment.

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References

Adams-Guppy, J.R., Guppy, A., 1995. Speeding in relation to perceptions of risk, utility and driving style by British company car drivers. Ergonomics 38 (12), 2525–2535.

Alfano, P.L., Michel, G.F., 1990. Restricting the field of view: perceptual and performance effects. Perceptual and Motor Skills 70, 35–45.

Allen, W.R., Cook, M.L., Park, G.D., 2005. Novice driver performance improvement with simulator training. In: Dorn, L. (Ed.), Driver Behaviour and Training, vol. 2. Ashgate Publishing, Aldershot, UK.

Alm, H., Nilsson, L., 1994. Changes in driver behaviour as a function of handsfree mobile phones—a simulator study. Accident Analysis and Prevention 26 (4), 441–451.

Brown, I.D., 2002. A review of the 'look but failed to see' accident causation factor. In: Behavioural Research in Road Safety XI. Department of Transport, Local Government and the Regions, London, UK.

Brown, I.D., Groeger, J.A., 1988. Risk perception and decision taking during the transition between novice and experienced driver status. Ergonomics 31, 585–597.

Borowsky, A., Oron-Gilad, T., Parmet, Y., 2009. Age and skill differences in classifying hazardous traffic scenes. Transportation Research Part F: Traffic Psychology and Behaviour 12, 277–287.

Chapman, P.R., Underwood, G., 1998. Visual search of driving situations: danger and experience. Perception 27, 951–964.

Consiglio, W., Driscoll, P., Witte, M., Berg, W.P., 2003. Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. Accident Analysis and Prevention 35 (4), 495–500.

Crundall, D.E., Underwood, G., 1998. Effects of experience and processing demands on visual information acquisition in drivers. Ergonomics 41 (4), 448–458.

Crundall, D., Underwood, G., Chapman, P., 1999. Driving experience and the functional field of view. Perception 28 (9), 1075–1087.

Crundall, D., Underwood, G., Chapman, P., 2002. Attending to the peripheral world while driving. Applied Cognitive Psychology 16 (4), 459–475.

Crundall, D., Van Loon, E., Underwood, G., 2006. Attraction and distraction of attention with roadside advertisements. Accident Analysis and Prevention 38, 671–677.

Deery, H.A., 1999. Hazard and risk perception among young novice drivers. Journal of Safety Research 30 (4), 225–236.

DeJoy, D.M., 1989. The optimism bias and traffic accident risk perception. Accident Analysis and Prevention 21 (4), 333–340.

Elander, J., West, R., French, D., 1993. Behavioral correlates of individual differences in road-traffic crash risk: an examination of methods and findings. Psychological Bulletin 113, 279–294.

Endsley, 1995. Toward a theory of situation awareness in dynamic systems. Human Factors 37, 62–64.

Findlay, J.M., Walker, R., 1999. A model of saccade generation based on parallel processing and competitive inhibition. Behavioral and Brain Sciences 22, 661–721.

Finn, P., Bragg, B.W.E., 1986. Perception of risk of an accident by young and older drivers. Accident Analysis and Prevention 18, 289–298.

Gregersen, N.P., 1996. Young drivers' overestimation of their own skill—an experiment on the relation between training strategy and skill. Accident Analysis and Prevention 28, 243–250.

Groeger, J.A., 2000. Understanding Driving: Applying Cognitive Psychology to a Complex Everyday Task. Psychology Press, Hove, UK.

Groeger, J.A., Field, D.T., Hammond, S., 1998. What hazard perception also measures. In: Paper Presented at the International Association of Applied Psychology, San Fransisco.

Harre, N., 2000. Risk evaluation, driving, and adolescents: a typology. Developmental Review 20, 206–226.

Horswill, M.S., McKenna, F.P., 2004. Drivers' hazard perception ability: situation awareness on the road. In: Banbury, S., Tremblay, S. (Eds.), A Cognitive Approach to Situation Awareness. Ashgate, Aldershot, United Kingdom, pp. 155–175.

Jackson, L., Chapman, P., Crundall, D., 2008. What happens next? Predicting other road users' behaviour as a function of driving experience and processing time. Ergonomics 20, 1–16.

Jamson, H., 2000. Driving simulation validity: issues of field of view and resolution. In: Proc. Driving Simul. Conf. DSC 2000, Paris, France.

Jessor, R., 1987. Risky driving and adolescent problem behavior: an extension of problem behavior theory. Alcohol, Drugs and Driving 3 (3–4), 1–11.

Lewin, I., 1982. Driver training: a perceptual-motor skill approach. Ergonomics 25, 917–924.

Matthews, M.L., Moran, A.R., 1986. Age differences in male drivers perception of accident risk: the role of perceived driving ability. Accident Analysis and Prevention 18 (4), 299–313.

McGowan, A.M., Banbury, S., 2004. Evaluating interruption-based techniques using embedded measures of driver anticipation. In: Banbury, S., Tremblay, S. (Eds.), A Cognitive Approach to Situation Awareness: Theory and Application. Ashgate, Aldershot, UK.

McKenna, F.P., Crick, J.L., 1991. Hazard Perception in Drivers: A Methodology for Testing and Training, Final Report. Transport Research Laboratory, Crowthorne, United Kingdom.

McKenna, F.P., Crick, J.L., 1994. Hazard Perception in Drivers: A Methodology for Testing and Training (TRL Report 313). Transport Research Laboratory, Crowthorne, United Kingdom.

McKenna, F.P., Horswill, M.S., Alexander, J.L., 2006. Does anticipation training affect drivers' risk taking? Journal of Experimental Psychology: Applied 12 (1), 1–10.

McKnight, A.J., McKnight, A.S., 1993. The effect of cellular phone use upon driver attention. Accident Analysis and Prevention 25 (3), 259–265.

Miura, T., 1990. Active function of eye-movement and useful field of view in a realistic setting. In: Groner, R., d'Ydewalle, G., Parham, R. (Eds.), From Eye to Mind. Information Acquisition in Perception, Search, and Reading. North-Holland, Amsterdam, pp. 119–127.

Patten, C.J.D., Kircher, A., O¨ Stlund, J., Nilsson, L., 2004. Using mobile telephones: cognitive workload and attention resource allocation. Accident Analysis and Prevention 36 (3), 341–350.

Pretto, P., Ogier, M., Bulthoff, H.H., Bresciani, J.-P., 2009. Influence of the size of the field of view on motion perception. Computers & Graphics 33, 139–146.

Recarte, M.A., Nunes, L.M., 2000. Effects of verbal and spatial imagery task on eye fixations while driving. Journal of Experimental Psychology: Applied 6, 31–43.

Recarte, M.A., Nunes, L.M., 2003. Mental workload while driving: effects on visual search, discrimination and decision making. Journal of Experimental Psychology: Applied 9 (2), 119–137.

Rosenbloom, T., Shahar, A., Elharar, A., Danino, O., 2008. Risk perception of driving as a function of advanced training aimed at recognizing and handling risks in demanding driving situations. Accident Analysis and Prevention 40, 697–703.

Sagberg, F., Bjørnskau, T., 2006. Hazard perception and driving experience among novice drivers. Accident Analysis and Prevention 38 (2), 407–414.

Sexton, B., 2000. Development of hazard perception testing. http://www.dft.gov.uk (accessed 29.06.06).

Strayer, D.L., Drews, F.A., 2004. Profiles in driver distraction: effects of cell phone conversations on younger and older drivers. Human Factors 46 (4), 640–649.

Toet, A., Jansen, S.E., Delleman, N.J., 2007. Effects of field-of-view restrictions on speed and accuracy of manoeuvring. Perceptual and Motor Skills 105, 1245–1256.

Wallis, T.S.A., Horswill, M.S., 2007. Using fuzzy signal detection theory to determine why experienced and trained drivers respond faster than novices in a hazard perception test. Accident Analysis and Prevention 39, 1177–1185.

West, R., French, D., Kemp, R., Elander, J., 1993. Direct observation of driving, self reports of driver behaviour, and accident involvement. Ergonomics 36, 557–567.