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Attending to the Peripheral World While Driving

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SUMMARY

Do inexperienced drivers see less of the world when driving? Previous research suggests that participants detect fewer peripheral targets while watching video clips of dynamic hazardous driving scenes due to increases in foveal demand (i.e. the presence of a hazard), increases in peripheral target eccentricity, and the lack of driving experience. The current study aimed to further explore the role of experience as a key factor in the potential narrowing of spatial attention, and the possibility of differences in the time course of attentional deployment. It was predicted that the amount of narrowing due to central processing demands would change as a function of driving experience, with more experienced drivers suffering less narrowing due to their mastery of central processing demands in road scenes. The data did not support the narrowing hypothesis, though they did support the alternative strategic difference between the driver groups in the time-course of attentional deployment. Learners seem to suffer attentional degradation in extra-foveal regions over a longer period of time whereas experienced drivers seem to invest peripheral attention at the hazard location in short but intense bursts. Copyright © 2002 John Wiley & Sons, Ltd.

INTRODUCTION

Since the 1970s, researchers have been probing the use of peripheral vision during driving tasks (Mourant and Rockwell, 1972; Lee and Triggs, 1976; Hughes and Cole, 1986; Ball *et al.*, 1988; Land and Horwood, 1995; Crundall *et al.*, 1999; Janelle *et al.*, 1999). Its relevance to driving has been noted in several sub-tasks such as lane-maintenance (Land and Horwood, 1995; Summala *et al.*, 1996) and hazard detection (Chapman and Underwood, 1998; Crundall *et al.*, 1999) though the application of theoretical models to this applied topic has largely been ignored. The experiment reported here is an attempt to distinguish between two rudimentary conceptions of attention that have been previously applied to real-world tasks, in an effort to describe differences that have previously been found in visual search patterns according to the participants' level of driving experience.

THE IMPORTANCE OF EXPERIENCE IN SAFE DRIVING

It is a well-documented fact that young drivers are over-represented in driving accident statistics (Maycock *et al.*, 1991; Cooper *et al.*, 1995). Though many factors are associated with this accident peak, such as social deviance (Elander *et al.*, 1993), smoking, drinking, and

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lack of sleep (Bierness and Simpson, 1991), and even car preference (Rolls *et al.*, 1991), the experiential factor remains an important underlying cause when many other factors are partialled out (Gregersen and Bjurulf, 1996). In an effort to reduce accident liability, many researchers have attempted to identify the changes that occur in drivers as experience increases. One considerable area of this research is concerned with visual information acquisition during driving. Several researchers have noted substantial differences between driver groups of varying experience in their eye movements while performing laboratory-based driving tasks, or actually out on the road (e.g. Mourant and Rockwell, 1972; Crundall and Underwood, 1998; Chapman and Underwood, 1998). For instance, Crundall and Underwood (1998) found experienced drivers to produce more varied horizontal scanning on a dual carriageway when compared to drivers who had just passed the driving test. Noting differences between such driver groups is, however, quite different from understanding why they occur. Do experienced drivers simply know where to look? Or does experience in the driving domain free up limited reserves of attention and allow experienced drivers to scan further (cf. Crundall *et al.*, 1998)? The basic decision between these two alternatives has important implications for whether or not it is safe to teach inexperienced drivers to emulate the search patterns of their more experienced counterparts (cf. Zwahlen, 1993). If it is the case that knowledge of where to look is the most important gain of experience, then eye movement training may possibly reduce accident liability if consistent patterns can be generalized across situations. If, however, the wider scanning of the experienced drivers simply occurs because they have more attention to devote to stimuli other than those immediately in front of the car, then teaching inexperienced drivers to use search strategies for which they do not have the attentional capacity may actually increase accident liability.

In an attempt to identify the underlying reasons for experiential differences in visual search during driving, Crundall *et al.* (1999) conducted an experiment to test the hypothesis that experience in the task domain releases attentional resources from the point of fixation. The study required participants to watch a series of dynamic driving scenes often termed hazard-perception video clips. These clips are filmed from the driver's perspective as if driving along a number of different road types. In every clip there was at least one particular hazard (such as the car in front suddenly braking). The primary task required participants to rate the clips according to the amount of danger and difficulty they perceived. A secondary task required the participants to press a mouse button whenever they saw a peripheral target light. It was found that experienced drivers spotted more peripheral target lights than non-drivers, with the performance of a group of novice drivers falling midway between the other two groups. The implications of this study were that driving experience had created an improvement in peripheral target detection though it was unclear whether this was a gradual improvement in the deployment of extra-foveal attention with increasing experience, or a sudden change that occurs as soon as one crosses the boundary from non-driver to driver. There were also further confusions as to the nature of the model that should be applied to explain the attentional degradation. The current experiment aimed to further illuminate the experiential influences on attention and to isolate which of two models best fit the data. The models of attention are discussed in the following section.

SPATIAL THEORIES OF ATTENTION

Since the advent of the initial spotlight theory (Eriksen and Eriksen, 1974), the ubiquitous 'beam of attention' has existed in several guises. One popular modification to the basic theory allows the previously fixed-width spotlight to vary in diameter according to the amount of attention one wishes to invest at any particular locus (e.g. Eriksen and Yeh, 1985; Eriksen and Murphy, 1987). This is often called the zoom lens theory of attention. Several other variants have been suggested in the previous decade, such as the 'theatre' of multiple spotlights (Sperling and Weichselgartner, 1995), or the concerns over the seeming ability to split focal attention into two separate spotlights (Casteillo and Umiltà, 1992; though see McCormick *et al.*'s, 1998, rebuttal). The greatest problem for spotlight theories of attention has come from the 'object-based attention' hypothesis. This suggests that we do not attend to an area of space; instead we attend to objects. Since the initial suggestion of object-based attention (Kahneman and Henik, 1981), a growing number of studies have demonstrated perceptual grouping on the basis of factors other than proximity (e.g. Driver and Bayliss, 1989; Bayliss and Driver, 1992) and have argued against attending to a contiguous area of space. However, recent research has suggested that object-based attention only works within a spatial spotlight (Lavie and Driver, 1996), and when this spotlight contracts (in response to a peripheral cue) object effects are removed as the objects then fall outside the beam.

The zoom lens analogy is the most relevant to the driving studies, as the majority of researchers in this field refer to the narrowing of attention, implying that the field of view of attention contracts according to processing demands at the point of fixation (Williams, 1982, 1985, 1988; Miura, 1990). Many researchers in related fields freely discuss the narrowing effects upon attention that occur under increased levels of demand or anxiety (e.g. Christianson, 1992; Hammond, 2000), even though recent evidence for an actual shrinkage of spatial visual attention is tenuous at the very least (e.g. Cnossen *et al.*, in press; Janelle *et al.*, 1999). The findings of the last two decades have produced an equal if not greater number of results pointing to a model of degradation that has previously been termed 'general interference' (e.g. Holmes *et al.*, 1977; Crundall *et al.*, 1999). This is represented by a general degradation that occurs equally for all extra-foveal stimuli regardless of their eccentricity from the point of fixation. The alternative model of a shrinking functional field of view, often termed 'tunnel vision' in applied contexts, if it exists at all, seems only to be produced under particular and stringent conditions. Williams (1988) stated that participants needed to be placed under three conditions in order to induce tunnel vision—a highly demanding foveal task, which increases the amount of processing required at the point of fixation; instructions to focus primarily on the central task rather than a peripheral task (despite the peripheral performance being the measure of prime interest); and speed stress on the primary task. One of the primary motivations for the current study was to provide the best conditions under which tunnel vision should occur, in order to test the validity of the assumption in driving research that attention narrows with increased foveal demand.

DEMAND-INDUCED DEGRADATION OF EXTRA-FOVEAL ATTENTION

Several previous studies have been concerned with the effects of demand upon extra-foveal, or peripheral attention during the driving task. Miura's research (e.g. 1990) stands out as the most comprehensive, leading him to conclude that various cognitively demanding aspects of driving lead to a narrowing of spatial attention (though see Crundall *et al.*, 1998). Other researchers however have questioned the appropriateness of using the term tunnel vision to describe the actual effect upon extra-foveal attention (e.g. Lee and

Triggs, 1976). More recently Janelle *et al.* (1999) assessed the effect of increased task demands upon peripheral target detection while playing a racing video game. They noted that in competitive racing (compared to the less stressful driving conditions) peripheral target detection decreased. They report this effect as evidence for attentional narrowing, though without controlling for peripheral target eccentricity the data are uninformative as to which model of degradation can be applied (tunnel vision or general interference).

The study by Crundall *et al.* (1999) perhaps came the closest to identifying which of the two models of degradation could be applied within the driving context. This study looked for differences between experienced, novice and non-drivers in their deployment of extra-foveal attention. It was predicted that as experience increased, this would release attentional resources from the point of fixation and increase the number of peripheral targets detected. A further prediction suggested that experienced drivers would be less susceptible to the increase in foveal demand that occurred when a hazardous event took place in the video clips shown to participants. It was possible that the different driver groups would even employ different models of degradation, with the experienced drivers suffering according to the predictions of general interference, while less experienced drivers endured the pattern of degradation indicative of tunnel vision. The results of this experiment showed however that though experienced drivers had a higher peripheral target hit rate than non-drivers, there were no interactions between demand and eccentricity (indicative of tunnel vision) or between demand and experience (suggesting that all participants were equally affected by the appearance of the hazard).

One problem with the design used by Crundall *et al.* (1999) was that it did not meet Williams' three criteria for tunnel vision. The design did have stimuli that increased in demand (the appearance of the hazards, noted by the inhibitive main effect of demand upon peripheral target hit rates) and participants were instructed to focus on the primary rather than the secondary task (the primary task required participants to form two separate judgements on each clip as to how dangerous they thought it was, and how difficult they thought they would find that route to drive), but there was no speed stress on the primary task (that is, there was no requirement upon the participants to make a speeded response). Participants gave the two ratings for each clip immediately after they had watched them. The primary task was therefore a passive accumulation of information that did not need a timed response that would otherwise required the participants to maintain a constant high level of vigilance.

The current study uses hazard detection as the primary task. These are foot-pedal responses, recorded in milliseconds, to the appearance of a hazard at particular points during the clip. This considerable improvement over the earlier methodology provides a number of benefits. The hazard-perception requirement places the participants in a more realistic driving situation in regard to the input of visual information. Rather than the simple accumulation of information as with the previous ratings task, the participant is engaged in active monitoring of the environment for potential threats to progress. This limits the areas of the screen that the participants would search to those parts that are relevant to hazard perception, and therefore more likely to represent the areas of the visual world that people would view when actually driving. In addition, as participants are told that the aim of the experiment is to record how fast they can respond to these hazards, it places them under the ideal conditions for revealing a pattern of tunnel vision degradation.

The second advantage of this primary task is that the hazard-perception response provides a precise indicator of when the participant believes the demands of the scene have suddenly increased. This allows extra-foveal performance to be judged against the individual participants' recognition of an increase in demand by looking at the distribution of hit rates around a typical hazard-perception response. With these data one can ask at what point does extra-foveal attention begin to degrade in the presence of a hazard. More interestingly, one can also ask whether the time-course of attentional degradation during the appearance of the hazard is similar for drivers of varying experience. This is a more subtle measure than aggregating the amount of degradation suffered over a hazard window and may reveal hitherto unrecorded experiential differences in the deployment of attention.

To summarize, the predictions of the experiment were that specific increases in foveal demand would reduce peripheral attention for target lights, producing an interaction between peripheral target eccentricity and demand indicative of tunnel vision. Furthermore the effects of increased foveal demand would vary according to the participants' level of driving experience, with more experienced drivers suffering less degradation.

METHOD

Participants

Forty participants were recruited to take part in the study. Twenty experienced drivers (13 females and 7 males, with a mean age of 22 years, 9 months, and a mean experience since passing the driving test of 56 months), and 20 learner drivers (15 females and 5 males, with a mean age of 20 years and 7 months, who had taken 13.6 one hour lessons and had an average of 30 hours supervised driving in total) were paid to take part. All the participants had normal vision. Experienced drivers were recruited through advertisements while the learner drivers were recruited through a number of sources including driving schools and through announcements on local radio. All participants were naïve to the stimuli and hypotheses.

Materials and apparatus

Participants were presented with 39 MPEG hazard-perception clips randomly presented within four counterbalanced blocks. Participants were allowed to rest between blocks. These were the same clips as used by Crundall *et al.* (1999), which presented the participants with a view from the driver's perspective moving through various road types such as rural roads and suburban/shopping streets. The clips lasted an average of 43 seconds (ranging 18 to 70 seconds in length), and featured at least one potentially hazardous event (with a maximum of four in one clip), such as the sudden braking of a car in front, or the sudden emergence of a cyclist from a side street. Though all clips contained at least one hazard, the varied clip lengths did not allow easy temporal prediction of potential hazards without attending to the stimuli. Participants were unaware of the number of hazards in each video clip.

The clips were presented on a video monitor that subtended 15.4° by 11.6° at a distance of 1 metre. This represents a compression to approximately 50% of the angle the images would have subtended in actual driving. The clips were played through a P90 PC interfaced with a SRI Dual Purkinje Generation 5.5 eye-tracker, produced by Fourward Technologies, to measure the participants' eye movements.

The primary task required participants to respond as quickly as possible to any hazards that appeared. A foot-pedal produced a millisecond accurate response time when depressed and an auditory tone as feedback. The secondary task required participants to

Figure 1. A still from a hazard perception clip with the four target placeholders

respond to peripheral target lights by clicking the PC mouse button. Peripheral targets appeared within one of four computer-generated, red place holders that were overlaid on the video screen, each one half-way along one of the four sides of the video display. The placeholders each subtended 0.7°. The left and right placeholders were 6.8° from the centre of the screen, while the top and bottom place holders were 4.4° from the centre. The peripheral targets were simple white squares, subtending 0.3 degrees, which appeared in the centre of the placeholders and lasted for 200 ms. The screen layout is presented in Figure 1.

One target light appeared in each full 5-second segment of a clip in a randomly chosen target placeholder. Within these 5-second windows, the target could appear at any point in time, providing that the onset was not within 1500 ms of another target. In total, 297 peripheral targets were presented to each participant across the 39 clips.

Design

The three factors involved in this mixed design were level of experience (experienced drivers versus learner drivers), level of processing demand ('high' versus 'low') and the onset eccentricity of each target (less than 5°, 5° to 5.9°, 6° to 6.9°, and 7° and above). The level of demand was calculated on the basis of an earlier study that required participants to view the hazard perception clips and press a button to record any potential hazards that they noted (Underwood *et al.*, 1997). All the clips were subsequently divided into 5-second segments and were termed either high or low demand on the basis of the mean number of hazard responses each five-second window elicited from participants. The measure of onset eccentricity recorded the distance from the point of fixation to the peripheral target at the time of onset. A peripheral target was considered to be *successfully* *presented* if the computer had recorded an onset eccentricity at the time of target onset. Peripheral targets without onset eccentricities were excluded from the calculation of hit rates (the percentage of peripheral targets correctly identified) and response times for the main analyses. Such *unsuccessfully presented* targets could occur due to calibration problems or the participant blinking during target onset. The average number of *successfully presented* targets per participant is subsequently reported with the relevant analyses. In addition to these measures, the average length of the participants' fixations (mean fixation durations) and the spread of search in the horizontal and vertical meridians (the variance of the fixation locations) were also calculated.

Procedure

At the start of the experiment participants were informed of the two tasks they were to perform. The instructions concerning the primary task required participants to search the scene as if they were the driver, while being vigilant for any potentially hazardous or dangerous events that might occur. Hazards were defined as anything that would prompt them to consider evasive action such as braking or steering to avoid a collision. As soon as they spotted something potentially or actually hazardous participants had to press a foot-pedal as quickly as possible.

In regard to the secondary task the participants were informed that white target lights would be briefly presented in the centre of the placeholder boxes. They were instructed to press a mouse button as soon as they saw one of these peripheral targets, though emphasis was placed on maintaining a normal search of the driving scene for hazardous events. Participants were explicitly told not to fixate the placeholders in an anticipatory fashion, as this would reduce their performance on the both the primary and secondary tasks.

RESULTS

The results will be presented in five subsections. The first addresses the main hypothesis of whether peripheral target detection rates are decreased according to the three factors of experience, demand and eccentricity. The second subsection investigates the time line of degradation before and after the hazard responses made by the participants via the foot-pedal. The third seeks to corroborate the first, through the analysis of reaction times to those targets that were correctly identified, while the fourth reports measures of the general search strategy. A fifth subsection reports the results of the primary, hazard perception task.

The data from four participants were removed from the following analyses. Two of these data sets (one experienced driver and one learner) were removed due to too few observations per cell. The other two sets of means were removed (again one experienced driver and one novice) as outliers with the overall hit rate means exceeding two standard deviations from the group means. Whenever sphericity was threatened the results of the analyses were modified using the Greenhaus-Geisser epsilon. Such modifications did not affect the acceptance of rejection of any null hypotheses. None of the analyses required modification due to heterogeneity of variance.

Peripheral target hit rates

The mean number of false alarms was very low, averaging five false reports for every 185 successfully presented targets (2.7%). The chance of any random mouse-button response occurring during the peripheral target period and being counted as an actual response to a peripheral target was 30% (with a response window of 1500 ms in every 5000 ms segment of video clip). As only 2.7% of the overall responses fell in the 70% of test time that was outside the 1500 ms target windows it is safe to conclude that the hit rates are not confounded by random button pressing. The hit rates were calculated from the number of successfully presented targets, that is, for those targets for which the computer recorded an eye location. A mixed design analysis of variance of the percentage hit rates of participants across the three factors produced three main effects and no interactions. The two main effects that are directly relevant to the hypothesis of a narrowing of attention are the level of demand ($F(1, 34) = 87.5, p < 0.01$) and onset eccentricity ($F(3, 102) = 30.5, p < 0.01$). High-demand video clip segments resulted in less peripheral targets detected than during low demand segments. Mean comparisons revealed that the differences within the levels of the eccentricity factor were primarily due to the large decrease in target detection beyond seven degrees. All levels of eccentricity differed significantly from the $7° +$ level ($p < 0.01$), though in addition a difference was found between the $< 5°$ level and the 6–6.9° level ($p < 0.05$). These two main effects provide further support for the hypothesis of reduced attention in the peripheral field with corresponding increases in both the level of demand and eccentricity. The addition of a speeded task in this experiment failed to produce the predicted interaction between demand and eccentricity ($F(3, 102) < 1$), thus the model of tunnel vision cannot be accepted. The means for the two effects can be viewed in Figure 2.

The mean eccentricity (beyond 7°) for targets that were spotted and those that were missed was calculated separately for experienced and learner drivers. A mixed ANOVA on these data revealed that the mean eccentricity of those targets that were detected was significantly nearer to the point of fixation than the mean eccentricity of those targets that were missed ($F(1, 34) = 15.1, p < 0.01$). The mean eccentricity of targets greater than 7° from fixation was 8.6° if they were spotted, and 9.1° if they were missed. These figures are consistent with the equivalent means found in the 1999 study reported by Crundall *et al.* (8.3° and 9.1° respectively).

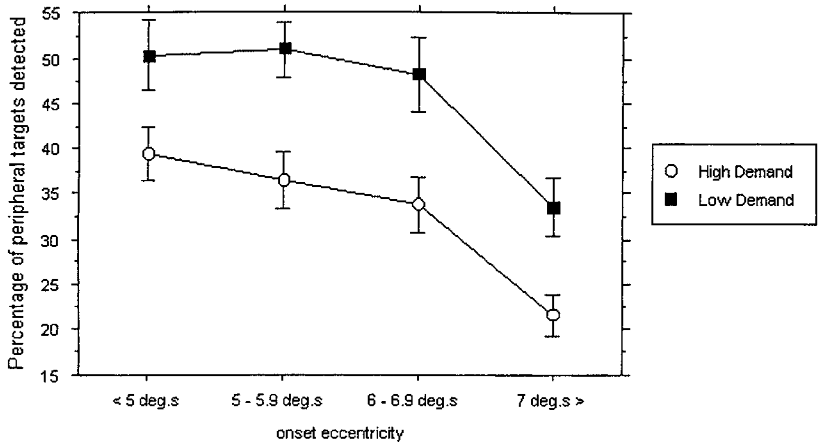

Figure 2. The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) across the factors of demand and onset eccentricity, with standard error bars added. The average number of targets per participant at each level of eccentricity was 44, 39, 41, and 66 respectively

Table 1. Percentage hit rates for learner and experienced drivers across demand and eccentricity (with standard deviations)

	Hit rates (%)							
	High demand				Low demand			
Eccentricity:	< 5°	5°	6°	7°+	< 5°	5°	6°	7°+
Experienced drivers	47 (15)	42 (19)	40 (21)	26 (14)	57 (22)	54 (15)	54 (24)	38 (19)
Learner drivers	32 (15)	29 (19)	27 (16)	16 (13)	44 (23)	47 (22)	41 (24)	27 (19)

A surprising result was attributed to the experience factor. In a comparison of target eccentricities, experienced drivers' average eccentricity for a target presentation over 7° was found to be further from the point of fixation than for the learner drivers ($F(1, 34) = 7.0, p < 0.05$). This was a surprising result as there should not be a systematic difference between the target eccentricities of the two groups. The solution to this problem was provided by subsequent analyses (see the subsection entitled 'Measures of the general search strategy').

The third main effect of experience ($F(1, 34) = 5.3$, $p < 0.05$) reflected the learner drivers' poorer performance at detecting the target lights. As this factor did not interact with any of the other factors, it seems that inexperience degrades performance equally under varying levels of foveal load and eccentricity. The mean hit rates across all three factors are presented in Table 1.

The time-course of attentional degradation around the hazard response

One strength of this experimental design is that the inclusion of hazard-detection responses as a primary task allows more precision in assessing the timing of any degradation effect. The analyses reported so far have concentrated upon the use of five-second windows of high or low demand. However, the current data have also produced a precise indicator of whenever each participant believed that the demands of the clip exceeded the threshold for reporting a hazard with a foot-pedal response. On this basis it was decided to look at the distribution of hit rates around these hazard-perception responses. The simplest form that such graphs could take would show a decrease in peripheral target responses around the time of the hazard response. For this frequency distribution the percentage of peripheral targets correctly identified was calculated for 500 ms bins around the hazard response. Data from all learner drivers (an average of 128 target presentations per 500 ms), and separately for all experienced drivers (an average of 123 target presentations per 500 ms) were amalgamated into two separate frequency distributions for each group. This method of pooling data does not allow inferential statistics to be performed, though it was considered that the distributions themselves may provide some visual clues to the time course of attentional degradation in the peripheral visual field. The initial distribution can be seen in Figure 3(a).

From the distribution in Figure 3(a) the experiential difference is extremely evident in terms of overall performance. There is also a noticeable decline in peripheral performance between -1500 and $+1500$ ms around the hazard response. This degradation is most

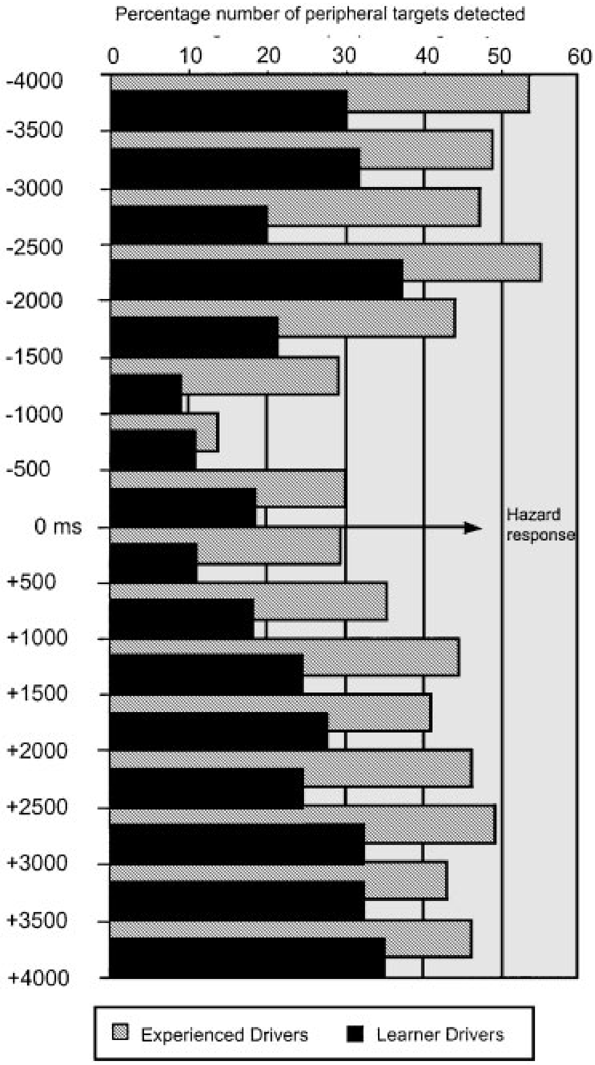

Figure 3(a). A frequency distribution of the percentage of targets that were spotted, split across 500 ms bins around the hazard response (at 0 ms) for both experienced and learner drivers

pronounced around the − 1500 to − 500 ms section of the distribution. The 3000 ms area around the hazard response was re-categorised across 200 ms bins to gain further detail on this interesting area of the distribution (Figure 3b). An average of 59 target presentations for the learners and 56 target presentations for the experienced drivers contributed to each 200 ms bin.

The second distribution shows that the hit rate for both groups sinks to a similar level at only one point, approximately 1000 ms before a response is made (− 1100 to − 900). This suggests that demand can degrade the deployment of extra-foveal attention to a comparable level in participants with different degrees of relevant experience. The influence of experience instead seems to affect the duration of the degradation. Experienced drivers

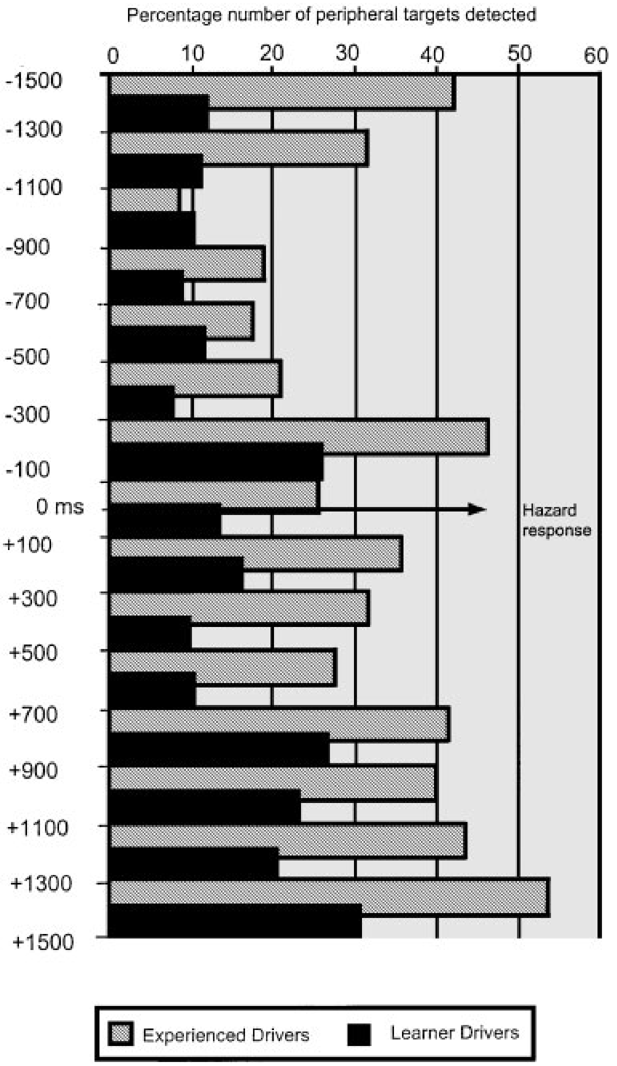

Figure 3(b). A frequency distribution of the percentage of targets that were spotted, split across 200 ms bins around the hazard response (at 0 ms) for both experienced and learner drivers

suffer considerable degradation over an 800 ms period (– 1100 to – 300) before and after which a hit rate of about 40% is maintained. Learner drivers however have consistently poor performance over a much wider time frame. At 1500 ms before a hazard response, peripheral target detection drops considerably to about 10%, and only picks up 700 ms after the hazard response.

Peripheral target reaction times

Of the 288 cells that contributed to this design (36 participants × 2 levels of demand × 4 levels of eccentricity), seven of them (2.4%) were replaced by the average of the row and column means due to insufficient numbers of observations per cell.

Table 2. Response times to peripheral targets (with standard deviations)

	Response times (ms)							
	High demand				Low demand			
Eccentricity:	< 5°	5°	6°	7°+	< 5°	5°	6°	7°+
Experienced drivers	674 (100)	663 (119)	659 (96)	661 (59)	598 (91)	646 (131)	611 (105)	651 (97)
Learner drivers	723 (147)	693 (153)	721 (130)	729 (117)	679 (134)	718 (190)	654 (123)	711 (161)

A mixed design analysis of variance was conducted on the reaction times to successfully presented targets that revealed both a main effect of demand ($F(1, 34) = 5.5, p < 0.05$) and a marginal effect of experience ($F(1, 34) = 4.0, p = 0.05$). All participants responded faster to peripheral targets presented during low demand windows, while experienced drivers were consistently faster than novices. The means of these data can be found in Table 2.

Measures of the general search strategy

The overall mean duration of fixations was calculated from the mean fixation duration (across all fixations) for each clip for each participant. Experienced drivers averaged 472 ms while learner drivers averaged 495 ms. The difference was not significant ($t(34) = 0.43$). Mean fixation location was also calculated for each participant group across each meridian though no experiential differences were found ($t(34) = 0.51$ for the horizontal meridian, $t(34) = 1.05$ for the vertical meridian) with both participant groups having a centre of gravity to their search patterns less than one degree from the centre of the screen.

In keeping with past research (e.g. Mourant and Rockwell, 1972), a marginal experiential difference was discovered in the analysis of the spread of search in the horizontal meridian ($t(34) = 1.95$, $p = 0.06$) with the experienced drivers producing a greater spread of search from left to right than the learner drivers. This may account for the surprising finding that peripheral targets presented to experienced drivers occurred at greater eccentricities than those presented to the learner drivers. If experienced drivers are searching more in the horizontal meridian this will increase the average eccentricity of a peripheral target occurring in one of the three placeholders from which the point of gaze is furthest. The variance of the fixation locations in the vertical meridian was also analysed though no differences were found ($t(34) = 0.19$).

Results of the hazard-perception test

A button-press, hazard-perception response was used in this experiment as the primary task. Participants had to make a foot pedal response when they thought a potentially hazardous event was occurring or about to occur. It has previously been reported that experienced drivers are faster at responding to hazards and will spot more of them (McKenna and Crick, 1994). In this study, however, simple response times to each hazard onset failed to differentiate between the groups ($t(34) = 1.11$). Similarly, no difference was noted between the learner and experienced drivers in regard to the number of hazards responded to ($t(34) = 0.13$).

DISCUSSION

The principal aim of the current experiment was to apply Williams' criteria in a task that was expected to evoke tunnel vision. However the two main effects of eccentricity and demand conform to the default general interference model. This experiment was unable to produce tunnel vision, though the results have however been illuminating concerning the nature of demand-modulated degradation of attention in the peripheral field. These insights will be discussed in the following subsections.

Peripheral target detection

The three main effects of the hit rate analysis support and extend the findings of Crundall *et al.* (1999). An increase in foveal demand tends to decrease extra-foveal attention, yet this does not vary with either experience or eccentricity. Despite the inclusion of a speeded response (primarily to meet Williams' three criteria and to thus create the conditions that should deliver an interaction between eccentricity and demand) evidence for a narrowing of attention remains elusive. The conceptualization of a spotlight contracting to increase attentional power at the point of gaze seems not to be appropriate in the current paradigm. Lee and Triggs (1976) questioned the term 'perceptual narrowing', often used to describe demand-modulated degradation of extra-foveal attention, as they found no evidence of a shrinkage in the spotlight of attention during driving. This experiment confirms their doubts, and adds to the evidence that argues against the easiest conceptualization of such attentional degradation. The few marginal results that have reported tunnel vision (Chan and Courtney, 1993; Williams, 1988) look increasingly to be task-specific at the very least.

The main effect of eccentricity, and the subsequent analysis of the target eccentricities in the 7°+ category (according to whether the peripheral target was detected or not), supports the noted drop-off in performance occurring around 8–9° reported by Crundall *et al.* (1999). In addition, however, the results revealed a gradual decline in ability over the nearer eccentricities, which was not found in the previous study. It seems that the inclusion of the speeded primary response has accentuated the effect of eccentricity.

The main effect of experience demonstrated that the process involved in improving the deployment of extra-foveal attention during a driving task is not a skill that is simply evoked the first time one sits behind the wheel of a car, but instead its development appears to be a gradual process. The learner drivers in this current study had not achieved a level of familiarity with the stimuli in the primary task such that they could devote as much attention to extra-foveal regions as the experienced drivers. The predicted interaction with demand did not occur, however. One might argue that an interaction with demand defined by the appearance of an accident-threatening hazard would not be expected, as the actual frequency of accidents for any individual in the real world is low, and therefore even experienced drivers may not have much experience with these type of stimuli. If this is the case then the appearance of a hazard should incur the same level of degradation in the extra-foveal regions across all participant groups, as the factor label of experience no longer applies. However, the actual hazard clips do not show accidents; they show stimuli that could precipitate an accident. In assessment of on-road accident liability, such events would be called near-accidents, and defined as incidents where the driver retrospectively considered there to be a possibility of an accident causing damage or injury. In a recent study on memory for near-accidents, Chapman and Underwood (2000) found that 43 participants reported 382 near-accidents across 3592 journeys (recorded on dictaphones after each journey). On this basis the number of experiences similar to the type of events portrayed in the clips will be considerably higher for any individual than the actual number of accidents they have had, and therefore the rise in exposure to such events with increasing driving experience should be more marked.

One further effect of experience was the finding that targets presented at over 7° eccentricity tended to be further away for experienced drivers than for the learners. This can be explained with regard to another experiential difference in the variance of the fixation locations across the horizontal meridian. It seems that the experienced drivers had a greater spread of search in the horizontal axis that could place the point of gaze further away from a target onset. If one looks toward the extreme left edge of the screen, then the placeholders at the top, right, and bottom of the screen will be further away than if the point of gaze remained in the centre. As there is a 75% chance that a target will appear in one of the three place holders that the point of gaze has moved away from, the onset eccentricities for peripheral targets will tend to be longer.

Benefits of a speeded response

The inclusion of a speeded response for the primary hazard-detection task did not produce tunnel vision. It did however make the peripheral target detection task considerably harder. A comparison of the experienced drivers in the current experiment with those in the Crundall *et al.* (1999) study produced a significant main effect of primary task (the task of clip rating verses hazard perception responses, $F(1, 36) = 20.1, p < 0.01$). The inclusion of the speeded response to the appearance of a hazard in the current study decreased peripheral target hit rates by such a magnitude that performance in the low demand windows of the current study are more akin to performance in the high demand windows of the previous study (Crundall *et al.*, 1999). As this main effect did not interact with demand it is safe to conclude that this decrease in secondary task performance was due to the anticipatory nature of the task rather than due to dual-task interference (which would predominantly occur in the high demand windows when participants were more likely to make a hazard response).

A further benefit of the foot-pedal response to the appearance of a hazard is that it allows greater accuracy in isolating the sudden increase in foveal demand. The results so far are based upon demand according to 5-second segments of clips, within which participants had tended to make a hazard response in an earlier study (Underwood *et al.*, 1997). The actual hazard onset may, however, occur at any time within the 5-second window. If a peripheral target light appears at the start of a high demand window but the hazard does not occur until the end of the window, then one could argue that the peripheral target was presented under relatively low demand conditions. A second problem lies with individual differences in the recognition of what is and what is not a hazard. The ability of the demand factor to decrease peripheral target detection in both the current study and that of Crundall *et al.* (1999) argues that this was not a serious problem when averaged across the participants. However, the use of the foot-pedal response as a signal for when an individual passed the hazard-recognition threshold does allow a fine-grained investigation of attentional degradation across a more sensitive time scale. This time scale hinges upon the self-report of a sudden increase in foveal demand. The resultant graphs display the effective time-course of attentional degradation for both experienced and learner drivers. Figure 3(b) shows that an increase in foveal demand can reduce the deployment of attention in both experienced and learner drivers to a similar level. At about 1100–900 ms before the participants' make a hazard response, both driver groups seem to have only around a 10% chance of detecting a peripheral target. This dip in performance probably reflects the increase in foveal demand due to the appearance of the hazard. The average response time to the appearance of a hazard is 1453 ms (averaged across both driver groups as there was no significant difference between them). This response time fits with the drop in peripheral target detection rates which occur between 1500–1300 ms before the hazard-detection response.

Despite this dramatic decrease in performance for experienced drivers (a larger decrease than that shown by the learners), they seem to recover almost immediately, doubling the peripheral task performance in the period 900–700 ms before the hazard response is made. The learner drivers' extra-foveal attention is degraded for a much longer period, however. Apart from a sudden peak in learner driver performance around 300–100 ms before the hazard response, their ability to detect peripheral targets degrades from 1500 ms before the hazard response, to 700 ms after it. From this graph it seems that the experienced drivers undergo a greater magnitude of degradation on the peripheral task than the learner drivers, though the effect is relatively short-lived. Learners, however, encounter a lesser magnitude of degradation over a longer period. The large decrease in the deployment of extra-foveal attention over such a short period may reflect the benefit of experience. It is possible that this is an implicit strategy developed by the experienced drivers that reduces the period of time in which they are effectively blind to stimuli in the peripheral field.

One initially puzzling aspect of the distributions is that the learner drivers seem to show the effects of degradation of attention before the experienced drivers do. In Figure 3(b), the learner drivers' peripheral performance sinks to a consistently low level 1500 ms before the hazard response, whereas the experienced drivers undergo a catastrophic decline in performance only 1100 ms before the hazard response. Does this mean that the learner drivers spot the hazards before the experienced drivers? If this were the case then this should have been (yet failed to be) reflected in a significant difference between the experienced and learner drivers' hazard-perception response times. However, if rapid changes in the direction and intensity of attention reflect a strategy of the experienced drivers, it is possible that, though they may notice the hazard at the same time as the learners, they defer investing attention until they are certain that such investment would be worthwhile. Such a strategy could be akin to Beck and Emery's (1985) suggestion of hypervigilance where an individual may become more aware of items in the peripheral field under anxiety-provoking conditions.

These issues raise further questions that cannot be answered from the current study, though the fact that such questions can now be asked reflects a step forward in both methodology and understanding of the underlying mechanisms that govern experiential effects on the degradation of extra-foveal attention in an applied setting such as driving.

CONCLUSIONS AND IMPLICATIONS

Hazardous and, therefore, demanding driving stimuli capture attention, redirecting resources away from extra-foveal regions to the point of fixation. The amount of extra-foveal degradation appears to be similar for both experienced and learner drivers, though overall peripheral performance does seem to improve with experience. The nature of the degradation reflects a diminishing of attention equally across all eccentricities, rather than the usual description of attentional narrowing employed by many authors without evidential support. Though experience does not moderate high demand, nor influence the appearance of tunnel vision, it does, however, seem to produce different time-courses of attentional deployment which are suggestive of different strategies in the close observation of hazards (though overall fixation durations did not differ between the driver groups).

These results have important implications for advocates of eye movement training in new drivers (cf. Zwahlen, 1993). Eye movements are generally accepted to be governed by attention (Underwood, 1985; Underwood and Everatt, 1992); abrupt onsets must fall within the functional field of view in order to elicit an exogenous saccade. Training eye movements without an understanding of the different attentional strategies employed at different levels of experience may well ask new drivers to perform visual searches that their attentional resources cannot cope with.

At the other extreme of the experience continuum these results raise several potential problems for high-risk driving behaviours conducted by expert drivers. For instance, police pursuit drivers will usually have the offender's vehicle within their line of sight, providing a constant source of foveal demand during the period of the chase. If general driving experience promotes a quick investment strategy in potential hazards, the question of how such experienced drivers attend to chronic, prolonged hazards remains. The current methodology will hopefully help to answer these questions in future research.

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