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Driving experience and the functional field of view

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Abstract. Research has suggested that novice drivers have different search strategies compared with their more experienced counterparts, and that this may contribute to their increased accident liability. One issue of concern is whether experienced drivers have a wider field of peripheral vision than less experienced drivers. This study attempted to distinguish between people of varying driving experience on the basis of their functional fields of view. Participants searched video clips taken from a moving driver's perspective for potential hazards while responding to peripheral target lights. Hit rates for peripheral targets decreased for all participant groups as processing demands increased (ie when hazards occurred) and as the eccentricity of the target increased, though there was no interaction. An effect of experience was also found which suggests that this paradigm measures a perceptual skill or strategy that develops with driving experience.

1 Introduction

Peripheral vision serves a number of functions during driving. Detection of abrupt onsets or contrast changes in the periphery serves to attract a saccade to the relevant stimulus. As the eccentricity of the stimulus increases, so does the possibility of the saccade requiring a head movement in order to reposition the point of fixation (Sanders 1970). If a hazard occurs while driving, one needs to first spot the stimulus and then process it before an appropriate response can be made. The usual procedure for spotting the onset of an abrupt peripheral hazard would involve the automatic capture of covert attention, which then guides the eyes to the salient stimulus.

Peripheral vision is also important in lane maintenance: the task of keeping a car or simulated vehicle between two peripheral markers (usually the road edges). Land and Horwood (1995) used a rudimentary simulator to demonstrate that the road edges close to the vehicle provide information that is vital to successful lane maintenance. They found that this information was perceived primarily through peripheral vision, as participants rarely fixated these important cues.

The primary limit on the usefulness of peripheral vision is visual acuity. The greater dispersion of receptors in the peripheral field produces a general falloff in acuity with greater eccentricity from the fovea. This is a hard-wired limit on peripheral performance.

There is evidence, however, for a more dynamic limit on peripheral performance, that of the functional field of view (henceforth FFoV). This has been given a number of similar definitions under slightly different names. Mackworth (1965) defined the FFoV as "the area around the fixation point from which information is briefly stored and read out during a visual task" (page 67). Ball et al (1988) define the useful field of view as "the total visual field area in which useful information can be acquired without eye or head movements (ie within one eye fixation)" (page 2210). With regard to the first example of hazard detection via peripheral vision, the FFoV can be described as the area of the visual field within which a target (or hazard) can be detected. This area is not fixed, as with retinal acuity (though acuity provides the upper limit for the FFoV), but changes in size and shape according to many factors such as age (Ball et al 1988), processing demands (Holmes et al 1977; Ikeda and Takeuchi 1975; Miura 1990; Williams 1982, 1985, 1988, 1995), and even anxiety (Shapiro and Lim 1989).

The question arises how does the FFoV react to the demands involved in driving? Initially this research was motivated by the accident peak that occurs in drivers within one year of passing their driving tests (Maycock et al 1991). Studies have shown that a high proportion of drivers have an accident in their first licensed year, relative to later years (Elander et al 1993). Analyses which have partialled out attitudes still suggest that a large component of this risk is skill based (see Gregersen and Bjurulf 1996 for a review).

One possible contributor to the excessive accident liability in novice drivers may lie with demand-modulated changes in the FFoV. Some studies suggest that the FFoV degrades or, according to the task, shrinks when processing demands at the point of fixation increase. This suggestion is similar to that of the zoom-lens model of attention (eg Eriksen and Murphy 1987) where the beam of attention can be reduced in diameter so that the resolving power at the point of fixation can be increased. If we accept that novice drivers are placed under greater demands than more experienced drivers, then any degradation of the FFoV should occur more often, and perhaps more severely, in those drivers who have just passed their test. If novice drivers cannot use peripheral vision to the extent of experienced drivers then they should have poorer performance on at least the two skills mentioned earlier: hazard perception and lane maintenance. Deficiencies in such skills, due to the inexperienced driver's susceptibility to FFoV degradation, could contribute to the recorded accident peak in newly licensed drivers.

The assumptions underlying the present study are as follows: that the FFoV (or some comparable form of spatial attention) actually exists; that it is reduced by increases in demand at the point of fixation; and that an individual's response to a central demand in terms of the effects upon the size of the FFoV is mediated by experience with the context. These assumptions require brief attention before examination of the more direct evidence that suggests such peripheral degradation does occur in the driving domain.

1.1 *The fluctuating functional field of view*

There are two views on the degradation of processing as the eccentricity of stimuli from the point of fixation increase (Banks et al 1991). The first view argues that a single spatial scaling factor can account for performance across all eccentricities. This reflects the decline in retinal acuity (Anstis 1974) and suggests that one could perceive a stimulus anywhere in the visual field provided it is scaled up purely to avoid acuity degradation. A second view, however, holds that no one single factor can explain performance decrements over all eccentricities. For instance, Levi et al (1985) found that degradation of Vernier acuity with increasing eccentricity was up to four times greater than with grating acuity. Furthermore they reported that the scaling factors used for both acuity tests suggested different physiological systems were in operation, with grating acuity fitting a pattern of retinal limitation while Vernier acuity was more likely to be influenced by the cortex.

Studies have shown that the FFoV is sensitive to the presence of external visual clutter [though not necessarily to the amount of visual clutter (Ball et al 1988)], while the internal processing requirements also seem to have an effect, with increases in processing demand at the point of fixation reducing the amount of information available in peripheral vision. This suggests that fixations upon a complex road sign may reduce attention to peripheral stimuli, reducing the driver's ability to spot an errant cyclist suddenly appearing from a side street.

The evidence for demand-modulated fluctuations in the FFoV is considerable. One of the more recent studies was conducted by Williams (1995). His participants were required to identify digits presented at either 1.5 deg, 3 deg, or 4.5 deg of eccentricity, under varying central loads. Williams reported a marginal interaction between foveal load and eccentricity (experiment 2, $p < 0.08$) which he said provided evidence for a tunnel-vision model of FFoV degradation. Tunnel vision is one of two models that describe the actual pattern of results due to a degradation of the functional field of view. It suggests that there is actual shrinkage of the functional field with the furthest eccentricities suffering the most. This narrowing of vision is the closest model to the original idea mentioned earlier of reallocating attention from the far peripheral field to the point of fixation, in this case to deal with the central letter task. The second model is termed general interference and is characterised by main effects of both foveal load and eccentricity though without an interaction. This suggests that there is a general degradation across all eccentricities; not so much a shrinkage of the functional field as a dilution of the attentional resources that are spread around the FFoV. The two models can be viewed in figure 1.

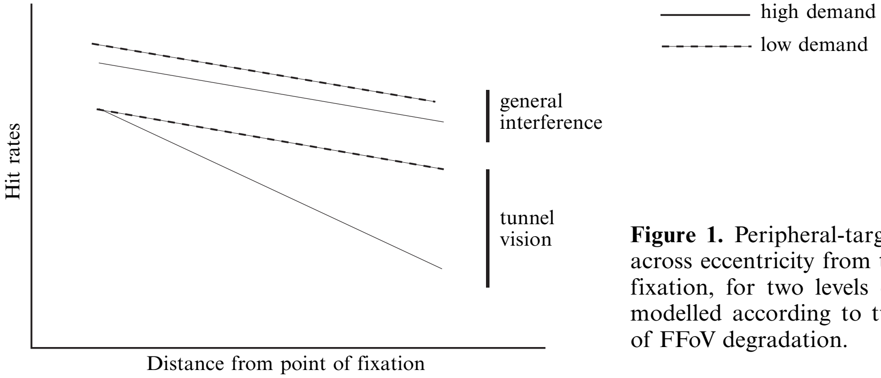

Figure 1. Peripheral-target hit rates across eccentricity from the point of fixation, for two levels of demand, modelled according to two theories of FFoV degradation.

Studies have had success in finding both general interference and tunnel vision under different test conditions, though some of the tunnel-vision interactions are marginal at best (Chan and Courtney 1993; Holmes et al 1977; Williams 1982). In order to induce tunnel vision instead of general interference Williams (1988) concluded that three things are necessary: a demanding central load (necessary also for general interference), speed stress on the central task, and instructions which focus attention on the central task.

Though the actual pattern of results may apply to one of two models, the evidence for a demand-modulated, dynamic field has been noted. But what evidence is there to suggest that experience may modulate a FFoV reaction to an increase in demand?

1.2 *Experience and the functional field*

A number of studies have touched upon the effect of practice upon peripheral-target detectability. There is some evidence to suggest the predisposition to process foveal stimuli before peripheral stimuli is a learned strategy. Holmes et al (1977) found that five-year-olds did not seem to employ a 'fovea-first' rule, though eight-year-olds and adults did. The functional field of view may actually be an adaptation to learned strategies such as these, or may be a strategy in itself.

There is certainly evidence that practice at the tasks used in these type of studies does improve ability to detect peripheral targets. Walsh (1988) found the performance of young and middle-aged participants improved over eighteen sessions in a test of FFoV, though notably older participants received no such benefit. Ball et al (1988) also looked at older participants (mean age 71 years). They noted that such participants' abilities on a test of the FFoV showed distinct age-related deficits. Continued practice at the task, however, improved performance and partially offset the age-related degradation.

These examples show that short-term experience on a task can improve performance. Of more importance, however, is how a more generalised experience (in this case, experience of the driving context) can influence peripheral-target-detection rates.

It is known that novice drivers use different search strategies from more experienced drivers. One reason for this may be that the new driver has problems with the level of demand placed upon him or her (Chapman and Underwood 1998; Crundall and Underwood 1998). When one begins to learn to drive, the task and all the visual elements within it are considered novel. Though one may have often been a passenger in a car, the extraction of visual data useful to the task requires more than passive observation of the world through the windscreen. This is not to say that video or passive simulators are redundant in driving research, merely that a nondriver may not know what visual information is important, or have not yet developed the correct strategies for extracting that information. A driving video shown to experienced drivers will produce a search pattern different from that of novice drivers (Chapman and Underwood 1998; Underwood et al 1997) just as experienced drivers produce different search strategies from novices when actually on the road (Crundall and Underwood 1998), and it may be the case that the strategy that an experienced driver uses to interrogate the visual scene is somewhat automatic.

With this borne in mind one can appreciate that novice drivers are likely to be placed under considerable demands which experienced drivers can easily cope with. Does the FFoV of the novice driver degrade accordingly? Do novice drivers suffer more degradation of the FFoV than experienced drivers, and if so does this contribute toward the accident peak noted in new licence holders?

Previous studies have led other researchers to conclude that degradation of the FFoV does occur in the driving task with increases in demand (Lee and Triggs 1976; Miura 1990; Pottier 1997; Summala et al 1996) though the measures used and the manipulations of demand that were adopted make generalisation of the results difficult (Crundall et al 1998). Little research to date has addressed the FFoV as something that develops with driving experience. This study aimed to investigate this hypothesis by using experienced drivers, novices, and nondrivers performing a central task in a driving context, while peripheral-target hit rates were used to estimate the effects of central demand on the FFoV.

2 Method

2.1 *Participants*

Sixty participants took part in the study. Twenty experienced drivers (twelve females and eight males, with a mean age of 24 years 1 month, and a mean experience since passing the driving test of 60 months), twenty novice drivers (eight males and twelve females, with a mean age of 19 years 3 months, and a mean experience since passing the driving test of 2.5 months), and twenty nondrivers (thirteen females and seven males, with a mean age of 19 years 5 months, with no experience of driving) were paid to take part. All the participants had normal vision. Experienced drivers and nondrivers were recruited through advertisements while the novices were recruited via questionnaires distributed through the Driving Standards Agency of Great Britain (DSA) to newly qualified drivers.

2.2 *Materials and apparatus*

Participants were presented with thirty-nine MPEG digital video clips of road scenes taken from a moving driver's perspective. The clips ranged in duration from 18 s to 70 s (with a mean duration of 43 s) and each contained at least one potentially dangerous or hazardous event. These were the same clips as those we used previously (Chapman and Underwood 1998; Underwood et al 1997). The hazardous events included many abrupt-onset hazards that ranged from a football rolling across the road to the sudden braking of a car in front. Slow-onset hazards, such as gradually being able to perceive a parked van as one gets nearer to it, tended not to capture attention immediately.

Instead participants invested attention in the study of these stimuli in order to decide if they were hazards or not. Both of these hazard types were represented in a wide range of settings from clip to clip. Rural, urban, suburban, and dual-carriageway clips all featured both abrupt-onset and slow-onset hazards.

The presentation of the clips was identical to the method we previously employed (Chapman and Underwood 1998). The clips were displayed on a video monitor with a 34 cm screen at a distance of 1 m from the participant. The overall display subtended 15.4 deg in the horizontal and 11.6 deg in the vertical meridian. 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 connected to a SRI Dual Purkinje Generation 5.5 eye tracker, produced by Fourward Technologies (1939 Friendship Drive, El Cajon, CA 92020, USA), to measure the participants' eye movements.

The primary task involved the participants actively viewing each scene, looking for any hazardous events in order to rate each clip on two 7-point Likert dimensions. These dimensions asked, first, how much danger is inherent in the clip, and second, how difficult would the scene be to drive through. These two scales have been previously found to distinguish between drivers groups on the basis of experience (Crundall et al 1998; Groeger and Chapman 1996), though for the purposes of this experiment the results of the primary task were of minor importance. In the case of nondrivers, they were asked to imagine, when considering the latter dimension, that they had just passed their driving test. As the participants were being eye tracked during the clips, they were placed in a chin rest and head restraint and therefore could not give verbal responses for the ratings. Instead, the dimensions were transferred to computer and the participants were able to control a cursor along a 7-point line on the screen via the PC mouse buttons.

For the secondary task four computer-generated, red place holders were overlaid on the video screen, each one half way along one of the four sides of the video display. The place holders each subtended 0.7 deg. The left and right place holders were 6.8 deg from the centre of the screen, while the top and bottom place holders were 4.4 deg from the centre. Participants were asked to press a button whenever they noticed one of the bright white, peripheral lights. These lights, which subtended 0.3 deg, lasted 200 ms and occurred in the centre of the place holders. A target light was presented in each 5 s segment of video. Within each 5 s window targets were randomised in regard to onset and which place holder they appeared in. The only stipulation was that two targets should not occur within 1500 ms of each other. An ideal testing session would last an hour with 297 targets presented to the participant while viewing the video clips

2.3 *Design*

The three factors involved in this mixed design were level of experience (experienced drivers, novice drivers, and nondrivers), level of processing demand (high versus low), and the onset eccentricity of each target. The level of demand was calculated from an earlier hazard-perception study (Underwood et al 1997) which used the same clips. In this previous hazard-perception test fifty-four participants watched the clips and pressed a button whenever they saw a potential hazard. Hazards were defined as anything that would make one consider taking evasive action such as braking or steering to avoid a potential danger. The number of button presses across participants were calculated for each 5 s segment within each of the thirty-nine MPEG video clips. This produced an index of demand termed the mean responses per participant per 5 s which ranged from zero for the uneventful 5 s clip segments, to 1.8 for the more hazardous clip segments. A median split (at 0.18) of the demand index produced a roughly equal number of high-demand and low-demand windows.

The onset-eccentricity factor is the distance from the current point of fixation to a target at the time of onset. The levels of onset eccentricity were chosen on the basis of the distribution of eccentricity scores of pilot data. Four categories were chosen: less than 5 deg, 5 – 5.9 deg, 6 – 6.9 deg, and 7 deg and above.

The main measure of peripheral performance was the percentage of targets spotted. Response times measured from the target onsets were also recorded.

Only targets which were given an onset eccentricity by the computer were designated as either a hit or a miss (ie targets which occurred at a moment when the computer was sure of the position of the participant's gaze on the screen). These were termed successfully presented targets. Targets without a given onset eccentricity may have occurred while the participant was blinking or during a saccade. These targets could not be assigned to a level of onset eccentricity and were therefore excluded from the analysis. This resulted in some participants having less than the 297 peripheral targets successfully presented to them, and it is for this reason that the statistics deal with hit rates as percentages. On average, each participant was presented with 273 peripheral targets and 188 of these were considered successfully presented.

The video clips were viewed in four blocks that were counterbalanced within groups. Progression from clip to clip within each block was self-paced.

2.4 *Procedure*

At the start of the experiment participants were informed of the two tasks they had to perform, and were given practice in using the computer-based rating system. The primary task (as far as the participants were concerned) was to rate each clip along two dimensions: how much danger they thought was inherent in the clip, and how difficult they would personally find the scene in the clip to drive through. These ratings were made after each clip by using the buttons on the PC mouse. Participants were instructed 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. They were told that any hazardous events that they noted would help them to judge each clip along the two dimensions. The secondary task was to respond to the peripheral targets by pressing a button on the PC mouse. Emphasis was placed on the rating task, and participants were explicitly instructed not to deliberately search for the peripheral targets.

3 Results

The results will be presented in three sections. The first section addresses the main hypothesis of whether peripheral-target-detection rates are degraded owing to the effects of increased demand and eccentricity (consistent with one of the two models of FFoV degradation), and whether these effects vary with driving experience. The second section seeks to corroborate the first, through the analysis of reaction times to those targets that were correctly identified, while the third reports some measures of the general search strategy.

3.1 *Peripheral-target hit rates*

The mean number of false alarms was very low, averaging 6 false reports for every 188 successfully presented targets (3.2%). An 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 degradation in the FFoV are the level of demand ($F_{1,57} = 95.8$, $p < 0.01$) and onset eccentricity ($F_{3,171} = 81.4$, $p < 0.01$). Mean comparisons showed that the onset-eccentricity significance lay primarily with the large decrease in hit rates of targets with eccentricities in excess of 7 deg from the point of fixation. The results suggest that as demand and onset eccentricity increase, the participant's ability to detect the peripheral targets decreases dramatically. The lack of an interaction, however, argues, in this particular instance, for acceptance of the model of general interference over the tunnel-vision model. These main effects can be viewed in figure 2.

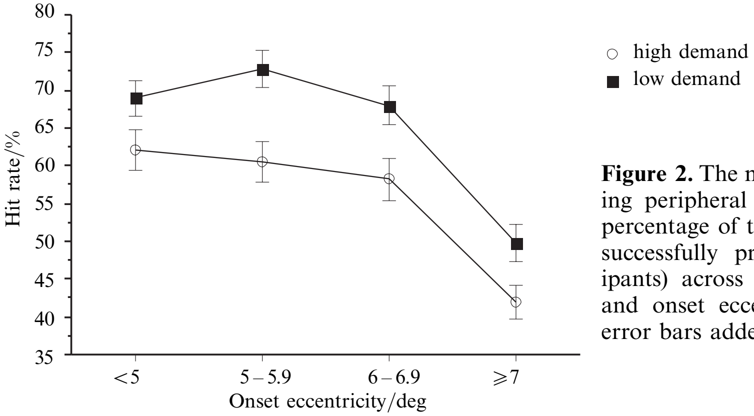

Figure 2. The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) across the factors of demand and onset eccentricity, with standard error bars added.

As a follow-up to the main analysis, the eccentricities in the furthest category were examined in more detail. Of the targets that were presented at eccentricities of 7 deg and beyond, those that were spotted were on average 8.3 deg from the point of fixation, while those that were missed were at an average distance of 9.1 deg. This difference was tested along with the experience factor in a mixed ANOVA. The experience factor did not reveal any significant differences though the difference in eccentricity between those targets that were detected and those that were not was significant ($F_{1,57} = 169$, $p < 0.01$).

The third main effect was found across the participants' varying levels of experience ($F_{2,57} = 4.5$, $p < 0.05$). A a posteriori Student – Newman – Keuls revealed that the significance lay between the experienced drivers and the nondrivers, with the novice drivers falling somewhere in the middle (though closer to the mean of the experienced drivers—see figure 3).

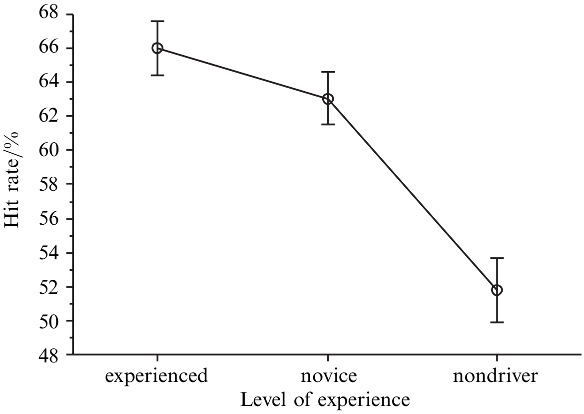

Figure 3. The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) according to level of driving experience, with standard error bars added.

Though the experience factor did not interact with processing demands or onset eccentricity, the main effect illustrates that the paradigm is not only suggestive of a demand-modulated FFoV, but that it also distinguishes between the participants on the basis of their driving experience. The lack of an interaction suggests that nondrivers have suffered more peripheral-task degradation than the experienced drivers, even under the easiest conditions. As the processing demands increase, or the onset eccentricity becomes greater, the hit rates of the nondrivers worsen proportionately with those of the other participants. The mean hit rates across all three factors can be viewed in table 1.

Table 1. (a) Peripheral-target hit rates, and (b) reaction times according to the three factors of driver experience, level of demand, and onset eccentricity (in degrees).

	High demand				Low demand			
	<5	5	6	$\geqslant 7$	<5	5	6	$\geqslant 7$
(a) Hit rates/%								
Experienced drivers	66	69	67	45	73	77	73	58
Novice drivers	65	63	61	43	72	76	76	48
Nondrivers	55	49	47	38	62	64	56	43
(b) Reaction times/ms								
Experienced drivers	569	595	566	569	542	532	531	566
Novice drivers	589	568	583	629	563	557	550	569
Nondrivers	663	665	657	688	645	621	609	641

There is a baseline chance of 30% that any random response will fall within a 1500 ms window where it would be accepted as a hit. The extremely low false-alarm rate, however, indicates that button responses were far from random with only 3.2% of responses falling outside the critical 30% of clip time.

The above analyses included only the successfully presented targets. Unsuccessfully presented targets were removed as they were not assigned an onset eccentricity by the computer. In order to assess the effect of removing the unsuccessfully presented targets, a separate analysis was conducted on all of the targets for each participant (ie all the targets that were displayed on the screen regardless of whether they were assigned an onset eccentricity by the computer). Though the factor of onset eccentricity could not be included in this analysis, experience ($F_{2,57} = 3.6$, $p < 0.05$) and level of demand ($F_{1,57} = 136.5$, $p < 0.01$) again produced main effects. This supports the earlier analyses of the successfully presented targets.

3.2 *Peripheral-target reaction times*

An ANOVA was conducted on the reaction times to successfully presented targets. This revealed a strong main effect of demand ($F_{1,57} = 31.0$, $p < 0.01$), with targets in high-demand windows taking longer to respond to, and a weaker effect of onset eccentricity ($F_{3,171} = 3.1$, $p < 0.05$). Comparisons of means of levels of eccentricity revealed that targets presented at eccentricities of 7 deg or greater were significantly slower than targets at 5 – 5.9 deg and at 6 – 6.9 deg, though no slower than targets below 5 deg ($p < 0.05$).

A main effect of experience was also found ($F_{2,57} = 4.1$, $p < 0.05$). Nondrivers were significantly slower in responding to spotted targets than the other driver groups, as revealed by an a posteriori Student – Newman – Keuls. The means of these data can be found in table 1.

3.3 *Clip ratings and measures of the general search strategy*

The ratings task was included to provide the participants with a central task that would it was hoped sensitise them to hazards in the video clips, and as such the results of the ratings task have no direct influence on the main hypothesis. However, the scores were compared in order to identify any possible reason for the differences in hit rates and reaction times due to differential perceptions of the clips. The dimensions measured perceived danger and difficulty on two 7-point scales. The mean rating for danger was 4.11 while difficulty averaged 3.68. An ANOVA revealed that, though all participants rated the roads as more dangerous than difficult ($F_{1,57} = 56.7$, $p < 0.01$), the lack of an effect of experience suggests that these two dimensions are not related to the decrease in peripheral detections between drivers of varying levels of experience.

Measures of participants' fixation patterns were also recorded in order to assess any effects on their general visual behaviour. An analysis was conducted upon the participants' overall mean fixation durations for each clip. Previous research suggests that fixation durations decrease as dynamic processing demands and visual complexity increase (Chapman and Underwood 1998; Crundall and Underwood 1998; Mourant and Rockwell 1972), and that experienced drivers tend to have shorter fixation durations than their less practised counterparts (Underwood et al 1997). These findings were not upheld to a level of significance ($F_{2,57} = 1.5$) though the means tended in that direction, with experienced drivers averaging 474 ms for a fixation, while novices and nondrivers produced mean durations of 554 ms and 542 ms, respectively. Analyses were also performed to assess potential differences in the mean fixation location (ie the centre of gravity for all the scan patterns for each participant) between participant groups, in both the horizontal and vertical meridians. Neither meridian revealed any difference due to experience ($F_{2,57} = 0.1$ for the horizontal meridian, and $F_{2,57} = 0.1$ for the vertical). The mean position for all groups in both meridians was less than 1 deg from the centre of the screen.

In order to assess possible differences between the groups due to the spread of search, comparisons were also made of the variances of the fixation locations in both meridians across the three participant groups. These measures have been noted to differentiate between novice and experienced drivers in previous experiments (Crundall and Underwood 1998), yet they failed to do so in this study ($F_{2,57} = 0.1$ for the horizontal meridian, and $F_{2,57} = 0.3$ for the vertical). This was possibly due to the presence of the place holder boxes. Despite explicit instructions to the contrary, the place holders no doubt did attract at least a small number of fixations, either in anticipation of a target or to confirm an onset.

One further measure was that of onset fixation duration (henceforth OFDs). This measure represents the length of the fixation that participants were engaged in at the time of the onset of a peripheral target. This measure encompasses the target onset time, and usually the whole time period in which the target is presented (ie few saccades are made during the 200 ms period of target presentation), and as such it is the closest measure to the time at which the target is detected.

OFDs were analysed across experience, eccentricity, demand, and whether the participant responded to each particular target. The most fundamental of these factors is the effect of spotting and responding to a peripheral target on OFDs. If a target is missed then these OFDs are merely the same as any other fixation duration that occurs without the presence of a target. In these analyses it was discovered that detection of a target coincides with an average increase of 405 ms in participants' OFDs ($F_{1,57} = 71.7$, $p < 0.01$). This may be due to suppression of the following saccade while processing the peripheral target (ie spotting the target peripherally increases the current fixation duration), or alternatively long fixations may improve chances of spotting a peripheral target. In order to distinguish between these two a posteriori hypotheses a further ANOVA was conducted between the portion of the OFDs that occurred before the peripheral-target onset and the portion that occurred after onset. Missed-target OFDs were not included in this analysis. A significant interaction of before/after target onset and eccentricity was found ($F_{3,171} = 4.0$, $p < 0.01$). Comparisons of means revealed that at eccentricities greater than 6 deg the long OFDs were due to the portion of the fixation before the peripheral-target onset ($p < 0.01$). This supports the latter hypothesis, that long fixation durations were necessary in order to detect targets, at least at large eccentricities. The OFD means for spotted and missed targets and for spotted targets, split into before onset and after onset fixations, can be viewed in table 2.

Table 2. Onset fixation durations in milliseconds (a) across participant groups and whether the peripheral target was detected, and (b) before and after peripheral-target onset fixations across eccentricities.

	(a) Participant group				(b) Onset eccentricity/deg			
	experienced drivers	novice drivers	nondrivers		<5	5	6	$\geqslant 7$
Spotted targets	991	1294	1237	Before onset	551	593	582	674
Missed targets	684	872	750	After onset	578	588	578	553

4 Discussion

The results presented in this paper have demonstrated a strong degradation of the FFoV in hazardous sections of driving-video clips. The peripheral-target-detection rates of all participants were adversely affected by increases in onset eccentricity and demand (as defined by the previous hazard-perception study). This is of interest in itself as it validates the index of demand that was created for this experiment. The main hypothesis that the FFoV will vary with driver experience was also upheld, with experienced drivers producing the best results and nondrivers producing the worst. As a laboratory exercise in assessing participants' functional fields of view it has been successful, but the significant difference between the participant groups suggests something extra: that the test measures a perceptual skill or strategy that develops with driving experience.

The findings from the hit rates were supported by the reaction-time data. Again, nondrivers had the worst performance while the experienced drivers had extremely fast responses to perceived targets. Targets in high-demand windows also had slower response times than targets that appeared in low-demand windows. The mean difference between response times to targets in high-demand and low-demand windows, though a very robust effect, was only 36 ms. This may merely reflect a time lag in disengaging attention from a hazardous event in a high-demand clip segment, compared with a low-demand 5 s window. In the latter case onset of a target light will probably have greater saliency, but will also have greater response priority as little else may be occurring in that segment of the clip. There was also an effect of eccentricity on reaction times with targets 7 deg or more from the point of fixation having markedly slower responses. This presumably reflects the cumulative probabilities of spotting a target located 7 deg or further from fixation compared with lesser eccentricities. The differences between 7 deg or more and 5 – 5.9 deg and 6 – 6.9 deg are 20 and 27 ms, respectively, and thus can be accounted for in terms of when the target was spotted during its 200 ms presentation.

Miura (1990) found similar results in his study of on-road peripheral-target detection. High demand (reflected by road type) increased reaction time to peripheral lights and produced more fixations between target onset and response. Miura reported that this was evidence of a reduced field of view, though the increase in fixations may have simply occurred to fill in the extra time between onset and response on the high-demand roadways.

One difference between the present study and that of Miura concerns the measurement of eccentricity. Instead of onset eccentricity Miura employed response eccentricity, which is the distance between the point of fixation and the target at the time of the participant's response. In order to measure this, however, targets must remain available for lengthy periods of time, or until the participant makes a response. If one safely assumes that the exact point in time at which a target is detected does not coincide exactly with the actual response then one cannot positively infer where the eye is at the time of detection. Miura actually states that as demands increase "the detection of a target requires a larger number of eye movements" (page 123). From this he concludes that the functional field of view is narrowing. However, if the fixations after onset are made in the direction of the target (Miura 1986), then this suggests that the target must already have attracted enough attention for participants to saccade toward it. Therefore the target must have originally fallen within the FFoV, thus making the measure of response eccentricity redundant in measuring the FFoV.

Alternatively, if a target with a short duration is employed (such as 200 ms, as in this experiment) any correct response must stem from a detection during that onset duration. The best estimation of fixation position at the time of target detection is the onset eccentricity, especially when it is noted that the average onset fixation duration was 967 ms. Thus the peripheral-target onset duration was usually embedded within a single fixation.

4.1 *Is general interference specific to the driving task?*

The results conform to the model of general interference. Peripheral detections decrease equally across eccentricity with an increase in demand. This finding may be particular to this specific paradigm, however. The series of experiments conducted by Williams during the 1980s suggested that slight modifications to his tasks could induce either of the models (Williams 1982, 1985, 1988, 1995). Two of the three criteria he believed were necessary for tunnel vision were applied in this experiment. The first was the increased foveal load, which was defined as those segments of the video clips within which participants from a previous study had made many hazard responses. The second criterion was an attentional strategy focused upon the central task, which in this study was the generation of the danger and difficulty ratings. The third criterion that Williams stipulated was that of speed stress on the central task. In this experiment the primary rating task did not lend itself to speeded responses. An alternative primary task with a timed response could replace the rating task though it may interfere with the responses to the peripheral targets (rather than interfering with their detection as one expects from a demand-induced reduction or dilution of the FFoV). In order to avoid within-modality interference other studies have employed verbal as well as motor responses. As mentioned earlier, however, this is not an option when eye tracking with a Dual Purkinje eye tracker. Despite these limitations it would be interesting to attempt the introduction of speed stress into the central task for two reasons. First, Williams's prediction of tunnel vision from the three criteria he set down could be tested. Second, if tunnel vision were induced, this may reveal further differences between participants with varying driving experience.

The results so far have suggested that as one gains driving experience so one develops a more efficient functional field of view, regardless of the level of demand one is placed under. As demand at the point of fixation increases, the functional field of view loses attention proportionately across all eccentricities for all three participant groups. This suggests that nondrivers find even the stimuli in the low-demand clip segments novel or demanding enough to reduce attention across the functional field of view. It is possible, however, that if participants were placed under speed stress, such as pressing a button to acknowledge a hazard, then this might create tunnel vision. A task including a speeded response is possibly a closer approximation to the real environment rather than the generation of danger and difficulty ratings, and may show further differences between drivers of varying experience.

One theory that may, however, account for these results without recourse to spatial attention suggests that attention can switch rapidly between different sources of information in the visual scene. If increased foveal demand reduces the probability of switching attention to an alternative source, then there is no requirement to rely on the

FFoV to explain the differences. One problem with this interpretation is that one cannot switch attention between a driving stimulus and an abrupt onset before it has appeared. In this experiment, however, a proponent of the attention-switching hypothesis may argue that a participant could switch attention between the driving stimuli and the peripheral-target place holders, increasing the probability of spotting a target light. If such switching did occur, however, it was still susceptible to the eccentricity effect, most notably the catastrophic decline in peripheral performance between 8.3 deg and 9.1 deg, which is perhaps suggestive of an attentional boundary. An argument for attention switching within a spatial area of attention, does not refute the findings presented here. Instead it asks a further question of what mechanisms of selection occur within a spatial area of attention. Lavie and Driver (1996) argue that object-based attentional biases control which stimulus one pays attention to, providing the objects fall within the spotlight. The question of whether attention is switched between objects within the spotlight, or whether all stimuli in the spotlight are available for processing, cannot be answered from this experiment. The different models are functionally equivalent in regard to the results in the present study. This experiment has dealt with the issue of limitations on the extent of spatial attention, and not with the attentional mechanisms within that area.

In conclusion, the paradigm developed for this study has demonstrated that the FFoV is improved with experience of the task context. The underlying assumption is that, as drivers become more comfortable with the visual extraction of information relevant to the driving task, this reduces the level of demand at the point of fixation. This frees up attentional resources that can then be used to increase the attention invested in the FFoV.

Lavie (1995) suggests something similar in her recent research on selective attention. She believes that the debate between early-selection and late-selection theories of attention can be resolved through consideration of processing demands. Early-selection theories are supported by studies where distracters have little disruption on the identification of a target. Lavie argues that this occurs because the central task is extremely demanding and there is no attention left to spend on the distracters. When distracters do interfere, she argues that the main task is simple enough to allow surplus attention to be directed to other items in the visual scene. Thus one processes distracters when the central task is not demanding enough to command all of our attention. She makes no judgment about the spatial area over which surplus attention is automatically distributed, though if one assumes that the point of origin starts at the point of fixation and spreads in a circular fashion, we are faced with a classic interpretation of the FFoV similar to LaBerge and Brown's (1989) gradient model of attention.

This study has marked the way for more research into the possibility that experiential FFoV degradations are linked to the accident liability of inexperienced drivers. From the tests on novice drivers it does seem that sensitisation to central driving demands is achieved quickly, producing peripheral detection rates almost as good as those of experienced drivers after a few months on the road, though addition of a speeded response component may further separate drivers of varying experience. It is possible that properly validated training techniques could improve the FFoV or teach strategies to compensate for any demand-induced degradation, which could ultimately reduce accidents on the roads.

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