ERGONOMICS, 1998, VOL. 41, NO. 4, 448–458

Effects of experience and processing demands on visual information acquisition in drivers

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Keywords: Driving; Vision; Demand.

This study investigated the differences between novices and experienced drivers in their distribution of visual attention under different levels of cognitive load imposed by different types of road, and as reflected in their visual search strategies. The task involved a 20-min drive on various roads while the drivers' eye movements were recorded. The measures taken included fixation durations, as an indicator of the time taken to assimilate fixated objects, and the variance of fixation co-ordinates to describe the spread of search in both the horizontal and vertical axes. Differences were found between novices and experienced drivers according to the type of road being driven. The results suggested that experienced drivers select visual strategies according to the complexity of the roadway, and that the strategies of novices are too inflexible to meet changing demands.

1. Introduction

Errors in perception and recognition have been reported as the most pervasive cause of road accidents involving normal, sober drivers (Sabey and Taylor 1980). With the importance of visual information for driving, and its causal connection with accidents, it is not surprising that an increasing number of studies has been conducted in this area over the past 30 years. These studies tend to focus on one particular factor such as experience (Mourant and Rockwell 1970, 1972, Renge 1980), the level of processing demands of the situation (Lee and Triggs 1976, Cohen 1981, Ranhimi *et al*. 1990, Hella *et al*. 1996) or the attentional instructions given to the subject (Hughes and Cole 1984) for example. Though the range of experiments is impressive it is often difficult to compare these studies directly due to the variety of methodologies employed. The objective of the present research is to identify differences between novice and experienced drivers to account for the excessive accident liability associated with drivers in their first year after passing the driving test. However, the investigations in the area of driver experience have tended towards simple descriptions of differences between novice and experienced drivers without identification of the underlying causes. The study reported here was designed to investigate differences due to a driver's experience set against the cognitive demands of the situation. Differences associated with driving experience were sought in the visual search strategies employed on different kinds of roads. In particular, we asked whether novices are as sensitive to roadway differences as more experienced drivers.

A review of the seminal papers relating eye movements to driving experience demonstrates some limitations of the research. The most influential papers in this

0014–0139/98 $12·00

area were published by Mourant and Rockwell (1970, 1972) and, though their samples were exceedingly small, they have laid down findings which have been replicated with varying amounts of success over the past 25 years. They noted that novice drivers tended to search a smaller area of the visual scene, that this area was closer to the car, and that they made fewer fixations on their mirrors. The fixations that they did make tended to be longer than those of the experienced drivers, and they made more pursuit tracking eye movements. They also found that the novices fixated lane control markers more often than the experienced drivers.

Other researchers have noted additional marked differences between the search strategies employed by novices and experienced drivers. Both Renge (1980) and Evans (1991) have noted the predominance of vertical search that occurs in novice drivers, at least at the very early stages of their driving careers. Evans reported that this effect disappeared after 1 month of driving tuition. Mourant and Rockwell (1970) also found that novices tend to produce a smaller horizontal search pattern than experienced drivers.

It is possible to explain the majority of these differences in terms of the excessive processing demands that visual stimuli in the driving scene place on the inexperienced driver. For instance, the suggestion that novices search a smaller area of the scene and make fewer mirror checks may reflect an attempt to limit the amount of visual input. Furthermore, the suggestion that novices' visual search stays closer to the car may be symptomatic of a lack of automatization of the control functions of the car, resulting in a search strategy that is dominated by the dashboard. In regard to the novices' predisposition to produce longer fixations, mean fixation durations have been reported to be indicative of the time required to process the objects that one foveates (Cohen 1981, Henderson *et al.* 1989, Underwood and Everatt 1992), and have been found to increase with a corresponding rise in the density of an optical array (Mackworth 1976), or with increased complexity (Loftus and Mackworth 1978), thus any increase in the mean fixation durations of novice drivers may reflect the extra processing time they require to extract the information they need. Similarly, increased fixation durations have been found in young children who require extra processing time to select the relevant information (Mackworth and Bruner 1970). If one views pursuit tracking as the foveation of a moving object (as the viewed image is fixated in the sense that it is held in place on the fovea), the increase in these movements may also be explained in terms of the extra processing time required by novices due to the novelty of the stimuli.

The tendency of novices to fixate lane markers is of particular interest and points toward a theory of perceptual narrowing which may explain the hypothesized effects of demand on experience. Before describing this theory, a recent study by Land and Horwood (1995) provides the suggestive link. Using a rudimentary simulator they found that experienced drivers extracted optimal information about road layout from two main sources: a far location nearly 16 m ahead (4° below the horizon), and a near location approximately 9 m ahead (7° below the horizon). The far point provided information on the curvature of the road which allowed a smooth drive, while the near point gave information on the driver's position relative to immediate lane markers, allowing lane maintenance. When the subjects viewed the road they tended to fixate 4° below the horizon, with very few fixations in the 7° section, suggesting that the latter source of information was acquired through peripheral vision. If novices fixate the lane markers more often than experienced drivers, as

Mourant and Rockwell suggest, and if the reason for this is to maintain lane position, then this may suggest a problem with the range of their peripheral vision: if their peripheral vision does not extend to the lane markers or they cannot extract information peripherally then fixation of lane markers may be a compensatory strategy.

An alternative hypothesis to explain the greater vertical search and fixation of road markers in novice drivers stems from the work of McLean and Hoffman (1971). Their research suggested that drivers increasingly use higher-order steering cues with experience, such as the yaw rate of the vehicle. These cues tend toward the focus of expansion and therefore provide the added advantage of preview for distant hazards. On the basis of a very small sample, McLean and Hoffman suggested that novice drivers are more predisposed to use 'positional' cues, such as the distance of the vehicle to the edge of the road or nearest lane marker. This theory suggests that the predominance of novices' vertical search over horizontal search, and their tendency to fixate lane markers far more than experienced drivers, is due to different information needs of the two driver groups rather than differences in the peripheral fields of such subjects. Brown and Groeger (1988) cited a study by Brown (1982) as evidence which they believe supports this view. Brown discovered that although novice and experienced drivers proved to have similar detection rates for identifying near hazards, the novices' ability declined the further away the hazard was. This study is indeed suggestive that novices were not focusing as high in the visual scene as the experienced drivers, though whether this was due to steering cues is unclear. This theory is not supported by the Land and Horwood (1995) findings. If experienced drivers extract steering information from higher in the visual scene then removing peripheral information should have little effect. Land and Horwood have demonstrated, however, that lane maintenance is dependent on information close to the car, though the drivers rarely fixated the area. The decision between the McLean and Hoffman study and the work of Land and Horwood is difficult as both effects were found with an extremely limited number of subjects or in unrealistic settings. As the present study does not address the question of steering control directly, our emphasis will be placed on the use of peripheral vision explanation.

From the results of Land and Horwood one could hypothesize that perceptual narrowing was occurring in the novice drivers. The cause of perceptual narrowing is an increase in cognitive load in the processing of foveated information, and the result is the shrinking of the peripheral visual field. This should reduce the benefit of any peripheral preview of stimuli resulting in the longer fixations that are found with novices, and would reduce the area from which stimuli may attract exogenous orientations of attention which precede reflexive saccades (see Sereno [1992] for a discussion of the relationship between exogenous shifts of attention and reflexive saccades). Thus with a reduced peripheral field of view novices may miss stimuli that would otherwise warn them of a hazardous situation, increasing the likelihood of an accident. Several studies have been undertaken to investigate perceptual narrowing in both general and driving-specific domains, though no study has specifically examined the effect of driving experience on perceptual narrowing during a driving related task.

Research on the phenomenon of perceptual narrowing has mainly focused on laboratory-based tasks with little attempt to generalize the findings to any applied field. Henderson *et al.* (1987, 1989) found a difference of up to 40 ms of fixation duration between two experiments involving parafoveal preview, with the only

difference between the experiments being the extra memory processing that the subjects with the longer fixations had to perform. They suggested, 'there may be a decrement in the ability to use [parafoveal] preview information when some attentional resources are involved with identifying and remembering a foveal object at the same time that extra foveal information is being acquired' (Henderson *et al.* 1987: p.201). Similarly Reynolds (1993) and Chan and Courtney (1993) found subjects to have a decreased response rate to peripheral items as the complexity of the foveal items increased.

Some researchers have addressed the problem of perceptual narrowing in drivers. Lee and Triggs (1976) noted a decrease in response rates to a series of lights set up along the dashboard of a car when the subject was driving along a highly demanding, shopping or suburban street, compared with similar responses when driving on a less demanding, rural road. Initial evidence suggested that the further along the dashboard these lights were the more likely they were to be missed. More evidence was reported by Miura (1986, 1990). In an early experiment he noted that over 120 h of driving, across two experienced subjects, response times to peripherally presented targets increased as the complexity of the road increased, and that search strategies seemed to compensate for the proposed reduction in the peripheral field with an increase in the search area.

The experiment presented here was conducted on a set route, using differing road types as indicators of the changing demands placed upon the driver (Lee and Triggs 1976, Hughes and Cole 1986, Hella *et al.* 1996) while subjects' eye movements were measured. It was hypothesized that differences between novice and experienced drivers would be revealed when compared across different levels of processing demand, and specifically that high-demand situations would be more likely to produce these differences.

2. Method

2.1. *Subjects*

Sixteen experienced drivers (11 male, mean age 27·7 years, mean experience 9·0 years) and 16 novices (7 male, mean age 17·9 years, mean experience 0·2 years) volunteered for the experiment, all with normal or corrected-to-normal vision.

2.2. *Apparatus*

Subjects' eye movements were measured using a NAC EyeMark VII head-mounted eye tracker while driving a car equipped with an NTSC video recorder on which the data were recorded. The data were analysed using a NAC Data Processing Unit linked to a P90 PC. The processing unit was set to recognize fixations where at least three data samples (measured at 30 Hz) fell within 2° of each other. This gave a minimum fixation duration of 100 ms and allowed pursuit tracking to be classed as a fixation.

2.3. *Materials*

Subjects were given in-car instructions to negotiate a 20-min route while wearing the eye tracker. From this drive three '1-min windows' were selected. The first window contained a rural, single-lane carriageway, the second consisted of a suburban road through a small village which contained some shops, parked cars and zebra crossings, while the third was a dual carriageway with two lanes of forward-moving traffic and more traffic merging from the left. The latter two were selected for

inclusion in the test route because they placed the driver under a higher level of visual demand than the rural road. The location-onsets of the three windows were constant for all drivers.

2.4. *Design*

This experiment used a mixed design. The between-subjects variable was experience and the within-subjects factor was processing demand reflected in the three types of roadway sampled within the 1-min windows.

2.5. *Procedure*

Subjects were taken on a 20-min familiarization drive with the experimenter sat in the rear of the car to give directions when necessary. At a particular point in the drive subjects were asked to stop the car and then had the eye tracker placed on their heads. After a brief calibration procedure subjects were asked to start the car and were given instructions to continue the drive. Subjects were instructed to drive in their normal style and to disregard the presence of the experimenter as much as possible while still following directions. These directions were given to the drivers when the relevant signs could be seen on the road, so that the subjects knew where to turn on a similar time scale to drivers who would be travelling with traffic signs as the basis of their navigational information.

3. Results

Four measures were taken from the recordings provided by each driver. Within each 1-min window the number of fixations and their durations were measured along with the variance of fixation coordinates along the horizontal and vertical meridians. Each measure was subjected to an analysis of variance. The analyses of the four measures will be described separately.

3.1. *Mean fixation durations*

A main effect of type of roadway was found for mean fixation durations, $F(2,60) = 7{\cdot}96$, $p < 0{\cdot}001$, and a significant interaction was discovered between the level of driver experience and road type, $F(2,60) = 3{\cdot}14$, $p < 0{\cdot}05$. The means for this analysis and all those that follow can be viewed in table 1, while the interaction is charted in figure 1.

Pairwise comparisons revealed that the novices had significantly shorter fixations on the suburban road when compared with the dual carriageway ($p < 0{\cdot}01$) while the experienced drivers had significantly shorter fixations on the suburban road when compared to the rural road ($p < 0{\cdot}01$).

3.2. *Number of fixations*

A main effect of roadway was found, $F(2,60) = 9{\cdot}73$, $p < 0{\cdot}001$. Means comparisons between the levels of roadway revealed that the suburban road produced significantly more fixations than the other two roadways ($p < 0{\cdot}01$).

3.3. *Spread of search along the horizontal meridian*

With regard to differences between the horizontal and vertical meridians for road type and experience, each axis was considered separately as the samples were not homogenous and could not be placed in the same analysis. Analysis of the variance of fixation locations along the horizontal meridian produced a main effect of type of

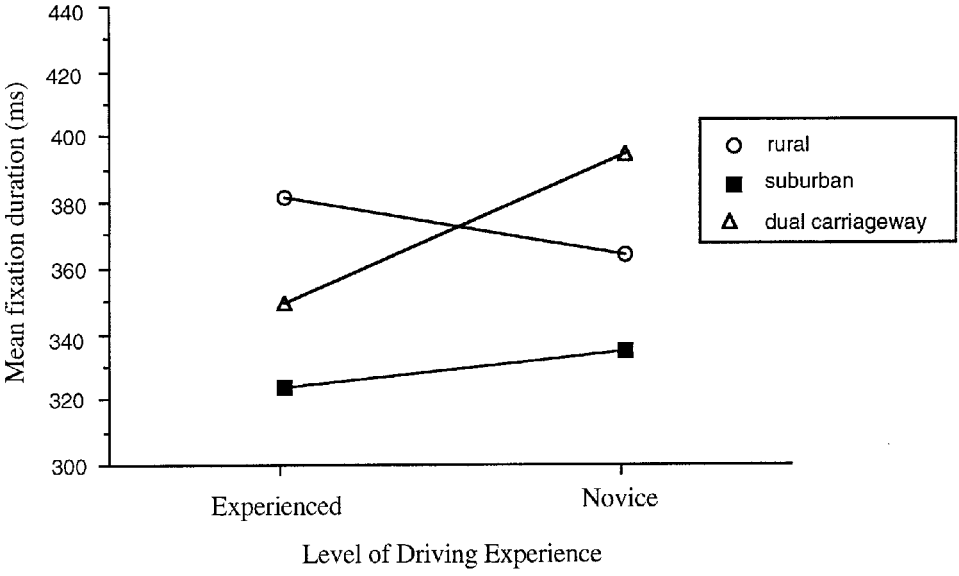

Figure 1. Mean fixation durations for novices and experienced drivers across road type.

Table 1. Means (SD) for eye fixation measures taken on three sections of roadway and for two levels of driving experience.

Road type:	Rural		Suburban		Dual carriageway	
Drivers:	Experienced	Novice	Experienced	Novice	Experienced	Novice
Mean fixation durations (ms)	381 (105)	364 (127)	324 (75)	335 (94)	349 (87)	395 (132)
No. of fixations	134 (25)	131 (22)	146 (29)	139 (22)	133 (21)	125 (28)
Horizontal axis variance (degrees)	38·7 (28.0)	43·0 (38·3)	48·4 (24·8)	47·2 (27·6)	82·4 (49·2)	45·9 (24·2)
Vertical axis variance (degrees)	12·5 (7·9)	22·4 (14·4)	12·1 (7·8)	21·0 (13·7)	23·8 (18·6)	24·1 (14·6)

roadway, $F(2,60) = 7{\cdot}76$, $p < 0{\cdot}001$, and a significant interaction between level of experience and road type, $F(2,60) = 6{\cdot}61$, $p < 0{\cdot}01$. This interaction is charted in figure 2.

Means comparison showed that the only significant difference in roadway was that the experienced drivers had a large increase in variance of fixation locations on the dual carriageway compared with the other two roads ($p < 0{\cdot}001$). A *post-hoc* Student – Newman – Keuls test revealed that the only significant difference was between experienced drivers and novices on the dual carriageway ($p < 0{\cdot}05$).

The results suggest that the experienced drivers increased their search in the horizontal meridian relative to the rural road on the dual carriageway, and to a lesser extent on the suburban/shopping route. The novice drivers tended to maintain the same level of horizontal search throughout all the road types, similar

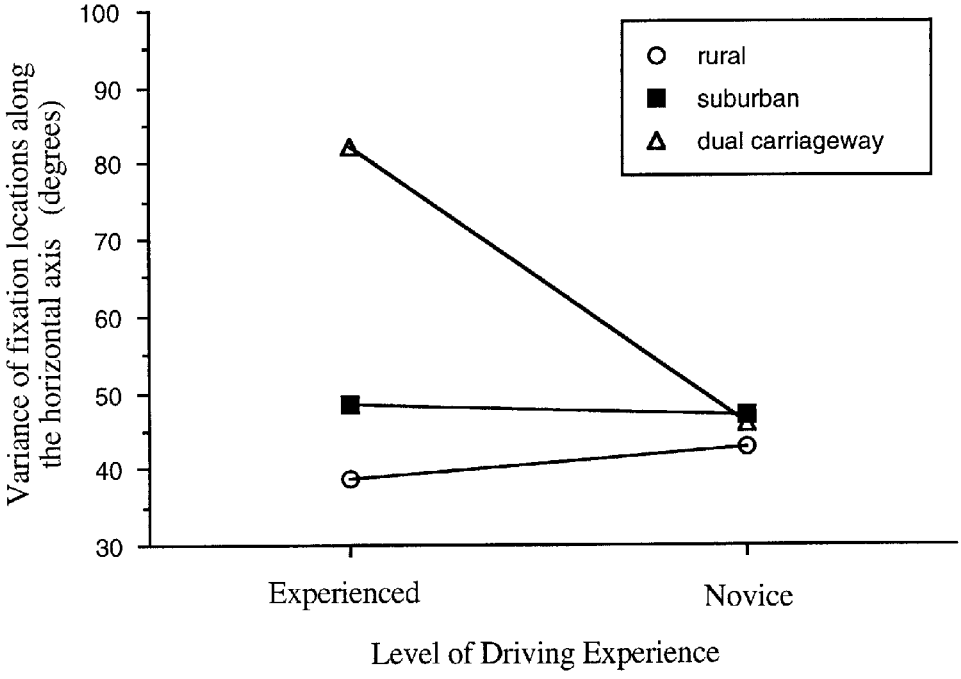

Figure 2. Spread of search along the horizontal axis for novice and experienced drivers according to road type.

to the level of horizontal search that experienced drivers produced on the suburban road.

3.4. *Spread of search along the vertical meridian*

The analysis of the variance of fixation locations along the vertical meridian produced a main effect of roadway, $F(2,60) = 4{\cdot}02$, $p < 0{\cdot}05$. The interaction failed to reach significance. Means comparisons of the levels of roadway found the spread of search for experienced drivers on the dual carriageway to be significantly different to the suburban road ($p < 0{\cdot}05$) and to the rural road ($p < 0{\cdot}05$). The means are presented in table 1.

In addition to analysis of the axes across experience and road type, the spread of search along both the vertical and horizontal axes were compared against each other. A significant horizontal dominance was discovered ($F(1,17) = 42{\cdot}90$, $p < 0{\cdot}001$). This is most likely due to the prevalence of information along the horizontal axis as opposed to the vertical.

4. Discussion

The analyses of mean fixation durations and the spread of search along the two axes suggest that there is an influence of experience on the effects of processing demands in driving. With regard to mean fixation durations, the reported finding that novices produce longer fixation durations than experienced drivers (Mourant and Rockwell 1972) is not a simple difference but one which depends on the type of road being

driven on at the time. Both the experienced and novice drivers displayed a sensitivity to the different road types in their fixation durations though their responses tended to opposite directions. If the rural road is viewed as the least demanding due to the low levels of traffic, lack of parked vehicles and pedestrians, and general absence of visual complexity, then the experienced drivers seemed to increase their fixation durations on the least demanding of the roads whilst novices increased fixation durations on the more demanding dual carriageway. The only roadway where the drivers distribute their visual attention in similar ways is the suburban route.

If one considers traditional research findings in the areas of reading or picture viewing, increased fixations are interpreted as extra processing time due to a complex foveal stimulus (Mackworth 1976, Loftus and Mackworth 1978, Henderson *et al.* 1987, Underwood and Everatt 1992). On the dual carriageway the novice's behaviour reflects this. The experienced drivers, however, have by this analogy found the dual carriageway and the suburb to be the least demanding. This may be the case, though one could also posit that the reduced durations may be part of a compensation strategy to deal with the increased demands (Miura 1990) by reducing the time spent foveating any one location so as to sample more of the scene on the complex roads, a strategy which the novices have yet to develop on the dual carriageway. Consistent with this explanation is the result that the suburban route produced the most fixations.

These results are similar to the findings of other studies which have also shown decreased eye fixation durations when driving through increasingly demanding roadways. Several researchers have noted a decrease in fixation duration and an increase in the number of fixations when driving through a curve compared with a straight (Shinar *et al.* 1978, Zwahlen 1993), and others have noticed an inverse correlation between fixation duration and speed (Cohen 1981).

The notion of a compensation strategy is supported by the finding that experienced drivers also increased their visual search in both the horizontal and vertical planes on the dual carriageway. Along both axes the experienced drivers gave an extremely wide search on the dual carriageway relative to their search on the other roads, and compared with the novices' horizontal spread of search. The rural road produced the narrowest search in experienced drivers along the horizontal meridian, which may reflect the length of the fixations that this road evoked. Thus the theoretically least demanding roadway produced an extremely small search strategy which increased as the situation became more demanding.

The novice drivers did not vary the size of their visual searches along either the horizontal or vertical across the three roadways. They produced a similar horizontal search to that of the experienced drivers on the suburban and rural roads, while their vertical search resembled the experienced drivers search strategy on the dual carriageway. The novices adopted the restricted search of the rural and suburb roads for the dual carriageway, and conversely imposed the vertical search strategy of the dual carriageway upon the rural and suburban routes. Regardless of the level of demand that they pitched their strategies at, the important thing to note is that they did not vary this strategy across the three roads. In this sense, their strategies seem to be too rigid to be adapted to the differing demands of the roads.

This description of events suggests that novices may not have developed the flexible approach to viewing dynamic scenes required in the real world of driving. Instead of expanding their visual search to cover demanding roads they restrict it, and concentrate on the area of the scene that proves the most novel, dangerous or

simply hard to process. They basically take the search strategy of the pedestrian or static picture viewer, and transfer this to the driving situation. When reading text, viewing a picture, or even walking down a street, concentrating attention on particular stimuli may be a valid strategy to process them, though when travelling at 30 mph any form of attentional capture could be dangerous. The novice's longer fixation durations on the dual carriageway may represent a form of attentional capture. Traffic in front, travelling in the same direction, grabs attention as it is the most likely source of any requirement for evasive manoeuvres, and it is certainly possible that this situation might arise more on the dual carriageway than on the rural road, if not the suburban route also. Perceptual narrowing may also play a role. If the dual carriageway is highly demanding then the peripheral field may shrink. The reduction of peripheral and parafoveal preview would also increase fixation durations (Henderson *et al.* 1989).

In a similar type of study Shinar *et al.* (1978) found inflexibility of visual search to correlate with high field dependency. They discovered that subjects who had scored poorly on an embedded figures test were unlikely to change their search patterns between an undemanding straight road and a more demanding curve. The results led them to suggest that 'field dependent drivers tend to concentrate their fixations within a narrow field of view and move their point of regard across shorter distances between successive fixations. It is possible, therefore, that field dependent drivers develop a mild form of tunnel vision or reduced peripheral capabilities' (p.556). Here we are provided with a link between a reduced search space, an inflexible strategy, and a suggestion of perceptual narrowing. From these results we know that experience can also be added.

Another example of novices who have not yet learned the optimum search strategy for driving was the consistent difference reported between novices and experienced drivers with regard to vertical search, with novices producing a wider search than experienced drivers seem to deem necessary (Renge 1980, Evans 1991). It has been suggested that this reflects novices' lack of sensitization to the horizontal axis as the major source of information. However, this study has shown that under certain circumstances experienced drivers may increase their vertical search to a level comparable with that of novices, and thus it would be a mistake to condemn an expanded vertical search strategy as the sole property of the inexperienced driver.

One of the major difficulties in interpreting the complex findings is that different causes may have the same effect when using such coarse measures. For instance, the decreased fixation durations of experienced drivers on the suburban road and dual carriageway may be due to a need for situational awareness but at the moment it is impossible to separate the effect from the long fixation durations of the novice drivers on the dual carriageway which are presumably due to increased demands and a corresponding increase in processing time at the point of fixation. This is not an insurmountable problem, however. Retesting of subjects is planned which should separate the causes and effects as those due to difficulty in novice drivers diminish, and new strategies are established based on the optimal sources of information. The effects can be distinguished by charting their position in the learning curve, as novice drivers replace ineffective strategies with those of the experienced drivers.

Similarly, it is difficult to interpret these findings in terms of perceptual theories, such as perceptual narrowing, due to the confounding of effect and compensatory strategies. If one believes that perceptual narrowing may occur in the driving situation then the effect would be most pronounced in novices as they are at the

lower end of the learning curve and may view the scenes as more complex. But what of the experienced drivers? One could imagine a decline in perceptual narrowing as experienced drivers become more comfortable with the visual elements of the driving task, but equally one could imagine strategies designed to overcome the limitations of this degradation of the peripheral field. The reduced fixation durations of the experienced drivers on the dual carriageway may represent ease of processing which would argue against perceptual narrowing as a reduced peripheral field would remove the preview of subsequent fixation locations resulting in increased durations (Henderson *et al*. 1989). Alternatively it may be a response to a diminished peripheral field, such as a strategy whereby objects in the scene are processed only in part to maintain a dispersed sense of situational awareness.

Acknowledgements

The UK Department of Transport and the UK Driving Standards Agency provided invaluable help in giving access to the recently qualified drivers. We are indebted to Ivan Brown and Peter Chapman for their help with the interpretation of the results presented here.

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