Driving Experience and the Acquisition of Visual Information

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The trouble with research is that it tells you what people are thinking about yesterday, not tomorrow. It's like driving a car using only the rear-view mirror.

-- Bernard Loomis

Report writing, like motor-car driving and love-making, is one of those activities which almost every Englishman thinks he can do well without instruction. The results are of course usually abominable.

-- Tom Margerison

Wing mirrors are like cat's whiskers. If they bend, you can't get through.

-- anon

Table of Contents

Abstract

The research presented in this thesis was initially motivated by the excessive accident rates for inexperienced drivers. Researchers have previously attempted to discover what type of experience is gained during driving, and how this reduces accident liability. This research was primarily concerned with the visual acquisition of information during driving, and how this ability varies with driving experience.

The first experiment was conducted to assess which of two methods was the better suited to the assess the hypothesis. The results favoured eye tracking drivers in both the laboratory and while actually driving in the real world. On this basis experiments 2 and 3 were conducted. Experiment 2 required participants to drive along a set route while being eye tracked, while experiment 3 measured the eye movements of participants as they watched driving videos in a laboratory hazard perception test. The former experiment revealed experiential differences that extended the findings in the literature. The latter experiment revealed very few experiential differences however. The failure of the hazard perception test to evoke such differences was discussed in regard to the limitations of eye tracking methodology. If experienced drivers have less accidents than their inexperienced counterparts, then one would expect differences to occur in their search strategies. However, if the differences between drivers of varying

experience lie within peripheral rather than foveal vision, the straightforward measuring of eye movements may not reveal the true differences. On the basis of the results so far and the literature, it was suggested that experience may allow greater deployment of attention in the peripheral field.

Three artificial experiments were undertaken to assess the relationship between foveal demand and eccentricity, before returning to the driving context. In the two final experiments participants of varying driving experience watched the same hazard perception clips previously used in experiment 3. The primary task was either to rate each clip along the dimensions of danger and difficulty, or to press a foot pedal in response to the appearance of a dangerous event. The secondary task required participants to press a button whenever they saw a peripheral target light. Peripheral detection ability was found to degrade with increases in foveal demand (the appearance of a hazard in the hazard perception clips) and eccentricity. Of most importance however was the effect of experience. As drivers gain experience they are able to devote more attention to the peripheral visual field, though the appearance of a hazard degraded peripheral attention across all eccentricities and levels of experience. A detailed analysis of the time line of degradation revealed that though the experienced drivers suffered a greater degradation of peripheral attention with the appearance of a hazard than the less experienced participants, this degradation occurred for only a split second. Learner drivers however suffered the effects of this demand-modulated degradation of peripheral attention for over two seconds. Together these results provide evidence for an attentional skill that modifies the timing and magnitude of attention focusing due to an increase in foveal demand. This is a skill that seems to be learned with driving experience. The implications of these results to pure attention research and driving research are considered.

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Though he refused to mark it on ethical grounds, he did leave me with the memorable comment, "You'll have to wait until university before you can do studies like that."

Declaration

I declare that this thesis has not been presented, in this form or any different form, to this or any other university in support of an application for any degree.

Signed,

D. E. Crundall

Chapter 1. GENERAL INTRODUCTION:
The case for differences in visual acquisition according to driving experience.

1.1 A brief introduction to the psychology of driving

This thesis is concerned with the identification of experiential differences in the visual acquisition of information during driving. The first chapter addresses the initial questions of why one should study driving, why experiential differences in visual information acquisition are of importance, and what evidence there is to suggest that these differences exist. The other chapters detail a series of experiments which range from a real world, applied study of driving, to context free laboratory experiments. A more detailed description of the structure of this thesis is presented at the end of this chapter.

In the course of the forthcoming chapters it is hoped that this thesis will explain something of the both theoretical and applied aspects of this research, as it describes the attempt to distinguish between participants with varying driving experience in regard to the visual acquisition of information.

1.1.1 What is so interesting about driving?

Over the past fifty years driving has become a fundamental aspect of everyday life. In the UK it has been calculated that over three quarters of the distance we travel in a year is by car. The length of the average journey has increased by 22% over the last decade from 5.2 miles in 1985-86 to 6.3 miles in 1995-97 (Focus on Personal Travel,1998). Not only is driving undertaken more often and for longer journeys, but the number of license holders is also on the increase. Over thirty seven and a half million people in the UK hold a license (including provisional). This is roughly 68% of the population of the UK, yet in the period 1975-76 this percentage stood at only 48%. The age band which has seen the greatest increase in the percentage of licenses per individuals is the 17-20 age group. In 1975-76 only 28% of 17-20 year olds held licenses. In the period of 1995-97 however it was calculated that 42% of the age group held a provisional or full license (Transport Statistics Great Britain, 1997; Transport Yearbook, 1999). Over the years the ubiquity of the motor car and other forms of road transports has increased steadily.

Not every driving related measure has increased however. For instance Table 1.1 shows the increase over time in the use of licensed motor vehicles and the length of the journeys made. It can be seen however that there is no noticeable increase in the number of hours traveled. This has been reported to reflect a different underlying increase, that of chosen driving speed. As cars have become faster, and roads have become safer, and the perception of the safety of cars has improved (through the inclusion of air bags, ABS, etc.), so the average person tends to drive faster.

Year	Miles per person per year	Journeys per person per year	Average journey (miles)	Hours traveled
72/73	4476	956	4.7	353
75/76	4740	935	5.0	330
85/86	5317	1024	5.2	337
89/91	6475	1091	5.9	370
94/96	6570	1057	6.2	358

Table 1.1. Increases in the amount of driving done in the UK (adapted from Transport Trends, 1998)

As traffic density and speed increase one would expect the number of reported accidents to increase also. However averaging over accidents of differing severity for the decade 1986-96 reveals a constant level of just over 300000 accidents. In 1997 there were 320302 road accidents where an accident is defined as involving injury to one or more people. These accidents resulted in 3598 directly related deaths (Transport Statistics Great Britain, 1997). The maintenance of a steady accident rate in the face of increased traffic volume, is more than partly due to Government policies. In 1987, the UK Government set the target of trying to reduce all UK road accident casualties by a third, compared to the levels reported from the period 1981-85. In some cases these policies have achieved impressive reductions. Though 3598 deaths on the road for 1996 is still unacceptable, the number of deaths in 1986 was 5382. Similarly, the combined category of casualties Killed or Seriously Injured (KSI) was reduced from 74134 in 1986 to 48071 in 1996 (Transport Statistics Great Britain, 1997). Despite these improvements in accident rates, the numbers of slight accidents over the same period increased by 60% (Wilding, 1999). The cumulative effect of these changes in accidents rates has resulted in a fairly stable number of accidents over the decade in question despite the increase in traffic. More impressively however, these accidents have also become less severe. Since the 1987 initiative to reduce accident rates drivers have witnessed the enforced fitting of rear seat belts in new cars (1987), the closing of emergency crossing points on motorways (1987), an increase in penalty points for various driving offenses (1989), the introduction of 20 mph speed limit zones (1991), the introduction of the Traffic Calming Act (1992) and speed cameras (1992), an extension to the MOT test (1993), and the introduction of the new theory test for learner drivers and motorcyclists (1996). There have also been many more policies that have had lower profiles, and a number of high profile television campaigns such as the "Kill your speed, not a child" campaign that was initially launched in 1992, and was subsequently re-launched in both 1994 and 1996 (Road Accidents Great Britain, 1996). In conjunction with improved safety in vehicles brought about by the motor companies (such as the inclusion of airbags), though the absolute number of accidents involving injury has not been reduced, the chances of surviving a crash, and sustaining only slight injuries have been greatly improved.

The average cost of an accident regardless of severity is £41900. This rises to a staggering £983710 when only considering accidents that involve a fatality (Road Accidents Great Britain, 1996). Despite the reductions that have been achieved so far the cost of accidents on UK roadways, both in financial and human suffering terms, still remains unacceptably high. The Government acknowledges this and is currently in the process of setting new accident rate targets for the year 2010 (Transport Yearbook, 1999).

It is this conjunction between the importance of the motor car in modern society and the inherent risk and resultant cost, that motivates most psychological research in this area. In addition to this however, driving research offers the opportunity to investigate an extremely complex set of sub skills which can begin to link together the reductionist, context-free studies of theoretical psychology, into an understanding of a complex, applied behaviour.

1.1.2 The model driver: factors that contribute to accident liability

Much of the research undertaken in driving psychology has, either explicitly or implicitly, the underlying motivation to make driving safer. This is operationalised in explicit studies as an attempt to reduce the accident liability of drivers. Accident liability is defined as the expected frequency of a driver's involvement in accidents over a given period of time (Maycock & Lockwood, 1993). When accident statistics are broken down across different categorisations of drivers, consistent over-involvement is noted for certain groups. This has led to the suggestion that there may be underlying psychological processes that make one group more vulnerable to accidents than another. Figure 1.1 shows a graph of fatal casualty rates per 100000 people across differing age bands. An exceptional casualty rate was recorded for car drivers between the ages 17 to 19 years old. This peak is repeated when considering accidents of all severity, rather than just fatalities. What causes this accident peak? Is it age, experience, or a youthful need for speed?

In order to hypothesise what underlying processes may cause different groups of drivers to be prone to accidents one must first have a theory of the components that constitute accident liability. In a recent model proposed by Gregersen and Bjurulf (1996) it was suggested that there are three areas which influence an individual's accident liability (see Figure 1.2). These were concerns of (a) the individual, such as demographics and personality, (b) the social situation, such as the effects of social norms upon driving, and (c) learning, which is comprised of teaching, training and experience.

With regard to demographics and personality it is well documented that young males are most at risk of an accident (e.g. Maycock, Lockwood & Lester, 1991; Cooper, Pinili, & Chen, 1995). Other factors such as "sensation seeking" (Moe & Jenson, 1990), social deviance (Elander, West & French, 1993), smoking, drinking and lack of sleep (Beirness & Simpson,1991), and even car preference (Rolls, Hall, Ingham & McDonald, 1991) are just a few of the individual and social influences that have been linked to accident liability.

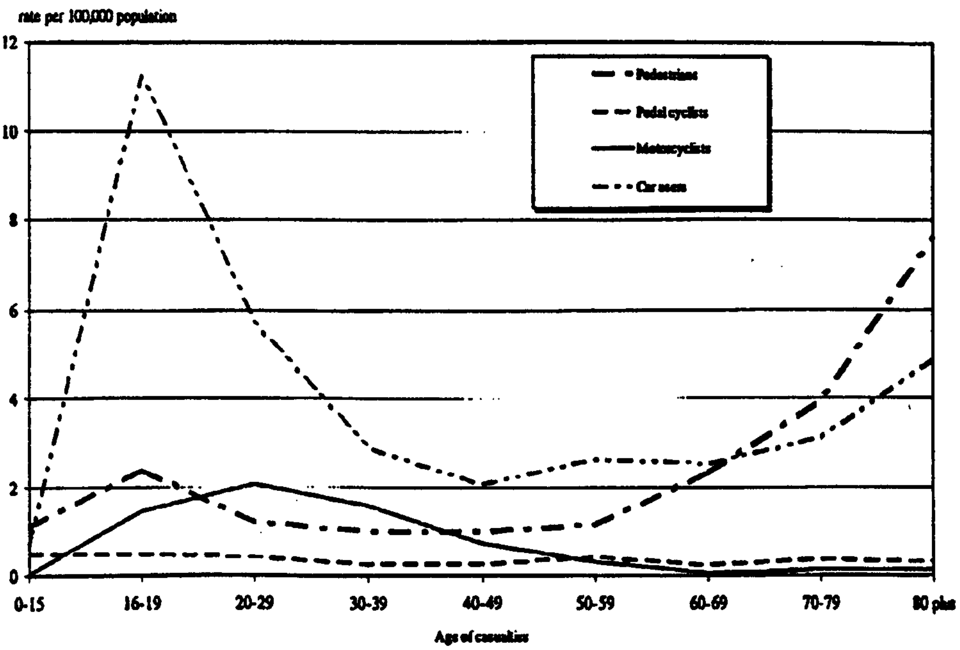

Figure 1.1 Fatal casualty rates, by age band and road user type for 1996 (Road Accidents Great Britain 1996)

The model of Gergersen and Bjurulf also allows accident liability to be influenced by a number of items subsumed under the heading "learning". One of these items is driving experience, and it is with such experience that this thesis is concerned. Driving experience can cover many areas however, and according to Figure 1.2 can affect accident liability through diverse routes such as automisation of tasks or the use of conscious knowledge. The particular area of skill which is examined in this thesis is the visual acquisition of information during driving. Specifically the rest of this chapter will focus upon the evidence for a general hypothesis that the acquisition of visual information during driving is a skill that varies with experience. This

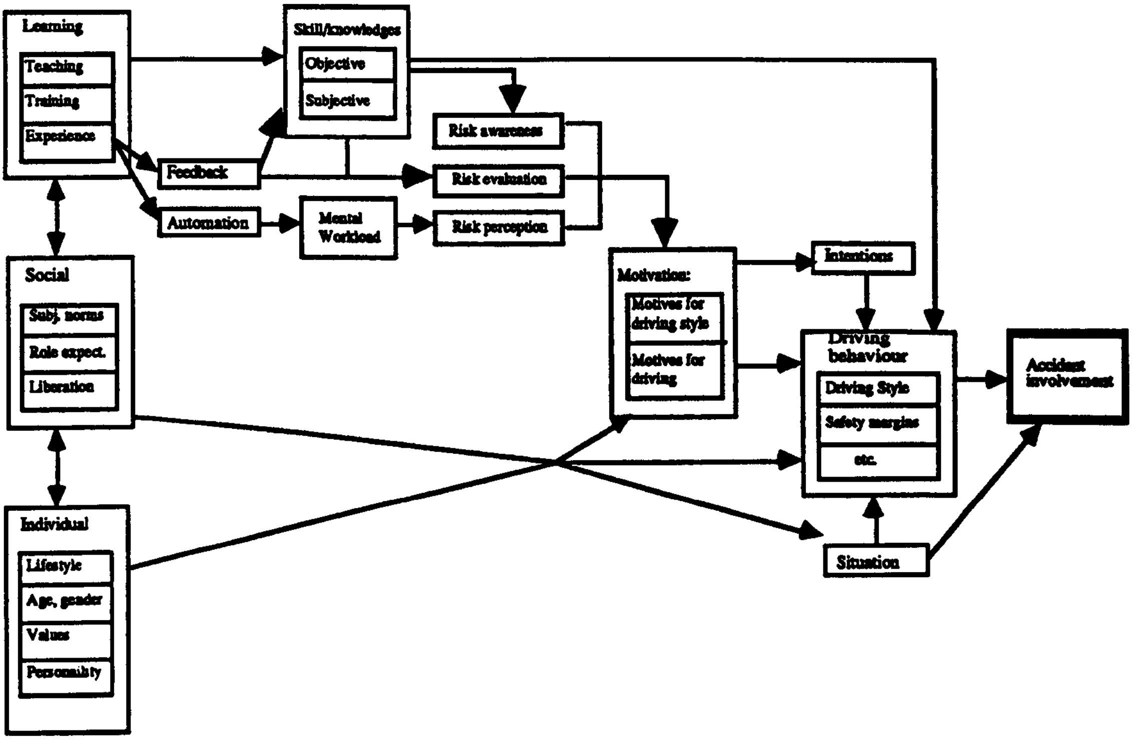

Figure 1.2 A model of a driver's accident liability (Gregersen & Bjurulf, 1996)

carries with it the assumption that experience in gathering visual information pertinent to driving is linked to accident liability. This assumption will be also discussed with reference to the current literature. It is generally hoped that if researchers can gain an understanding of the underlying mechanisms which are optimised through experience, then we could be hopefully some way closer to reducing the accident liability of those who lack the experience necessary for optimal visual acquisition. This is just one small aspect of only one of the contributing factors to accident liability mentioned in Figure 1.2, though this should hopefully add to the understanding of the driver as a complete system. When all components of accident liability are fully understood we should have the knowledge to reduce the accident liability of all drivers. This grandiose aim is unfortunately outside the bounds of this thesis, though it is hoped that the application of theories of perception and attention will lead to a greater understanding of experiential differences in visual inspection of dynamic scenes while driving.

1.2 The varieties of driving experience and its role in accident liability

With regard to Gergersen and Bjurulf's model of accident liability, experience plays an ostensibly small role. Age, attitudes and social norms have a more high-profile link with accident liability. All of the road safety campaigns targeted at drivers are directed toward social and personality factors. This does not mean that the Government or other interested parties are unaware of the need for experience in driving. The inclusion of the theory test to the driving test (1996) is part of the Government's commitment to ensuring the high driving standards of those who pass. In the private sector, the British School of Motoring are currently equipping all of their offices with driving simulators. However it would be an error to marginalise the influence of general driving experience before or after licensing.

One problem with the factor of experience is that it is usually confounded with age. Figure 1.1 showed a large increase in accident liability for a group of drivers that are both young and inexperienced. Studies have been conducted however which have managed to tease the two apart. One example is that of Maycock, Lockwood and Lester (1991) who found that though the initial risk in a group of novice drivers decreased by 31% due to age factors in the first few years, there was a 59% decrease due to experience. The definition of a novice driver usually refers to drivers who are within one year of passing their test, though stricter definitions may limit this to three months after passing. Other researchers (e.g. Spolander, 1983) have noted that the ratio of accidents/mileage decreases as mileage increases. Though experience is obviously correlated with age (Quimby & Watts, 1981), Gregersen and Bjurulf 's review of the literature in this area concluded that "it seems clear that experience is of greater importance than age" (p231).

Examples of experiential differences vary from strategic to tactical levels. Miltenburg and Kuiken (1991) suggested that strategic differences may be mediated by the quality of relevant scenarios stored in memory. They suggest that such scenarios, or schemas, are accessed from memory when a similar situation is encountered in the real world. This allows the driver to predict what may happen in a certain situation and which areas of the visual scene require the most sampling during visual search. Evans (1991) suggested one such schema that would be modified through experience. He stated that experienced drivers will modify their behaviour on the approach to a set of traffic lights on the basis of how long the lights have remained on one colour. For example, if the experienced driver has had a long preview distance and has noted that the lights have stayed red during the approach, she is less likely to slow down than if the light changed to red during the approach. General driving experience and knowledge of the particular junction help to form the driver's opinion that it is not necessary to brake. The speed of the car, the distance to the traffic lights and the length of time they have been red suggest that the lights will turn green before she reaches them.

Tactical or control-level, differences were found between drivers of differing experience by Quenault and Parker (1973). They compared age-matched groups with varying levels of experience (from one week to one year after passing the driving test) and found a general increase in car control with experience. When compared to a highly experienced group of drivers, the novices were noted for the more errors and near accidents. Support for experience influencing car control was reported by Michels and Schneider (1984), who also noted that inexperienced drivers showed greater inattention to the visual scene. Other behaviours that have been linked to experience include headway (the distance between one's vehicle and the vehicle in front) and hazard perception (the detection of hazardous or potentially hazardous elements within a driving scene). With regard to the former, Evans and Wasielewski (1983) found that young, inexperienced drivers tended to allow less headway between themselves and other traffic, while poor hazard perception scores on video or simulator based displays have also been linked to novice drivers (Quimby & Watts, 1981; McKenna & Crick, 1994). In one study of hazard perception ability in which age was controlled, Ahopalo (1987) found that the speed of response times to potential hazards in participants with a median age of 24 varied according to whether they had under 10000 miles experience or over 40000 miles.

From the studies reported above one can note the variety of driving behaviours that can be modified by experience, and that such skills seem to be linked with the risk of accidents (e.g. Maycock et al., 1991). There is a subset of skills however that have been barely touched upon in the preceding discussion, yet the domain of these skills is one of the most important in driving. These are the skills involved with visual information acquisition. The next section will discuss the importance of visual skills in the driving task, and the evidence that such skills change with experience.

1.3 Experiential benefits in visual information acquisition during driving

It is an oft quoted statistic that over 90% of all information in the driving task is visual (Gioia & Morphew, 1968; Rockwell, 1972). Though this unfortunately does not reflect the proportion of driving research devoted to vision, there has still been a continuing research effort over the past three decades in this area.

Eye movements have long been regarded as a useful tool to help probe the cognition that underlies many behaviours. The search pattern of fixations has been described as a 'window on cognition' (Yarbus, 1967). The assumption is that this will lead to a better understanding of the driving task, not simply at a visual input level, but also at a higher level with regards to the underlying saccade programming processes, and ultimately the cognitive processes which direct our search strategies (Cohen, 1981). Research so far has linked search strategies and fixation patterns of drivers to accident avoidance (e.g. Quenault, 1967; Staughton & Storie, 1977), level of perceptual processing demand (Shinar, McDowell & Rockwell, 1977;

Zwahlen, 1993), age (Mackworth & Bruner, 1970), and experience (Mourant & Rockwell, 1970, 1972; Cohen & Studach, 1977).

If the evidence suggests that visual strategies play a part in determining the risk of an accident (and the relationship between experience and extraction of visual information from a driving scene is accepted), then one avenue that researchers could take would be to train inexperienced and learner drivers to emulate the visual strategies of their more experienced counterparts. The following sub-sections will assess the evidence for experiential differences in visual acquisition, and also address the link with accident liability.

1.3.1 The evidence for visual skills that change with driving experience

The most cited studies of experiential differences in visual search strategies are those of Mourant and Rockwell (1970, 1972), with the earlier study acting as a pilot for the larger study that followed. In the 1972 study six 'novice' drivers were recruited and tested at three points in their learning curve: before they had any driving experience, at a half way point through their driving course, and just after they had completed the course. Four experienced drivers (with neither ticket or insurance blemish) were also tested. Two routes were used (suburban and freeway), each with a number of sub-tasks such as an approach to traffic lights on the suburban route, and lane changing on the freeway. The participants performed all the drives while wearing a head mounted eye tracker. The eye tracker used a corneal reflection to record eye movements in a similar fashion to the Nac VII eye tracker which is explained in more detail in Section 2.3.3.4.

The results showed little of interest between the various subtasks, though they did discover a number of differences between the visual search styles of the two groups. Their main results suggested that the novice drivers tended to search a smaller area of the visual scene, and that the locus of this area on the suburban route was nearer to the car (lower in the visual field) and further to the right than that of the more experienced drivers. The search area of the novices actually *decreased* as training progressed. The smaller search area of the novices was said to reflect detailed examination of specific elements in the visual field; an examination which the experienced drivers no longer needed to do as their familiarity with the typical driving scene rendered much of the information redundant. As an explanation for the different locus of attention, Mourant and Rockwell suggested that the novice drivers were excessively sampling the edge of the curb near the car in order to maintain lane position. This is supported by their 1970 study which reported that novices tended to view lane markers close to the car while the more experienced drivers looked further ahead of the vehicle.

On the trials which retained mirror usage as a variable it was noted that experienced drivers used both the rear view and driver's side mirror more often than the novices, though this situation was reversed with regard to glances at the speedometer. Mourant and Rockwell attempted no discussion of the use of mirrors, but in regard to the speedometer differences they suggested that the experienced drivers were "more skilled in its use" (p332). Presumably by this they are referring to the experienced drivers' automatisation of sub-routines which involve decisions on the basis of speed. For example, inexperienced drivers who have not automatised gear changing may still look at the speedometer for an indication of when to change up or down. More experienced drivers however may use a combination of other factors (such as the sound of the engine, the expansion rate of an image of the retina, or the speed of optic flow) which have been fully compiled into an automatised routine.

A further finding was that only novice drivers engaged in pursuit fixations. These fixations occur when the eye attempts to maintain the position of a stimulus on the retina while it is moving in relation to the observer. This results in a slow movement of the eye across the visual field while still foveated on a particular object. When the observer is moving, the stimulus could be a stationary part of the scenery. In this particular case Mourant and Rockwell reported that 70% of pursuit fixations were on lane markers or road edges, again suggesting that novice drivers have a greater need to foveate sources of information for lane maintenance.

From these results Mourant and Rockwell concluded that the novice drivers' visual skills did not approximate to those of the more experienced drivers, even after extensive training. They suggested that this may in part be due to "psychomotor feedback loops [which relate] vehicle changes in direction and velocity to control movements [which] may take more time to develop into perceptual reflexive responses than is generally realised" (p334). An alternative interpretation was that the novices could not use peripheral vision to the extent of experienced drivers. Novices foveated a lot of information such as lane markers which the experienced drivers may have taken in through peripheral vision.

Despite the lack of understanding behind these differences, and the fact that only ten participants were used, these results are commonly held as the cornerstone of all research on vision in driving. Other investigations have partially supported the conclusions drawn by Mourant and Rockwell. Mourant and Donahue (1977) found novice drivers to use their mirrors less, while Summala, Neiminen and Punto (1996) found novice drivers to have poorer peripheral vision than experienced drivers.

Equally however there have been studies which question Mourant and Rockwell's results. One such study was conducted by Miltenburg and Kuiken (1991). They tested four groups of drivers with varying levels of experience (novices, inexperienced, experienced and highly experienced drivers, with time since passing the driving test and subsequent mileage increasing across the groups). They were tested on a number of routes with a variety of sub-task measures such as the fixation durations upon a particular stop sign. Their three main hypotheses were that (a) fixation durations decrease with experience, (b) time taken to fixate relevant stimuli would decrease with experience, and (c) that novice and inexperienced drivers would focus attention closer to the car. The evolution of these hypotheses can be traced from the findings of Mourant and Rockwell. However the results of Miltenburg and Kuiken were too inconsistent to suggest acceptance of any of the hypotheses. The majority of the analyses failed to reveal any significant results, while those that did were either sporadic or in the opposite direction to that predicted (the more experienced drivers were found to be actually slower to fixate some relevant stimuli in the road scene). Unfortunately this promising study was undermined by a large amount of missing data replaced with group means and high within-group variance which render all findings suspect. Furthermore, the concentration upon individual sub-task items reduces the generalisability of the results. If experiential differences are found on the fixation durations upon one stop sign but on nothing else, then this tells us little of interest.

A further study of experiential differences, which does not quite follow the mould of Mourant and Rockwell's earlier findings and speculations, was conducted by Cavallo and Laurant (1988). They wished to discover the main factors behind the estimation of time-to-collision (TTC). Twelve experienced drivers and 12 'beginners' participated in the study. Participants were seated in the passenger seat of a car and had to make a TTC estimate concerning an obstacle ahead. As the driver approached the obstacle a photoelectric cell automatically closed the visor on a helmet worn by the passenger. From the prior visual input participants then had to judge the TTC with the object.

Amongst their findings Cavallo and Laurant noted that though both beginners and experienced drivers constantly underestimated the TTC, experienced drivers were significantly closer to the actual times. Their explanation for this effect was concerned with the respective safety margins that the participants chose based on a self assessment of their own skill. Equally however this effect could be derived from a demand characteristic of the situation: the beginner drivers know that crashing is worse than stopping short of the obstacle, and due to anxiety at being negatively judged by the experimenter, they may choose the safer option of an early response rather than later. With this explanation participants do not need to self assess their abilities and create the appropriate safety margin. Instead they are merely responding to the social situation in which increased anxiety due to an acknowledged inferior status leads to social inhibition and a strategy of erring on the cautious side.

A harder effect to dismiss in the Cavallo and Laurant study however, is the marginally significant interaction between the available visual field and driver experience. In the restricted visual field condition the participant's helmet had been modified to only allow ten degrees of visual angle, while in the control condition a full visual field was allowed (until the visor closed automatically). Only the beginners benefited from the full visual field, though performance still failed to reach that of the more experienced drivers.

Cavallo and Laurant concluded that experienced drivers no longer need to use peripheral vision for speed estimation and instead rely on a single check of distance estimation (possibly on the basis of the expansion rate of the image on the retina). This contradicts the conclusions of Mourant and Rockwell (1972) and later studies on peripheral vision in driving (Summula, Neimen & Punto, 1996) which suggest that experienced drivers excel over less experienced drivers in the use of the peripheral field.

The few studies discussed here point to definite experiential differences in visual information acquisition in drivers. Even Miltenburg and Kuiken (1991) found some effects that they could not easily account for. However, the results are not consistent and the methods often differ widely. It seems that experience does modify visual skills, though the precise nature of this relationship is controversial.

1.3.2. The link between visual information acquisition and accident liability

The previous section has reported on the evidence for differences in visual search strategies across drivers according to their level of experience. As an academic theory in an applied domain this in itself is worthy of study. However, if novice drivers are over-represented in the accident statistics, and this difference persists even after partialling out the other factors that Gregersen and Bjurulf (1996) detail in their model (such as the social pressures and norms placed on young drivers), then it is a very short theoretical jump to suggest that experiential differences in visual acquisition may play a role in the accident liability of the novice driver. Though little research has addressed this possible link between experience, visual perception and accident liability directly there is evidence for a definite link between perceptual errors and road accidents. This section will briefly review the findings in this area and assess the possibility that perceptual errors can account for a large proportion of non-alcohol related accidents. If this is the case then the role of experience in this relationship becomes all the more probable.

One early classification of the causes of accidents was undertaken by Nagayama (1978). The main causes of 38625 accidents were placed into categories. Fifty four percent of the accidents fell into the category of visual perception errors. Within this category, 21.6% of the accidents were reportedly caused by the driver failing to notice the source of the collision, or being occupied with other things in the visual scene. These findings are supported by a similar study from Australia (Cairney & Catchpole, 1991).

Visual scanning patterns have also been linked to accident avoidance (Quenault, 1967; Staughton and Storie, 1977), and experience in driving has been found to be related to the number of potential hazards that can be spotted and identified in the visual driving scene (Renge, 1980). Koornstra (1993) pointed out that though the link between road accidents and visual perception problems is accepted in driving research, the majority of research within the area was lacking in relevance to the driving scenario. Koornstra argued that static viewers, responding to static stimuli, were not relevant to the safety of drivers, and though more relevant experiments with both dynamic stimuli and perceivers are on the increase, he urged more research in this area. This issue is discussed further in Chapter 2.

1.4. Thesis overview

The previous sections have outlined the need for psychological research into driving on the basis of reducing accident liability. Though not all psychological research explicitly states this as the prime motivation, the ultimate and sometimes implicit aim of most driving research is to add to the corpus of data in the hope that this will aid others in the reduction of road accident casualties. It was also pointed out that driving research provides an excellent opportunity to transfer theoretical hypotheses formed under laboratory conditions, to a context-rich, applied setting.

It is hoped that this thesis will provide information on experiential differences in the visual acquisition of information that may ultimately help in the reduction of accident liability. Furthermore it is the intention to achieve this aim through the employment of theory rather than mere exploration and post-hoc explanation. Specifically this thesis should ideally pin point skill differences between participants with varying levels of driving experience. Once identified these differences can be added to the massing data that feeds into the typical models of driver accident liability (such as that by Gregersen & Bjurulf, 1996), and hopefully provide future researchers with one more building block in their efforts to reduce accident liability. Hopefully an understanding of these results will be achieved through the attempt to relate psychological theories to the underlying differences that are identified, and to design experiments on the basis of theoretical hypotheses and the experiential differences that are identified.

1.4.1 The structure of this thesis

The research that is reported in this thesis ranges from an applied, on-road study that was conducted around the city of Nottingham, to a series of simple laboratory studies that were designed to test a specific, context-free theory. Chapter 2 discusses some of the methodological issues in driving research and presents an experiment designed to identify which of two methods would provide the better data. Chapter 3 then reports two large scale experiments that were exploratory in nature, looking for experiential differences in visual information acquisition in both the laboratory and on the road. On the basis of some of the effects found in chapter 3 (and also on the basis of the absence of certain effects that were expected) a theory was developed from previous research on spatial attention. Chapter 4 details a series of short experiments based upon the theories of spatial attention, that demonstrated a demand modulated degradation in attention given to extra-foveal stimuli. Once this had been achieved in a context-free setting, it was decided to return to the driving context and to develop a driving experiment based upon the theories and findings in chapter 4, relating to the extent of the deployment of attention in the peripheral visual field. The resultant studies are detailed in chapters 5 and 6. In the chapters 3 to 6, the experiments describe the attempt to first identify experiential differences (chapter 3), then to test an appropriate theory in order to identify the basic effects in a context-free situation (chapter 4), and finally to integrate theory and experiential differences in order to understand something of the underlying processes (chapters 5 & 6). The success of this attempt is reviewed in the concluding chapter 7.

Chapter 2. EXPLORING THE TOOLS OF THE DRIVING RESEARCHER:

Research and discussion on the methods used in contemporary studies.

2.1 Introduction to methods

The initial aim of this thesis was to identify potential differences between drivers of differing experience in visual acquisition of information. In order to achieve this first aim, decisions had to be made in regard to the type of method to be used. As with many other domains, both theoretical and applied, several research paradigms exist even within the relatively small area of vision in driving.

At the start of this research there were several design questions which needed to be carefully addressed before committing to one particular methodology. As driving research is often both expensive and time consuming, effort put into identifying the most fruitful method of conducting research at the start of a project is often repaid later. This chapter will focus upon two questions of methodology that were most pertinent to this project.

The first question asks in which medium the driving task should be represented. The clearest distinction between media is whether to observe participants in the real world and record behaviour while actually driving, or whether to use a safer, reductionist approach, based in the laboratory. A review of the literature was conducted and a discussion of the merits and flaws of each approach is presented below.

The second question asks how visual information acquisition of drivers should be recorded. A number of indirect methods were considered and dismissed. This left two main contenders: concurrent verbalisation (Renge, 1980; Cole & Hughes, 1984; Hughes & Cole, 1986a) and the use of eye tracking technology (Mourant & Rockwell, 1970, 1972; Cohen 1981; Land & Lee, 1994). Discussion of these two alternatives is included in the sections below, along with the results of an experiment that was conducted to assess whether the cheaper technique of concurrent verbalisation could produce results as useful as the more expensive eye tracking systems.

2.2 Which medium should be used?

2.2.1 Whither lab or car?

Before discussing evidence from both the laboratory and from on-road research there are a number of theoretical, ethical, and practical points that should be raised.

With regard to theoretical considerations the laboratory approach allows precise manipulation of variables, and ultimate control within a reductionist environment such that causal conclusions can be drawn. With this approach many researchers attempt to break down complex behaviours into such small component tasks that the participants may not notice the relation between the experimental task and the behaviour under investigation. One example comes from the work of Williams (1995) who attempted to find attentional differences on a simple letter/digit identification task between participants with varying levels of experience in aviation. The relationship between the experimental task and the act of flying was extremely tenuous yet Williams did find aviators to perform better than non-aviators. This led Williams to conclude that as one learns to fly, certain perceptual skills are developed that can be detected on a simple letter/digit task. Despite the precision of the laboratory, there is however a balance that needs to be struck between the level of control one has over variables, and the ecological validity of the stimuli and generalisability of the results.

Ethically one must also consider the risk to both the general public and the participants if a study is to be conducted in the real world. Some studies have employed a secondary task that participants attempt while driving among normal traffic (Lee & Triggs, 1976; Miura, 1990). The majority of models of attention, from the early single channel models (e.g. Broadbent, 1958) to the latest conceptions of the spotlight (Lavie & Driver, 1996), recognise that attention has a limited capacity. The use of a secondary task may therefore reallocate attention away from the primary task of driving, increasing the risk of an accident. Studies that do not involve any secondary task may still run a higher risk of an accident, as the mere presence of an observer in the test vehicle may lead to social inhibition. Early studies in this area suggested that participants who were well practiced and confident with a particular behaviour benefited from a passive audience. Conversely, participants who were unpracticed tended to do worse (Zajonc, 1965). Thus placing a nervous participant into a new car with an experimenter (whose prime responsibility - as far as the participant is concerned - is to make value judgements on the quality of the driving) may lead to a deterioration of ability, increasing the risk of an accident. This possibility may be of especial concern if one is testing inexperienced drivers.

Practical considerations stem partly from the ethical points raised. If an experimenter deems that the risk of placing drivers among real traffic while performing a secondary task is too great, then alternate arrangements need to be made. In the case of Summala, Nieminen and Punto (1996) they used an enclosed military road to test their novice and experienced drivers under varying secondary loads. Other potential closed routes include runways or motor racing circuits, while researchers in the UK can obtain access to a specially designed closed loop circuit which belongs to the Transport Research Laboratory (TRL). As well as reducing the ecological validity of the driving task, there are often problems with the expense and availability of such sites. The cost incurred in hiring a test circuit is compounded by the expense of creating a test vehicle that usually needs to be instrumented in order to record various elements of the driving task.

Of the three issues raised only the theoretical considerations can be addressed through experimentation. Previous research has compared the benefits of testing in the real world and testing in the laboratory. Evidence from particular studies will be considered in the following sections.

2.2.2 Comparison studies of field and laboratory media

One particular area of driving research that has compared results of studies undertaken in the real world with those of laboratory experiments was investigated by Hughes and Cole (Cole & Hughes, 1984; Hughes & Cole, 1986a). This involved manipulation of the conspicuity of targets along the roadside. The first on-road study is discussed below, and is then compared to the later laboratory experiments that were designed to replicate the findings of the earlier study.

One of the earliest attempts to quantify conspicuity was undertaken by Engel (1971). He suggested that the maximum distance from the fixation point at which a target was still noticed could be used as the conspicuity measure for that target. The general assumption was that this measure of conspicuity would reflect the ability of a particular target to attract attention. Cole and Hughes (1984) refined the definition further by distinguishing between attention conspicuity and search conspicuity in their study of visual attention while driving. They suggested that attention conspicuity was the traditional power of a target to attract attention, while search conspicuity reflects how easy the target is to find when it is actively searched for. Fifty participants drove a 22 km route that contained 35 reflective target signs at varying intervals. There were five different sign types assigned randomly for each participants' drive across the 35 locations. The types of sign differed in their reflectivity and size, though as these factors are irrelevant to the discussion at hand they will not be mentioned further. The participants were either told to verbally report anything that they paid attention to while driving, or to verbally report any target signs that they saw on the route. The latter condition was designed to measure the search conspicuity of the targets (by priming the participants to look for the signs), while the former measured attention conspicuity. In this field study they found that participants were three times more likely to report a target sign in the search conspicuity condition.

In a follow up study Hughes and Cole (1986a) reported three laboratory based experiments that attempted to reproduce the findings from the earlier, on-road study. Two of the studies involved tachistoscopically presented slides of the roads used in the original study (with and without target signs). In the first experiment the slides were displayed for 1500 ms and participants were asked to give verbal reports according to the two types of conspicuity instructions. The second tachistoscope study had a display time of only 250 ms so as to discourage eye movements. In this experiment participants had to fixate the center of the slide and report whether a target sign was present, and if so whether it was to the right or left of fixation. A third experiment used a 16 mm film of the test route. Participants in this study were given the same instructions that were given in the on-road study and the first tachistoscope study.

Analysis of the results showed that the 16 mm film was the best medium for predicting target detection rates during driving, closely followed by the tachistoscope experiment which used 250 ms displays. The 1500 ms displays were the least predictive, most probably because they were the least like the real world display. The film captures the dynamics of the real world situation, whilst a 250 ms display could be said to represent a sample of what the participant would see in the real world with just one fixation. The 1500 ms display however is the most artificial departure from a dynamic, real world scene.

Though the film gave the greatest parallel with the real world data, it produced better results when predicting performance in the attention conspicuity condition than in the search conspicuity condition. Hughes and Cole suggested that this occurred because the degradation of the stimulus on film compared to the real world is less noticeable for attention conspicuity, primarily because this form of conspicuity is more likely to make use of peripheral vision. As the peripheral field has greatly degraded acuity compared to the fovea, they argued that the reduced quality of the film may not actually decrease the quality of the image that is passed on from the retina to the occipital lobe.

The evidence from this study does seem to suggest that certain laboratory based tasks can emulate performance on similar real world driving tasks. However it should be noted that the conclusions of predictability from lab to the real world were not based on a regression analysis but on the lack of significant differences between the lab and field studies when analysed by Chi Square.

Earlier research using still images of driving scenes was conducted by Cohen (1981). He compared on-road eye movements with the search pattern obtained in a laboratory experiment with a slide displayed for five seconds. Data from both studies were recorded with a NAC III eye tracker. The scene depicted on the slide was chosen from the test route. During the drive the participants would make a left turn into a side street to be suddenly confronted with a crane in the middle of the road. To avoid the crane the drivers had to steer the car up a ramp onto the pavement to get past. The slide image was taken from the scene that presented itself to the drivers once they had immediately turned left into the blocked road. It was presented to participants for five seconds.

Results showed large differences between the lab and real world in terms of what objects in the scene were viewed and for how long. Unsurprisingly the participants in the on-road study tended to fixate the small ramp the most. Out of the six categories chosen by Cohen the crane was fixated for the shortest amount of time. Participants in the laboratory study however gave the crane the most of their attention.

From these results Cohen concluded that the slide did not accurately reflect the on-road performance. He suggested this was due to the lack of danger in the laboratory situation, which failed to shape participants' search strategies. Whilst driving, the focus of attention was tasked with ensuring a route around the obstacle (which required the driver to fixate the ramp). When participants looked at the slide however it seemed that attention was instead attracted to the visually salient objects such as the large, yellow crane in the center.

From these results Cohen argued against the validity of laboratory based driving studies. Koornstra (1993) also took up the argument against the use of static images presented to participants from the view point from a static observer. Koornstra regards such experiments as the least relevant studies in the driving literature in regards to the ongoing efforts to reduce driver accident liability.

The negative response to the use of static driving images may have been over-exaggerated however, at least in the case of Cohen's study. Two points need to be considered. First, participants were explicitly told to view the static slide as if they were going to attempt to navigate through it. However, as there was no requirement to interact with the slide, there could also be no motor feedback (or necessity for feedforward) to guide visual search over the five second recording period. For instance, visual information from the tangent point of a curve in a road has been found to provide information which feeds into the motor loop in order to maintain smooth steering around the bend (Land & Lee, 1994 - see section 2.2.3). The lack of interaction, which would have changed the scene from moment to moment in the on-road study, places totally different demands on the participants despite attempts to make instructions for the two experiments as similar as possible.

Secondly, the five second display would have altered the availability of objects in the visual scene. The crane was both visible and salient for the full five seconds of presentation of the slide, whereas in the on-road study, as the driver moved toward the ramp (to the left of the crane), the retinal image of the crane would have become more eccentric, less salient, and less available to fixate. It has already been noted that as the presentation time of a still image increases, the less predictive of on-road visual behaviour the results seem to be (Hughes & Cole, 1986a). This effect seems to have been taken to extremes in the Cohen study undermining the extreme negative conclusions toward the use of still images.

Whatever the status of still imagery in driving research, the use of dynamic visual scenes is an obvious improvement, as noted by Hughes & Cole (1986a) and Koornstra (1993). Staplin (1995) recognised the use of dynamic scenes in driving experiments, though she questioned which particular format such stimuli should be presented in. To compare different dynamic media Staplin presented her visual task in one of three formats: a video image presented on a 20 inch screen (compressed image, low resolution), a projection video (correct size and perspective but also low resolution), and a 35 mm cinematic presentation (correct size and perspective with very good resolution). The task required participants to estimate the last safe moment to make a turn into a side road across the lane of an oncoming vehicle. Results from the three non-interactive dynamic views were compared to results gained from a real-world study where participants performed the same task in the location that was used for the laboratory stimuli. Participants were seated in the passenger seat of a car and asked to press a button on a hand held unit at the last safe moment to turn. Staplin found that the 35 mm film gave the closest estimation of the real world responses to oncoming traffic. She suggested that the higher resolution of the film allowed a greater contrast between the oncoming car and the background, which would make it easier to judge the approach speed on the basis of the expansion rate of the image on the retina. Though the video presentations failed to emulate the performance of the 35 mm film, it should be noted that the video resolution used in this study (300 lines) was lower than the normal resolution of NTSC recordings (which permits 525 lines of resolution). This occurred due to the transfer of the video recordings onto laser disk for presentation. One cannot conclude that all video presentations would therefore reduce the generalisability of results to the same extent as this study suggests, particularly in certain driving studies in which the expansion rate of objects is not important.

Quimby and Watts (1981) raised a further question concerning the validity of the stimuli used in dynamic displays. This stemmed from work they conducted which compared an on-road study with a 16 mm projection of similar road scenes. The task they used was a forerunner for, what is now known as, the hazard perception test. Quimby and Watts' version of this test required participants to continually adjust a lever while watching the film in order to reflect the level of danger they perceived in the driving scene at any particular moment. During the on-road study participants were asked to rate the possibility of having an accident at 45 predetermined points on a 26 km test route, and to report any potential hazards they observed. They found an inverse correlation between the number of hazards reported and driving errors noted on the test route. This correlation was not found between driving errors and the laboratory measure of hazard perception. They suggested that the lack of a correlation in the laboratory was due to the inclusion of possibly inappropriate stimuli in the hazard film. When the clips were compared individually to the participants' accident rates over the previous three years, they noted that certain hazards were more predictive than others of accident liability. The incidents which, when combined together, produced the greatest correlation tended to be sudden traffic light changes and the emergence of traffic from either side into one's perceived direction of travel. This lead Quimby and Watts to suggest that increased care over the selection of stimuli could improve the ability of such tests to predict accident liability.

2.2.3 Concluding remarks on the discussion of experimental media

To summarise, one of the important issues in driving research methodology concerns at which point on the nomothetic-ideographic continuum that one approaches the hypotheses. Though no laboratory based paradigm can perfectly represent the real world it has been noted that even simple letter/digit discrimination tasks can access complex visual skills developed through specific behaviours (Williams, 1995). When considering the use of specific driving stimuli however, previous research can point one in the right direction. It seems that dynamic images prove to be more representative of studies in the field than still images. If still images are to be used however they should only be displayed for extremely short durations. Other issues, such as the resolution of the images, depend on the particular task.

One issue that has received only a little discussion is that of interaction with dynamic scenes, though it can be briefly mentioned here as an example of task dependency in the choice of media. One would imagine that an interactive simulator would produce the most representative results of the real world. This depends however on the quality of the simulator and the hypothesis that it is addressing. For instance, the simulator used by Land and Horwood (1996) ran from a BBC micro. The display consisted of two converging white lines that would turn to the left or right according to the layout of the 'road' ahead. This system was perfectly adequate for their hypothesis: that peripheral vision of the road edges guide lane maintenance. Other systems involve full colour displays and realistic graphics. The price of these latter systems is however extremely high, and the benefits they bring are arguable (McKenna & Crick, 1994).

If one could have a realistic display with full interactivity, what evidence is there to suggest that the necessity of motor responses, dependant on visual information, would influence the way that information is gathered? If this were the case, then the argument for interactivity in the study of visual information acquisition during driving would be a strong one.

One study that produced such evidence (mentioned in section 2.2.2) was conducted by Land and Lee (1994). In this study three experienced drivers drove along a single lane, one-way road around a hill in Edinburgh. The road was steeply banked on both sides such that the drivers could not look through the bend to see the road beyond. Land and Lee noted that, under these conditions, the tangent point of a curve is fixated 1-2 seconds before the steering wheel is turned. While driving through the curve they found that 80% of fixations were devoted to the tangent point. They suggest that visual information acquisition is dictated in part by the requirements of the motor system. If any subsequent study places no requirement on the participant to navigate through a bend, then it is possible that there is also no requirement to fixate the tangent point of the curve. Without field studies or interactive simulators, this would not necessarily be noted in the search patterns of drivers. Other researchers have noted a change in visual search patterns when negotiating a curve from driving along a straight road (Shinar, McDowell & Rockwell, 1978; Zwahlen, 1993). One change indicative of an increase in demand is the reduction of mean fixation time (which increases the number of fixations that one can make in the same time frame). Though curves naturally increase the visual complexity of the visual scene, Land and Lee argue that the motor requirements feed forward into the more complex scene and are therefore responsible for the change in visual search strategies.

Despite this argument, other studies have failed to notice any differences in visual information acquisition due to the inclusion of the motor element of the task (Lee & Triggs, 1976; Staplin, 1995). In the study by Lee and Triggs, they compared the peripheral visual information acquisition of both drivers and passengers in the real world and found no differences. They suggested that the important factor was the complexity of the visual scene that one views, rather than any need to navigate. It is possible however that when a participant is placed in an experimental vehicle they may search the road ahead *as if* they were actually driving, complete with the typical visual search strategies that are born out of motor requirements. Such behaviour would be similar to passengers who stamp a foot in the passenger footwell, as if attempting to brake. This anecdotal behaviour may occur when something (such as an obstruction) in the visual scene triggers some sort of automatised braking action. If those visual search strategies that had evolved to provide input for motor responses were triggered without the requirement to perform those motor tasks, then the search strategies must have instead been triggered by the visual stimuli. At this point the question returns to how realistic driving displays must be to trigger the sort of visual search strategies that are required when actually driving.

Regardless of the arguments that are present in the literature, the decision of whether or not to include interactivity in a laboratory driving task must ultimately rest with the type of task given to the participants, and the underlying mechanisms that one is trying to probe. The issue of interactivity in the hazard perception test will be returned to in Chapter 5.

The suggestion of referring to the underlying hypotheses to guide the methodology is one that should be applied not just to the decision of whether to include interactivity in a driving task, but also to the wider decision of whether to study driving behaviour in the real world or in the laboratory. On this basis (and with regard to the discussion in the previous sections) it seems that one cannot proscribe either the real world or the laboratory on the basis of theoretical considerations alone. The practical and ethical considerations are also extremely important, and severely restrict the choice between the real world and the laboratory. For instance, one could not conduct research on drivers' abilities to spot potentially hazardous stimuli in the real world without staging the hazardous events and placing the participant in a dangerous situation. Such a situation would be ethically and practically problematic. After such decisions have been made, theoretical considerations may alter the methodology. If the theory under investigation will be confounded by an unrealistic setting, yet it would breach ethical and practical limits to do so, then perhaps that research should not be undertaken. Once a compromise has been achieved in the choice of setting then the research noted above should be consulted in order to operationalise the design.

2.3 Verbal report versus eye movements as the best indicator of visual search during driving (experiment 1)

2.3.1. Potential solutions to eye tracking problems

Despite the usefulness of eye-tracking, it is not without its problems. In terms of practicality eye trackers are expensive and require a lot of effort to run and maintain. Eye tracking systems that rely on infra-red reflections (such as the purkinje image) may experience difficulties when testing participants wearing glasses or contact lenses. In regard to ethics, some of the older systems are invasive, while even the more recent commercial eye trackers can give some discomfort, especially with prolonged use.

There are also a number of theoretical problems that stem from flaws in the eye-mind assumption (Underwood & Everatt, 1992). This assumption suggests that processing only occurs in foveated locations. However, a foveal fixation upon a target does not necessarily equate with recognition of that target. In this case 'recognition' specifically means that one has processed an object sufficiently to react appropriately. For instance, one may fixate on a red traffic light yet still fail to 'see' it (i.e. recognise the stimulus and carry out the appropriate modifications to current actions, such as braking). This phenomenon of 'looking without seeing' was reported as a major cause of traffic accidents in female drivers (Storie, 1977), which suggests that fixations may not be sufficient to produce perception, though there is also the possibility that fixations are not *necessary* for perception. It is known that attention can be moved independently of the eyes (e.g. Posner, 1980), and Henderson (1992) has proposed a sequential attention model which suggests that attention moves to a new location to begin processing a new stimulus while the eyes are still fixated on the original stimulus. In either of these cases the particular fixation point of the eye is of little help in identifying what is currently being processed (Luoma, 1988).

Luoma circumvented this problem by asking the participant questions about driving scenes they had just passed. The argument behind this methodology is that recall only accesses those items that the driver perceived regardless of fixation. Recall is however subject to other confounding processes, such as differential decay for differently processed stimuli (e.g. the difference between motor encoding and verbal or visual encoding -- Mohr, Engelkamp & Zimmer, 1989), and as such its validity for use in this setting is questionable (Hughes & Cole, 1986b).

One alternative that has been discussed already is the use of hit rates for particular targets (Cole & Hughes, 1984; Hughes & Cole, 1986a). This methodology can record what participants perceive under different conditions (such as the two conditions of conspicuity that Hughes and Cole used – see section 2.2.2). However it cannot give any information about other stimuli that the participant may look at without the inclusion of eye tracking technology. Neither can it distinguish between the use of foveal vision or peripheral vision in the detection of a target.

A further possibility is the use of 'concurrent verbalisation'. With this methodology participants are asked to provide an on-line protocol of what they are doing, or in this instance, what attracts their attention or what they direct attention to. This method is actually used as a training technique by the Royal Society for Prevention of Accidents (RoSPA) in their advanced driving course, and by the police for their advanced courses. Hughes and Cole have employed concurrent verbalisation extensively to produce both hit rates for artificial targets and general information on other items in the visual scene that were processed (Cole & Hughes, 1984; Hughes & Cole, 1986a; Hughes & Cole, 1986b). In their studies Hughes and Cole grouped utterances into categories of scene features such as 'road ahead' and 'oncoming traffic'. From these analyses they were able to note which categories attracted the most attention in the driving scene.

Renge (1980) argued that beyond the fixation/perception problem, the use of concurrent verbalisation could distinguish between a glance at the lane markings, looking at rubbish on the road, or merely checking to see if the way ahead is clear. In all these cases the fovea may fall on the same position in the road yet the participants could be looking at different things for different reasons. Furthermore a participant's protocol may provide information about why certain objects are fixated, and whether the perceived object was expected.

Hughes and Cole (1986b) suggest that verbalisation of what participants attend to should not appreciably affect the processing demands placed on the driver, providing that they are not asked to comment on anything else (such as inferences of why they looked at a particular object).

The precise use of this tool has however come under debate. Hughes and Cole (1986b) criticised Renge (1980) for the use of 'continuous report'. This required participants to maintain an ongoing protocol without pauses. Hughes and Cole argued that drivers may not always attend to particular objects but may sometimes adopt a diffused attentional state, and thus the use of continuous report could lead participants to attend to objects that they would normally ignore, in order to maintain continuity.

An additional problem with verbalisation is that certain perceptual actions may be compiled into an automatised action, thus making such behaviour inaccessible to verbal report (LaBerge, 1981; Underwood and Everatt 1996).[1] Other researchers in various fields such as fire fighting, neonatal intensive care nursing, and anesthesiology have shown that information that was thought to be tacit can be revealed using protocol analysis and other knowledge elicitation tools (for a review see Hoffman and Shadbolt, 1996). Alternatively, the act of concurrent verbalisation of an automatised task may reduce it to a controlled process, which may then be performed differently.

Other researchers have expressed doubts as to the ability of verbalisation to reflect the perceptual processes. Lynch and Rivlin (quoted in Renge, 1980) noted that "the process of perception is so

[1] In defense of verbalisation Hoffman, Shadbolt, Burton and Klein (1995) noted that it has not been demonstrated that participants have knowledge that is proceduralised to such an extent that it is non-verbalisable.

rapid and complex, and is often so difficult to verbalise, the findings must be regarded only as the perceptions 'at the top of the heap' in the whole conscious-unconscious sensing of the environment".

The most contentious point however remains whether the inclusion of a verbalisation task interferes with the primary task. Cole and Hughes (1984), and Hughes and Cole (1986a) believe it does not increase processing demand, though other researchers have noted the additional strain of protocol reports on the driving task (e.g. Fisher, 1992; Gregersen, 1994). One mechanism that could account for interference is *verbal overshadowing* (Schooler & Engstler-Schooler, 1990). This suggests that the act of verbalisation focuses the participants' attention on that which is easily reportable, and thus overshadows other, less reportable information which one may normally attend to. Verbalisation has even been found to interfere with participants' ability to rate the taste of various strawberry jams. Wilson and Schooler (1991) found that participants who did not have to verbalise their thought processes gave ratings for jam preference which were closer to ratings given by experts, than participants who had to report their reasons. Schooler, Ohlsson and Brooks (1993) noted however that both Wilson and Schooler's, and Schooler and Engstler-Schooler's experiments used retrospective verbalisation, which makes it harder to generalise an overshadowing effect to concurrent verbalisation. In order to be sure that the use of on-line protocols is a valid method for investigating search strategies one needs to examine the extent of any proposed interference that such verbalisations may have with the sampling of the visual scene.

In order to assess this problem an experiment was conducted which is discussed in the following section. The study compared the eye movements and fixation durations of participants who viewed a modern version of the early hazard perception test of Quimby and Watts (1981). Eye movements were compared between groups who had been given different protocol instructions in an attempt to discover if concurrent verbalisation interfered with search strategies while viewing dynamic driving scenes.

2.3.2. An experiment to assess the effects of concurrent verbalisation upon visual information acquisition during a driving task

This experiment aimed to investigate whether concurrent verbalisation affects what it purports to measure: in this case the search strategy or fixation pattern of drivers; and whether any effects are passed on to higher order skills such as hazard perception. It also examines the utility of verbalisation in regard to its relationship with what participants actually look at in the driving scene.

The hypotheses for this study are that the use of verbalisation will affect the search strategy of participants in terms of fixation durations and the size of the search area, both horizontally and vertically. Mean fixation durations were chosen as a dependant variable as they are viewed as a measure of the time taken to identify the locus of fixation (Henderson, Pollatsek & Rayner, 1989). The horizontal and vertical spread of search measures were chosen on the basis of findings that suggest the distribution of visual search over the road scene is linked to experience (Mourant & Rockwell, 1972), and the ability to spot potential hazards in a hazard perception test (Underwood, Chapman, Wright & Crundall, 1997). Underlying this hypothesis is the suggestion that if participants have to verbalise what they look at, then fixation durations may be increased while the extra processing of accessing a verbal code is performed. Furthermore, the search area may be enlarged owing to the pressure to report more than participants would normally attend to (if they normally search a very narrow area in a certain visual scene), or decreased in an attempt to reduce the number of attended objects that they could report (if they normally search a large space in a certain visual scene), perhaps owing to verbal overshadowing. An extreme example of the former situation may occur when a participant watches a particularly sparse rural road, while required to provide a continuous narrative. In this situation the ideal solution may be to maintain a point of gaze at the focus of expansion (as this is the most likely source of any hazard). However the participants may feel that they should be reporting more stimuli in the scene, and thus increase their search space. Even without the need for a continuous report, the effect of increasing an otherwise narrow search space may occur. The possibility of a decreased search space due to the influences of a verbal report may simply arise as an attempt to restrict the amount of input to be reported.

If differences are found between the search strategies of participants in the report group and in the control group (both measured with eye tracking equipment) then this suggests that the use of concurrent verbalisation is questionable in studies of drivers' search strategies. In order to further investigate the hypothesised interference of concurrent verbalisation, two forms of verbal report were used. These were 'natural report' (a free flowing narrative) and 'restricted report' (where participants were asked to keep their utterances about any single object or event restricted to one or two words). If the hypothesised interference of verbalisation is due to articulation, then reducing the length of time verbalising (as the restricted report condition was designed to do) would produce differences between the two conditions. For instance, the length of time spent giving a report on a certain stimulus may increase the time spent fixating it, which would become apparent with the inclusion of the restricted report condition.

Two further hypotheses were included. The first was the suggestion that verbalisation would affect *what* participants looked at in the driving scene in terms of certain object categories, while the second proposed that the effects of verbalisation on scanning strategy would affect the higher cognitive task of hazard perception. The former hypothesis was chosen to identify the possible effect of verbal overshadowing. One cannot immediately extrapolate fixation duration data to differences between the groups in their behaviour, or even to the range of objects interrogated in the driving scene (e.g. a narrower search strategy may indicate a participant who perceives very little, or one who perceives a lot but at a long pre-view distance). Because of this it was necessary to examine the possibility of differences in what the participants looked at, rather than simply where and when. For this reason total gaze durations within certain categories of road stimuli were analysed between groups.

The latter hypothesis was designed to identify whether the theoretical effects upon fixation durations, spread of search and object category analyses affected a higher cognitive task. A modern hazard perception test was chosen as it provides a visually rich environment in which to test eye movements under potentially dangerous situations. This test recorded participants' response times to potential hazards perceived on a series of digital video clips, each containing an incident that could be considered as a potential hazard. The eye tracking data were taken from an intensive study of a typical clip. The particular hazard perception test, and the rationale for its use are explained in section 2.3.3.2.

A comparison was also made between what participants looked at, and what participants verbalised, both in terms of object categories. If the results show that the use of concurrent verbalisation does not affect the search strategy used, and that it does reflect what participants actually looked at, then one may be somewhat surer of the validity of concurrent verbalisation as a methodological tool for investigating drivers' search strategies. However, differences between what participants look at and what they verbalise do not necessarily invalidate concurrent verbalisation as a tool in its own right, as these differences may merely represent the problem of fixation without perception (or vice versa). The choice would then lie with whether one viewed the precision of fixation patterns as more important than the ostensible pertinence of the items given through a verbal report.

2.3.3 Method

2.3.3.1 Participants

Thirty-five participants (17 males) were initially recruited from a university campus population. Five participants (4 males) were later removed from the analyses owing to missing data. All participants were in possession of a driving licence. Participants' ages ranged from nineteen to forty three with a mean age of twenty four. All participants had normal or corrected-to-normal vision (contact lenses only).

2.3.3.2. Materials: the hazard perception test

The current hazard perception test used in this study was designed by the National Foundation for Education and Research (NFER). For this particular study 13 clips were used, though 39 were available in total. As this test has been used in several experiments it will be explained in some detail in this section.

The video clips were filmed in and around Cambridge by NFER using a video camera with a telephoto lens mounted in a car. This allowed potential hazards to actually seem close enough to be of some danger. The view is taken from the driver's perspective looking through the windscreen though the edges of the windscreen (and mirrors) are not visible. A typical clip lasts for an average 43 seconds (clip length varies between 18 and 72 seconds) and contains one or more potential hazards. The road can be either rural, urban or suburban and involves a variety of natural distracters that befit the setting. For instance a particular clip may contain a road through a busy village with shops, pedestrians, and parked cars on either side of the road. A suitable potential hazard for such a clip would be the sudden emergence of a pedestrian from behind a parked car. Other hazards include cars pulling in front of the participant's perceived vehicle, horses, joggers, cyclists, and even an errant football. Participants' button response times to these potential hazards can then be calculated. An example of a hazard can be viewed in the still taken from a clip in Figure 2.1. In this clip a parked car suddenly reverses into the road from a drive way. A summary of the potential hazards in each clip, their onset times, and which experiments each particular clip has been used in are presented in Appendix 1.

Proponents of the modern hazard perception test argue that it taps into the higher cognitive functions that contribute to the driver's mental model of the driving task. McKenna and Crick (1994) believe that simple simulations merely tap into the visual-motor elements of the driving task, and that the neglect of higher cognitive functions may account for the failure of previous advanced driver training courses (Jonah, Dawson & Bragg, 1982). Following on from the early work of Quimby and Watts (1981), a

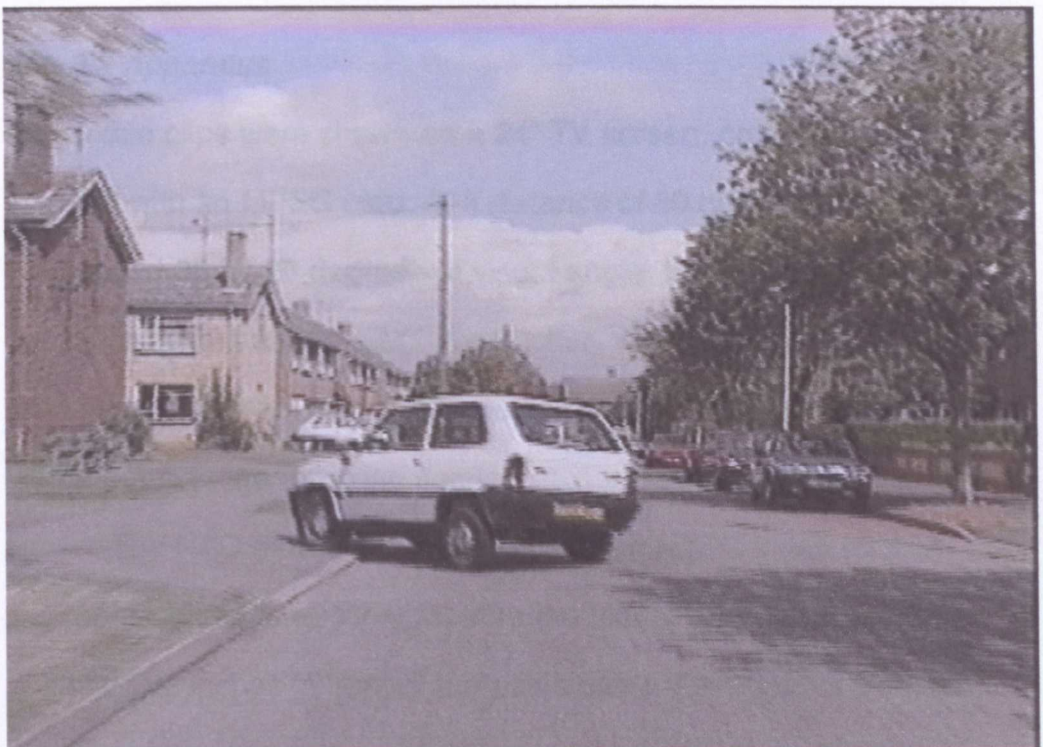

Figure 2.1. A typical hazard taken from one of the hazard perception clips. A Fiat Panda suddenly reverses from a driveway into the path of the participant's perceived direction of travel.

shortened version of their test revealed significant correlations between hazard perception scores and accident involvement (Quimby, Maycock, Carter, Dixon & Wall, 1986). The use of the hazard perception test in this study allowed comparison of the report conditions across this cognitive element of the driving task, although the initial reason for the use of these clips was to use complex visual stimuli in a controlled setting to assess the potential disruptive effects of verbalisation.

Of the 13 clips used for this initial study response time data to potential hazards were taken for 12 of the clips with one clip used as a practice for participants to become acclimatised to both the video presentation and the verbal report condition that they had been assigned to.

2.3.3.3 Apparatus

The video clips were shown on a 24" TV screen, controlled by a 486 PC with an MPEG card. At a distance of 80 cm the screen subtended 35 by 26 degrees of visual angle. Eye movements were monitored using a NAC-EM7 eye tracker, with control box. As the NAC eye tracker is used in other experiments it will be explained in some detail in the following section.

The NAC data was recorded on to an NTSC video tape. A microphone added auditory input to the video, and was placed on a stand five inches in front of the participants. Participants were given a button box with which to record their responses to any hazards they perceived.

2.3.3.4 The NAC-EM7 Eye tracker

The NAC-EM7 is a light weight, head mounted eye tracker, which measures the point of gaze of a participant from the corneal reflection of an infra-red light from the right eye. It has two video cameras, the first of which is termed the field of view camera. This camera points straight ahead to give a picture of where the participant is looking. If the participant moves her head to the left or right, the field of view shifts accordingly as the camera is attached to the head band of the eye tracker (see Figure 2.2).

The second camera points downwards and records an image of the participant's right eye. The image is filmed from a reflection in a piece of perspex glass which hangs down in front of the participant's eye. The participant still has an unrestricted view of the world through the perspex reflector. This reflection produces a close up picture of the eye to aid alignment of a reflected infra-red beam which is emitted from a light source combined with the eye camera. The reflected infra-red light is visible on the video output of the eye camera as a white dot reflected off the cornea. This reflection is translated into an *eyemark*. This is a white square which is overlaid on the video output from the field of view camera. This small square can be calibrated to reflect where the participant is looking in the visual scene. Saccades are represented as sudden jumps of the eyemark around the field of view. The position of the eye can be calculated from the relationship between the infra-red reflection and external markers against which the tracker must be calibrated. Calibration of the different values of the pupil-reflection relationship with what the participant is looking at, produce the point of gaze of the participants in the real world. The experimenter asks the participant to look at dots on a calibration chart or at objects that are visible directly ahead, and can then adjust the eyemark via horizontal and vertical (X and Y knobs) adjustments to the eye camera so that it falls upon the dots or objects that are being viewed. Manual calibration such as this takes roughly two to five minutes, and may require fine tuning during an experiment. Within the laboratory adjustments to the calibration can be easily achieved between trials.

The two camera images can be alternately viewed on an NTSC monitor, with the output recorded on an NTSC video recorder. The eyemark is superimposed on the field of view camera in real time which allows detection of any slip in calibration. The NTSC video format allows 30 frames per second

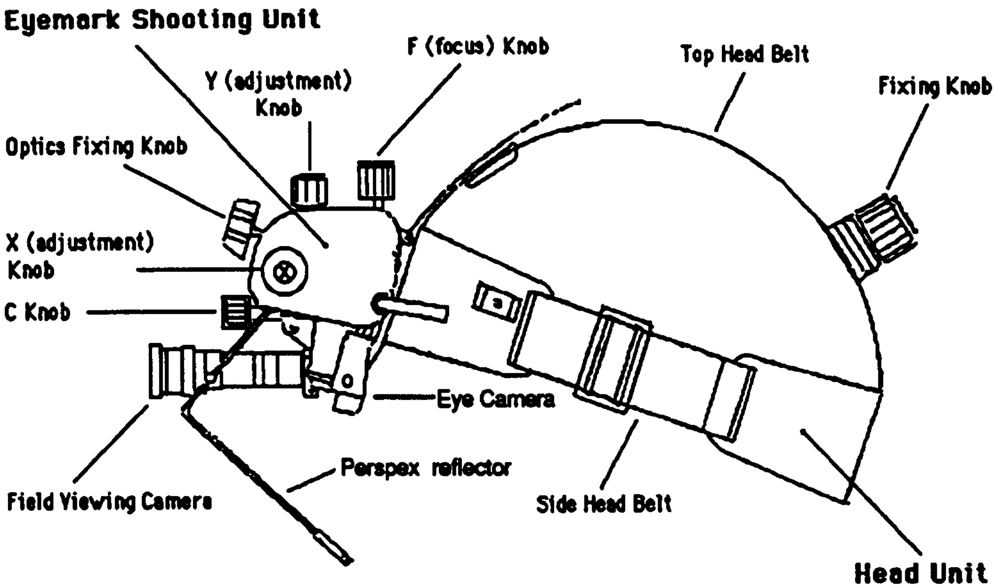

Figure 2.2. A side view of the NAC-EM7 eye tracker

to be recorded (30 Hz), thus gaze position (in angular coordinates) is recorded every 33 ms. A fixation was defined as at least three data samples which fell within 2 degrees of the previous sample. This allowed pursuit tracking to be classed as fixations. The stream of eye coordinates was put through a Data Processing Unit (DPU) with dedicated NAC software in order to parse the data into fixations and saccades.

2.3.3.5 Design

The experiment used a between-groups design with *report condition* as the factor. The three levels of report condition were *natural report* (N=11, a free flowing narrative which elicited reports such as, "I am looking at the cyclist on the pavement..."), *restricted report* (N=10) where participants were asked to keep their utterances about any single object or event restricted to one or two words, and a control group (N=9) who were not required to make verbal reports. The above example for the natural report would ideally be reduced to the one word utterance of "cyclist" in the restricted report condition). The control software which displayed the video clips did not allow randomised presentation for this experiment, though this was rectified for later studies involving the hazard perception clips. The measures recorded included response times to the appearance of a hazard (the time between hazard onset and button press), and the overall number of responses over the time span of the clip. Eye tracking data taken from one of the clips allowed calculation of fixation durations (three samples of eye coordinates each within two degrees of the previous sample) and spread of search in the horizontal and vertical meridians (the variance of the coordinates of fixations). In addition the visual scene in the example clip was segmented into five categories: road ahead, oncoming traffic, car in front, cyclists, and general surroundings. Gaze duration within these categories was recorded. The category of general surroundings is a miscellaneous category that included all fixations that focused on anything else in the scene that is not included in the first four categories.

2.3.3.6 Procedure

Each participant was seated one metre from the TV screen and the general hazard perception instructions were read to them by an experimenter. These instructions asked participants to view the scene as if they were driving through it. They were also asked to watch for potentially hazardous situations ahead, and to react as quickly as possible by pressing the response button. A hazardous situation was defined as one in which participants "might consider there to be risk of accident or near accident; one in which you might consider it necessary to take some kind of evasive action, by braking or steering etc." (McKenna & Crick, 1994). Additional instructions were given to two thirds of the participants concerning the verbalisation task. One third were asked to report anything to which they paid attention, or anything they found themselves looking at or thinking about, while the other third were given the same instructions but were asked to keep their utterances limited to one or two words. Both experimental groups were told that they did not have to verbalise continuously if they felt that nothing was sufficiently salient for them to comment on at any particular time. This was done in order to avoid forced reports (Hughes & Cole, 1986b). The experimenter then answered any questions.

Each participant then had the NAC unit placed on their head and were taken through a calibration procedure. After this each participant was reminded of the instructions and asked to keep their head as steady as possible throughout the clips. They were then presented with a practice video clip. At the end of the clip those participants who did not verbalise according to their assigned condition were reminded of the requirements. The pace of the experiment was under participant control, allowing gaps between each clip. If the eye tracker calibration slipped during a clip, the participant was recalibrated between clips.

2.3.4 Results

2.3.4.1 Analysis of response times to perceived hazards

The mean response times to a perceived hazard across the three types of report condition are shown in Table 2.1 (omitting two of the clips due to a large number of empty data cells). Responses were included in calculation of the means if they fell within a certain time window around the hazard onset. This was a two second window which began 500 ms before the actual appearance of the hazard, and as such it included button presses immediately prior to the hazard onset which were presumably based upon the antecedent conditions leading up to the actual hazard. One example of such antecedent conditions involved a car in front braking sharply. Immediately prior to the brake lights appearing however, the car decelerated which increased the eccentricity subtended by the image of the car.

Report condition	Mean response time to hazard (ms)	Standard error
Natural	849	45.0
Restricted	917	50.6
Control	838	46.0

Table 2.1 Mean response times (ms) to a perceived hazard within a two second window.

The mean correct responses to a perceived hazard were subjected to a between-subjects analysis of variance. No significant differences were found between report conditions, $F_{(2,27)}<1$. Analysis of variance was also performed on each clip individually in case a lack of homogeneity was obscuring any differences, though no significant differences were forthcoming.

The mean number of overall responses per participant (including responses outside the hazard window) were also compared across report condition, in order to check for any general effects of verbalisation on response rate. No significant differences were found, $F_{(2,27)}<1$.

2.3.4.2 Analysis of eye-tracking data

In order to assess the effects of verbalisation on participants' search strategies an in-depth micro-analysis was performed on the data from one of the clips. Fixations were defined as durations of at least 100 ms where the fixation co-ordinates were no more than two degrees away from the last sample. This allowed pursuit movements to be classed as fixations.

The particular clip chosen for eye movement analysis was 41.5 seconds long. It presented a suburban route in which the participant's vehicle was following a car in front. The hazard occurred 25.8 seconds into the clip at which point the car in front braked and simultaneously indicated to turn left. A hazard window was defined around the hazard onset. This window was set at two seconds, with 500 ms before hazard onset and 1500 ms after onset. The window started half a second before the hazard to include reactions to the antecedent conditions (such as deceleration of the car in front).

Overall mean fixation durations

The mean fixation durations for the whole clip, for thirty participants, were compared using an analysis of variance. No significant differences were found across the natural, restricted and control report conditions, $F_{(2, 27)}=1.2$. The mean fixation durations are shown in Table 2.2.

Report condition	Mean fixation duration (ms)	Standard error
Natural	483	31.1
Restricted	428	33.4
Control	492	32.5

Table 2.2. Mean fixation durations across report conditions for the whole of a typical clip.

Mean fixation durations before and during a hazard

A comparison was made between participants' mean fixation durations within the two second hazard window (500 ms before the car indicator starts to flash, to 1500 ms after) with the mean fixation durations within a two second window immediately prior to the hazard window. This pre-hazard window was presumed to represent eye movements and fixation durations under normal conditions (in the absence of potential hazards). The inclusion of this measure allowed the report conditions to be compared across different levels of task demand (assuming that the presence of a hazard and the subsequent requirement to respond increases the level of processing demand).

A significant main effect was found between the two windows. Mean fixations were found to be significantly longer in the pre-hazard window than the hazard window itself, $F_{(1,27)}=6.3$, $p<0.05$. A main effect was not however found for the report condition ($F_{(2,27)}<1$), and a significant interaction was not forthcoming ($F_{(2,27)}<1$). The means are shown in Table 2.3.

	Natural (ms)	Restricted (ms)	Control (ms)
Pre-hazard window	783	849	908
Hazard window	604	336	588

Table 2.3 Mean fixation durations (ms) before the hazard and during the hazard window for the eye-analysed clip compared across report conditions.

Spread of search along the horizontal and vertical meridians

The variance of fixation co-ordinates was taken as a rough indicator of the spread of participants' visual search along the horizontal and vertical meridians. These variances were compared against each other, and across report conditions in a mixed anova. A significant main effect was found for the comparison between the two meridians, $F_{(1, 27)}=183.8$, $p<0.01$, though no effect of report condition was noted. The means can be viewed in Table 2.4

	Natural (degrees^2)	Restricted (degrees^2)	Control (degrees^2)
Horizontal meridian	23.1	26.2	25.9
Vertical meridian	5.8	2.6	2.0

Table 2.4 Mean variance of participants' fixation locations along the horizontal and vertical meridians for the whole of the eye-analysed clip.

2.3.4.3 Analysis of verbalisations and fixations on categorised objects

Thirty participants' gaze durations for the eye-analysed clip were coded according to which of five categories they were fixating. The categories were 'car in front', 'cyclists' (moving non-hazards), 'oncoming traffic', 'the road ahead' and 'general surroundings' (e.g. anything other, such as scenery). No differences were found between the report conditions for time spent fixating the particular categories, except for the category of 'road ahead', $F_{(2, 27)}=3.7$, $p<0.05$. The restricted report group were found to spend more time fixating the road ahead than the control group (Scheffé $F=7.0$, $p<0.05$). Gaze durations within these categories are shown as percentages in Table 2.5.

Verbalisations for both report conditions were also coded according to these categories. The natural group produced more verbalisations concerning the car in front ($F_{(1, 22)}=15.9$, $p<0.01$), and significantly less verbalisations concerning the cyclists than the restricted group ($F_{(1, 22)}=9.3$, $p<0.01$). The data for the two verbalisation report groups can also be viewed in Table 2.5.

	Report condition	Road ahead	Oncoming traffic	Car in front	Cyclists	General surroundings
% gaze durations	Natural	16	20	52	8	4
	Restricted	20	22	42	7	9
	Control	13	21	51	8	7
% utterances	Natural	0	7	54	30	9
	Restricted	0	15	13	57	15

Table 2.5 Percentage of the clip spent in each category in terms of gaze duration and verbalisations

Spearman rank correlations were conducted on the data from the natural report group and the restricted report group separately. These analyses were intended to identify any relationships between the percentage of time that each participant spent fixating a category and the percentage of their utterances that were relevant to that category. A significant relationship between gaze duration and verbalisations was only found for the natural report group, within the category of general surroundings, $r=0.842$, $N=11$, $p<0.01$. This suggests little overlap between the protocols and the time spent looking at the different categories.

2.3.5 Discussion

The hypotheses suggested that the use of concurrent verbalisation would affect *how* participants search a dynamic road scene (in terms of fixation durations and spread of search), and *what* participants would look at (in terms of gaze duration within certain categories). It was also postulated that such interference would also effect the higher order skill of hazard perception.

2.3.5.1 The effects of concurrent verbalisation on search strategies

The results showed no significant differences in the search strategies of participants across report condition. Mean fixation durations (a suggested measure of the processing demands placed upon a driver) for the whole of one clip were compared yet no differences were found across the three levels of report condition. Durations were also compared across report conditions for both a two second window prior the hazard window, and the hazard window itself. It was found that the average fixation duration decreased in the hazard window compared to the pre-hazard window. The spread of search along the horizontal and vertical meridians (which has also been linked to processing demand and experience) were also compared for the three groups. Again, no significant differences were found.

Participants' gaze durations were also coded in terms of what they were looking at, and, in the case of the two verbalising report conditions, what they reported looking at (within five categories of objects). No significant differences were found between the natural report condition and the control condition, though the restricted report group were found to spend more time fixating the road ahead than the control group. This solitary effect is unlikely to be due to verbalisation as neither the restricted or the natural report groups commented on the 'road ahead'. With regard to the frequency of verbalisations, the restricted report group were found to mention the 'cyclists' more often and the 'car in front' less often than the natural report group.

These results suggest that the use of concurrent verbalisation, certainly in a natural format as used by Hughes and Cole (1986b), does not affect one's visual search strategy to any great extent. The differences between the two report conditions have not shed any light on the hypothesised interference of verbalisation with the search strategy of participants as the interference failed to materialise. It does however emphasise the difficulties in the instruction of participants in the use of this methodology, for in this experiment the different verbalisation instructions have given rise to differing data sets.

Spearman rank correlations were performed on the data between the fixations and verbalisations within each category for the natural report and the restricted report groups. A correlation could not be calculated on the category 'road ahead', as no verbalisations fell into this category. This is similar to the findings of Hughes and Cole (1986a) who found only 2.7% of verbalisations were concerned with the 'road ahead'. The only significant relationship that was found was the link between gaze duration and verbalisations within the category of 'general surroundings', and as this was the miscellaneous category one should not view this as of immense significance. This suggests that though the use of concurrent verbalisation (at least in a natural report format) did not interfere with search strategies, neither did it reflect what participants actually looked at in terms of gaze duration in the five designated categories.

In an attempt to investigate whether verbalisation interferes with the higher order skill of hazard perception participants' reaction times to perceived hazards were also compared but no significant differences were apparent.

On the basis of these results this study failed to demonstrate that concurrent verbalisation significantly affects the search strategies of drivers engaged in a driving task, or that it will affect the higher order skill of hazard perception.

2.3.5.2 Does it matter that eye fixations do not correlate with the verbal reports?

Previous research has found large correlations between verbal reports and fixation patterns (Winikoff, 1967; Deffner, 1983). Deffner's study found that over 90% of verbalised references to visually displayed stimuli could be linked to a fixation of the same items. Despite these early findings with static displays, the current study failed to find any correlation between verbal reports and gaze duration within set categories in a dynamic driving scene.

One of the main arguments for using verbal reports is that it overcomes the problem of fixation without perception (and vice versa) which eye trackers cannot detect. Therefore the argument that verbalisation is not a useful tool because it does not accurately reflect the pattern of fixations that a participant produces really depends on the object under investigation. If one is attempting to assess the perceptions of the participant within, perhaps, a priority hierarchy, then concurrent verbalisation may be a more valid method than charting fixation patterns. Though verbal protocols are often lengthy, they are still a naturally parsed version of the raw eye movement data. One does not however have a complete understanding of the parsing process that turns raw eye movement data into a verbal report. This parsing process may not be appropriate for answering certain experimental questions. For instance a participant viewing a driving scene which involves closely following a car ahead may only report that their attention is given to that vehicle. They may however also spend some time scanning to the left and right of the vehicle in front in case a sudden hazard appears. If no hazard appears the participant may not bother to report this extra scanning.

Hughes and Cole (1986a) acknowledge the possibility that verbal reports of what attracts a driver's attention may not validly represent the particular fixation pattern of the participant. Though their laboratory based study replicated the detection rates for disks along the roadside in their 1984 field study they note:

> "Cohen (1981) demonstrated that eye-movement behaviour when viewing a road scene in a lab was different from that when driving. If this is so then the ability of the lab trial to predict the field experiment suggests that the pattern of eye-movements is not a critical factor in determining attention conspicuity when driving."
>
> [Hughes and Cole, 1986a, p1108]

Though they found similar verbal reports from both the lab and field, they acknowledge Cohen's finding that eye movements differ across the two settings. One immediate problem with their subsequent argument lies in the validity that they attribute to Cohen's results (see section 2.2.2). However on this basis they suggested that verbal reports do not necessarily reflect eye movements; furthermore such a correspondence is not actually required as concurrent verbalisation taps into a higher level of processing than mere eye movements - a level which reflects their measure of attention conspicuity but is not affected by the media employed in the experiment. As attention conspicuity (the ability of a stimulus to attract attention) can be said to, at least partially, underlie hazard perception, one might stretch their statement to suggest that a participant's ability on a hazard perception test has nothing to do with where their eyes are looking.

Acceptance of this suggestion depends on the view one takes of attention conspicuity. Cole and Jenkins (1982) said that if an object is

conspicuous then "there should be a high probability that the target will be seen regardless of the object's eccentricity from the line of sight." Thus an object with a high level of attention conspicuity should attract attention regardless of wherever one is looking.
An alternate view mentioned earlier is that of Engel (1971) who said that conspicuity should be viewed as the area around the fixation point within which a target would be noticed. This theory is more akin to the zoom lens/gradient models of attention (Eriksen & Yeh, 1985; Eriksen & St. James, 1986; LaBerge 1983) which hypothesise an aperture of attention. Support also comes from the work of Miura (1990), who found that as driving task demands increased, participants were less able to detect peripheral targets. Similarly Shinar, McDowell and Rockwell (1977) were among the first to note that drivers tend to fixate lateral control markers (such as the kerb or lane markings) more often when driving through curves than on straights. One suggestion to arise from these findings is that though drivers usually take in lateral control information through peripheral vision, without the need to fixate the markers (Land & Horwood, 1995), negotiating a curve is generally considered more demanding than driving along a straight section of road, and thus the increase in task demand may reduce the area within which Engel believes stimuli become attended to. As lane markers are thus unavailable through peripheral attention, drivers therefore need to fixate them.

Engel's views on attention conspicuity fit with the general models of attention and with the specific work done in the field with drivers. If one subscribes to this theory over that of Cole and

Jenkins, then Hughes and Coles' argument, that differing fixation patterns do not affect attention conspicuity, must be in error as the position of the eye at any one moment constrains the peripheral, visual field which limits the attention conspicuity of stimuli. In this study the results suggest that verbal reports do not reflect eye movements on even a simple category analysis (the same sort of analysis that Hughes and Cole used, and from which they made statements concerning what participants look at while driving). If eye position does influence attention conspicuity and hazard perception, then the lack of correlation between verbal reports and eye movements poses a problem. One cannot discard an average of 18% of the total gaze durations (across the natural and report conditions) upon the road ahead simply because that category was not verbalised. This is not a matter of fixation-without-perception. Instead it is more likely that the participant was watching for potential hazards ahead. If no hazards occur then no verbalisations are made. One must question Hughes and Coles' report that only 2.7% of their participants' time was taken up with viewing the road ahead. It was no doubt considerably higher (especially in the 1984 study when the participants were actually driving). The lack of sensitivity of concurrent verbalisation to the anticipation of hazards, suggests that it is not the right tool to use, at least in the case of hazard perception.

2.3.5.3 Other effects from the eye tracking data

Two significant effects were found in the analysis of the eye tracking data that correspond with the literature. First, it was found that fixation durations tended to decrease during the hazard window, compared to the period immediately prior to the hazard window. This resembles the findings of Shinar, McDowell, and Rockwell (1977), and Zwahlen (1993) who found fixation durations tend to decrease under conditions of higher levels of processing demand. This decrease in duration contrasts with the *increases* in fixation duration that are noted in other research areas such as reading. For instance, fixation durations tend to increase when foveating an unfamiliar word. One explanation for this decrease in fixation duration in demanding driving scenes is that the dynamic nature of the stimuli encourages an increased sampling rate: the appearance of a hazard reduces the average fixation duration as the participant tries to sample more of the scene, perhaps trying to view the hazard within the context.

It should be noted however that this particular finding may not be as valid as the eye tracking measures that are averaged over the whole clip. The measures of overall fixation duration and the spread of search in the horizontal and vertical meridians are averaged across over 40 seconds of a dynamic, changing environment. This may not allow generalisations to environments other than the particular residential road in which the clip was filmed, though it is safer to generalise these measures to other clips and situations than it is to compare the findings of the hazard and pre-hazard windows to other situations. Without other hazardous situations to average across, the findings are left on a par with the analyses of Miltenburg and Kuiken (1990) that were criticised in chapter 1 for focusing upon individual elements of the driving scene (such as the length of a fixation duration upon one particular stop sign).

The possibility that the results may be relevant only to this particular situation is increased when one considers the average fixation durations across the whole clip. In the natural report, restricted report and control conditions the average fixation durations were 483 ms, 428 ms and 492 ms respectively. Compared to the fixation durations within the hazard window (604 ms, 336 ms, and 588 ms), except for the restricted report condition, the fixation durations appear to have increased above the average rather than decreased. It is possible that the significance of the main effect of hazard window does not reflect a decrease in the fixation durations, but instead it may reflect the considerable increase in fixation durations in the pre-hazard window (783 ms, 849 ms, and 908 ms) compared to the overall fixation durations. This could be explained in terms of the specific hazard that the participants witnessed. During the two seconds preceding the hazard onset window, the main salient stimulus in the scene was the car in front. As participants were warned to keep alert for potential hazards it is possible that they maintained their fixations upon the car in front waiting for a hazard to occur. This does seem to be the case looking at the percentage of total gaze duration devoted to the category of the car in front (52, 42, and 51%). When the expected hazard finally appears, any variation in the durations of the fixations will reduce the average fixation duration compared to the pre-hazard window. While the effect still remains interesting and is definitely worthy of further research, the possibility that this finding is specific to this particular hazard renders the effect suspect until it can be corroborated through the analysis of fixation durations averaged across many different types of hazard.

The second significant effect that was discovered in the eye tracking data was the difference between the spread of search along the horizontal and vertical meridians. The variance of the fixation co-ordinates along the horizontal meridian was, on average, found to be over nine times greater than search along the vertical meridian (in terms of the variance of fixation locations). Evans (1991) has reported that a pronounced horizontal search is typical of experienced drivers. This effect is almost certainly an artifact of the driving context. In the driving environment the majority of the information available in the visual scene is contained close to the horizon. For instance, the focus of expansion is widely considered to be the optimum fixation location in order to respond quickly to any new stimuli, because it is the source of all stationary and many dynamic objects and thus gives the maximum preview distance (Shinar, McDowell & Rockwell, 1977). Other sources of stimuli are likely to be side roads, pedestrians on the pavement, shop fronts, billboards, etc., all of which appear to the left or right of the focus of expansion creating a side-to-side scan pattern (Liu, Veltri & Pentland, 1999).

2.3.5.4 Concluding remarks on the comparison of concurrent verbalisation with eye tracking

There were no significant differences found between the natural report condition (as used by Hughes and Cole, 1986b) and the control condition at any of the levels tested. The restricted report condition differed to the control condition only in the amount of time spent fixating the road ahead, which was revealed in the analysis of total fixation duration within the five categories selected. These results suggest that the use of concurrent verbalisation will not affect the search strategy of drivers, or the higher order skill of hazard perception.

However, though the use of concurrent verbalisation did not affect the visual search strategy of drivers, neither did it *reflect* it (shown in the lack of correlation between the visual and verbal categories). One cannot argue that 18% of the overall gaze duration within the category 'road ahead' was not reflected in the verbal reports due to a problem of fixation-without-perception. This discrepancy is not the advantage of concurrent verbalisation that was sought for. Instead it seems that the two methods used in this study were recording both qualitatively and quantitatively different information. As mentioned earlier, the lack of sensitivity of verbalisation to the hazard perception task suggests eye tracking to be the superior tool in this instance. Furthermore, the particular instructions given to the two verbal report groups seemed to elicit different data sets, which suggests that any results could be artifacts of the instructions. The fact that there is little consensus in the literature as to the implementation of concurrent verbalisation provides a problem as there is no definitive set of instructions.

Conversely the eye tracking data provided some interesting results that were separate to the issue of whether verbalisation affects search strategy. Fixation durations and the spread of search are two measures that can be easily taken from the data. They are informative about how the participant views the scene, and because they deal with averages across the whole clip (unlike the comparison of fixation durations between the hazard and pre-hazard windows), the results are more generalisable across situations than those drawn from individual fixations.

In conclusion the measures of eye movements produced the most flexible and convincing data. On the basis of this, the following experiments rely primarily upon eye tracking as the method of investigation.

Chapter 3. A FORAY INTO LAB AND FIELD: *Initial attempts to find experiential differences in the visual strategies of drivers.*

3.1 The need for replication

It was noted in the first chapter that there are several studies of visual information acquisition during driving which suggest an experiential difference. It was also noted that the wide range of methodologies employed often makes it difficult to compare these studies directly. This makes it especially difficult to draw conclusions when different studies produce contrasting results. For instance, the naturalistic methodology of Mourant and Rockwell (1972) led to the suggestion that novice drivers were less able to use peripheral vision for driving, whereas the contrived (but more controlled) methodology of Cavallo and Laurant (1988) produced evidence that novices can actually make better use of peripheral vision than experienced drivers.

The studies in this chapter aimed to replicate and further investigate potential differences in visual information acquisition during driving according to driving experience. Replication of differences between novice and experienced drivers was necessary due to the contrasting results found by other researchers (e.g. Mourant & Rockwell, 1972; Miltenburg & Kuiken, 1991). Furthermore, the limited sample used by Mourant and Rockwell calls into the question the validity of the differences that they reported. The large amount of variance that accompanies the measurement of any complex, real world skill ideally requires a large pool of participants to increase the statistical power of any analyses.

A further aim of the two studies reported here was to investigate experiential differences set against the cognitive demands of the situation. In particular, we asked whether novices are as sensitive to roadway differences as more experienced drivers (experiment 2), and whether experience influences a driver's sensitivity to the appearance of hazardous events (experiment 3).

3.1.2 The role of cognitive demand in determining attentional deployment and eye movements

Cognitive demands placed upon a participant may actually affect what they perceive and how they perceive it. At a basic level one can say that a busy urban road probably places more demands upon the driver than an empty, rural road. This is because the urban road has many more elements to it than the rural road. The parked cars, pedestrians, and oncoming traffic provide many more opportunities for potential hazards to occur, while bill boards, shop windows, and the general carnival of human nature fight to divert our limited attention away from the task of driving. This example highlights two separate issues in assessing the demands placed upon drivers; increases in both visual complexity and cognitive demand.

An increase in the visual complexity of the road scene can be viewed as an increase in the number of stimuli that one could fixate. Research has shown that attention is given to irrelevant stimuli even when they are not fixated. Underwood (1976) found evidence of semantic interference when trying to identify a target picture from adjacent words that were previously believed to be unattended. Other researchers have demonstrated that unattended words can have semantic interference effects without the occurrence of eye movements (e.g. Lambert & Voot, 1993). Though these experiments have been criticised for using resource-limited rather than data-limited stimuli (with the accompanying suggestion that participants may have covertly attended to such parafoveal distracters; Hollender, 1986) this does not detract from the fact that irrelevant stimuli can attract attention. An increase in cognitive demand however is an increase in the amount of processing that a particular stimulus or task may require.

Both visual complexity and cognitive demand can be increased individually without a corresponding increase in the other. In driving research however one would find it hard to separate the effects of the visual clutter of the scene from the extra demands that are involved in the successful navigation of a vehicle through a crowded street.

Recent research by Lavie (1995) has shed some light upon the relationship between visual complexity or clutter, and the cognitive demands of the situation. Her studies have produced evidence that consideration of cognitive demands may resolve the issue of early-verses-late selection in visual attention. She found that the extent of interference from peripheral distracters upon a central task (the interfering effect of peripheral clutter) diminished as the cognitive demands of the central task increased. To explain this effect she refers to the zoom lens theory of attention (Eriksen & Murphy, 1987) which suggests that the spotlight aperture of attention is reduced in diameter under conditions of high cognitive demand at the point of fixation. This would then increase the 'resolving power' of the spotlight allowing more resources to be devoted to a particularly demand task, while the peripheral distracters would be left outside the beam of attention, unable to interfere with the processing of the central task. According to these results it is the cognitive demands of the situation that constrain the effects of visual complexity: the harder a central task the more attention is devoted to it, resulting in less spare attention to be attracted by irrelevant stimuli.

There is a considerable amount of evidence which suggests that cognitive demand can influence the deployment of attention over the visual field. There is an even greater amount of research that has focused on the effects of cognitive demand upon eye movements (see Rayner, 1998 for a review). For instance there is a large body of work which focuses on regressive saccades during reading. These generally occur when the demands of the task increase (i.e. when a sentence contains ambiguous grammar). The timing of eye movements is also constrained by demand. Fixation durations are regarded as a measure of the amount of time required to process a particular stimulus (Henderson, Pollatsek & Rayer, 1989), and have been consistently noted to increase when fixating low-frequency (and therefore highly demanding) words (Rayner, 1998).

Is there however any evidence that cognitive demands may influence visual search strategies in drivers?

3.1.3 The effects of increased demand on drivers' visual search strategies

One problem in attempting to manipulate the level of demand in an experiment is the identification of a suitable independent variable. There is a lack of consistency in the relevant literature in the adoption of a demand manipulation with the result that it is very hard to compare across studies. The one common feature that the majority of these studies share however is that their demand manipulation is concerned more with the task demands of factors such as road geometry or traffic density (both of which also increase visual complexity), rather than assessing just the cognitive demands placed on the participant. Despite the disparity between the factors chosen to represent demand on the road, the following discussion highlights the consistent results that an increase in the demand of the driving task (and thus an increase in the visual complexity) tends to *increase* one's active search of the scene, producing a wider spread of search and an increased sampling rate. This was the effect reported between the pre-hazard and hazard windows in experiment 1.

The use of road geometry as a demand manipulation has focused mainly on how visual search strategies differ between driving along straight roads or when driving through curves. It was briefly mentioned in chapter 2 that Shinar, McDowell and Rockwell (1977) were among the first to note that the increased processing demands associated with the negotiation of a curve were related to a more active visual search pattern, as compared to observations on a straight road. The increase in demand occurs due to a shift in the loci of important, visual information sources. Fry (1968) suggested that the focus of expansion is the most important point of information for driving as it maximises preview time for objects directly in the path of travel. Evidence confirms that experienced drivers tend to fixate close to the focus of expansion, while information concerning lane maintenance is obtained through peripheral vision from near the car (Land & Horwood, 1995). However, when driving through a curve the focus of expansion becomes less important for direction as the car's immediate heading is offset from the expansion point. Lane maintenance also becomes more difficult: a curve is rarely of constant arc and this necessitates constant monitoring of one's position in relation to the edge of the curve. The increased importance of road markings for lane maintenance, and the corresponding decrease in the importance of the expansion point create a more dynamic visual search pattern. Shinar et al. (1977) found the participants tended to switch rapidly between fixating the road ahead for long term directional information, and fixating the road edge or lane markings in order to stay within their lane. To accommodate the increased number of fixations on the road markers, fixation durations decrease during curve negotiation. Shinar et al. suggested that the visual processing of a high speed curve during driving suggests that the participants were collapsing a two process system (directional information from foveating the focus of expansion, and lane maintenance information through peripheral vision) into one, where the fovea is attention switching between the two sources of information. Zwahlen (1993) also found curve negotiation to involve a more active search strategy than on straights. He noted that fixation durations were markedly shorter in the curve, and equated this finding with the American Automobile Association's "brief glance technique" where drivers are advised to keep fixations short in order to avoid "captured attention".

Another measure of processing demand that has been used is traffic density. As traffic increases, so does the danger of any driving situation up to the point of traffic congestion. Rahimi, Briggs and Thom (1990) looked at eye and head movements of a driver at two American intersections, one busy and one quiet. The subject performed 20 left turns (crossing the line of traffic) at each junction alternately, while head and eye movements were recorded via video. They found that the busy intersection produced more fixations than the quiet junction, which suggests a corresponding reduction in fixation durations as demand increased.

There is also evidence that the demands placed upon a driver due to the proximity of other vehicles may affect visual search patterns. The work of Hella, Laya, and Neboit (1996) suggests that the closer one is to the car in front, the shorter the fixation durations upon that car become, though there is a corresponding increase in the total number of fixations upon it. They discovered this by comparing the eye movements of drivers on a three lane motorway. Interestingly, they did not discover any visual search changes due to the speed of the car (which was dictated in part by the lane they were in at the time). The decreased fixation durations support the suggestion that as drivers find the task demands and visual complexity increasing they respond by increasing the sampling rate of the scene.

Miura (1979) used four separate levels of task demand to investigate fixation durations. These were stable running, passing parked vehicles, entering into a narrower route, and overtaking. He found that entering the narrower route and the act of overtaking significantly reduced mean fixation durations. This mirrors the results of studies of curves and intersections.

Despite the lack of consistency in the manipulations of demand, it seems fairly well documented that general increases in task demands and visual complexity tend to reduce mean fixation durations and increase the sampling rate. In the earlier examples of the effects of demand upon reading however, it was reported that increases in demand tend to *increase* fixation durations.

The important difference between the domain of driving and that of reading no doubt lies in the dynamics of the driving scene and the locus of the increase in demand. An increase in traffic density provides the driver with more stimuli which may attract attention, whereas the static nature of a low frequency word on a page of text, allows the full devotion of attention if need be. It is possible however that both these reported effects of increased demand upon visual search strategies could occur within driving; an increase in fixation durations in one case, and a decrease in fixation durations in the other. For instance, the extra demands that a busy urban street place upon the driver are quite different to the type of demands that the sudden appearance of a pedestrian from between two parked cars would produce. In the latter case, the increase in demand has a definite focus and may well act like a low frequency word in a reading study, attracting longer fixation durations which reflect the increased processing that is required. The former case of the busy urban road is however more of a general increase in demand. Rather than having one specific locus of demand, the driver is aware of many different locations that could produce a potential hazard. In these situations, it makes sense for the driver to increase their sampling rate of the scene in order to monitor all potential sources of hazards.

The findings from experiment 1 suggest however that the abrupt onset of a hazard tends to decrease fixation durations, rather than increase them. This suggests that the onset of the hazard acted in a similar fashion to the increases in traffic density or road geometry that tend to increase the driver's sampling rate of the scene. Reservations however about this particular finding have been detailed in chapter 2. Further corroboration is required before accepting this result on the basis of just one instance of a hazard.

The effects of increased demands upon visual search need to be understood. One reason for this is that the ways in which the visual information acquisition system responds to increased demands may help to differentiate drivers according to experience. Inexperienced drivers may respond to low demand situations in a normal and safe manner. It is in the situations of high demand however that experiential differences may become more apparent. The following section discusses this possibility.

3.1.4 Are novices more susceptible to high demands than experienced drivers?

Inexperienced drivers are likely to encounter capacity problems with attention more often and more severely than experienced drivers. Though recently licensed drivers will have no doubt gained experience on actual roads there will still remain much that is novel. Faced with new stimuli an inexperienced driver may take longer to process it in the same way that an infrequent word will tax a novice reader more than an experienced reader. This may become especially apparent in a busy urban street where the experienced driver may actually reduce fixation durations to increase the sampling rate. In addition, depending of the amount of practice they have received, novice drivers may still have to automatise certain sub-routines of the driving task. One such task, which is widely believed to be automatic, is that of changing gear.

Inexperienced drivers have been noted as being slower gear changers than more experienced drivers (Duncan, Williams & Brown, 1991), which suggests a failure to completely automatise the task.[1] One of the benefits of automatising this is that the task will no longer need attention. The experienced driver can then allocate all attention to other matters, while the novice drivers may still have to apportion some to gear changing. This should not be a problem when cognitive demands on the driver are low, but as demand increases the inexperienced driver may suffer a degradation of either the gear changing or the other tasks which are competing for attention. This provides a theoretical basis for predicting an experiential difference under increasing demands, but is there any evidence of such an interaction?

In order to address this question it is necessary to recap the major findings so far in studies of drivers with different levels of experience.

Mourant and Rockwell (1972) 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 studies have noted the predominance of vertical search that occurs with inexperienced drivers, at least at the very early stages

[1] The view of gear changing as an automatic task is not universal in driving research. Groeger and Clegg (1997) have argued that the large variability in the time taken to perform the various sub-tasks involved in changing gear does not reflect the typical view of automaticity.

of their driving careers, and the tendency to produce a smaller horizontal search pattern than experienced drivers (Mourant & Rockwell, 1970; Renge, 1980).

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 upon the inexperienced driver. For instance the suggestion that novices search a smaller 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 automatisation 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, it has already been mentioned that mean fixation durations have been reported to be indicative of the time required to process the objects that one foveates (Cohen, 1981, Henderson, Pollatsek & Rayner, 1989, Underwood & Everatt, 1992). Fixation durations have also been found to increase with a corresponding rise in the density of an optical array (Mackworth, 1976), or with increased complexity (Loftus & Mackworth, 1978). Any increase in the mean fixation durations of novice drivers may therefore reflect the extra processing time that they require to extract the information they need. This may be particularly problematic for inexperienced drivers if, as the evidence reviewed in section 3.1.3 suggests, increases in demand and complexity should normally elicit decreased fixation durations, so as to increase the spread of search and the sampling rate of the scene.

Similarly, increased fixation durations have been found in young children who require extra processing time to select the relevant information (Mackworth & Bruner, 1970) and in drivers who have consumed alcohol (which is considered to reduce attentional resources; Mortimar & Jorgeson, 1975). 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 noted by Mourant and Rockwell (1972) may also be explained in terms of the extra processing time that is required by inexperienced drivers, perhaps 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 hypothesised effects of demand on experience. Before describing this theory a recent study by Land and Horwood (1995), that was briefly mentioned earlier, should be explained as it provides the suggestive link. Using a rudimentary simulator (see section 2.2.3), they found that experienced drivers extracted optimal information about the road layout from two main sources: a far location nearly sixteen metres ahead (4° below the horizon), and a near location approximately nine metres 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 participants 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 though peripheral vision. If novices fixate the lane markers more often than experienced drivers, as Mourant and Rockwell propose, and if the reason for this is to maintain lane position, then this suggests a problem with the range of their attention in the peripheral visual field. In the light of Lavie's (1995) findings that demonstrated a decrease in peripheral distracter interference with an increased foveal load, one could suggest that the increased demands that novices are under leads to a narrowing of the zoom lens of attention. This is the basic tenet of perceptual narrowing: that attention in the peripheral, or extra-foveal region of the visual field is reduced or narrowed, as more attention has to be allocated to the currently foveated stimulus due to its increased processing demands. If this occurs, and attention does not extend far enough into the peripheral field to cover the lane markers, then fixation of such markers may be a compensatory strategy.

An alternative theory that tries 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 inexperienced 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. Brown and Groeger offer this as support for the view that novices do not focus as high in the visual scene as the experienced drivers. While this may support their initial claim for experiential differences in regard to the height that drivers tend to focus in the scene, whether this was due to steering cues is unclear. It is also possible that the novices' problems with hazards at greater eccentricities may reflect a problem in their deployment of attention in the peripheral field.

Brown and Groeger's interpretation is not supported by the Land and Horwood (1995) findings. If experienced drivers extract steering information from higher in the visual scene, then removing the peripheral information should have little effect. Land and Horwood have demonstrated however that lane maintenance is dependent upon information that is close to the car, though the drivers rarely fixated the area. The decision between the McLean and Hoffman's study and the work of Land and Horwood is difficult as both effects were found with a limited number of participants and in unrealistic settings.

Though there are disagreements between the various influential viewpoints as to the underlying mechanisms or strategies, all of the theories can allow for the possibility of experiential differences. It was on the basis of these studies that the initial hypothesis was made. It was predicted that an increase in the level of processing demands during driving related tasks would help to distinguish between drivers of varying experience.

3.1.5 Two experiments to investigate potential differences in the search strategies of novice and experienced drivers under conditions of varying demand

The two studies reported in this chapter were designed on the basis of information discussed in chapter 2. The complimentary benefits of both testing in the real world and in the laboratory were acknowledged. For this reason experiment 2 explores differences in search strategies as participants were actually driving on British roads, while experiment 3 used a hazard perception test in a laboratory. The benefits of dynamic stimuli in the laboratory were also noted in chapter 2, and it was hoped that such visual stimuli would help in distinguishing between two groups of drivers on the basis of their experience.

Data on the search strategies of the participants was obtained through eye tracking. This method was employed on the basis of the information and the experiment discussed in section 2.3.

The first experiment presented here was conducted on a set route, using differing road types as indicators of the changing demands placed upon the driver (Lee & Triggs, 1976; Hughes & Cole, 1986; Hella, Laya & Neboit, 1996) while participants' eye movements were measured. It was hypothesised that differences between novice and experienced drivers would be revealed when compared across different levels of demand (indicated by road type), and specifically that high demand situations would be more likely to produce these differences. In the second experiment drivers watched driving scenes containing hazardous events. Processing demands were considered to increase during the appearance of a hazard.

3.2 Experiments 2 & 3 : Two studies designed to examine experiential differences in drivers visual search strategies

3.2.1 On-road methodology for Experiment 2

3.2.1.1 Participants

Sixteen experienced drivers (11 male, mean age 27.7 years, mean experience 9.0 years) and 16 novices (7 male, mean age 17.9, mean experience 0.2 years) volunteered for the experiment, all with normal or corrected-to-normal vision. The experienced drivers were recruited from advertisements in the local press while novice drivers were primarily recruited via questionnaires distributed through driving test centres.

3.2.1.2 Apparatus

Participants were asked to drive a 1996 Ford Escort around a set route while their eye movements were measured using a NAC EyeMark VII head-mounted eye tracker (see section 2.3.3.4). The data were recorded on an in-car NTSC video recorder and were analysed using the NAC Data Processing Unit linked to a P90 PC. The temporal and spatial fixation filters used in Experiment 1 were also employed for this study.

3.2.1.3 Materials

Participants were given in-car instructions in order to negotiate a 20 minute route while wearing the eye tracker. From this drive three one minute 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 demand than the rural road. The location-onsets of the three windows were constant for all drivers.

3.2.1.4 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 that were sampled within the one minute windows. As a set route was used the three windows could not be counterbalanced. To avoid practice effects on the specific road types, a twenty minute familiarisation drive preceded the main testing period. The familiarisation drive included examples of all three road types that were used in the measurement windows.

3.2.1.5 Procedure

During both the twenty minute familiarisation drive and the twenty minute test route the experimenter sat in the rear of the car to give directions when necessary. These directions were given to the drivers when the relevant signs could be seen on the road, so that the participants 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. At a particular point during the drive participants were asked to stop the car in an off-road car park. The eye tracker was then fitted and participants were calibrated against pre-chosen features on the wall of the building opposite to the car park. After a brief calibration procedure participants were asked to start the car once more, and were given instructions to continue the drive.

The participants were instructed to drive in their normal style and to disregard the presence of the experimenter as much as possible while still following directions. If calibration was lost due to a bump in the road disturbing the alignment of the eye camera, the participant was asked to pull over if it was safe to do so, and they would be recalibrated before reaching the next recording window.

3.2.2 Results of Experiment 2

Four measures were taken from the recordings provided by each driver. Within each one minute window the number of fixations and their durations were recorded, and the variance of fixation co-ordinates along the horizontal and vertical meridians were calculated. Each measure was subjected to an analysis of variance. The means of these four measures can be viewed in Table 3.1, though the four analyses will be described separately.

3.2.2.1 Mean fixation durations

A main effect of the type of roadway was found for mean fixation durations, $F_{(2,60)}=7.96$, $p<0.001$, and a significant interaction was discovered between the level of driver experience and road type, $F_{(2,60)}=3.14$, $p<0.05$. The interaction is charted in Figure 3.1, below.

Pairwise comparisons revealed that the novices had significantly shorter fixations on the suburban road when compared with the dual carriageway ($p<0.01$) while the experienced drivers had significantly shorter fixations on the suburban road when compared to the rural road ($p<0.01$).

3.2.2.2 The number of fixations

A main effect of roadway was found, $F_{(2,60)}=9.73$, $p<0.001$. Means comparisons between the levels of roadway revealed that the suburban road produced significantly more fixations than the other two roadways ($p<0.01$).

	Rural		Suburban		Dual Carriageway	
	Exp. Drivers	Novice Drivers	Exp. Drivers	Novice Drivers	Exp. Drivers	Novice Drivers
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 Search Variance (degrees^2)	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 Search Variance (degrees^2)	12.5 {7.9}	22.4 {14.4}	12.1 {7.8}	21.0 {13.7}	23.8 {18.6}	24.1 {14.6}

Table 3.1. Means (and standard deviations) for eye fixation measures taken on three sections of roadway and for two levels of driving experience.

3.2.2.3 Spread of search along the horizontal meridian

In regards to differences between the horizontal and vertical meridians for road type and experience, each meridian was considered separately

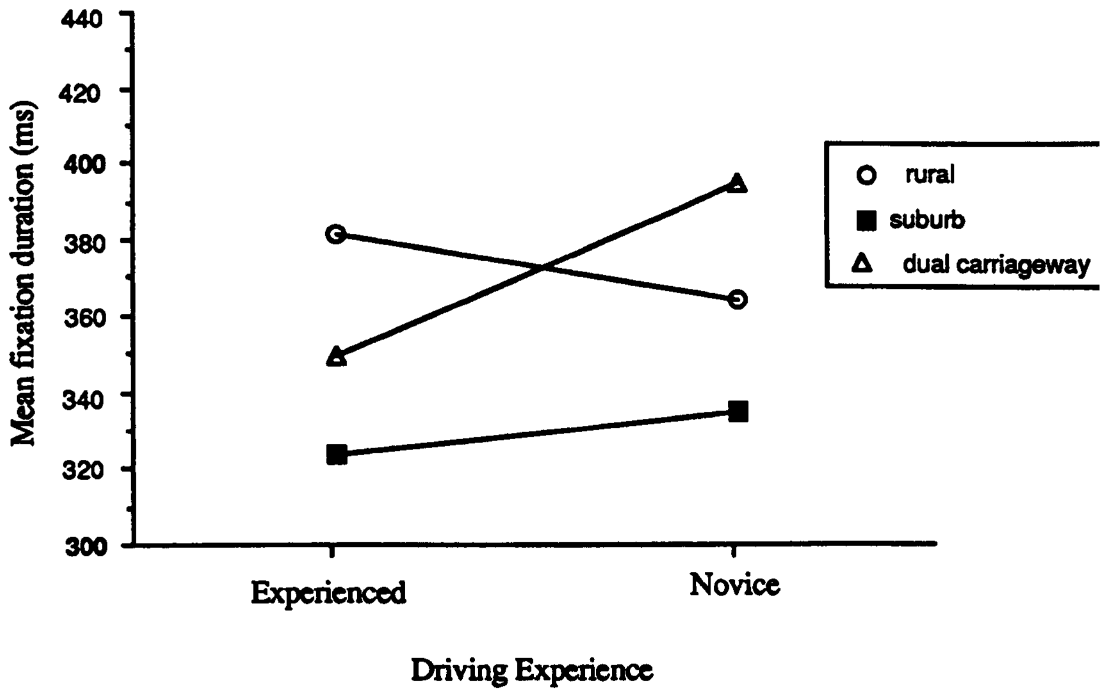

Figure 3.1: Mean fixation durations for novices and experienced drivers across road types

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 roadway, $F_{(2,60)}=7.76$, $p<0.01$, and a significant interaction between level of experience and road type, $F_{(2,60)}=6.61$, $p<0.01$. This interaction is charted in Figure 3.2.

Means comparisons 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 to the other two roads ($p<0.001$). A post hoc Student-Newman-Keuls test revealed that the only significant difference was between experienced drivers and novices on the dual carriageway ($p<0.05$).

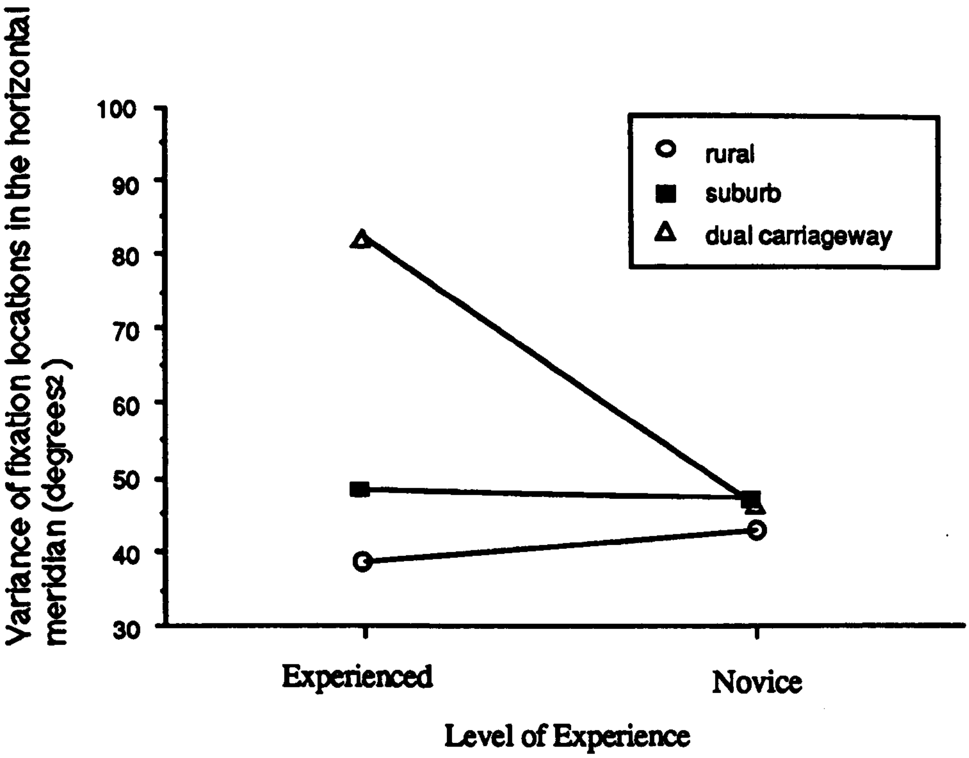

Figure 3.2: Spread of horizontal search for novice and experienced drivers across road types

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

3.2.2.4 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, $F_{(2,60)}=4.02$, $p<0.05$. The interaction failed to reach significance, however 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 ($p<0.05$) and to the rural road ($p<0.05$). This pattern of results can be viewed in Figure 3.3.

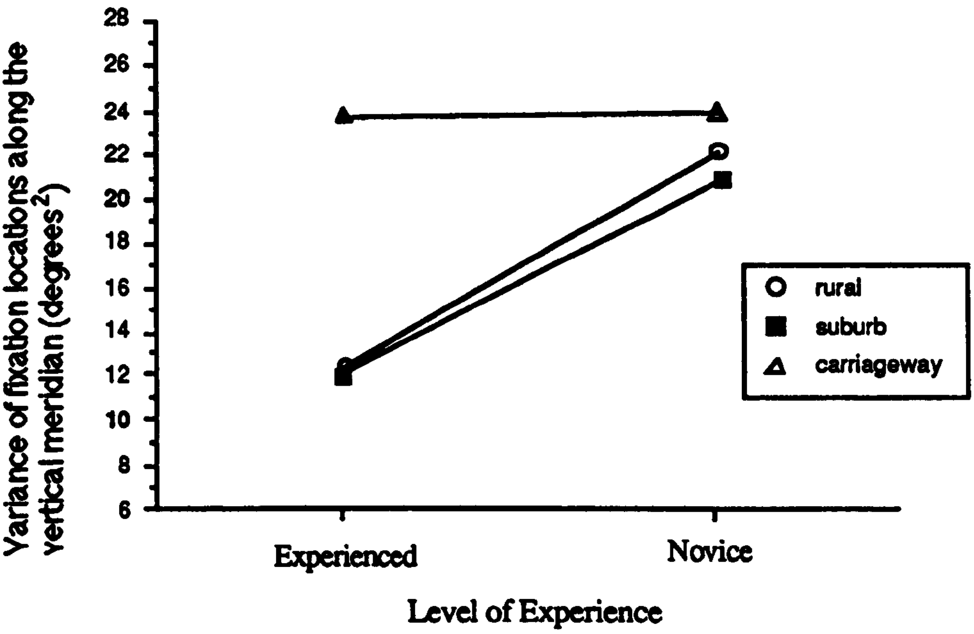

Figure 3.3: Spread of vertical search for novice and experienced drivers across road types

3.2.2.5 What did the drivers look at?

A subset of the drivers' data in experiment 2 were further analysed in order to examine what the drivers actually looked at in the three different road types. Data from five novices and five experienced drivers were selected on the basis of the quality of the calibration of the eye tracker. When comparing fixation durations and search variances, the calibration may slip so that the indicator of eye position is slightly offset from what participants are actually looking at, but this will not affect the results. When categorising what the participants look at when driving, a slight offset in the calibration may mean the difference between classifying a fixation as focused on the car in front, or oncoming traffic. This can be an especial problem at long preview distances where the images on the video output are extremely small.

The same fixation filters were applied to samples of eye co-ordinates that fell upon stimuli within certain categories. Unlike the categorisation used in section 2.3.4.3, the road scenes changed from one participant to another. Though the basic stimuli such as the particular shops along the suburban route remained the same across participants' drives, other transitory stimuli varied in quantity. For instance the amount of time that a driver was following a car ahead changed according the amount of traffic on the road at the time of the test drive. The complexity and diversity of the different road types and the individual test drives necessitated a more in-depth categorisation of stimuli. Following on from section 2.3.4.3., and the work of Hughes and Cole (1986), eleven different categories were identified. These categories and their occurrences on the different road types are listed in Table 3.2. A pictorial representation of two of the categories (a tangent point and an example of fixating the road ahead through a curve) are displayed in Figure 3.4.

	Category	Rural	Suburban	Dual Carriageway	Explanation
Road related	Focus of expansion (FOE)	√	√	√	The point of origin for optic flow (2° diam.)
	Road ahead	√	√	√	From in front of the car to the FOE
	Road ahead through corner	√	x	√	See Figure 3.4
Lane maintenance	Lane markings	√	√	√	White lines and kerbs
	Tangent Point	√	√	√	See Figure 3.4
Moving vehicles	Vehicle ahead	√	√	√	In the lane(s) ahead
	Oncoming vehicle	√	√	x	In the oncoming lane
Car related	Mirrors	√	√	√	Rear and wing mirrors
	Dashboard	√	√	√	
Other	Parked vehicles	x	√	√	To the left and right of the road
	Off-road environment	√	√	√	Anything other than the above

Table 3.2. A list of the categories of stimuli viewed by participants while driving, and their occurrence on the different road types.

Some of the categories overlap. The focus of expansion is considered to be a special case of the road ahead category and so would count toward both when totaling the gaze duration within these classifications. Similarly the tangent point of a curve is considered to be a special case of lane markings. On left hand bends the tangent point was often on the kerb or road

Figure 3.4. A representation of a fixation upon a tangent point and a fixation point through the bend.

verge, whereas on right hand bends the tangent point was considered to be upon the centre lane markings or the right hand verge.

The category that monopolised the viewing time of the participants was the 'road ahead', the majority of which was devoted to the area of two degrees diameter defined as the 'focus of expansion'.

Analyses of variance were conducted upon the category gaze durations, the means of which can be viewed in Table 3.3. It should be noted that the gaze durations do not necessarily add up to the minute of video that was analysed for each participant. This is due to the overlap of important categories such as 'road ahead' and 'tangent point', where the latter is a special case of the former. Though such analyses cannot be accepted at face value due to the low number of participants, it was hoped that they would help clarify some of the results found with the full pool of participants.

A main effect of experience was discovered for the 'focus of expansion' category ($F_{(1,8)}$=7.2, $p<0.05$) and for the dashboard ($F_{(1,8)}$=6.6, $p<0.05$). Experienced drivers tended to fixate the focus of expansion more than novices though this difference was

	Category	Rural		Suburban		Dual Carriageway	
		E	N	E	N	E	N
Road related	Focus of expansion (FOE)	22.74	11.95	23.51	9.72	18.13	7.63
	Road ahead	28.75	21.27	27.73	20.33	23.01	17.73
	Road ahead through corner	9.35	2.58	n/a	n/a	3.14	3.05
Lane maintenance	Lane markings	6.06	8.05	3.61	3.31	7.47	7.50
	Tangent Point	2.30	1.17	0.36	0.21	0.77	0.93
Moving vehicles†	Vehicle ahead	19.7	4.9	6.7	22.2	15.4	14.3
	Oncoming vehicle	11.0	3.3	17.0	7.1	n/a	n/a
Car related	Mirrors	2.10	2.25	2.76	2.18	6.51	3.05
	Dashboard	2.90	8.45	2.15	3.83	5.63	10.19
Other	Parked vehicles	n/a	n/a	5.99	2.57	n/a	n/a
	Off-road environment	3.26	2.18	3.51	4.88	3.03	1.49

Table 3.3. The mean gaze duration given to the above categories (in seconds) during a sixty second measurement window for experienced (E) and novice (N) drivers.

† As moving vehicles were present in the scene for different amounts of time for each participant, the gaze durations afforded to the two categories of vehicle ahead and oncoming vehicle are represented as percentages of the amount of time that such vehicles were available to be fixated during each participant's drive.

reversed for gaze durations upon the dashboard. The failure to find an experiential difference in the gaze durations on the category of 'road ahead' suggests that novices were not fixating the road ahead at as great a preview distance as the more experienced drivers (otherwise the difference between the drivers in the 'focus of expansion' category - which is a special instance of fixating the road ahead - would not have been significant. Instead their fixations on the road ahead remained closer to the car. This may reflect the novices pre-occupation with the dashboard.

Three interactions between experience and road type were also noted. The first interaction was found for gaze durations on the road ahead through the corner ($F_{(1,8)}$=5.8 $p<0.05$). Means comparisons revealed that experienced drivers increased the time they spent fixating through the curve on the rural road compared to the novices ($p<0.01$), but not on the dual carriageway, which had markedly lower gaze durations through the curve for both groups of drivers. The second interaction was found for gaze durations in the category of vehicle ahead ($F_{(2,16)}$=6.1, $p<0.05$). Experienced drivers spent more time fixating a vehicle ahead than the novice drivers on the rural road ($p<0.05$), though this was reversed for the suburban road ($p<0.05$).

The third interaction was found in the category of mirror usage ($F_{(2,16)}$=4.0, $p<0.05$). Means comparisons revealed that all drivers used their mirrors equally on all of the road types except for the experienced drivers on the dual carriageway. Gaze durations upon mirrors in this condition were found to be significantly increased over all other conditions ($p<0.05$). This may explain the increase in search variance noted for the experienced drivers upon the dual carriageway.

Though no experiential differences were noted concerning the other categories, a main effect of road way was discovered for gaze durations on tangent points ($F_{(2,16)}=6.9$, $p<0.05$), with the rural road accruing the longest gaze durations ($p<0.05$). All other analyses were found to be non-significant.

Before discussing any of these results in further detail, the method and results of the laboratory study will be summarised. The subsequent general discussion will then compare and contrast the data from the two studies.

3.2.3 Laboratory methodology for Experiment 3

3.2.3.1 Participants

Thirty two novices (19 male, mean age 18.1 years, mean experience 0.2 years), and 22 experienced drivers (11 male, mean age 27.6 years, mean experience 9.0 years), performed a hazard perception test. All the participants had normal or corrected to normal vision and were recruited from the same sources as the participants of Experiment 2.

3.2.3.2 Apparatus and materials

Thirty nine hazard perception clips were split into three sets of thirteen clips. One set of clips was presented to each participant on a P90 PC (see section 2.3.3.2 for a description of the hazard perception test; see Appendix 1 for a description of the individual clips and individual hazard onset times). Each participant had an equal chance of being allocated any one of the three sets of clips. Each set of clips had a set number of road types (five rural, four suburban and four urban roads) which had previously been categorised according to a cluster analysis performed on all 39 clips (Chapman & Underwood, 1998). Participants thus all saw the same proportion of road types, though the actual stimuli differed across the three sets. In this manner it was hoped to avoid restricting any findings to one particular set of clips rather than to the overall hazard perception test. A mouse button was provided for participants to make responses to the appearance of potential hazards. At a distance of one meter the full screen display subtended 15.4° in the horizontal meridian, and 11.6° in the vertical meridian.

The PC was linked to a monocular Dual Purkinji Image eyetracker (DPI). The DPI is a fixed bench eyetracker that requires the head to be restrained in a chin and head rest. As this eyetracker is used in subsequent experiments it is described in more detail in the following section.

3.2.3.3 The Dual Purkinje Image eyetracker

The DPI eyetracker measures the disparity between two reflections of an infra red light source that is shone into the right eye. The two reflections are referred to as the first and fourth purkinje images. The first image is the reflection of the light source from the convex front surface of the cornea, while the fourth image is the reflection from the concave surface of the back of the lens. As the eye rotates, the distance between the two reflections changes. These changes in disparity are recorded as voltage outputs by the eyetracker. These voltages can be converted to screen co-ordinates by preceding any test with a calibration routine. Similarly to the manual calibration of the NAC eye tracker, this procedure requires the participant to fixate certain points on the viewing screen. At each calibration point the computer records the voltages associated with the two purkinje images, to provide reference points for the subsequently collected data.

The sampling rate of the DPI eyetracker in this study is limited by the presentation speed of the MPEG clips to 60Hz, or one sample every 16 ms. The temporal fixation filter was set to recognise six samples (100 ms) as the minimum fixation duration. This is the same filter that was used in experiments 1 and 2. The spatial filter was reduced to a quarter of a degree (0.24°, equivalent to 10 pixels at a distance of one meter) to account for the increased accuracy of the DPI eyetracker over that of the NAC. Despite the extremely restricted spatial filter, pilot data showed that this still allowed for pursuit tracking eye movements to be classed as fixations.

3.2.3.4 Design

This experiment used a mixed design. The between-subjects variable was experience and the within-subjects factor was the quasi-manipulation of cognitive load. The levels of this factor consisted of three time windows: a pre-hazard window, a hazard window, and a post hazard window. The hazard window was considered to provide the highest level of processing demand, and the length of it varied from clip to clip according to the amount of time that each particular hazard was in view. The pre- and post-hazard windows were as long as the individual hazard windows that they accompanied, and occurred immediately before and after the hazard window, respectively. The hazard window applied to only the first hazard in a clip if there were more than one. All the clips were randomly presented.

Several eye movement measures were averaged across the whole clips to look for any differences between novice and experienced drivers regardless of demand. These included fixation durations for participants over each whole clip, and the variance of fixation locations along the horizontal and vertical meridians. In order to look for general sequential patterns in clusters of fixations a measure of zero, first and second order distance between the loci of subsequent fixation points was also recorded (referred to as d_0,, d_1, and d_2). An example of these measures can be seen in Figure 3.5.

In addition to these general measures, fixation durations and d_0 were recorded within the three demand windows to look for differences across participants due to the processing demands. The length of the 'response fixation' was also measured within the hazard window . This is the length of the fixation that occurred during the button response to acknowledge a hazard. The rationale underlying this measure, providing one assumes that the

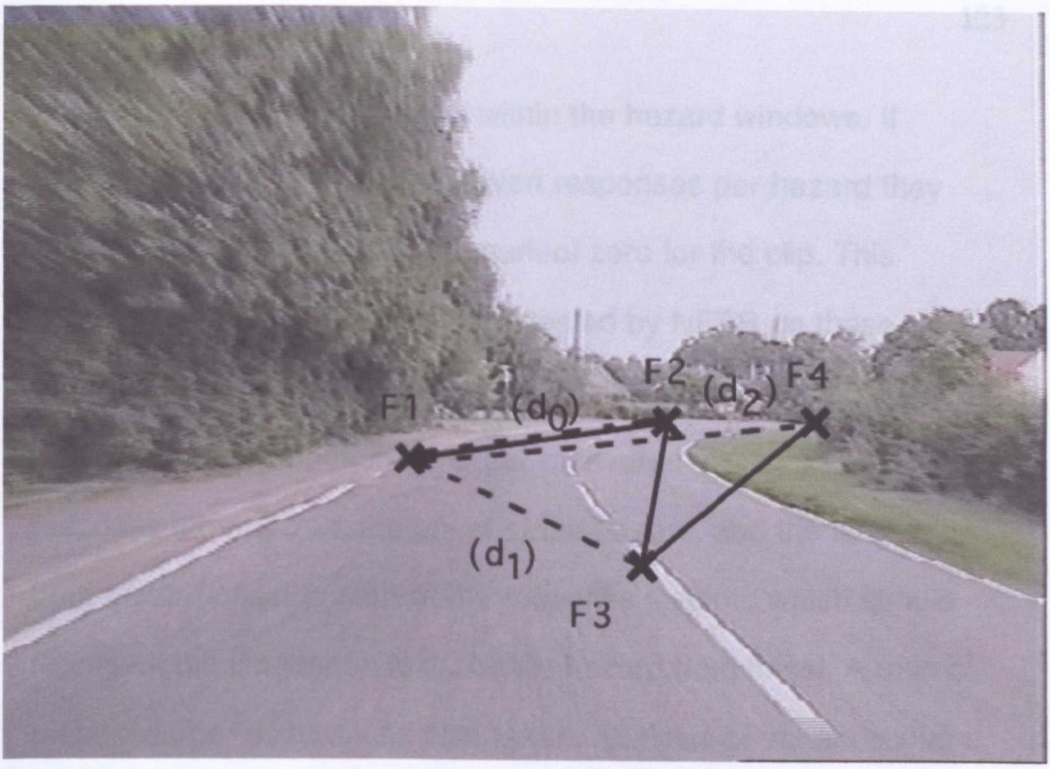

Figure 3.5. A pictorial representation of the measures of d. F1, F2, F3, and F4 refer to the locations of four sequential fixations. The dotted lines represent the distance between F1 and F2, F1 and F3, and finally F1 and F4. These distances make up the zero, first and second order measures of d.

participant presses the button while still fixating the hazard, is that this fixation duration will give the most immediate measure of processing time needed for the hazard. The response fixation was split into 'before response' and 'after response', with the former portion of the fixation representing the processing that occurs before a response is executed, while the latter represents any post-response lingering of gaze.

Further measures were also taken that were independent of the eye tracking data. These included the participant's score on the hazard perception test. This was obtained by dividing each hazard window into five equal segments and awarding a maximum score of five points per hazard if the participants gave a response within the first fifth of the hazard window. The score diminishes point by point as responses occur later within the hazard windows. If participants made more than seven responses per hazard they were automatically awarded a mark of zero for the clip. This scoring system was designed and tested by NFER on these particular clips. A more detailed description of the scoring systems can be found in Appendix 1. Other measures included the response latency from the onset of the hazard, and the latency from hazard onset to start of the response fixation, which should represent the time taken to fixate the hazard from onset. A ratio of responses per hazard was also taken. Analysis of variance was performed on all of these measures.

3.2.3.5 Procedure

Participants were told to that they would see 13 clips from the driver's perspective and that their task was to view these scenes as if they were the driver, and to press a mouse button as quickly as possible whenever they spotted a potential hazard. A potential hazard was described as anything that would make one consider braking, decelerating, swerving or performing any other form of evasive maneuver. Participants were also informed that there would be at least one major potential hazard in each clip. They were then placed in the head restraint and chin cup, and the eyetracker's calibration procedure was conducted. The pace of the experiment was controlled by the participant who had to press a button between clips to proceed. After each button press, a count down from five to one would be displayed at the centre of the screen before the clip started. If calibration degraded during a clip, the experimenter had the opportunity to halt progression between clips and attempt to recalibrate the participant before allowing them to continue.

3.2.4 Results for Experiment 3

The results section is divided into three sub-sections. The first section reports the measures that compare the windows of differing demand (before, after and during the first hazard of each clip). The second sub-section covers the general eye movement analyses taken from whole clips analysed across experience, and other incidental measurements such as hazard perception reaction times. The means for the measures recorded across the windows are shown in Table 3.4, while the means for the whole clip measures are displayed in Table 3.5. After these analyses were performed, the data were recategorised according to the road type depicted in the clip. Further analyses were then conducted with the type of road replacing the appearance of a hazard as the demand factor. These are detailed in the final sub-section of the results.

3.2.4.1 Visual search strategies compared across different demand windows and experience

A mixed design analysis of variance was performed on the mean fixation durations to compare the pre-hazard, hazard and post-hazard windows across experience. A significant main effect of demand window was found, $F_{(2,104)}=52.4$, $p<0.01$, though the interaction with experience did not prove to be significant. The

	Novice drivers		Experienced drivers	
Pre-hazard mean fixation duration (ms)	500	{109}	451	{80}
Pre-hazard d_0 (degrees)	1.87	{0.38}	1.86	{0.48}
Hazard mean fixation duration (ms)	698	{214}	615	{131}
Hazard d_0 (degrees)	1.65	{0.38}	1.68	{0.35}
Post-hazard mean fixation duration (ms)	514	{143}	480	{144]
Post-hazard d_0 (degrees)	1.88	{0.43}	1.78	{0.48}

Table 3.4 Means {and standard deviations} for the eye movement measures across the three demand windows from Experiment 3.

main effect of window was investigated with means comparisons. These comparisons revealed that the hazard window had significantly longer fixation durations than the pre- and post-hazard windows ($p<0.01$). Though the hazard window did prove to change fixation durations compared to the windows immediately around the hazard onset, this did not prove to differentiate between novice and experienced drivers.

The same analysis was conducted upon the zero order measure of saccade distance (d_o). A main effect of window on the mean length of d_o was found, $F_{(2,104)}=7.55$, $p<0.01$, though, as with the mean fixation durations, a significant interaction was not forthcoming. Means comparisons across the different demand windows revealed the significance to lie with the hazard window which produced shorter saccade lengths than both the pre-hazard window (p<0.01) and the post-hazard window (p<0.05), suggesting a more contained visual search during the appearance of the hazard.

	Novice Drivers		Experienced Drivers	
Mean Fixation Duration (ms)	439	{75}	411	{64}
d_0 (degrees)	1.93	{0.29}	1.90	{0.34}
d_1 (degrees)	2.19	{0.31}	2.17	{0.31}
d_2 (degrees)	2.36	{0.36}	2.27	{0.29}
Mean horizontal search variance (degrees)	6.57	{2.61}	5.86	{0.91}
Mean vertical search variance (degrees)	0.51	{0.41}	0.26	{0.11}
Hazard Perception Score (NFER criteria)	40.7	{11.2}	41.6	{12.3}
Response Times to hazards (ms)	1172	{452}	1089	{448}
Fixation Prior to Hazard (ms)	510	{160}	477	{267}
Fixation After Hazard (ms)	559	{218}	493	{186}
Time to Fixate the Hazard (ms)	663	{430}	612	{309}
Response/Hazard Ratio	1.6	{0.6}	2.1	{1.0}

Table 3.5 Means {and standard deviations} for the hazard perception measures taken from the whole clips from Experiment 3.

3.2.4.2 Measures taken from each whole clip analysed across experience

Mean fixation durations for the whole clips were compared though no significant differences were found between drivers of varying experience (t_{52}=1.44). Analysis of d_0, d_1 and d_2 found no differences across experience ($F_{(1,52)}<1$), and no interaction that would suggest a repetitive pattern of saccadic movements ($F_{(2,104)}=1.24$). There was however a main effect of distance order, $F_{(2,104)}=149$, $p<0.01$. Means comparisons showed all levels of *d* to be different from each other with d_0 giving the shortest length between fixations and d_2 giving the longest distance suggesting a simple linear relationship between the order and the actual distance between the fixation points. The variance of fixation locations across the whole clips was also analysed according to experience. No difference was found in the spread of search in the horizontal meridian ($t_{52}=1.1$) though novices were found to have a significantly larger spread of search than experienced drivers in the vertical meridian ($t_{52}=2.88$, $p<0.01$). Neither the mean time taken to fixate a hazard after onset ($t_{51}=0.47$) or the mean fixation duration that occurred when a hazard response was made ($t_{51}=1.03$) were found to discriminate between novice and experienced drivers. Splitting the fixation duration at the time of response into that which occurred before the response and that which occurred after failed to show anything of interest ($F_{(1,51)}=1.06$). One novice driver was removed from these latter analyses due to a low number of observations per cell.

The hazard perception scores did not differ for the two groups of drivers ($t_{52}=0.29$) and neither did the basic measure of response time to hazards ($t_{52}=1.03$). Experienced drivers did however make more responses per hazard than novices ($t_{52}=2.43$, $p<0.05$) suggesting either that they have different criteria for judging what events constitute hazards, or that they perceive more events as being potentially hazardous.

3.2.4.3 Measures taken from each whole clip analysed across road type

The thirty nine clips were recategorised according to the three road types identified by an earlier cluster analysis performed on the clips (Chapman & Underwood, 1998). Though the three road types of rural, suburban and urban roads did not match the on-road study directly it was considered that this classification of demand was closer in comparison with that of experiment 2, than the classification of demand according to the appearance of a hazard. In the course of the reclassification of the data two novice participants were discarded because of empty cells due to eye tracking problems. The reclassified means can be viewed in table 3.6.

A mixed design analysis of variance compared the three road types across experience. A main effect of road type was discovered ($F_{(2,100)}=24.83$, $p<0.01$). Means comparisons revealed that the difference in durations was significantly different at each level of road way ($p\leq0.01$), with urban roads producing the shortest fixations and rural roads producing the longest. A similar analysis was conducted on the variance data from both the horizontal and vertical spread of search. A similar effect of road type was discovered ($F_{(2,100)}=64.27$, $p<0.01$) for the horizontal data, and

	Rural		Suburban		Urban	
	N	E	N	E	N	E
Mean Fixation Durations (ms)	463 {88.31}	430 {75.79}	431 {74.18}	419 {62.00}	418 {79.97}	387 {63.27}
Mean horizontal search variance (degrees^2)	5.19 {1.54}	4.80 {1.17}	5.76 {1.30}	5.84 {1.13}	7.09 {1.58}	7.43 {1.50}
Mean vertical search variance (degrees^2)	0.62 {0.81}	0.24 {0.14]	0.40 {0.26}	0.22 {0.15}	0.47 {0.27}	0.30 {0.12}
d_0 (degrees)	1.73 {0.30}	1.67 {0.33}	2.01 {0.33}	1.96 {0.37}	2.08 {0.27}	2.09 {0.34}
d_1 (degrees)	1.95 {0.36}	1.85 {0.29}	2.28 {0.35}	2.24 {0.30}	2.40 {0.32}	2.42 {0.40}
d_2 (degrees)	2.17 {0.63}	1.96 {0.28}	2.41 {0.33}	2.36 {0.30}	2.53 {0.29}	2.53 {0.38}

Table 3.6 Means {and standard deviations} for the eye movement measures across road type and experience (N=novice, E=experienced)

again all road types were found to be significantly different from each other ($p<0.01$), with the urban roads producing the widest search, and the rural roads producing the narrowest search. In the analysis of the variance data in the vertical meridian, road type was found to have no significant effect, though a difference was found again due to experience ($F_{(1,50)}=8.99$, $p<0.01$) with the more experienced drivers producing less vertical search. The measures of distance between zero, first and second order fixations (d_0, d_1,

d_2) were analysed together. A main effect of both roadway ($F_{(2,100)}$=90.57, p<0.01) and the level of *d* ($F_{(2,100)}$=158.03, p<0.01) were found. Means comparisons showed that all road types and levels of *d* were significantly different from each other at a level of p<0.01. Rural roads produced the shortest levels of *d* while urban produced the longest. The pattern of measures of *d* across orders (zero, first and second order) reflected the pattern noticed in the whole clip measures, with subsequent fixations occurring further away from previous fixations, suggesting no return to the area of the original fixation until after the fourth subsequent fixation at the least (on average).

3.2.4 Discussion of the results of experiment 2: On the Road

Both the analyses of eye movements and the comparisons of gaze durations within certain categories have shown significant effects of experience, and several significant interactions with road type. This suggests that there is an influence of experience on the effects of processing demands in driving.

In regard to mean fixation durations it seems that the reported finding that novices produce longer fixation durations than experienced drivers (Mourant & Rockwell, 1972) is not a simple difference but one which depends on the type of road they are driving 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. Novices however increased fixation durations on the more demanding dual carriageway. The only roadway where the drivers apportion their visual attention in similar ways is the suburban route.

As noted previously, traditional research findings in the areas of reading or picture viewing interpret increased fixations as extra processing time due to a complex or demanding foveal stimulus (Henderson, Pollatsek & Rayner, 1987, 1989; Loftus & Mackworth, 1978; Mackworth 1976; Underwood & Everatt, 1992). On the dual carriageway the novice's behaviour may reflect this. The experienced drivers however have, by this analogy, found the dual carriageway and the suburban route to be the least demanding. This may be the case, though it is more likely that the reduced durations may be part of a compensation strategy to deal with the increased demands (Miura, 1990). Reducing the time spent foveating any one location may be a strategy to allow one 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, which is the most visually complex (if not the most demanding overall) of the three, produced the most fixations.

These results are similar to the findings of other studies reported earlier that have also shown decreased eye fixation durations when driving through increasingly demanding roadways. As reported in section 3.1.3 several researchers have noted a decrease in fixation duration and an increase in the number of fixations when driving through a curve compared to a straight (Shinar, McDowell, Rackoff & Rockwell 1978; Zwahlen, 1993), while others have noticed a positive relationship between fixation duration and headway (Hella, Laya, & Neboit, 1996), and traffic density (Rahimi, Briggs & Thom, 1990).

The spread of search in both the horizontal and vertical meridians was also found to produce significant effects. Experienced drivers were found to drastically increase the variance of their fixation locations in both meridians for the dual carriageway. Novice drivers however maintained the level of variance in the spread of search across all road types. Ostensibly the novice drivers did not increase their spread of search in the horizontal meridian for the dual carriageway, nor did they decrease their vertical search upon the rural and suburban roads.

The category analysis may aid interpretation of these results. It was found that the subset of (experienced drivers viewed the dashboard less often than the subset of novices across all road types, though they produced longer gaze durations on the mirrors when on the dual carriageway) (The novices' propensity for excessive search in the vertical meridian may reflect their lack of sensitisation to the informative areas of the road (Renge, 1980),) though it may also, in part at least, be accounted for by the (increased number of fixations on the dashboard. These dashboard fixations would increase the spread of search in the vertical meridian.)

Similarly the increase in gaze durations upon mirrors while on the dual carriageway would increase the spread of search in both meridians as wing mirrors and the rear view mirror are checked more often. This would be expected on a dual carriageway where knowledge of overtaking or merging vehicles is of vital importance.

Regardless of the underlying causes of the variance effects it should be noted that the novice drivers failed to respond to the differing demands imposed by the changing road types. Experienced drivers were more flexible however.

In a similar type of study Shinar, McDowell, Rackoff and Rockwell (1978) found inflexibility of visual search to correlate with high field dependency. They discovered that participants 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" (p556). This study provides a link between a reduced search space, an inflexible strategy and a suggestion of a decreased attention in the peripheral field. The current results suggest that the factor of experience can also be included.

A number of significant experiential effects were discovered for other categories of road stimuli. The finding that experienced drivers fixate the focus of expansion more than novices is in line with previous research that demonstrated experienced drivers fixate further in front of the car than novices (e.g. Mourant & Rockwell, 1972). Fixating the FOE gives the maximum preview of obstacles ahead. This effect cannot be an artifact of how much total attention is devoted to the road ahead, as no significant differences were discovered for this category. The conclusion is that novice drivers fixated the road ahead as much as the experienced drivers though their gaze fell nearer to the car.

Experienced drivers were also found to look through the curve more than novices when on the rural road. This may be a further example of the experienced drivers trying to maximise the preview of the road ahead: the true focus of expansion is shifted in respect to the driver when negotiating a curve such that one must look through the curve to gain maximum preview. The fact that experienced drivers did not maintain this preview through curves on the dual carriageway is perhaps testament to the more tactical demands of this road which preclude strategic planning.

Experienced drivers were also noted to give more attention to the vehicle in front than novices, but only on the rural road. This effect was reversed upon the suburban road. As any vehicle ahead in the same lane poses the most immediate threat to safety it makes sense that this should be fixated. However the experienced drivers seem to inhibit their need to fixate the vehicle ahead on the dual carriageway and to a greater extent on the suburban road. This corresponds to the increase in relevant stimuli in the road scene that could be fixated. This again may reflect the need to increase the sampling rate of the scene as the sources of information and potential danger increase. Novice drivers however devoted their gaze to the vehicle in front for over 22% of the time that such a vehicle was present on the suburban road. Compared to the 7% of experienced drivers, this suggests that novices depend on the car in front too much as a source of important information when on the suburban route.

Regardless of the mechanisms that underlie these effects, the results strongly demonstrate that novice and experienced drivers react differently to road scenes of differing demands.

3.2.4.1 A tangential digression

The category analysis that was conducted upon the tangent point data showed no effect of experience. An effect of roadway was found however which suggested that tangent points were fixated more upon the rural road than on the suburban road or the dual carriageway. Though this is of less interest to a study primarily concerned with experiential differences, the results warrant a brief discussion of their relevance to previous research.

Recent work by Land and Lee (1995) suggested that the tangent point was one of the most important sources of information for negotiating curves. The rural road they tested their three participants upon was described as tortuous, and involved sharp corners with little visibility through the curves. One criticism of this study is that the drivers may not have fixated the tangent points for information on how far to turn the steering wheel (as Land and Lee suggested). Instead participants may have used the tangent points as the most informative points of preview information in the absence of being able to see through the curves. Although the rural road used in this study is certainly not tortuous, participants still fixated the tangent points of these curves more than those of the other roads even though visibility through the curves was good. The experienced drivers actually spent nearly two and a half seconds of the 60 second window gazing through the curves (15.6%). Thus the tangent point does not receive such high gaze durations on the basis that the best source of preview information (through the curve) is unavailable. Thus fixating the tangent point must provide some other form of information, such as steering information as suggested by Land and Lee.

It does seem that when drivers have little else to occupy their gaze they can afford to sample all sources of information, though as demands increase they will reduce the sample time given to sources of information according to their usefulness. If the time spent fixating tangent points is compared to the time spent looking through a curve then one will note that experienced drivers consistently view tangent points for 25% of the total time they spend gazing through the curve on both the dual carriageway and rural roads. If one assumes that the experienced drivers' gaze durations reflect the usefulness of particular areas of the scene, then this suggests that though the tangent point may be a useful source of information for curve negotiation, looking through the curve is four times as important. On the basis of the results from this study it would be hard to make definitive statements on the relative importance of different parts of a curve, though this may provide an interesting starting point for such research. As no experiential differences were found however, the current remit of this thesis did not permit further investigation at this point.

3.2.5 Discussion of the results of experiment 3: In the lab

Comparisons of mean fixation durations and d_0 from the three windows, before, during and after the first hazard in each clip, failed to produce any interactions of demand level with experience. It was found that the hazard window produced the longest fixation durations in both the experienced and novice drivers. Similarly the comparison of d_0 across the windows produced a main effect localised in the hazard window, within which all participants tended to reduce the distance between the start points of two subsequent fixations when in the presence of a hazard. During the hazard window the participants are ostensibly concentrating for longer periods in smaller areas, most probably at the localisation of the hazard. It seems that the hazard has captured attention - fixation durations are increased as the participant processes the increased demands, and any saccades are unlikely to move the point of regard outside the immediate influence of the hazard.

These results, however, contradict both the literature reviewed earlier in the chapter, and the evidence from experiments 1 and 2, which showed that fixation durations decreased (and thus sampling rate increased) with a corresponding increase in demand.

There is however one way to combine this contradictory evidence. In section 3.1.3 a scenario was put forward to reconcile the differences between the driving literature and the reading literature in regard to the length of fixation durations under increases in demand. The suggestion was that fixations may only decrease in the driving literature (and in experiment 2) because of the increase in visual complexity. Though cognitive demand and complexity are confounded in experiment 2, the increase in visual complexity between a rural road and the suburban road is considerable. Does, however, an increase in complexity (or the number of things to look at), indicate an increase in cognitive demands? As the number of sources of information increase, so do the sources of potential hazards. One could say that demand has also increased, though this demand is dispersed across the driving scene, unlike when a hazard finally appears. The appearance of a hazard is a definite localised increase in processing demand, though it would also entail a localised increase in visual complexity. Though both manipulations of demand (road type or appearance of a hazard) confound processing demand with visual complexity, it seems intuitively valid to say that the increase in complexity is the more salient increase from roadway to roadway, whereas an increase in processing demand is the more salient with the onset of a hazard. As complexity increases, there are more stimuli to look at. This suggests that busier roads would require an increased sampling rate. The appearance of a hazard however should require more processing (in a similar manner to a low frequency word), which should be reflected by increased fixation durations and a concentrated search strategy.)

This post hoc explanation does explain the differences between experiments 2 and 3, and may reconcile the driving literature with the findings of reading and picture viewing research, but it still does not explain the differences between experiment 1 and 3. In experiment 1 it was suggested that the finding that fixation durations decrease during the hazard window was possibly specific to the antecedent conditions, that created artificially high durations in the pre-hazard window to which it was compared. The average fixation duration in the pre-hazard window was 846 ms compared to an average in the hazard window of 509 ms. The average fixation duration across the whole clip was only 468 ms (which includes the artificially high pre-hazard fixations). If one disregards the pre-hazard fixations then the durations in the hazard window seem to increase slightly above the average. This is in keeping with increases witnessed in the hazard perception test in experiment 3, in which pre-hazard, hazard, and post-hazard windows were averaged across 39 clips to avoid any individual situation influencing the fixation durations. The pre- and post-hazard windows fixation durations (476 ms and 497 ms respectively) are both comparable to the overall fixation durations for both experiment 1 and 3 (468 ms and 425 ms). The average fixation duration in the hazard window was 657 ms. This is a clear indicator of fixation durations increasing in the presence of a hazard that has been achieved by averaging over many situations to avoid the specificity of a single scenario. The suspicions of the finding in chapter 2 were upheld, and the improved design of experiment 3 actually revealed a more robust effect in the opposite direction to that found in the first study.

If one accepts that the findings of experiment 3 are more likely to reflect an actual effect rather than a confound (as suspected with experiment 1) then this no longer hinders an explanation of the differential effects according to the different demand manipulations used in experiments 2 & 3. On this basis it does seem acceptable that the increase in the visual complexity of the road types increased the sampling rate and decreased fixation durations. The appearance of a hazard however tended to do the opposite, restricting search and increasing fixation durations due to an increase in the processing demand.

To confirm that the differences in the responses to the two different demand manipulations were not simply due to differences between the laboratory and on-road settings, an analysis of the hazard clips according to road type was undertaken. As the road type clusters (Chapman & Underwood, 1998) did not exactly conform to the road types used in the on-road study the comparison is not perfect. Whereas the on-road study used rural, suburban and dual carriageway road types, the clusters of the hazard perception clips were defined as rural, suburban and urban.

A main effect of road type was discovered for the measures of mean fixation duration, variance of the horizontal search, and zero, first and second order fixation distances. In all three analyses the rural roads produced the narrower search with higher fixations, followed by the suburban road, with the urban road producing the widest horizontal search, the largest measures of *d*, and the shortest fixations (which equate to an increased sampling rate of the scene). It seems then that the spread of search and the sampling rate is increased with corresponding increases in the visual complexity of the road scene. This is in keeping with the suggestion from the on-road data that the experienced drivers decrease their fixation durations on the visual complex suburban road so as to increase the sampling rate of the scene.

Regardless of the differences between the effects of localised actual hazards and dispersed hazard potential, it was surprising not to find any differences according to experience.

Of the possible reasons that could explain the lack of an interaction between demand and experience in the lab one could not argue that the quasi-manipulation of demand used in the laboratory was insufficient to produce differentiation between demand levels. The increase in mean fixation durations and corresponding decrease in saccade distance display the effect of demand quite clearly.

The localised demand therefore had an effect (though a different effect to the on-road increase in demand between road types). Furthermore, though the latter differentiated between novice and experienced drivers, the appearance of an actual hazard did not. It may be feasible to say that experienced drivers know how to deal with an increase in the visual complexity of the environment from one road to another, though they have no advantage over the novices when a hazard actually appears. The experienced drivers did not spot the hazards sooner than the novices, nor did they react to them faster. If fixation durations are a measure of the processing time involved, then the experienced drivers took the same amount of time to process the hazardous stimuli as the novice drivers.

It seems that though experienced drivers may know where to look on different road types, they do not deal with the appearance of a hazard better than novice drivers.

There is of course a confound in that novice drivers may fare worse with a hazard while actually driving due to their inexperience with the controls of the car. Experienced drivers could also fare better than novices if spotting a particular hazard is facilitated by looking in the mirrors, or adversely affected by excessive fixations on the dashboard. Both of these areas were found to produce significant experiential differences in the on-road data, though as the hazard perception test does not include mirrors or a dashboard it is impossible to test whether these effects would affect one's hazard spotting ability in the laboratory.

The single significant experiential difference that was found in the hazard perception was the greater vertical search produced by the novice drivers across all road types. This fits with the on-road results, for if the variances for the dual carriageway (which do not occur in the hazard perception test) are removed from the on-road data the insignificant main effect of experience ($F_{(1,30)}$=3.50, p=0.07) is replaced by a highly significant difference ($F_{(1,30)}$=7.71, p<0.01).

The fact however that no other experiential differences were discovered poses a problem for an easy interpretation of the results. Previously it was argued that the difference in the nature of the demands between the two studies may have accounted for the lack of similarity in the results: that experiential differences were discovered in the on-road study due to increases in demand, but not in the laboratory study. The differential nature of the demands was then revealed through the analysis of the hazard perception data according to road type. It seems that the increase in visual complexity that occurs between road types tends to increase visual search, whereas the increased processing demands that occur with the appearance of a hazard tend to capture attention. If it were the case that experiential differences (other than just the vertical search) were also discovered in the re-analysis of the hazard clips according to road type, then one might conclude that visual complexity differentiates between drivers of varying experience whereas increased processing demand does not. Instead one needs to question what the important differences between the on-road study and the laboratory experiment were that could cause experiential differences due to visual complexity in one setting but not the other.

Perhaps the hazard clips were not treated as driving stimuli by the participants but just as moving images? Road type differences merely reflect the fact that there is more to look at in some road scenes than others, while the appearance of hazards may merely demonstrate the ability for novel stimuli to capture attention. Neither of these findings suggest that the clips need to be viewed specifically as if driving related. The one extremely strong experiential difference that was found in the hazard perception data suggests otherwise however. If this experiential difference reflects novices' lack of sensitisation to the vertical meridian when driving (Renge, 1980) then this suggests that the participants are viewing these dynamic scenes according to the experience they have gained through driving. Another important thing to note is that the persistence of the vertical search effect in both the laboratory and on-road settings suggests the excessive vertical search is not solely due to the novices' tendency to refixate the dashboard many times.

It is more likely that the reason for experiential differences in the on-road study stem from the need to maintain the vehicle on the road. Several studies have already been noted that have produced evidence that eye movements are guided to some extent by steering requirements. The lack of interactivity (and the need for survival) in the laboratory study may account for the failure to differentiate between novice and experienced drivers.

3.2.6 Conclusions

The basic conclusion that has been drawn from this research is that the level of demand placed on drivers under various road conditions (that differ primarily in visual complexity) may well be a useful tool for teasing apart the differences between experienced and inexperienced drivers through on-road study. This does not invalidate the usefulness of the laboratory approach to driving research in general, or the use of the hazard perception test in particular. As previously noted the measures taken from both studies were, on the whole, coarse grain. The flexibility and safety of the use of any simulator must still make it a valuable addition to driving research.

The experiential difference noted in the vertical search variances in the hazard perception data suggest that the drivers are treating the stimuli as driving stimuli. Differences in the other measures may not reflect this treatment of the stimuli, due to the exclusion of other factors such as the lack of interaction. If one is to continue with the safer use of the laboratory method then the measures recorded should reflect the difference between the novice and experienced drivers' treatment of the stimuli.

Chapter 4. DEMAND AND ECCENTRICITY: Investigating the factors that influence peripheral attention

4.1 The effects of foveal demand upon peripheral attention

4.1.1 The story so far

The results from the previous chapter suggested that experienced drivers know where to look on different road types whereas novice drivers do not. It seems that experienced drivers have adapted different schemata for the different roads, while novice drivers maintain an inflexible, default schema which guides their search strategies across all road types. In regard to hazard perception ability however, experienced drivers seemed no better than the novice drivers at spotting, processing or responding to hazards. Why does hazard perception fail to differentiate between these groups of drivers when it has already been noted that novice drivers are involved in more accidents than their more experienced counterparts (even after the exclusion of social and demographic factors)?

It may simply be the case that hazards occur so seldomly in the real world that even relatively experienced drivers do not encounter enough to give them any advantage over novice drivers. This seems plausible when considering actual accidents that involve damage to vehicles or injury to people. A more common incident however is the 'near accident'. These near accidents are events in which the driver judges that there was a significant chance of a collision, though luck or skill on one of the participants' parts avoids disaster. In one audio diary study of drivers' near accidents, 100 drivers were asked to record any near accidents that they were involved in. The average mileage of each driver over a two week period was 229 miles, from each driver reported an average of 2.9 near accidents. Some of the drivers in the sample reported up to 26 near accidents in the two weeks, though this did correlate with mileage (Underwood, Chapman, Wright & Crundall, ~~1999~~). From this study it can be seen that near accidents are much more frequent than actual accidents. The fact that the drivers recognised the potential danger of the situations suggests that they may receive similar feedback to that gained by actually being in a crash. On the basis of this, one could not say that the hazards viewed in experiment 3 (such as a car suddenly emerging from a side street to challenge the driver's right of way – the most common type of near accident report in the Underwood et al. study) are uncommon in real driving.

The two alternatives that remain are that the lack of interaction with the clips failed to evoke true driving behaviour in the experienced drivers or that the measurements taken are not sensitive to the true differences between drivers in this situation. The former hypothesis has already been argued against in the previous chapter. The fact that novice and experienced drivers consistently differ in at least their vertical search, both on-road and in the laboratory, suggests that the hazard perception clips are being treated as driving stimuli by the participants. There may be more subtle differences that the lack of interactivity in the laboratory has removed, though short of staging on-road hazards to check this, one could never really be sure that lab-based hazards evoke true behaviour. The second alternative - that the particular measurements recorded were not sensitive enough to detect underlying driver differences - provides a less ethically challenging hypothesis (though it should be noted that the two hypotheses are not mutually exclusive).

The discussion in section 2.3 reviewed the limitations of eye tracking. If the measures employed in experiment 3 are lacking, then it is to these limitations that one must turn. One such limitation is the validity of the eye-mind assumption, that what one looks at equates to what is processed. The paradigm of preview benefit in reading has consistently shown that partial processing of text may occur up to 14 characters to the right of fixation (Rayner, 1998). Eye tracking methodology will not reveal the extent to which attention is distributed beyond the fovea. Of the literature reviewed so far however there has been much speculation and import given to the role of peripheral vision in driving. The next stage of the current research was designed to search for more subtle experiential differences in the deployment of extra-foveal attention according to changes in processing demand. This necessitated a return to the laboratory. The rationale for choosing this particular avenue of research is discussed in the following section.

Subsequent sections discuss the nature of spatial attention and its interaction with demand, before detailing three experiments that investigate the relationship between demand and attention.

4.1.2 The rationale for experiments 4-6

The decision to study the effects of demand upon spatial attention was derived from the results of experiments 2 and 3. As many other avenues of research could have been followed it is perhaps important to note the factors that lead to this particular path of research being chosen.

The visual complexity of the road type has already been noted to significantly distinguish between novice and experienced drivers. The lab-based manipulation of demand (the appearance of a hazard) failed to do so. One might therefore argue that the schemata for road types of different visual complexity would provide more fruitful research results.

It is the lack of experiential differences however that makes the hazard perception test an interesting case. Drivers do learn to drive more safely with experience, and therefore must pick up some advantage that helps them to avoid accidents. But if highly experienced drivers are sensitised to driving stimuli, one would imagine that they would be able to spot, process, and respond faster to a hazard. In other words, because the driving stimuli are easier to process for experienced drivers, one would expect that they have more resources to devote to the task, which should therefore be undertaken more efficiently. Why is this not the case?

If the assumption that experienced drivers have more attention available is correct (due to the lesser demands of stimuli that are more familiar to them than to less experienced drivers), then there is another possible explanation. Instead of devoting excess attention to the speedier processing of the current hazard, any spare attention may be devoted to the peripheral visual field. If attention is completely captured by a particular hazard the driver's awareness of the immediate surroundings will decrease dramatically. Maintained awareness of the environment is no doubt still important in a hazardous situation. For instance if the car ahead suddenly brakes, at least two hazard avoidance strategies become available: brake sharply, or overtake. A successful decision depends on information about the distance from oneself to the car in front, the current speed, the weather conditions, the proximity of cars behind oneself, and whether there is any oncoming traffic In regard to spatial attention, the zoom lens would have to be set extremely wide to take in such information at the same time that one is processing the hazard (assuming that longer fixation durations on the hazard preclude a visual search of the scene). A similar consideration comes from the Land and Horwood study (1996 - section 3.4.1) that revealed the importance of peripheral information from lane markers to the task of lane maintenance. If the appearance of a hazard (or any other localised demand increase) reduces attention in the peripheral field, then drivers will not be able to monitor the lane markers and may drift from their lane. This could be especially problematic when driving through a curve during which the driver cannot maintain a default (straight-on) heading. Not only may the appearance of a hazard cause an accident directly, but the capture of attention that may accompany the hazard may reduce peripheral attention to lane markers resulting in a loss of control, and an indirect accident.

Inadequate lane maintenance has been reported previously as a relatively large source of accidents. For example, Lestina and Miller (1994) reported that 9% of all accidents from a Californian sample of 15 to 19 year old drivers were due to poor lane maintenance.

The theory of perceptual narrowing was mentioned briefly in chapter 3 with reference to the work of Land and Horwood (1996) and Lavie (1995). The evidence that Lavie has put forward suggests that an increase in cognitive demand at the fovea reduces the amount of attention that can be given to extra-foveal stimuli. Thus the harder a particular word in a line of text is to process, the less information one will get from extra-foveal words through peripheral attention. This occurs due to the contraction of the zoom lens, which reduces in size to increase the resolving power at the point of gaze. If experienced drivers do have spare attention due to the familiar nature of driving stimuli, then instead of using it to speed the processing of the currently fixated stimulus , they may use it to keep the zoom lens as wide as possible, instead of allowing it to contract with an increase in demand at the point of fixation. This would then aid lane maintenance and increase awareness of the surroundings, further reducing the chances an accident.

The experiments discussed in this chapter aim to demonstrate a reduction in peripheral attention as cognitive demand at the fovea increases. All the following experiments are extremely reductionist in their methodology compared to the applied research of chapter 3. It was considered important to demonstrate the underlying theoretical assumptions of the interaction between demand and peripheral attention however before attempting to replicate these findings in a driving setting. Despite this move away from realistic driving stimuli, the factor of driving experience was retained in experiment 4, though it failed to reveal a significant difference. The rationale for the inclusion of experience in experiment 4 is presented with the introduction to that particular study (section 4.2).

4.1.3 Definitions of spatial attention and the problem of object-based attention

Spatial attention exists in many guises. A reduction of attention due to an increase in demand at the fovea is most easily conceptualised in terms of the zoom lens. This is not however the only representation of spatial attention that exists in the literature. Many terms such as the Functional Field of View (FFoV), the spotlight, the gradient model, and perceptual span have been used to describe the area of the visual field from which extra-foveal information is gained. As this chapter is concerned with the reduction of attention devoted to peripheral stimuli it is necessary to first mention something of the nature of spatial attention in its many forms.

All of the models mentioned above conceive of spatial attention as an area around the point of fixation within which certain information can be processed, though this area does not have to be circular or symmetrical. As the experiments in this chapter are designed to reduce attention in the peripheral visual field, it may be beneficial to first explain the nature of spatial attention in relation to these models.

The spotlight, zoom lens and gradient models of attention represent a refinement of the spatial theory of attention. The spotlight (Eriksen & Eriksen, 1974) was initially conceived as a beam of attention of a fixed width that can be moved across the visual scene. The zoom lens (e.g. Eriksen & Yeh, 1985) allows the beam to alter in diameter, while the gradient model (LaBerge, 1983) allowed for a fall off of attention further away from the point of fixation. The recent work of researchers such as Lavie (1995) and LaBerge, Brown, Carter, Bash and Hartley (1991) strongly suggests that increases in foveal demand decrease the size of the attentional aperture.

The FFoV and perceptual span are possibly the most different of the spatial attention models. The FFoV describes the ultimate boundary somewhere in the peripheral field beyond which stimuli will not be identified. Though it is limited by visual acuity, some researchers believe that the actual shape and size of the function field changes according to several other factors such as general arousal (Rinalducci, Lassiter, MacArthur, Piersal & Mitchell, 1989), anxiety (Shapiro & Lim, 1989), cognitive demand (Williams, 1982), or even the mere presence of a foveal stimulus, regardless of whether there is a need to process it, and in some cases when participants are specifically told to ignore it (Holmes, Cohen, Haith & Morrison, 1977; Chan & Courtney, 1993). Of interest here is the evidence of the FFoV being modulated by demand.

At its most basic, it is the area of the visual field wherein peripheral targets can still be detected at a set threshold and it is on this basis that the majority of researchers in the area of functional fields have focused their research. Certain seminal theories of perception however fail to acknowledge the functional field of view. Findlay and Gilchrist (1998) noted that one of the assumptions of Treisman and Gelade's (1980) feature integration theory is that all areas of a visual display will available for attentional processing. As Findlay and Gilchrist recognised, this implicitly ignores the many studies that have demonstrated reductions in the functional field of view of participants.

Whereas the FFoV is considered to be very large, the perceptual span is an extremely small, asymmetric spotlight referred to in reading studies. This window allows information to be gathered from up to 13 characters to the right of the currently fixated letter (though only 2 or 3 characters to the left of fixation). Preview benefit is measured in terms of the reduction in fixation durations on a stimulus that occurs if it was available for pre-fixation processing in the periphery beforehand. Though reading studies only find this at very small eccentricities (e.g. Rayner, 1998), Henderson, Polletsek and Rayner (1987, 1989) found preview benefit at four degrees of eccentricity.

Further blurring of any spatial distinctions between these descriptions of spatial attention is found through comparison of studies in the literature. For instance, Lavie and Driver (1996) referred to the spotlight of attention covering the whole 13° of their display, while Williams (1995) refers to the FFoV in a study with a maximum eccentricity of 4.5°.

To simplify matters, this thesis will merely refer to the 'spotlight of attention', described as the area around fixation within which stimuli can be spotted and processed. The size and shape of this area can be changed according to many factors (arousal, etc.) though this chapter is mainly concerned with the affects of foveal demand on the deployment of peripheral attention.

One further complication is that spatial descriptions of attention have competition from object-based theories. In 1981, Kahneman and Henik pointed out that spatial proximity is confounded with the Gestalt principles of grouping stimuli features into objects. They suggested that attention is directed to such groups of features rather than to contiguous areas of space. For instance, the Flanker Compatibility Effect of Eriksen and Eriksen (1974) showed that incompatible flankers created less interference with a foveal recognition task the further away they were from the centre. This was interpreted as evidence for a spatial boundary for attention, beyond which the distracters would not be processed. Kahneman and Henik suggested however that the important factor may actually be that the distracters are no longer considered part of the same object the further removed they become.

However it was not that easy to design the first experiments looking for object-based attention due to the fact that objects and space are confounded. An object appears in a region of space, so how do we remove space from the experimental design? Rock and Guttman (1981) attempted to overcome this problem by superimposing a red line drawing on top of a green line drawing. Participants were asked to make an aesthetic judgement on, for instance, the green pictures. Later they were given a surprise recall test for the red pictures. Their poor recall scores were taken as evidence for object-based attention, for if the spotlight covered the green image it would also cover the red image and therefore both should be processed to a similar extent. There were obvious problems however for such experimental designs, in that a masking effect may occur between superimposed images. Furthermore the use of a memory test to assess whether attention had been given to the red objects is confounded by the differential processing given to the two pictures.

Improved designs were employed by Driver and Bayliss (1989) and Bayliss and Driver (1992). They used the basic Flanker Compatibility Effect design, where the participants have to respond to the centre letter of a five letter string. Usually the nearest flankers (the second and fourth letter in the string) produce the greatest effect on reaction times to the central letter. In these two studies however, Driver and Bayliss demonstrated that the two furthest flankers (the first and fifth letter) could have a more powerful effect than the nearer flankers if they were grouped with the central letter on the basis of common movement (1989) or colour (1992). Thus the use of other Gestalt grouping factors overcame the default grouping factor of proximity, suggesting that attention is indeed object-based.

Recent work has however suggested something of a compromise between these two ostensibly disparate descriptions of attention. Lavie and Driver (1996) criticised previous attempts to obtain evidence of object-based attention on the basis that previous research had either used just separate objects (effects which could

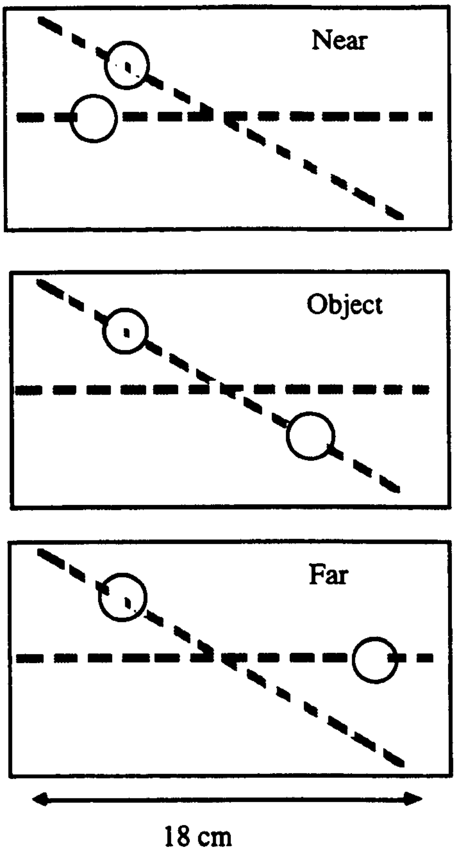

Figure 4.1 The three conditions in Lavie and Driver's (1996) study. The targets (a dot or a space) are circled for each condition.

include both spatial and object-based influences), or superimposed objects (which may have created inhibition through masking). They wanted to vary the targets across several eccentricities yet still retain two objects displayed in the same amount of physical space. The answer was to use big objects. They used two dashed lines of different colours that subtended 13° (see Figure 4.1). One line was horizontal, the other was tilted 18° clockwise form the horizontal. The target task involved the comparison of two of the elements at the ends of the lines; either a dot or a space in place of a dash. This gave rise to three conditions that varied over eccentricities and across objects. The initial study found the object condition to produce the fastest reaction times to judge whether the two targets were the same or different, faster even than the near condition where the two targets were only 1.5° apart. This suggested that object-based attention was at work. However, in a later experiment they pre-cued one side of the display by having the dashed lines come on a split second before the other side. Participants were told that this cue meant that the two targets were likely to be in the near position. If the spotlight does exist then the pre-cue should focus the spotlight on one half of the screen. Seventy per cent of the time the targets were indeed where the cue predicted them to be, and unsurprisingly the participants were quicker at spotting valid, near targets than any other (because attention was already in the area waiting for the targets to appear). However the interesting results occurred when the target locations disobeyed the cue. Fifteen per cent of the time they would appear in a far pattern and 15% in an object formation. If the spotlight did not exist one might still expect the near condition to be fastest as attention has been drawn over to this side. One would also expect the object condition to still be faster than the far condition as the object bias would still occur. This did not prove to be the case, as the focusing of the spotlight removed the object-based advantage when compared to the invalid near and far conditions.

The evidence suggests that the object-based advantage that was recorded in the first experiment of Lavie and Driver (and in two subsequent experiments) only occurred within the spotlight of attention. If the objects fall outside of a focused spotlight then object-based attention will not occur. Thus object-based attention appears to be a second stage of selective attention that can only operate within a spatial area. This integration of space-based and object-based attention has also been addressed by Logan (1996) in his CODE Theory of Visual Attention. This theory describes how bottom-up and top-down features combine to form spatial areas that can be attended to, and a race model for selecting individual objects within the spotlight. After several years of persecution at the hands of object-based attention, it seems that the spotlight is having something of a renaissance.[1] The following experiments are explained from a spatial viewpoint, though any distinctions that arise between the two theories on the basis of the reported data will be discussed with the particular experiment.

4.1.4 Previous studies that have manipulated foveal demand

The recent work of Lavie (1995) has already been reported as evidence that an increase in foveal load decreases attention to extra-foveal stimuli. However similar work was conducted much earlier. One such study was published by Ikeda and Takeuchi (1975). They varied the foveal loads at the centre of a tachistoscopic field and measured the effect that the central identification task had upon the secondary task of locating a peripheral target within a noisy background. When more complex foveal stimuli were employed the eccentricity of successfully spotted peripheral targets was reduced.

Interestingly they also showed that the spread of spatial attention could be consciously extended in a desired direction, which suggests that results from research in this area could be used to modify people's awareness of what is around them, providing that research suggests that this would be the preferred strategy.

The preview benefit effect can also be used to investigate the effects of foveal demand upon the allocation of attention. If perceptual narrowing occurs and a stimulus which is subsequently intended to be

[1] Despite the renewed interest in spatial theories of attention, at least one new theory suggests that there is no need to postulate any form of attention, and that the effects we observe can be explained in terms of competitive inhibition in the salience map (Findlay & Walker, 1999), though paradoxes common to theories of attention are still apparent in this theory (Crundall & Underwood, 1999).

fixated falls outside the retreating functional field then any pre-fixation processing that would normally be done during the fixation of the current stimulus is lost. This should result in longer fixation durations on stimuli which are fixated immediately after processing a demanding, previous stimulus, compared to a less demanding, previous stimulus.

Use of this measure has been made in certain reading experiments such as the study by Blanchard et al. (1989). This experiment used a moving window placed over the currently fixated word which allowed participants to see all of the words to the left of the fixated word, with zero, one or two words to the right. An increase from zero to one word to the right of fixation increased the reading speed from 200 words per minute (wpm) to 300 wpm. A second word merely increased speed further by 30 wpm. This suggested that having a word which is to be fixated available in the parafovea reduced the fixation durations on that word once fixated, further suggesting that pre-fixation processing, or preview benefit, was occurring. Further support comes from Rayner (1986), and Henderson and Ferreira (1990) who reported that placing unfamiliar words before the target word increased fixation durations on the target. As unfamiliar words require more processing than familiar words they place the participant under a higher level of demand. This in turn decreases the amount of parafoveal attention that can be given to the target before it is fixated.

The studies mentioned so far have dealt with peripheral attention at very small eccentricities. Lavie (1995) used peripheral distracters that were only 1.9° away from the centre of the foveal stimulus. If we are to ultimately relate such theories to driving then one would hope that evidence exists for effects beyond the parafovea. One study that used slightly larger eccentricities was conducted by Reynolds (1993). He found that errors identifying a peripheral target 4° from the fovea increased when a complex picture was displayed at the point of fixation rather than when a letter or geometric shape was presented instead.

4.2 Experiment 4: An initial attempt to reduce attention to extra-foveal stimuli due to an increase in the cognitive demand of a foveal stimulus.

This experiment aimed to use preview benefit to measure the reduction of attention to peripheral stimuli rather than approaching this through the use of peripheral flankers whose influence on the processing of a central stimulus can be noted through their inhibitive or facillitory effects (Eriksen & Eriksen, 1974; Lavie, 1995). This approach is more relevant to, for instance, the processing of peripheral hazards during driving. A pedestrian waiting at a zebra crossing lies in the extra-foveal region of the retina and therefore must be noticed with peripheral attention in order that the fovea can be directed toward the person. Peripheral preview benefit is probably a closer estimation of attention in this case, rather than the inhibitive effects of a peripheral stimulus. Such inhibitive effects could be usefully employed in the study of the effects of bill boards on the driving task. While these two approaches seem to measure the same mechanism simply from different angles, one cannot expect two separate tasks to measure the same identical phenomenon (Kwak, Dagenbach & Egeth, 1991).

One criticism of previous experiments which attempt to manipulate foveal load is that such studies often confound increases in cognitive load with perceptual load (Williams, 1982). This experiment was an attempt to induce a reduction in the allocation of peripheral attention through increasing the cognitive demand of the foveal stimulus, without altering its perceptual complexity. If a decrease in peripheral attention occurs, fixation durations upon subsequent stimuli in the parafoveal or peripheral fields should then be increased as they will have lost the preview benefit afforded them by extra-foveal attention. If this does not occur, and preview benefit is a completely parallel process independent of other claims on a participant's attention, then one could hypothesise that fixation durations on the target in the high demand condition will actually be reduced in comparison to the low demand task, because with the increased fixation durations on the central stimuli in the complex task, the target is available for longer in the peripheral field. Providing that there is not a ceiling effect for preview benefit (or at least that this ceiling has not been reached by the central fixation in the low demand task), the target may be increasingly processed before fixation, enhancing the preview effect.

An additional hypothesis of this study concerns itself with the potential difference between novice and experienced drivers in regard to their peripheral preview loss. It has been suggested by other researchers that the development of any complex skill which involves a large amount of visual processing will change one's perceptual strategy, possibly improving general visual strategies outside the context of the particular skill area.

Direct evidence of this came from Williams (1995). He chose aviators as participants who had developed a skill that requires distinct modification to perceptual strategies. In a comparison of aviators and non-aviators Williams found that the aviators had better accuracy than non-aviators in identifying peripheral targets under conditions of high cognitive load at the fovea. The experiment involved a memory task at the fovea (involving letters presented in the centre of a tachistoscopic field) and naming digits at various eccentricities in the peripheral field. This has little immediate relevance to the task of flying which suggests that the perceptual strategies of the aviators did generalise to tasks other than piloting a plane to some extent. It was therefore hypothesised that an increase in the cognitive complexity of the foveal load would not only reduce preview benefit of the peripheral stimulus, but that it would also distinguish between the driver groups.

4.2.1 Methodology for experiment 4

4.2.1.1 *Participants*

Fifteen experienced drivers (8 male, with a mean age of 22.3 years, and a mean experience of 5.4 years) and 15 novice drivers (9 female, with a mean age of 18.3 years, and a mean experience of 2.3 months) were tested. All participants had normal vision and none suffered from colour blindness. Experienced drivers were recruited through newspaper advertisements. Novice drivers were recruited from questionnaires distributed through the Driving Standards Agency of Great Britain.

4.2.1.2. Materials and apparatus

JPEG frames were presented on a P90 PC one metre from the participant whose head was restrained in a chin and forehead support, while eye movements were tracked using a Dual Purkinje Generation 5.5 Image tracker with millisecond accuracy. Participants' responses were recorded via a mouse which had the right button labeled with "Y" and the left button with "N". Before each frame was presented the computer checked that the participant was fixating a cross at the centre of the screen. The frames contained two triangular signs. One sign, positioned 4.8 degrees to the left or right of centre contained either a staggered junction symbol or a right-bend junction. This formed the basis of the discrimination task. Both signs had a red border and subtended one degree wide and 0.9 degrees tall. They were identical to the relevant warning, traffic signs. The second sign was positioned at the centre of the screen and contained either a consonant (R, F, V) or a vowel (A, E, U) within a red border identical to the peripheral sign. Each letter appeared an equal number of times, and was balanced with an equal number of left/right presentations of the peripheral sign, and with equal presentations of either the staggered junction or the right-bend junction.

4.2.1.3 *Design*

The two factors involved were driver experience and the repeated measure of task demand. Participants completed two counterbalanced blocks of 24 randomly presented trials. Each block contained identical slides with different instructions. The high cognitive demand block required participants to process the central letter stimulus while the low demand condition instructed participants to ignore it. Regardless of instructions, the participants always had to fixate at the centre of the screen before the computer would display the next frame. To test the hypothesis of reduced peripheral preview with increased cognitive demand at the fovea, measures of first fixation duration and gaze duration upon the peripheral target were recorded. Other measures included saccade latency from the central stimulus, saccadic inaccuracy (distance from the target in minutes after saccading to it from the central stimulus) and the number and duration of any pre-target fixations (i.e. fixations that occurred after disengaging from the central stimulus but before reaching the peripheral target), as well as response times to discriminate between the peripheral targets, and the accuracy of those responses. A fixation was considered to have occurred when the eye remained within 10 pixels (0.24°) for at least 50 ms.

4.2.1.4 *Procedure*

At the start of each block participants were calibrated on the eye tracker and then presented with the instructions on the monitor. Before each frame appeared participants were instructed to focus on a central cross. Frames were presented once the computer recognised that the participants were fixating the cross. For the low demand block, participants were required to saccade from the centre of the frame to the location of the peripheral target, either to the left or the right of centre, and to respond as quickly as possible according to the peripheral target symbol (Y for the staggered junction, and N for the right-bend junction). For the high demand condition participants were asked to first decide whether the central letter was a vowel (A, E, U) or a consonant (R, F, V). If it was a consonant they were instructed to respond with a N. If it was a vowel they were asked to then saccade to the peripheral target and identify it as per the low demand condition.

4.2.2 Results of experiment 4

Across the conditions, 88% of trials were subjected to analysis on seven measures. Twelve percent of trials were rejected due to incorrect responses or loss of calibration with the eye tracker. The means for the seven measures across driver experience and task demand are shown in Table 4.1. The results are reported in the chronological order of the occurrence of the measures, while Figure 4.2 displays the means for five of the measures over the time course of each trial (only across the demand factor). The graph should reveal how the different measures of saccade latency, pre-target fixation duration, first fixation duration, gaze duration and response time record different elements of each trial.

Saccade latency is the time taken to disengage from the central stimulus and to saccade to the peripheral target. In the low demand task the central stimulus does not hold any relevant information, though in the high demand task the same central stimulus must be

Measures taken	Experienced Drivers No Demand	Experienced Drivers Demand	Novice Drivers No Demand	Novice Drivers Demand
Saccade Latency (ms)	269	609	226	543
Saccadic inaccuracy (minutes)	2.0	2.1	1.8	1.7
Probability of a Pre-Target Fixation (%)	13.7	17.3	21.7	21.9
Gaze Duration of Pre-Target Fixations (ms)	120	133	145	167
First Fixation Duration on target (ms)	296	416	331	406
Gaze Duration on target (ms)	434	690	473	588
Response Times (ms)	869	1644	875	1429

Table 4.1 Means of the seven recorded measures across participant groups and levels of demand.

processed before saccading to the target. The increase in complexity between the tasks was reflected in a significant main effect of task demand with saccade latencies for the high demand task greater by 329 ms on average ($F_{(1,28)}=165.9$, $p<0.01$). A marginal effect was also found between the novices and experienced drivers ($F_{(1,28)}=3.6$, $p=0.07$), with the experienced drivers taking an average of 55 ms longer to saccade away from the centre than the novices, which may be a reflection of the age differences between the two groups.

After disengaging from the central stimulus a saccade was initiated toward the peripheral target. On 18.7% of trials the saccade fell short of the target, or overshot the intended landing area and the eyes either moved within the boundaries of the fixation filters onto the target, or saccaded once more to the target. In the latter case, the

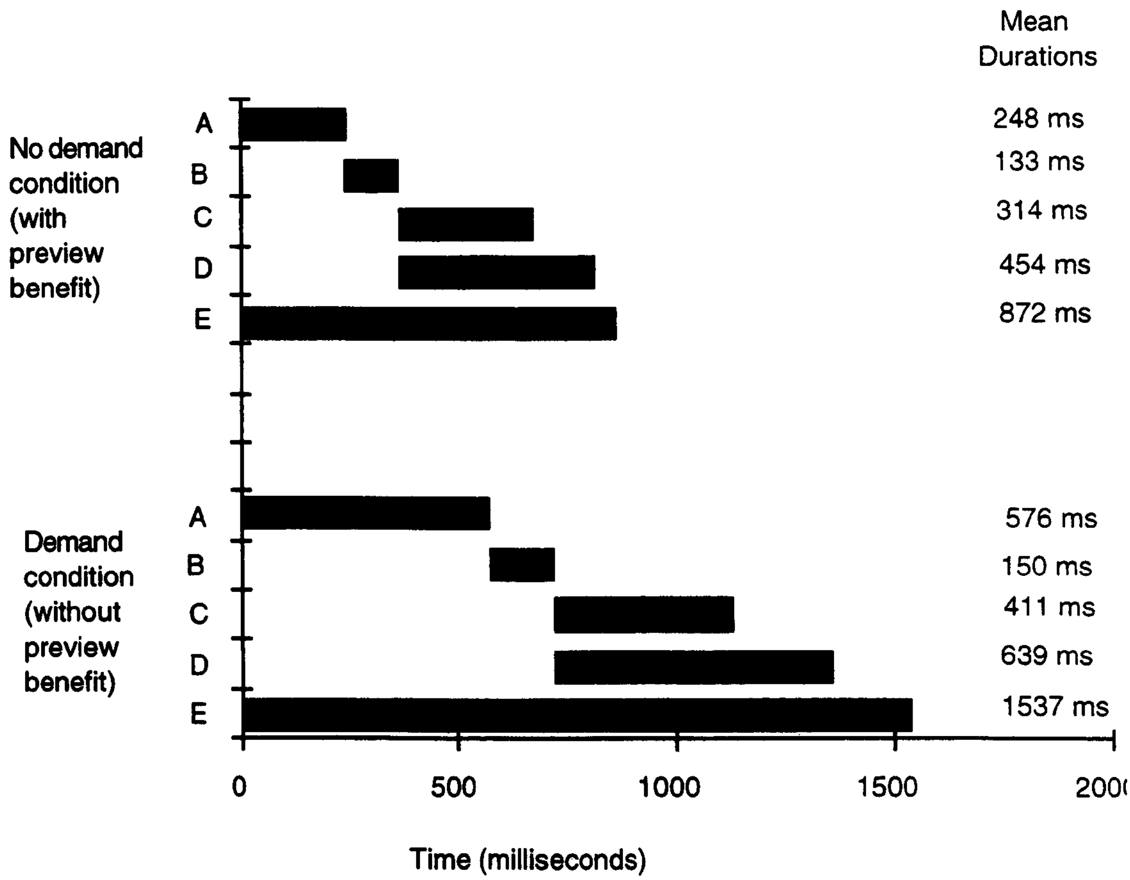

Figure 4.2 A graphic representation of five of the measures and the time course of when they were recorded during each trial: (a) saccadic latency, (b) pre-target fixations, (c) first fixation durations on target, (d) total gaze durations on target, and (e) response times.

fixation between the two saccades was termed a pre-target fixation. Mean saccadic inaccuracy (distance from the saccadic landing position to the target in minutes) was minimal and showed no significant differences across conditions ($F_{(1,28)}<1$). Similarly, the percentage chance of a pre-target fixation occurring did not differ according to driver experience or task demand ($F_{(1,28)}<2.5$). Due to the limited number of trials where a pre-target fixation occurred, an analysis was not conducted on the duration of these fixations. Despite the small increase in pre-target fixation durations in the demand conditions, the effect would have probably not been acknowledged at the accepted levels of significance.

Comparison of participants' first fixation durations on the target produced a main effect of task demand ($F_{(1,28)}$=31.9, p<0.01), with the high demand task attracting nearly 100 ms more than the low demand task on average. This difference increases to approximately 180 ms when total gaze duration on target is considered ($F_{(1,28)}$=18.0. p<0.01). Though the target was theoretically available to peripheral processing for longer in the demand condition (due to the increased saccadic latencies), the increases in first-fixation durations and gaze durations suggest that such processing was actually removed due to the manipulation of cognitive demand. These increases in the two on-target fixation measures should represent the loss of peripheral preview benefit in the demand condition, suggesting that there was a reduction in the amount of attention available to extra-foveal items. Both measures however, failed to distinguish between the two driver groups.

The difference in the overall response times taken to discriminate the peripheral targets reflected the increase in saccade latency due to task demand, and the increase in first-fixation durations and gaze durations on the target. The analysis revealed a sole main effect of task demand ($F_{(1,28)}$=90.6, p<0.01). The measures of saccade latency, first-fixation durations and gaze durations could not fully account for the increase in reaction times however. The extra component in the later button responses reflects post fixation processing of the peripheral target. This is delayed in the demand condition due to the lack of preview which would normally speed up the visual information acquisition from the target prior to fixation.

Response times also failed to discriminate between novice and experienced drivers.

4.2.3 Discussion of experiment 4

This initial study seemingly demonstrated that peripheral preview information can provide evidence that is consistent with the hypothesis of a reduction in the functional field of view as the cognitive demand of a foveal stimulus increases. This point shall be explained first before discussing the lack of distinction made between novice and experienced drivers.

The high demand condition required increased processing, above that of the simple, low demand task. This was reflected in the significant increases in both saccadic latency and response times that were produced by both groups of drivers with the more complex task. The saccadic latency increase occurs owing to the extra processing time necessary to interrogate the central stimulus in the high demand task, while the response times incorporate this increase with pre-target fixations, fixations on the target and any other fixations (such as the refixation of the central stimulus after the peripheral target has been fixated and processed, but before a response), as well as post fixation processing.

Owing to the manipulation of demand, significant differences were recorded for the first fixation durations on the target, said to reflect the difficulty of object identification (Henderson et al., 1987, Underwood & Everett, 1992), and for gaze durations on the target, which some researchers suggest may include post identification processes such as memory integration (Henderson et al, 1987). Both of these measures showed an increase in duration as the foveal load at the centre of the screen became more important. This effect would be further exaggerated if one included the pre-target fixations which also increased in the high demand task. These pre-target fixations were extremely close to the target and would have probably provided their own preview benefit of the target.

According to the preview benefit effect, this increase in the first fixation duration on target and the subsequent gaze durations may represent a lack of pre-fixation, or extra-foveal, processing. In many reading studies this has been demonstrated by using a moving window (McConkie & Rayner, 1975) to mask extra-foveal stimuli. In this experiment the preview benefit has ostensibly been removed without recourse to masking, but instead by reducing the attention that is normally available for such extra-foveal processing. It has been noted by Kwak et al. (1995), that the use of a mask in studies of spatial attention may confound any natural deployment, lessening the validity of any conclusions.

The second hypothesis was not upheld. The task failed to distinguish between the participants on the basis of their driving experience. The predicted discrimination was based on the evidence that experienced drivers develop new perceptual strategies over time (Mourant & Rockwell, 1970, 1972; experiment 2), that the circumstances under which the deployment of attention may change are adaptable according to experience and learning within different task domains (Holmes et al., 1977, Pollatsek Bolozky, Well, & Rayner, 1981) and that such strategy developments may be visible in simple lab based tests such as the one used here (Williams, 1995). One or more of these assumptions was breached. The evidence for the first two assumptions has higher validity than that of the latter. Williams only found differences between aviators and non-aviators. At the outset of his research he did not find any differences between aviators of differing experience. It is possible that general tests such as those used in this study and by Williams are not sensitive enough to distinguish between grades of experience, though any overall change may be noticed through comparison with a control group uncontaminated by exposure to a particular applied setting. An extension of this research would be to collapse across the novice and experienced drivers and to compare directly to one such uncontaminated control group. This was the procedure that Williams eventually took.

4.2.4 Limitations of the current design

The identified limitations of this initial study relate to both of the hypotheses. In regard to the prediction of discrimination between experienced and novice drivers it has already been noted that the strictly nomothetic, reductionist approach may have removed any ability to distinguish between participants on the basis of driving experience. The differences in search patterns noted in chapter 3 are not reflected in such a simple laboratory experiment. This suggests that any driver differences noted on the road are context dependant, in the same manner that the asymmetrical deployment of attention outside the fovea noted during reading does not manifest in more general contexts. An obvious improvement to the design would be to include stimuli more relevant to the driving context.

If the findings that support the first hypothesis had been unequivocal then this would be the next logical step to take. However, there are some concerns with the evidence that supports the reduction in attention to peripheral targets with a concomitant increase in foveal load.

First it should be noted that the use of the go/no-go condition, which was used to increase cognitive demand at the fovea, resulted in 50% of the high demand trials acting as catch trials. This greatly reduced the number of trials which contributed to the participants' measures in the high demand condition. In a block of 24 trials only 12 'go' trials actually produced data for the subsequent analyses. This may have reduced the power of the factor. Despite this the predicted effects of an increase in cognitive demand at the fovea were still found.

A more serious problem may have arisen with a dual task confound. In the high demand condition, participants may have only partly processed the letter in the centre triangle. The subsequent increase in first fixation duration and gaze duration on the target in the high demand condition may then have occurred due to the participant engaging in post-fixation processing of the central stimulus. Thus the increase in time taken to process the peripheral stimulus may not have been due to the loss of preview benefit, but instead due to the participant not having fully processed the central stimulus in order to work out whether they should have saccaded in the first place. The fixation time on the peripheral target would therefore consist of the processing time for that particular target (less any preview benefit) plus the time taken by the participant to confirm that the central target was actually a 'go' trigger. This would suggest that the saccade is made after the stimulus has been identified as a vowel or consonant, but before it is identified as a 'go' or 'no-go' trigger.

This would not produce an obvious increase in the number of errors of the 'go' trials, as a participant may saccade to the peripheral target, yet once they have fixated the target realise that the centre letter was a 'no-go' trigger and thus press the N button. As the trials are randomly presented, half of the targets will require a negative response anyway.

In order to counteract this argument an analysis of pre-emptive saccades on the 'no-go' catch trials would need to be undertaken. Such saccades were not recorded for this experiment.

To summarise, experiment 4 ostensibly showed that an increase in the cognitive demand at the fovea reduced the allocation of attention available to extra-foveal stimuli. This was evident through the increased first fixation durations and gaze durations on the targets which reflected the loss of preview benefit. The study failed however to distinguish between novice and experienced drivers. A return to driving related stimuli seems inevitable in order to pursue the predicted driver differences. Before this course was taken however, it was considered important to demonstrate the validity of the basic hypothesis that an increase in foveal demand can reduce extra foveal attention. Before one can apply a theoretical hypothesis to an applied domain one must be sure that the initial hypothesis is supported. The subsequent experiments explored this basic hypothesis within a purely theoretical framework. It was considered important to establish the validity of the hypothesis before attempting to extend its remit.

4.3 Experiment 5: Manipulating foveal load with two extra-foveal stimuli

This particular experiment addressed the basic hypothesis that as central demand increases, so extra-foveal attention decreases. In addition it attempted to achieve this aim without the wasteful 'no-go' trials, and while avoiding a possible dual task confound. The experience factor was left out of the experiment due to its previous failure to discriminate between novice and experienced drivers in such a context-free study. With this factor also went the traffic sign symbols. The triangle signs were retained as placeholders, and had letters placed within them. Thus the task became one of letter discrimination rather than traffic sign discrimination.

A number of improvements and simplifications were made to the methodology. The major change involved removing eye tracking measures as the main dependant variables. Instead of fixation durations on peripheral targets, a hit rate was calculated for the number of peripheral letters correctly identified while the participant remained fixated at the centre of the screen.

In experiment 4 participants were encouraged to move their eyes to correctly identify the target sign. Without eye tracking however the position of the eyes needs to be controlled. For this reason participants were first required to report one of the features of the stimulus in the central triangle, before reporting the peripheral letter.

This was designed to focus the participants' attention upon the central stimulus. Coupled with this, the slide with both central stimulus and peripheral target was only presented for 300 ms. This is too brief to allow a saccade, especially when processing is required at the centre. This tachistoscopic presentation, coupled with a primary task at the centre of the screen, ensures that the point of gaze remains upon the centre stimulus throughout all the trials. This should mean that the peripheral targets are at a constant eccentricity for all participants.

In the previous experiment the processing of the central stimulus was either irrelevant (in the low demand condition) or produced a 'go/no-go' trigger. In order to avoid the large loss of data through catch trials (the 'no-go' trigger trials) it was decided to use two peripheral stimuli (one to the left and right of the central stimulus). The processing of the central stimulus can then dictate which of the two peripheral letters should be reported. The peripheral targets to the left and right had to be reported an equal number of times. This provided an extra control to ensure participants focused their eyes at the centre of the screen by removing any benefit that might be gained by fixating either to the left or right of centre.

The central stimulus was either a red or green arrow head. As such it contained two features; direction and colour. Feature Integration Theory (Treisman & Gelade, 1980) would predict that reporting either the colour or direction of the arrow (i.e. reporting a single feature) should require no attention whereas a response which required the processing of both features together would require the allocation of attention. This acted as the manipulation of central demand, and managed to completely eliminate the wasteful catch trials while keeping visual complexity constant.

The other major advantage of this design is that it removes the dual task confound that may have occurred in experiment 4. Whereas in the previous experiment the dependant variables of first-fixation duration and gaze duration on target could be influenced by post-fixation processing of the central stimulus, the use of simple hit rates in the current experiment should avoid this.

The basic hypothesis predicts that an increase in demand at the fovea would reduce the hit rate for correctly identified peripheral targets. Other modifications to the methodology are outlined below in the method section.

4.3.1. Methodology for experiment 5

4.3.1.1. Participants

Twenty-four psychology undergraduates were recruited for the study (with a mean age of 18.9 years, 12 were males). All participants had normal, or corrected to normal vision. None of the participants suffered from colour blindness.

4.3.1.2 Materials and apparatus

Three blocks of trials were presented to participants, with blocks containing 30 trials. Each trial consists of three slides: a fixation slide (of 1000 ms duration), the target slide (of 300 ms duration), and a mask slide (which lasts until the participant presses a button to continue). An example of a typical triplet of slides is shown in Figure 4.3.

The fixation slide contained a cross within a triangular placeholder at the centre of the screen. This focused the participants' attention at the centre of the screen.

The target slide consisted of a triangle in the centre of the screen flanked by two triangles positioned 3.5° to the left and right of centre (with participants seated one metre from the screen). These triangles were taken from experiment four (see section 4.2.1.2.) though the red warning borders were changed to black for this study and the road signs had been removed. In place of the road sign symbols one of six letters could appear. The letters used were A, E, U, G, K, and P. The two triangles either side of the centre arrow would always contain one vowel and one consonant. All combinations of letter pairings, arrow directions and arrow colour were created. The thirty target slides used in each block were drawn randomly from this corpus.

The mask slide displayed three triangles with all the elements that could appear in each triangle superimposed upon each other. It was hoped that this would decrease the influence of iconic memory in the reporting of the peripheral letters.

The three blocks drew their target slides from the same corpus. The only consistent difference between the blocks was the instructions to the participants which manipulated the cognitive demand of the foveal arrowhead (but not the visual complexity).

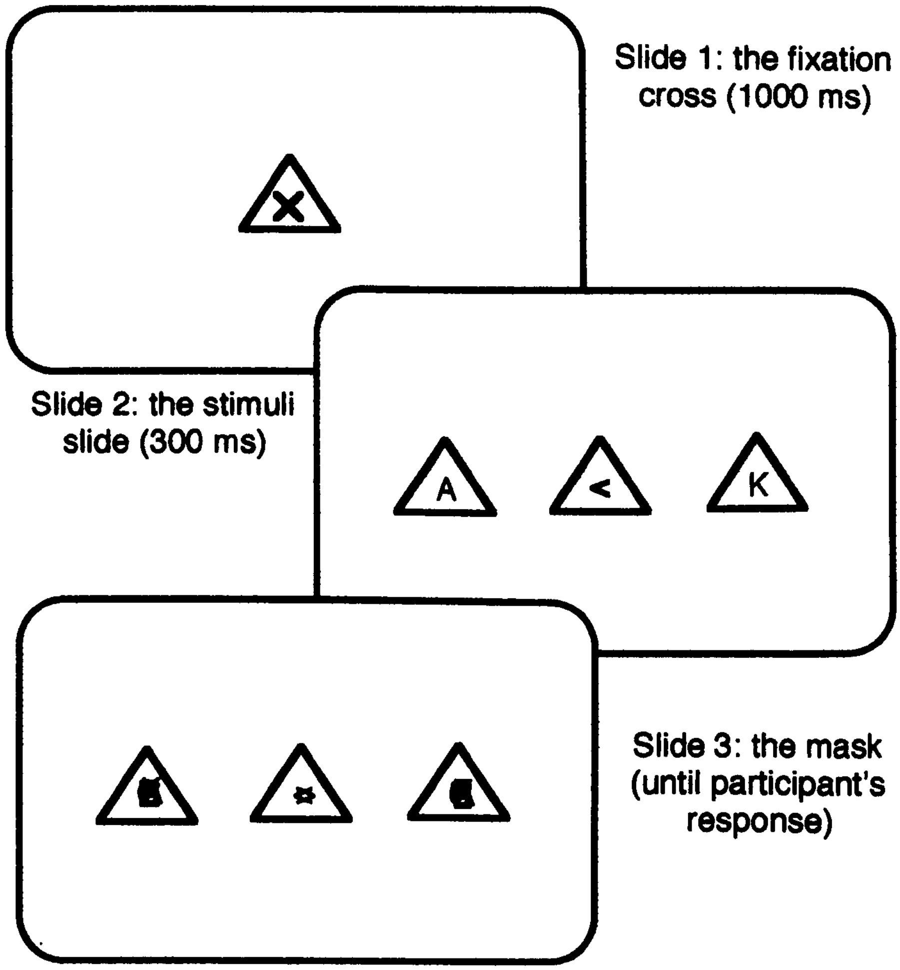

Figure 4.3. A diagram of the three types of slides (and durations) that make up a trial. Slides 1 & 3 are constant, while slide 2 is chosen from a list of 30.

4.3.1.3 Design

A simple one-factor within-groups design was employed for this study. There were three counter-balanced levels of foveal demand: the *orientation feature* condition, the *colour feature* condition and the *feature integration* condition. The orientation feature condition required participants to verbally report the direction of the foveal arrowhead and then report the letter it was pointing at. The colour feature condition required the report of the arrow colour and the letter to the left (if the arrow was green) or the right (if the arrow was red). The feature integration condition required participants to combine the colour and orientation features. In this condition they had to report the direction of the arrow if it was green, or the opposite direction if the arrow was red, and then identify the letter that appeared in the direction they had just reported.

Performance was measured by the accuracy in identifying the extra-foveal letters. Trials were not included in the subsequent analysis if the participants responded incorrectly to the central arrowhead. This removed trials in which the participant may not have been fixating the centre of the screen. Similarly any trials with overt eye movements noticed by the experimenter were also excluded from the analysis.

4.3.1.4 Procedure. All participants were seated one metre from the screen and given the instructions for the first condition (which could have been either colour, orientation, or feature integration according to the counter-balancing). Participants were told that they were going to view a series of slides displaying three signs, each of which would be preceded by a fixation cross and followed by a mask (see Figure 4.3). They were asked to stare at the fixation cross throughout the experiment, and to report both the interpretation of the arrow head, and the target letter identified by the arrow. For instance, if the arrow head in Figure 4.3 was red, a participant in the feature integration condition should respond with “Right, K”. Instructions on how to interpret the central arrowhead were only given immediately before the particular block of trials that they referred to. Before the start of the first block of slides participants were allowed five minutes practice to familiarise themselves with the speed of the stimuli and the required method of report.

4.3.2 Results and discussion of experiment 5

A one way analysis of variance was conducted on the three levels of the within groups factor of central demand. A main effect was discovered ($F_{(2,46)}$=5.21, p<0.01). Tukey post hoc comparisons revealed the predicted difference between the orientation feature level and the feature integration level, with the latter producing a higher accuracy rate on the identification of the peripheral letters (p<0.01). The predicted difference between the colour feature level and the feature integration level was not found (q=1.40). The relatively large difference between the two single feature conditions was not significant, which is in line with the hypothesis. The means can be viewed in Figure 4.4.

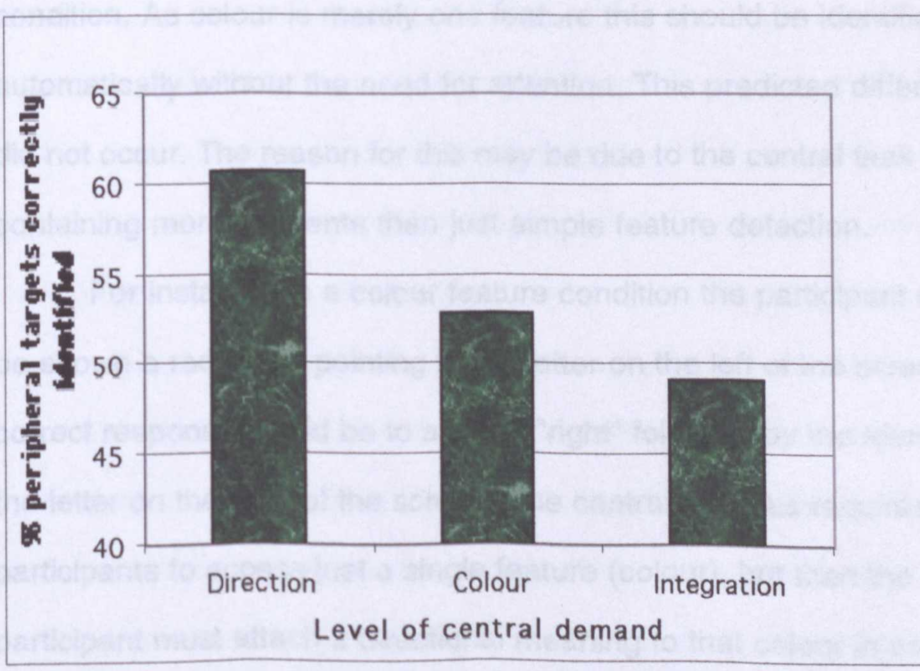

Figure 4.4. The % of peripheral targets detected according to the level of central demand

This particular result does suggest that less attention was available to identify peripheral targets in the more demanding feature integration condition than in the less demanding orientation feature condition. Treisman and Gelade's Feature Integration Theory argues that identifying only the orientation of the arrow should require little or no attention as this is merely one feature. When participants are asked however to report the direction of the arrow when it is green, or the opposite direction of the arrow when it is red, this requires both the orientation and colour of the arrow to be integrated. This is a process that does require attention. As attention is limited, this implies that the more attention that is required at the point of fixation, the less attention there is to give to extra-foveal stimuli. This is reflected in the drop in peripheral target identification accuracy that occurs in the feature integration condition.

Feature Integration Theory also predicts a significant difference between the colour feature condition and the feature integration condition. As colour is merely one feature this should be identified automatically without the need for attention. This predicted difference did not occur. The reason for this may be due to the central task containing more elements than just simple feature detection.

For instance, in a colour feature condition the participant may be shown a red arrow pointing to the letter on the left of the screen. A correct response would be to answer "right" followed by the identity of the letter on the right of the screen. The central stimulus requires participants to access just a single feature (colour), but then the participant must attach a directional meaning to that colour in order to know which peripheral letter to report. In the orientation feature condition once the orientation of the arrow has been noted it is easy to assign it a direction due to the consistent mapping that occurs between the orientation of arrows and direction in every day life. The relationship between the colour and the direction it signifies is, however, arbitrary; more arbitrary in fact than the role it plays in the feature integration condition. In this latter condition the colour green is used to signify that the participant should report the peripheral target in the direction of the arrow, while the colour red signifies that the participant should stop processing according to orientation and actually reverse the decision of direction. Again, the use of green as a 'go' signal and red as a 'stop' signal occurs in everyday life.

If consistent mapping occurs repeatedly between two things (such as the orientation of an arrow head and its associated direction) identification of the particular stimulus becomes automatic, requiring no attention. Shiffrin and Schneider (1977) demonstrated that the identification of a letter from a display of digits seemed to require no attention. Increases in the memory set size or the visual display had no effect on the time taken to detect the targets, which seemed to pop out as the result of a parallel search. Letters and digits have well learned responses associated with them that differentiate between the two. Shiffrin and Schneider argued that this consistent discrimination between letters and digits is learned through experience with literature and mathematics, and allows automatic identification of a digit amongst a display of letters, and vice versa. They have even demonstrated that this effect of automatic discrimination can be learned in a relatively short time. They repeated the letter/digit discrimination task with a new target set and a new distracter set. In this experiment participants had to identify letter targets from the first half of the alphabet, embedded in a display of distracter letters from the second half. After over 2100 trials, with targets and distracters consistently taken from the same sets, performance began to approximate that of participants in the letter/digit task.

These results can be used to explain the lack of difference found between the colour feature condition and the feature integration condition. Though the integration of two features requires attention in this experiment (a feature integration task), the integration between the stimulus and its meaning also requires attention if the participant has had no practice in linking the two beforehand (a symbolic integration task, that is the integration of symbol with meaning). As participants are all experienced in linking the orientation of arrowheads with the direction that it represents, this requires no more attention. The arbitrary linking of colour with direction would require a lengthy training period before the symbolic integration of feature and meaning required no attention.

As well as feature integration and symbolic integration, there is a third possible process that requires a verbal code to be accessed for the central stimulus. It is unlikely however that this would influence the distribution of attention in the 300 ms of the target slide presentation, as any verbal codes are most likely generated after the slide has disappeared. Furthermore evidence has already been reported that suggests eye movements are unaffected by verbalisation (see experiment 1, section 2.3.4.2). It is possible that attention would be unaffected also. Even if verbalisation did affect peripheral target identification accuracy, any effects should apply equally to all conditions. The cumulative effects of the two main processes involved in identification of the different central stimuli are listed in Table 4.2.

On the basis of this post hoc theory, the orientation feature condition is classified as requiring little or no attention, while both the colour feature condition and the feature integration condition are considered to be demanding to a roughly equal extent. This makes the assumption that the amount of attention required for a feature integration is similar to that required for a symbolic integration. However, though the means for the three conditions followed this

	Single Feature Tasks		Feature Integration Task
	Orientation	Colour	Orientation & Colour
Identifying the feature(s)	Automatic feature pop out	Automatic feature pop out	Feature integration (require attention)
Identifying the direction	Prior experience = automatic symbolic integration	Symbolic integration task (requires attention)	Prior experience = automati symbolic integration*
Which requires the most attention?	Orientation <	Colour =	Direction & Colour

Table 4.2. A list of the automatic and controlled processes involved in making a decision as to which peripheral stimulus (left or right) the central stimulus refers to.
* If one argues that both the symbolic integration of orientation with direction, and colour with a 'go/no-go' trigger are automatic then it should not make a difference that two symbolic integrations are occurring instead of just one.

pattern, the difference between the orientation feature and the colour feature conditions was not significant. It is unlikely that the assumption of equal processing required for feature and symbol integration is valid, so differential processing may confuse the issue. Regardless of theoretical musings to explain the unexpected findings of the colour feature condition this study was more concerned with the use of feature integration as a tool to manipulate demand. The one important point that has been identified from this experiment is that when using Feature Integration Theory to manipulate central demand a simple feature detection should involve no other processing that may confuse matters. In this case, a clear cut distinction was found between orientation and the negation of orientation through the integration of colour. These findings form the basis of the subsequent experiment.

4.4 Experiment 6: Investigating the influence of eccentricity

Experiment 5 demonstrated that an increase in cognitive demand at the fovea (while visual complexity is held constant) produces a corresponding decrease in the attention that is given to peripheral stimuli. This finding supports the basic premise of the theory of perceptual narrowing mentioned in chapter 3, that central load decreases peripheral attention. However, the conceptualisation of perceptual narrowing presented in section 4.1.3 suggests that the spatial spotlight contracts, leaving peripheral stimuli unattended as the attentional tide retreats. In order to support this conceptualisation an interaction should be discovered between the two factors of demand and eccentricity. If a reduction in peripheral attention due to increased foveal demands degrades performance on the furthest peripheral targets more so than nearer targets, then this would suggest some form of shrinkage of spatial attention. Without this interaction, any effects of demand could apply equally to space or object-based interpretations of the results. Without the interaction between demand and eccentricity, any main effects of the two factors would suggest that an increase in foveal load results in less attention devoted to peripheral stimuli regardless of their distance from the point of fixation. This explanation requires no tide or boundary of attention. Experiments 4 and 5 cannot distinguish between these two alternatives as the eccentricities of the targets were not varied. The following section will report evidence from previous studies that have tried to demonstrate a difference between these two models before reporting the results of experiment 6 which included an eccentricity manipulation.

4.4.1 Perceptual narrowing or attentional dilution?

The primary limit on the usefulness of peripheral vision across varying eccentricity is visual acuity. The physical structure of the retina places emphasis on the fovea, with a high density of cones in this region requiring a proportionally larger area of the cortex to process the information. The greater dispersion of receptors in the peripheral field produces a general fall off in acuity with greater eccentricity from the fovea. This is a hardwired limit on peripheral performance.

There are two views on the degradation of processing as the eccentricity of stimuli from the point of fixation increase (Banks, Sekuler & Anderson, 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, Klein and Aitsebaomo (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.

There is some evidence for demand modulated fluctuations in peripheral attention across eccentricities. Williams' (1995) study, previously mentioned in regard to the experiential effects found between aviators and non-aviators, used stimuli across varying eccentricities. His participants were briefly presented cards with a digit at either 1.5°, 3°, or 4.5° from a central fixation point. The centre either contained nothing or an uppercase letter. The cards without a letter were considered low load and only identification of the digit was required. Responses to cards with a letter at the centre required participants to first say whether the letter belonged to a memorised target group, and then identify the digit. This high load condition was split further on the basis of the central target set size that had to be memorised, with the larger set necessitating more processing of the central letter.

After analysis he reported a marginal interaction between foveal load and eccentricity (experiment 2, $p<.08$) which he said provided evidence for a tunnel vision model of spatial attention. Tunnel vision is one of two models that describe the pattern of results due to a degradation of attention in the peripheral field. It suggests that there is actual shrinkage of spatial attention with the furthest eccentricities suffering the most. This equates to the conceptualisation mentioned earlier of the zoom lens contracting to increase the resolving power at the point of fixation when demand at this point increases. The second model is termed general interference and is characterised by main effects of both foveal load and eccentricity though without an interaction. This has been said to reflect 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 spotlight of attention. The two models can be viewed in Figure 4.5.

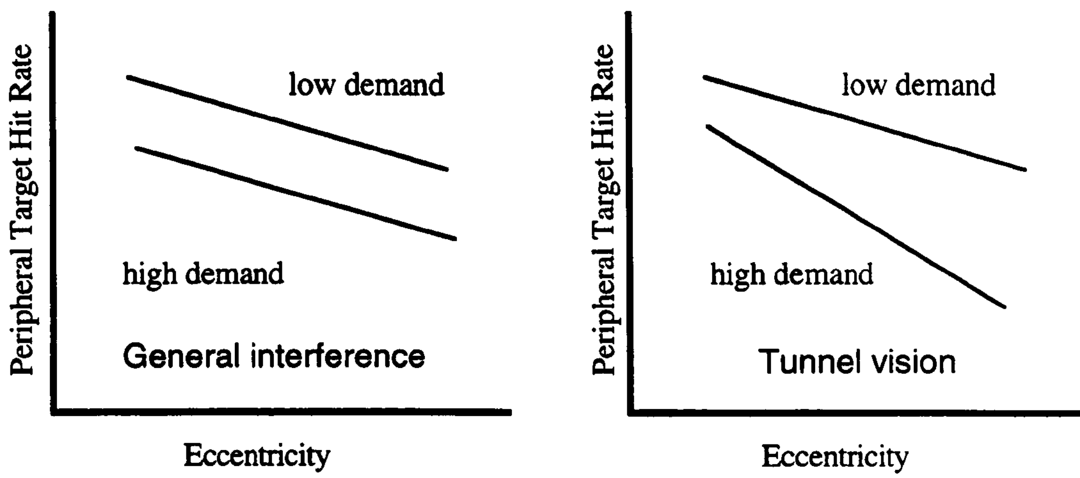

Figure 4.5. Peripheral target hit rates across eccentricity from the point of fixation, and for two levels of demand, for the two models of perceptual narrowing (adapted from Williams, 1995).

It should be noted that these schematics cannot be extrapolated back to zero eccentricity. They specifically deal items in the extra-foveal region while processing upon a foveal target occurs simultaneously.

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 & Courtney, 1993; 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.

The researchers that have worked in this area have explicitly (Holmes et al., 1977; Williams, 1982, 1988, 1995) or implicitly (e.g. Lavie, 1995) interpreted their data in regard to theories of spatial attention. Certainly the model of Tunnel Vision definitely implies that some form of spotlight is in use. The model of General Interference however is something of a default theory. This model implies no actual shrinkage of an attentional area, merely a dilution of attention within that area (with, of course, a single scaling factor of degradation across eccentricities due to visual acuity). This model however could equally be applied to an object-based description of attention. Only the Tunnel Vision model makes a strong case for spatial attention.

Experiment 6 was designed to look for a potential interaction between demand and eccentricity that would support the model of Tunnel Vision. This experiment draws heavily on the design of experiment 5, and as such the following method section is suitably shortened.

4.4.2. Methodology for Experiment 6

Ten psychology undergraduates were recruited for the study (with a mean age of 19.0 years, 5 females). All participants had normal, or corrected to normal vision. None of the participants suffered from colour blindness. These participants had previously taken part in experiment 5, and as such were comfortable with the procedure.

The same materials and apparatus used in experiment 5 were employed in the current experiment. The design was changed to a 2 factor, within-groups design. The two levels of the demand factor were taken from experiment 5, and required participants to report the central stimulus and the peripheral stimulus on the basis of the orientation of the arrowhead in one condition, or on the basis of a feature integration of colour and orientation in the other condition. The eccentricity factor was split into two levels. For one level of eccentricity the participants sat at one metre distance from the screen which placed the peripheral stimuli at 3.5° distance from the central arrowhead. In the other level of eccentricity participants were seated 50 cm from the screen, which increased the eccentricity of the targets to 7° from the centre. All four blocks were counter-balanced across participants, and all the controls used in experiment 5 were employed in this experiment. The procedure also followed that used in the previous experiment. Hit rates for accurate identification of the peripheral targets were analysed across the conditions of eccentricity and demand.

4.4.3. Results and discussion of experiment 6

A two-way analysis of variance was conducted on the data. A main effect of both demand ($F_{(1,9)}=21.4$, $p<0.01$) and eccentricity ($F_{(1,9)}=42.5$, $p<0.01$) were discovered, though no interaction was found. The demand manipulation produced a similar effect in this study as it did in experiment 5. Peripheral accuracy declined as the peripheral targets were presented further into the periphery, though the lack of interaction with the demand factor fails to support the Tunnel Vision model of attention degradation. The two main effects can be viewed in Figure 4.6.

On the basis of these data it seems that the increase in demand does reduce the amount of attention devoted to peripheral stimuli, and this attention does seem to decline along with visual acuity the further into the peripheral field that one investigates. It cannot be concluded however that the standard conceptualisation of a narrowing of the zoom lens stands up to scrutiny, as the predicted interaction did not occur.

One possible confound with the eccentricity factor is that as the screen was brought nearer to the participant (and the eccentricity of the peripheral stimuli increased) the relative size of the stimuli also increased. The larger size of the peripheral stimuli in the 7° condition may have counteracted the predicted greater degradation with a high

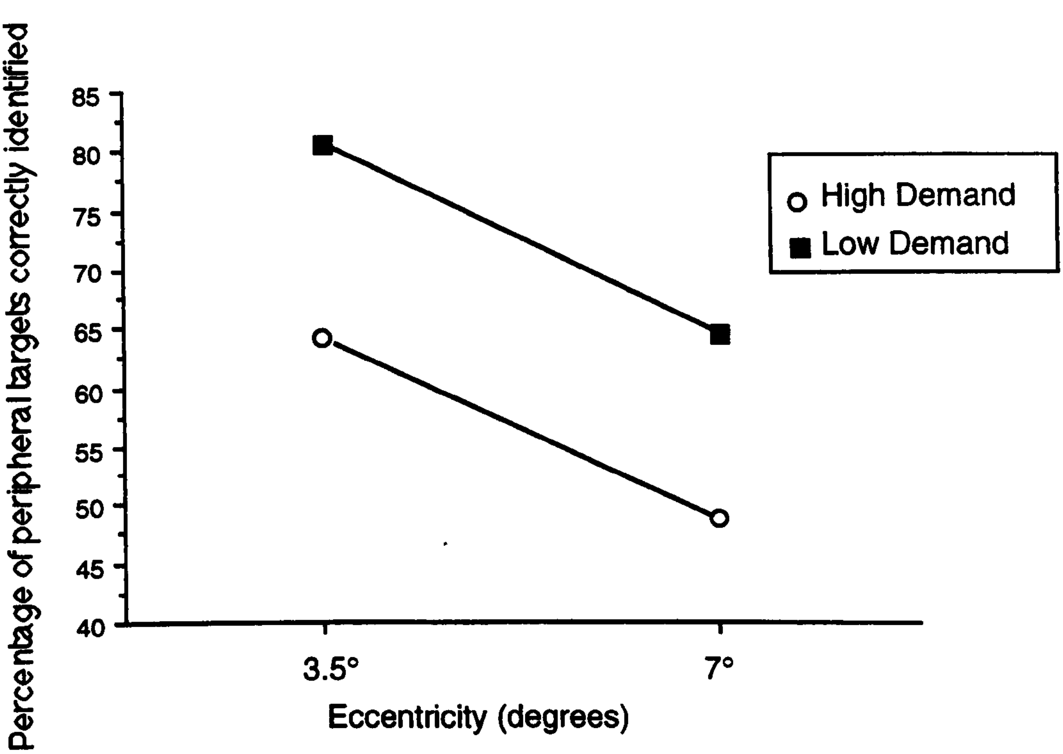

Figure 4.6. The percentage accuracy of peripheral letter discrimination across the factors of demand and eccentricity.

foveal load. Despite this possible confound the main effect of eccentricity was still found, though the lack of an interaction may have been partially due to this.

4.5 General conclusions from experiments 4-6

At the start of this chapter the possibility that drivers suffer from a demand induced degradation of extra-foveal attention was raised. The experiments reported in this chapter attempted to provide evidence for this hypothesis outside of the driving context. The results suggest that increases in demand at the point of fixation do degrade the deployment of extra-foveal attention. Though experiment 4 suffered from at least one considerable confound, the subsequent experiments 5 and 6, repeated the findings under more controlled circumstances.

One cannot conclude from these results however that the degradation occurs within a spatial spotlight of attention, or within an object-based framework. The default model of general interference does not allow a distinction to be drawn between space-based and object-based attention. Despite this, the degradation does occur in a context-free environment.

The lack of a driving context may be the main reason that differences were not discovered between novice and experienced drivers. Williams (1995) found evidence to suggest that aviation experience was noticeable in simple letter/digit discrimination tasks, yet no such experiential effect was found for driving in experiment 4. There are a number of possible reasons for this. First, the experiential difference was found between aviators and non-aviators. Novice aviators were indistinguishable from their more experienced counterparts. It is possible that experience can be accrued very quickly such that novice drivers (and aviators) can transfer attentional skills to context-free settings to the same extent as the experienced participants, though both groups out perform participants who have had no exposure to driving (or flying). However, if one context can have such an effect on a context-free experiment (especially with the limited exposure that novices receive), then all contexts that all participants have been exposed to could theoretically have an effect. Experience with computer games, tasks in the workplace that involve visual monitoring, and even reading, are all contexts which could theoretically influence a context-free task, even with minimal exposure. If this is the case, then it would be surprising to find any effects due to the high levels of noise in the system.

A second possible explanation for the lack of experiential differences is that the strategies that are developed in a particular context are not transferable. Instead of experience developing a strategy which can be applied across different setting, the hypothesised experiential difference may occur because the stimulus at the point of fixation is less demanding for those individuals who have experienced such stimuli on may occasions. In this case the requirement for an experiential effect is that the foveal load needs to be related to the context from which the experience is derived. Perhaps the use of a staggered junction or a right-bend junction would have been better suited as the central stimulus rather than the peripheral targets?

In conclusion, the experiments reported here have demonstrated that a demand induced degradation of attention does occur with an increase of demand at the point of fixation. The subsequent chapters attempt to relate these results back to the driving context, so as to identify possible experiential differences.

Chapter 5. PERIPHERAL ATTENTION IN A DRIVING CONTEXT: Can driving experience moderate the loss of attention under increased demands?

5.1 Do novice drivers see less of the world?

5.1.1 The story so far

The lack of experiential differences noted in experiment 3 raised the possibility that subtle differences may exist between the driver groups, though the hazard perception test may not be sensitive enough to detect them. Several other explanations were discussed but dismissed. One particular theory was chosen as a candidate for experiential differences on the basis of the limitations of the eye-mind assumption (Underwood & Everett,1992), the importance of peripheral information to drivers (e.g. in lane maintenance; Land & Horwood, 1995), and theoretical evidence to suggest increases in foveal demand decrease attention to extra-foveal stimuli (e.g. Lavie, 1995). Chapter 4 set out to demonstrate the latter point, and concluded that an increase in demand (in terms of a feature integration task) did reduce ability to discriminate peripheral stimuli across varying eccentricities. On the basis of Williams' (1995) study it was also predicted that the simple laboratory based tasks may actually discriminate between drivers. This follows the assumption that experience in a certain visual task (such as aviation or driving) may lead to generalisable skills that transfer to context-free settings. This prediction was not upheld (experiment 4).

This chapter aims to develop the research of chapter 4 toward a more driving-based context, though first one must ask what evidence there is to suggest that novice drivers may be more prone to such degradation of peripheral attention than experienced drivers? Unfortunately no research addresses this question directly. Two sub-questions can be answered however.

First, one should ask whether experience in any task can influence the deployment of extra-foveal attention. Limited evidence has already been reported by Williams, though the failure of experiment 4 to uphold the prediction of experiential differences (which was derived from Williams' study) calls this evidence into question. On this basis it would be wise to review other evidence for an experiential effect upon the of deployment extra-foveal attention.

The second question is whether demand induced degradation of attention in the peripheral field occurs at all in driving. If such degradation does occur in drivers, and experience has been shown to be a factor in other task domains, then it is a short step to predict that driving experience may influence visual search through a cognitive demand-based reduction of attention in the peripheral visual field. The following sections will address the evidence that answers these questions. Following this review of evidence, experiment 7 will be reported. This is a study that directly attempts to answer the question of whether experiential differences affect extra-foveal attention in a driving related task.

5.1.2 Does experience modify deployment of extra-foveal attention?

In regard to the effects of experience, Holmes, Cohen, Haith and Morrison (1977) suggested that the spread of spatial attention across different situations is a skill that is learned, rather than a natural response to the changing environment. They tested 18 adults, 18 five year olds, and 18 eight year old children in a simple study to assess ability to identify stimuli at various eccentricities under differing foveal loads. They found effects of foveal load and eccentricity (as in experiment 6) though did not find an interaction indicative of Tunnel Vision. In addition to this they discovered that the increase in age across the participant groups corresponded with an increase in the accuracy of identifying the peripheral targets. Age of course does not equate to experience, and as such the link between the results and the inferred consequences for experience is not perfect. Furthermore the varying foveal loads confounded visual complexity and cognitive demand: in the low demand condition the peripheral stimulus was presented without a central stimulus, while in the other two conditions a geometric shape was presented foveally. Participants were told to report the central stimulus in one condition and to ignore it in the other. They found an equal level of attentional degradation for both conditions with central stimuli compared to the condition without a foveal stimulus. The mere presence of a central stimulus (an obvious increase in visual complexity, but less obviously related to cognitive processing) induced a deterioration of peripheral processing. This finding is contradicted by experiments 4 to 7, which held the visual complexity constant and varied the cognitive processing that was required.

If there is an influence of age upon the spread of attention in the peripheral field that is independent of experience then one may expect the relationships to differ. Whereas one would expect experience to have a linear relationship with performance on peripheral detection tasks until asymptote, there is evidence to suggest that age has an inverted U relationship. Ball, Beard, Roenker, Miller and Griggs (1988) measured the Useful Field of View (a term that is seemingly synonymous with the Functional Field of View) of groups of young, middle aged, and older participants (with respective mean ages of 25, 45 and 69 years). They found that the older participants had a reduced amount of attention devoted to the peripheral field. More interesting however was the finding that a considerable amount of training could redress age related deficits. This suggests a direct link between experience (at least within a particular context) and deployment of extra-foveal attention.

Other studies of picture or shape identification in the peripheral visual field have noted a training effect (Engel, 1971, Ikeda and Takeuchi, 1975; Walsh, 1988). When participants have experience in peripheral detection experiments they become more resilient to attentional degradation in the peripheral visual field.

There is also evidence from reading studies on the role of learning in the deployment of attention in the perceptual span. One example of this is a study that was conducted to assess the perceptual spans of Israeli participants reading both English and Hebrew (Pollatsek, Bolozky, Wells & Rayner, 1981). While reading English the participants had a preview window of up to 15 letters to the right of fixation, yet only 3 or 4 letters to the left. This is a consistent finding reported earlier in chapter 4. When reading Hebrew however, which reads from right to left, this visual asymmetry was reversed. In this instance the perceptual span was adapted to the particular language.

Experience in reading produced the two opposing attentional strategies that Pollatsek et al. discovered. Rayner (1986) also found that the perceptual span of average readers was 20 % bigger than of people with poor reading ability.

These studies do not however directly assess the underlying causal link between experience and performance. One contender (explicitly stated in section 4.1.2 in regard to the driving context) is that experience decreases the attentional requirements of the foveated stimulus, which in turn frees up more attention for the peripheral field. However there must also be an element of experience that shapes the deployment of attention regardless of the processing required at the point of fixation. Asymmetric perceptual spans demonstrate this. Henderson, Pollatsek and Rayner (1989) proposed the Sequential Attention Model of attention which suggests that attention is deployed in the part of the peripheral field to which the eyes will subsequently move. Thus experience with the reading context tells the reader that English requires a left to right movement of the eyes, and attention is deployed accordingly. In a situation where there is no definite order to eye movements (such as driving) then attention will be deployed over those areas in which relevant information is likely to occur (such as the road ahead, and to the left and right).

The evidence reported in this section does suggest that experience can increase performance on peripheral detection and discrimination tasks. The following section assess the few studies which have attempted to find demand induced decrements in peripheral attention in the driving context.

5.1.3 Does peripheral attention deteriorate with increases in demand in a driving context?

The second question concerns whether degradation of peripheral attention has ever been recorded in the driving domain. An early series of in-car studies of peripheral detection rates was conducted by Lee and Triggs (1976). Their experiments consisted of up to 12 participants driving along various roadways such as a freeway, a suburban road and a shopping centre route, or along a private road while attempting to keep the vehicle following a thin line on the road surface, while verbally responding to peripherally presented lights. Four target lights were mounted on the dashboard and body of the car, the furthest two at 70° from a fixation straight ahead, and the nearest two at 30° from fixation. They noted that as the processing demands increased, such as when driving through the shopping centre or when the margin of error for line following was reduced, peripheral detection rates fell with a pronounced decrement occurring in the two targets furthest from centre.

Miura (1990) reported an experiment involving two participants who were eye tracked while driving for a total of 120 hours over the course of 10 months. The participants drove along a number of roads selected on the basis of traffic density and task demands. During the drive participants had to verbally respond to peripherally presented target lights in a similar manner to the studies of Lee and Triggs (1976). Miura noted that as the demands of the roadway increased there was a corresponding increase in reaction times to peripheral lights. From this he concluded that peripheral attention was degraded by the foveal demand of the driving stimuli. He also identified a negative correlation between response eccentricity (distance of the target from the fixation point at the time of a response to a target light) and the demands of the roadway. As the roadway becomes more complex the participants saccaded closer to the target before responding, and used a greater number of fixations to do so. Miura's explanation is that as the spatial representation of attention shrinks due to increased foveal demands, drivers tend to search toward the extremes of the spotlight to increase their active search space. This can be described as a compensatory strategy developed to overcome the limits of peripheral vision under conditions of high demand. This corresponds with the results reported in experiments 2 and 3 that demonstrated an increased level of visual search with the increasing complexity of the road way. A similar compensatory strategy was proposed by Beck and Emery (1985) who suggested that a state of hypervigilance (increased awareness and search of peripheral stimuli) can occur under anxiety provoking circumstances.

From the work of Lee and Triggs (1976) and Miura (1990) degradation of peripheral attention does seem to occur under driving conditions. Evidence has also been reported that links task experience to the shape and size of the spatial deployment of attention. The proposition that experience may play a role in the effective size of the peripheral attentional field of drivers is supported by evidence from culmination of these two research areas. The following sections describe an experiment that was designed to test this hypothesis.

5.2 Experiment 7: The effect of experience upon detecting peripheral targets during a driving related task

Experiment 7 was designed to test the specific prediction that driving experience influences the amount of attention devoted to the peripheral field during a driving-related task. It was decided to return to the hazard perception clips for stimuli in order to identify a difference between experience groups beyond the limitations of straight forward eye tracking. As the hazard perception test had previously failed to show differences between novice and experienced drivers, perhaps in part due to the insensitivity of the test to real underlying differences, it was decided to increase the range of experience (or lack of it) by introducing a group of non-drivers as a control. In addition to this peripheral target lights were presented at varying eccentricities across different levels of demand. This made it possible to test for the model of Tunnel Vision.

One issue in the development of any test is the choice of measures that should be recorded. As there is some debate as to the precise nature of the measures that should be used in studies such as this one, the rationale for the measures used in this study will be presented in this section before giving a more detailed description in the method section.

Miura (1990) said that the two most important indices of peripheral performance are response time to peripheral targets and response eccentricity (the distance from the target to the point of gaze at the time of response). However, the use of reaction time as a valid measure is dependant on the presentation of the peripheral targets. If the targets are only presented for a few hundred milliseconds then a response time can add little information to our knowledge of when the light was seen and will mainly consist of post-detection response bias, unless the difference in reaction times between groups is shorter than the presentation time of the target. If the light remains on until a response is made, then the time of response is more informative about when the light was noticed. During the time between target onset and response however, one cannot identify the motivations underlying the search strategy. The participant may note the stimulus and saccade toward it for verification, or they may simply 'stumble' across it in their inspection of the visual field. For this reason it was decided to use simple detection rates of short duration targets as the primary indicator of attentional degradation, though reaction times were retained for additional information.

Similarly the measure of response eccentricity can be misleading. Miura's findings suggest that response eccentricity is inversely correlated with demands and the size of the usable field of view. This means that the smaller the spread of attention, the nearer one must be to the target before responding. However, if a purposeful saccade is made toward a target, then this presupposes that the stimulus has captured exogenous attention and has produced a reflexive eye movement (Serano, 1992). If this is the case, the spotlight must be at least as wide as the furthest eccentricity from which a peripheral target elicits a saccade. Instead of using response eccentricity this initial study has focused on onset eccentricity - the distance from fixation to target at target onset. Coupled with the detection rate of peripheral targets which are presented for extremely short durations, these measures reflect the true distance at which participants' can detect peripheral abrupt onsets.

5.2.1 Methodology for experiment 7

5.2.1.1 Participants

Sixty participants took part in the study. Twenty experienced drivers (12 females and 8 males, with a mean age of 24 years, 1 month, and a mean experience since passing the driving test of 60 months), 20 novice drivers (8 males and 12 females, with a mean age of 19 years, 3 months, and a mean experience since passing the driving test of 2.5 months), and 20 non-drivers (13 females and 7 males, with a mean age of 19 years and 5 months, with no experience of driving) were paid to take part. All the participants had normal vision. Experienced drivers and non-drivers 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.

5.2.1.2 Materials and apparatus

Participants were presented with the 39 MPEG hazard perception clips (see section 2.3.3.2 for a general description of the hazard perception clips, and Appendix 1 for a listing of hazard onset times and descriptions for each clip). The apparatus was the same as that used in experiment 3.

The primary task required the participants to view each scene, looking for any hazardous events in order to rate each clip on two, seven-point Likert dimensions. These dimensions asked, first, how much danger is inherent in the clip, and secondly, how difficult would they find the scene to drive through. These two scales have been previously found to distinguish between drivers groups on the basis of experience (Groeger & Chapman, 1996), though for the purposes of this experiment the results of the primary task were of minor importance. 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 seven 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°. The left and right place holders were 6.8° from the centre of the screen, while the top and bottom place holders were 4.4° from the centre. A bright white, peripheral target light was presented in every five second segment of video. These lights, which subtended 0.3°, lasted 200 ms and occurred in the centre of the place holders. Within each five second window targets were randomised in regard to onset time and which placeholder 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 during the viewing of the 39 video clips. An example of the screen set up is shown in Figure 5.1.

Figure 5.1. A still from a hazard perception clip with the four target placeholders

5.2.1.3 Design

The three factors involved in this mixed design were level of experience (experienced drivers, novice drivers and non-drivers), level of processing demand ('high' verses 'low') and the onset eccentricity of each target. The level of demand was calculated from the results of experiment 3 which used the same clips. In this previous hazard perception test 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 five second segment within each of the 39 MPEG video clips. This produced an index of demand termed the *mean responses per participant per 5 seconds* which ranged from zero for the uneventful five second clip segments, to 1.8 for the more hazardous clip segments. Most clips did not divide perfectly into five second windows, which meant that a few seconds at the end of each clip had to be disregarded from analysis. For instance a 47 second clip may be made up of a mixture of nine high or low demand windows, with a two second section at the end. As it was impossible to dictate whether a target would be presented in those two seconds (as opposed to the other three seconds which would normally make up the five second window) any such data were deleted. A median split (at 0.18) of the *mean responses per participant per 5 seconds* produced a roughly equal number of *high* and *low demand windows* (51.5% of the 297 five second windows were classified as high demand).

The onset eccentricity factor is the distance from the current point of fixation to a target at the time of onset. At the precise moment of a peripheral target onset, the computer would record the eccentricity from the point of gaze to the centre of the particular placeholder in which the target appeared. These measures of onset eccentricity were placed into categories chosen on the basis of the distribution of eccentricity scores of pilot data. Four categories were chosen: less than 5 degrees, 5 - 5.9 degrees, 6 - 6.9 degrees, and 7 degrees and above.

The main dependant variable was the percentage of targets spotted across the three factors of demand, eccentricity and experience. In addition to this response time data was also recorded.

Only targets that were given an onset eccentricity by the computer were designated as either a hit or a miss (i.e. 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.

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

5.2.1.4 Procedure

At the start of the experiment participants were informed of the two tasks they were to perform and were given practice in using the computer-based rating system to record their estimates of how much danger they thought was inherent in the clip and how difficult they would personally find the clip to drive through. In the case of non-drivers, they were asked to imagine that they had just passed their driving test when considering the latter dimension. In order to estimate values for each clip 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 required the participants to respond to the peripheral targets by pressing a button on the PC mouse. Though the data relevant to the hypothesis was obtained through this secondary task, emphasis was placed on the rating task. Participants were also explicitly instructed not to deliberately search for the peripheral targets. It was pointed out to them that searching for target lights (e.g. saccading from one placeholder to another in anticipation of a target onset) would reduce the likelihood of spotting them as the chance of a target light appearing in any one particular placeholder was only 1 in 4.

It was also stressed a preoccupation with the placeholders would reduce their chances of making accurate estimates for each clip.

5.2.2 Results of experiment 7

The results will be presented in three sections. The first section addresses the hypothesis of whether peripheral target detection rates are decreased through the effects of increased demand and eccentricity, consistent with one of the models of attentional degradation (Tunnel Vision or General Interference). The main hypothesis that these effects will vary with driving experience will also be examined. 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.

5.2.2.1 Peripheral target hit rates.

On average, each participant was presented with 273 peripheral targets (out of a possible 297) and 188 of these were considered successfully presented (i.e. the computer successfully assigned each target an onset eccentricity). The mean number of false alarms was very low, averaging 6 false reports for every 188 successfully presented targets (3.2%). The mean hit rates across all three factors can be viewed in

Table 5.1.

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 which are directly relevant to the

	Hit Rates (%)							
	High Demand				Low Demand			
	<5°	5°	6°	7°+	<5°	5°	6°	7°+
Experienced Drivers	66	69	67	45	73	77	73	58
(average no. of targets for each participant)	(19)	(23)	(19)	(33)	(18)	(18)	(15)	(29)
Novice Drivers	65	63	61	43	72	76	76	48
(average no. of targets for each participant)	(22)	(24)	(23)	(38)	(18)	(20)	(21)	(35)
Non-drivers	55	49	47	38	62	64	56	43
(average no. of targets for each participant)	(22)	(23)	(21)	(37)	(20)	(19)	(17)	(31)

Table 5.1. Peripheral target hit rates expressed as percentages according to the three factors of driver experience, level of demand and onset eccentricity.

hypothesis of attentional degradation 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 seven degrees from the point of fixation. The results suggest that, as both 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 default model of General Interference over Tunnel Vision. These main effects can be viewed in Figure 5.2.

The third main effect was found across the participants' varying levels of experience ($F_{(2,57)}=4.5$, $p<0.05$). A post hoc Newman-Keuls revealed that the significance lay between the experienced drivers

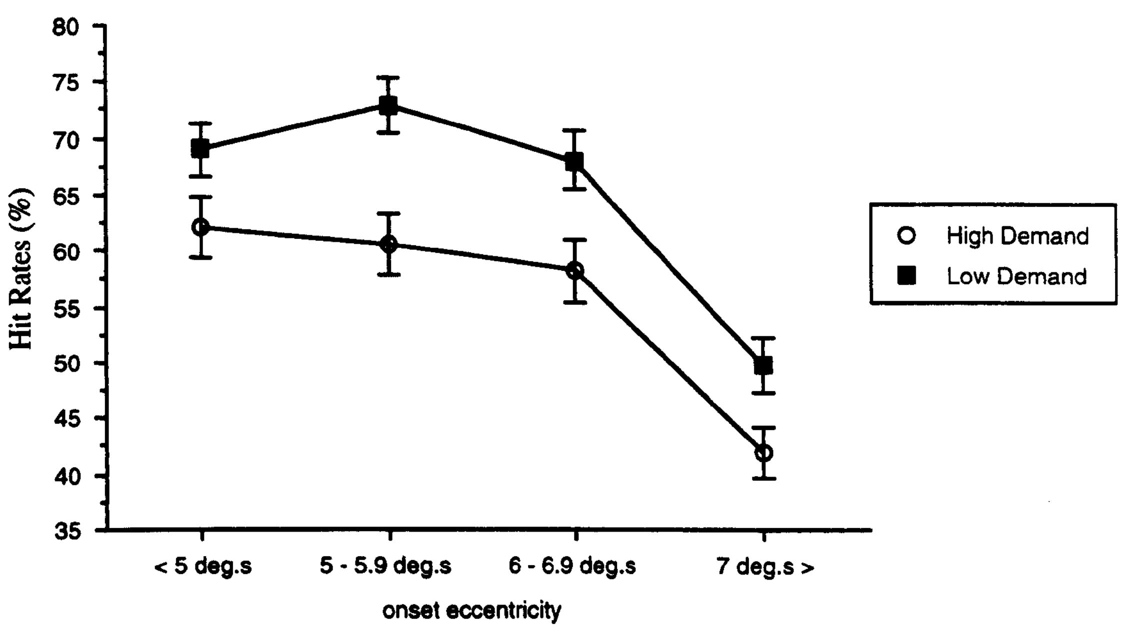

Fig. 5.2. The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) across the factors of demand and onset eccentricity (with standard error bars added).

and the non-drivers, with the novice drivers falling somewhere in the middle (though closer to the mean of the experienced drivers - see Figure 5.3).

Though the level of experience of participants did not interact with processing demands or onset eccentricity, the main effect illustrates that the paradigm is not only suggestive of demand modulated attention in the peripheral field, but that it also distinguishes between the participants on the basis of their driving experience. The lack of an interaction suggests that a lack of experience decreases peripheral attention even under the easiest conditions. As the

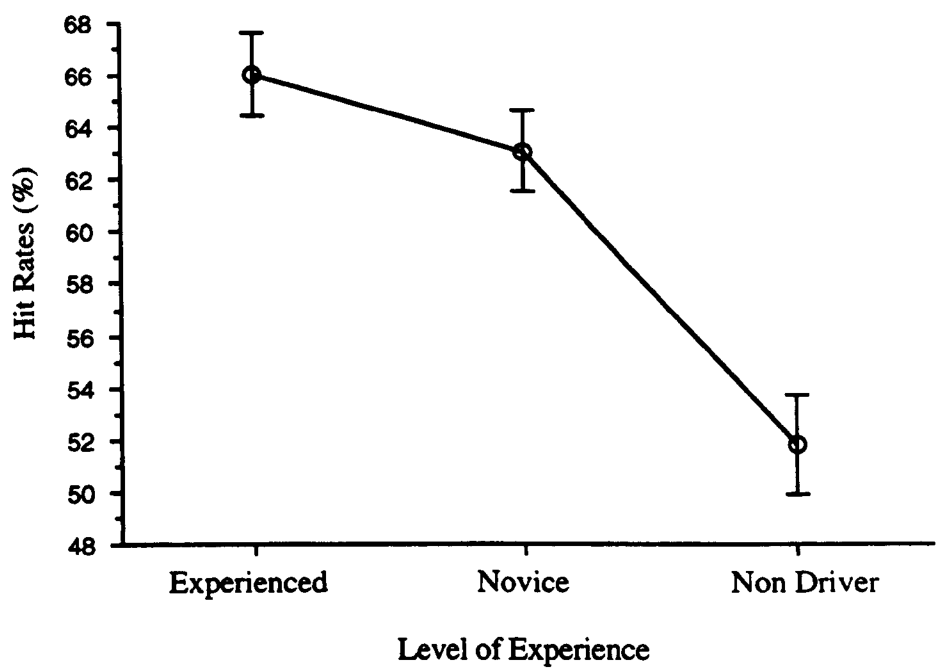

Fig. 5.3. The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) according to level of driving experience (with standard error bars

processing demands increase, or the onset eccentricity becomes greater, the hit rates of the non-drivers worsen proportionately with those of the other participants.

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 (i.e. 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.

5.2.2.2 Peripheral target reaction times

An analysis of variance was conducted on the reaction times to successfully presented targets and 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. A weaker effect of onset eccentricity was also noted ($F_{(3,171)}$=3.1, $p<0.05$). Means comparisons of levels of eccentricity revealed that targets presented at eccentricities of 7° or greater were significantly slower than targets at 5-5.9° and at 6-6.9°, though no slower than targets below 5° ($p<0.05$).

A main effect of experience was also found ($F_{(2,57)}=4.1$, $p<0.05$). Non-drivers were significantly slower in responding to spotted targets than the other driver groups, as revealed by a post hoc Newman-Keuls. The means of these data can be viewed in Table 5.2.

	Reaction Times (ms)							
	High Demand				Low Demand			
	<5°	5°	6°	7°+	<5°	5°	6°	7°+
Experienced Drivers	569	595	566	569	542	532	531	566
Novice Drivers	589	568	583	629	563	557	550	569
Non-drivers	663	665	657	688	645	621	609	641

Table 5.2. Peripheral target hit rates in milliseconds, according to the three factors of driver experience, level of demand and onset eccentricity.

5.2.2.3 Clip ratings and measures of the general search strategy

The ratings task was included to provide the participants with a central task that would require them to pay attention to the hazards in the video clips as these formed the basis of the demand manipulation. 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 analysis of variance 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. No significant differences were found between the participants groups [$F_{(2,57)}=1.5$] though the means tended toward a reduction for experienced drivers (averaging 474 ms for a fixation) compared to novices and non-drivers (who produced mean durations of 554 ms and 542 ms respectively). Analyses were also performed to assess potential differences in the mean fixation location (i.e. 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 one degree 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 experience drivers in both experiments 2 and 3, 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 may have attracted 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 (i.e. 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.

Onset fixation durations 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 (i.e. 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 post hoc hypotheses a further analysis of variance was conducted between the portion of the onset fixation durations 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 ($F_{(3,171)}=4.0$, $p<0.01$) with means comparisons revealing that at eccentricities greater than six degrees 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 the spotted target means split into before onset and after onset fixation durations, can be viewed in Table 5.3.

a)

	Experienced drivers	Novice drivers	Non-drivers
Spotted targets	991	1294	1237
Missed targets	684	872	750

b)

	<5°	5°	6°	7°+
Before Onset	551	593	582	674
After Onset	578	588	578	553

Table 5.3 (a & b). Onset fixation durations in milliseconds across (a) participant groups and whether the peripheral target was detected, and also (b) split into before and after peripheral target onset fixations across eccentricities.

5.3 Discussion of experiment 7

The results of experiment 7 revealed that driving experience does influence the amount of attention that is devoted to the peripheral field as demand increases when measuring performance in a driving context. This suggests that deployment of attention in the peripheral field when driving is a skill or strategy that is developed through exposure to the relevant context. As there were no interactions between the factors the effect of experience and the effects of demand and eccentricity will be discussed separately in the following sections.

5.3.1 The effects of experience on peripheral target detection

The effect of experience upon hit rates revealed that the non-drivers were significantly worse than the experienced drivers at detecting the peripheral targets. The hit rates of novices drivers fell in-between the experienced and non-driver scores, and did not differ significantly from either. Although driving experience relates to the number of peripheral targets detected, it seems that the novices' deployment of attention in the peripheral field has reached a similar level to that of the more experienced drivers. It seems that very little driving experience since passing a driving test is required before the strategy or skill that guides the deployment of attention reaches toward an asymptote. Despite this failing, the main effect of experience is interesting in itself as this shows how driving experience implicitly improves one's awareness, or potential awareness, of the surroundings.

On the basis of these results it is also possible that differences according to experience would have been found in experiment 4 if a non-driving group was used. This was the course of action eventually taken by Williams (see section 4.5).

The experiential effect from the hit rates was supported by the reaction time data. Again, non-drivers had the worst performance while the experienced drivers had extremely fast responses to perceived targets. The difference between the mean experienced and non-driver response times to the targets is less than the presentation time of the target lights, with experienced drivers responding an average of 90 ms faster than non-drivers. It is possible therefore that this could reflect a difference in the time taken to spot the brief 200 ms presentation of the target.

None of the other measures distinguished between the participant groups. This was particularly surprising in the analysis of the spread of search along the horizontal and vertical meridians, as these measures had previously been shown to differentiate between the groups both on the road (experiment 2) and on the hazard perception test in the laboratory (experiment 3). It was noted in the results section that this may have been due to saccades directed toward the placeholders in anticipation of a target appearance (searching for a target) or to confirm a target onset (a reflexive or controlled saccade attracted by the peripheral target onset).

5.3.2 The effects of demand and eccentricity on peripheral target detection

The hit rate analysis revealed two main effects of demand and eccentricity though an interaction between the two did not occur. On this basis one cannot conclude that a spatial spotlight is contracting, causing targets to be missed as the field of attention contracts around the point of gaze. Instead the default model of General Interference is supported. It has already been pointed out that this model however need not imply any shrinkage as such. Therefore the term 'perceptual narrowing', used to describe such effects in the literature seems inappropriate in this instance.

The effect of demand upon the detection rates supported the categorisation of high and low demand on the basis of the previous study (experiment 3). Experiments 4 – 6 used a demand manipulation that presented stimuli fixed at the point of gaze, and did not vary in visual complexity across the levels of demand. This was not possible to achieve with such varied stimuli, and so it was hoped that by using previous participants' self-ratings of when they believed the demands had increased (hazard responses from experiment 3) the issue of precisely defining what is high and low demand is circumvented. Instead of absolute demand levels (as with the differences between single feature and feature integration tasks), average self reported levels of demand were used. The similarity between the effects noted in this experiment and those reported in the previous chapter suggest that this categorisation was successful in terms of replicating the demand effect on attention using driving stimuli.

The eccentricity effect revealed a gradual, insignificant decrease in hit rates from low to medium eccentricities, with a sudden drop off beyond 7°. 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° and beyond, those that were spotted were on average 8.3° from the point of fixation (with a standard deviation of 0.53°), while those that were missed were 9.1° away on average (with a standard deviation of 0.55°). This difference was tested along with the experience factor in a mixed anova. The experience factor did not reveal any differences at an acceptable level of significance, though the comparison of eccentricities between those targets that were detected and those that were not, produced a large effect that is unlikely to have occurred by chance ($F_{(1,57)}=169$, $p<0.01$).

Despite the lack of an interaction producing evidence for the narrowing of a spotlight of attention, the sudden drop off for detectability of targets could be interpreted as evidence for the existence of a boundary beyond which targets are infrequently spotted. This boundary does not coincide with a sudden decrease in photo-receptors on the retina. Cones (sensitive to bright light) decrease in number much more rapidly from the fovea outwards at short eccentricities. Between 8-10° the number of cones begins to level off at a constant background density, which continues across further eccentricities up to 70 or 80°. If the sudden drop off of cones outside the fovea created the eccentricity effect one would expect a result where the degradation settles at further eccentricities (see Figure 5.4). This is the opposite of the results that were actually obtained. The

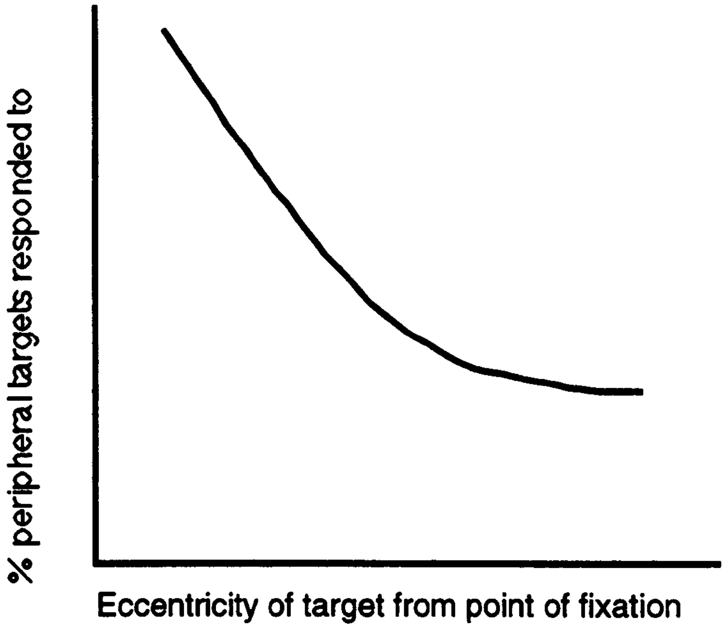

Figure 5.4. A hypothetical function of eccentricity of the target against the percentage hit rates if the effect were solely due to cone density

sudden decline in peripheral ability cannot be due to the density of the rod receptors either. Rods increase in number dramatically outside the fovea up to about 18° from the point of fixation, at which point they decline in density over the remaining peripheral field, though they still remain more prevalent than cone receptors (Boff & Lincoln, 1988).

One other alternative explanation may lie with the contrast sensitivity function which also changes with increasing eccentricity. The sudden decline in hit rates may reflect the necessary spatial frequencies for detecting the peripheral targets. Unfortunately the experimental design precludes any firm conclusions on the existence of a spatial boundary (regardless of the underlying cause) due to the non-linear eccentricity scale. A linear scale is impractical due to the small number of observations per cell that would occur if the category of 7° and above was broken into individual degrees.

The data from the response times mirror the effects of demand and eccentricity found in the hit rate data. Targets in high demand windows elicited slower responses than targets that appeared in low demand windows. The mean difference between responses to targets in high and low demand windows, though a very significant 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 to a low demand five second 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° or more from the point of fixation having markedly slower responses. This presumably reflects the cumulative probabilities of spotting a target located 7° or further from fixation compared to lesser eccentricities. The differences between 7°+ and 5-5.9° and 6-6.9° 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's concerns the measurement of eccentricity. Instead of onset eccentricity he used response eccentricity, which is the distance between the point of fixation and the target at the time of the participant's response. The problems of the measure of response eccentricity have been explained earlier (see section 5.2).

Onset eccentricity was chosen as the eccentricity measure for experiment 7. 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.

5.3.3 A comment on the measure of onset fixation durations

Though the measures of overall fixation durations and spread of search did not show anything further about the underlying experiential effect, the measure of onset fixation durations did reveal something of the detection process. It seems that longer fixation durations increase the chances of spotting peripheral targets, especially at long eccentricities. On the basis of these data one might be tempted to suggest that attention is deployed from the point of gaze outward at the start of each fixation. At the start of a fixation, the foveal stimulus is full of unmined information. As the fixation progresses, this information is extracted and the foveal stimulus becomes less important. It may occur that as the informative level of the foveal stimulus decreases, so the amount of attention to extra-foveal stimuli increases. The limited data however preclude such a strong conclusion, though the interaction with eccentricity supports a spatial representation of attention being deployed further afield as the fixation duration on the current stimulus increases.

5.3.4 Conclusions and suggestions from experiment 7

The three main effects found in the analysis of the hit rates support the main hypothesis that deployment of attention in the peripheral field is modified by experience, and also support the General Interference, or attentional dilution, model over the conceptualisation of a narrowing spotlight. The effect of experience has demonstrated the occurrence of a skill or strategy that develops and improves with experience. This ability is still highly variable and may contribute to accident liability in those inexperienced drivers who have yet to reach the full potential of attentional deployment. These results were mirrored by effects in the response times of participants to the peripheral lights.

Chapter 6: HAZARD PERCEPTION AND PERIPHERAL DETECTION: Learner drivers and the search for Tunnel Vision

6.1 How can Tunnel Vision be evoked, and what would this reveal about driving experience?

6.1.1 The story so far

On the basis of the experiments 4- 6, and on the scant literature that addresses the topic of demand modulated attentional deployment in driving, it was predicted that simple detection rates for peripheral lights would differentiate between participants with varying driving experience, across the factors of demand and eccentricity in a driving context. Experiment 7 was designed to test this hypothesis. It was decided to return to the hazard perception clips used in experiment 3 as the primary task. Though these clips did not reveal any experiential differences in experiment 3, the hypothesis to be tested in experiment 7 was well suited to the stimuli. The stimuli had to have a categorical increase in demand, to be driving related, and allow control over what was basically a visual dual task under safe conditions. The hazard perception clips met all these criteria. It was noted in chapter 3 that the appearance of a hazard tended to increase the observer's fixation durations, a sign regarded as a reflection of an increase in the amount of processing required. The classification of high demand and low demand was achieved through the use of the hazard perception responses of participants in experiment 3. The clips were broken down into five second segments and each segment was categorised as either high or low demand on the basis of the number of hazard responses it attracted in experiment 3. The eccentricity factor had four levels (based on pilot data). The eccentricity of the point of gaze to the onset of a peripheral target was calculated by the computer, and then grouped according to one of the four levels.

The results of experiment 7 revealed main effects for target hit rates across all three factors of experience, demand and eccentricity. Non-drivers spotted significantly less targets than experienced drivers (with novice drivers in the middle). High demand, and far eccentricities both reduced hit rates as well. Response times to the target lights mirrored the hit rate results.

The lack of an interaction between the demand and eccentricity factors failed to support the Tunnel Vision model. The results suggest that an increase in foveal demand does not seem to reduce the diameter of the spotlight, but instead dilutes the spread of attention.

Williams (1988) would suggest however that the primary task used in experiment 7 (rating each clip on danger and difficulty) was not sufficient to produce Tunnel Vision. If this is truly the case, then further experiential differences may have been hidden. This chapter acknowledges the criticism that the ratings task may have not been as realistic as it could have been with the current stimuli, and reports a variation of experiment 7 in a further attempt to elicit experiential differences by trying to evoke Tunnel Vision.

6.1.2 Why is Tunnel Vision so elusive?

The elusive interaction has been found previously by other researchers (Chan & Courtney, 1993; Williams, 1982; Williams, 1995) though such results are often marginal. Many more experiments have failed to find the required interaction between eccentricity and demand (e.g. Holmes et al., 1977; Ikeda & Takeuchi, 1975; Lee & Triggs, 1976).

The series of experiments conducted by Williams during the 1980s led him to suggest that the occurrence of either Tunnel Vision or General Interference is particular to the experimental task. His results suggested that slight modifications to his tasks could induce either of the models (Williams, 1982, 1985, 1988). Two of the three criteria he believed were necessary for tunnel vision were applied in experiment 7. The first was the increased foveal load, which was defined as those segments of the video clips within which participants from experiment 3 had made more hazard responses than average. The second criterion requires an attentional strategy to be focused upon the central task. This was the rationale behind the inclusion of the ratings task. It provided a reason for the participants to view the scene as if they were the driver, looking for potentially hazardous events. This criterion was presumably noted by Williams in order to avoid controlled covert or overt movements of attention. The third criterion that Williams stipulated was that of speed stress on the central task. In the previous experiment the ratings task did not lend itself to a speeded response. If an alternative task was used with a timed response it may have interfered with the *responses* to the peripheral targets (rather than interfering with their *detection*, which is what one expects from a demand induced reduction or dilution of attention). In order to avoid within-modality interference other studies have employed verbal as well as motor responses. Such cross-modal tasks have been noted to produce less interference than that caused by within-modal competition (e.g. McLeod, 1977). As mentioned earlier however, this is not an option when eye tracking using a Dual Purkinje eye tracker, as participants are strapped into a forehead and chin rest which precludes any verbal response.

6.1.3 How may experience influence the degradation of attention under a Tunnel Vision model?

Experiential benefits may differ according to the model of degradation that occurs in the peripheral visual field. If demand dilutes attention equally from all eccentricities, then the lack of interaction between experience and the factors of demand and eccentricity is understandable. Those who are less experienced with driving stimuli, especially hazardous stimuli, may require more attention to be devoted to them. One might expect a high demand foveal stimulus to differentiate between groups more than a low demand stimulus, though this has not proved to be the case so far. Instead even low demand stimuli seem to affect the inexperienced participants' ability to detect peripheral targets.

If the model of Tunnel Vision occurred however, one may expect experience to interact with eccentricity. Instead of the less experienced participants simply having less attention to spread around, the size of the area within which attention is deployed may actually be reduced to compensate. So far this has not occurred, but there is a possibility that the primary task used in experiment 6 did not provoke Tunnel Vision and so did not identify this possible interaction between experience and eccentricity. If a speeded response replaces the primary rating task of experiment 7, which according to Williams should evoke Tunnel Vision, then any potential interactions should become apparent.

6.1.4 The choice of a speeded response for the primary task

There are two questions that need to be answered when choosing a speeded response for a primary task. The easiest to answer concerns what the response should signify. The hazard perception clips were initially designed to test speeded responses to potentially hazardous driving stimuli so this seems the obvious choice for this experiment also. Hazard response times have already failed to differentiate between novice and experienced drivers (experiment 3) and therefore should not add any additional confounds in regard to participants' reactions to the stimuli, across the groups.

The second question concerns the nature of the response. The limitations of the DPI eye tracker have already been noted, ruling out any verbal response. This means that any primary task response will require a motor output, and thus risk within-modality interference with responses to the peripheral targets (McLeod, 1977). As a compromise the software for experiment 8 has been designed to take input from both the PC mouse used in experiment 7, and a foot pedal. The foot pedal provides the participant with a method of recording a response to a hazard, which, although it does not completely solve the within-modality issue, does limit the confusion for participants between motor responses.

6.2 Experiment 8: An attempt to produce Tunnel Vision through the inclusion of a speeded response as the primary task

This study is based upon the design of experiment 7. Two significant changes have been made which are detailed more fully in the method section. The first change was the inclusion of the foot pedal. It was predicted that the speeded response required to the onset of hazards would create Tunnel Vision, and this would hopefully reveal any further experiential differences in the degradation of extra-foveal attention. The use of a speeded response is closer to actual demands that would be placed on a driver under real hazardous conditions. The second change was to recruit a group of learner drivers to compare directly to a group of more experienced drivers. As the previous experiential difference in experiment 7 fell somewhere between the non-drivers and the experienced drivers, it was considered that a group of learner drivers would be useful to close the gap in which the difference lies. There was also a more practical reason that there is a finite number of both non-drivers and novice drivers available to test (though experienced drivers are plentiful). Learner drivers however, provided an untapped source of potential participants.

6.2.1 Methodology for experiment 8

6.2.1.1 Participants

Forty participants were initially 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 spent 30 hours behind the wheel on average) 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.

6.2.1.2 Materials and apparatus

Participants were presented with the same 39 MPEG hazard perception clips that were used in experiment 7 (see section 2.3.3.2 for a general description of the hazard perception clips, and Appendix 1 for a listing of hazard onset times and descriptions for each clip). The majority of the apparatus was the same as that used in experiment 7 with one exception. Instead of the primary task requiring participants to grade each clip along the dimensions of danger and difficulty, they were required to press a foot pedal to record any hazardous or potentially hazardous events that they spotted. The foot pedal produced an auditory tone when pressed.

For the secondary task the four computer generated, red place holders were used again. The exact dimensions of the display, and the frequency of the peripheral target lights, are fully detailed in section 5.2.1.2.

6.2.1.3 Design

The three factors involved in this mixed design were level of experience (experienced drivers and learner drivers), level of processing demand ('high' verses 'low') and the onset eccentricity of each target (less than 5°, 5° to 5.9°, 6° to 6.9°, and 7° and above). The definition of the different factor levels, the measures recorded, and the presentation of trials and blocks is described in section 5.2.1.3. The one exception is that the two ratings for each clip were not collected. Instead a response time measured from the time of each hazard onset was recorded via the foot pedal, from which a hazard perception score was derived (see Appendix 1 for details of how to calculate a hazard perception score).

6.2.1.4 Procedure

At the start of the experiment participants were informed of the two tasks they were to perform. The instructions from the primary task instructed 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. As soon as they spotted something potentially or actually hazardous participants had to press a foot pedal as quickly as possible. Participants were asked to place their feet either side of the pedal on the floor. This served two purposes. First, as participants are unable to see the pedal once they are strapped into the eye tracker head restraint, this ensured that they knew where the pedal was at all times. Secondly, this removed any spuriously fast hazard responses by explicitly telling participants not to leave their foot hovering over the pedal ready to press it. As all hazard responses were initiated with the foot positioned on the floor next to the pedal, the response times across participants are less variable.

Instructions for performance on the secondary task were exactly the same as in section 5.2.1.4.

6.3 Results of experiment 8

The results will be presented in six sections. The first section addresses the main hypothesis of whether peripheral target detection rates are decreased according to the three factors of experience, demand and eccentricity. The second section investigates the time line of degradation centred around the hazard responses made by the participants via the foot pedal. The third section seeks to corroborate the first, through the analysis of reaction times to those targets that were correctly identified, while the fourth reports some measures of the general search strategy. A fifth section reports the results of the primary, hazard perception task. The sixth and final section compares the experienced driver data from both experiment 7 and the current study.

The data from four participants were removed from the following analyses. Two of these data sets (one experienced driver and one novice) were removed owing to too few observations per cell (owing to problems with calibration, some cells had less than five successfully presented targets). The other two sets of means were removed (again one experienced driver and one novice) as outliers with the overall hit rate means equaling or exceeding two standard deviations from the group means.

6.3.1 Peripheral target hit rates

The mean number of false alarms was very low, averaging 5 false reports for every 185 successfully presented targets (2.7%). 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 which are directly relevant to the hypothesis of a reduction in the area covered by spatial attention are the level of demand ($F_{(1,34)}$=87.5, $p<0.01$) and onset eccentricity ($F_{(3,102)}$=30.5, $p<0.01$). Mean comparisons showed that similarly to the results from experiment 7 the significant 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, thus the model of Tunnel Vision cannot be accepted. The means for the two effects can be viewed in Figure 6.1.

As with experiment 7 the location of the sudden decline in peripheral detection rates was investigated further. The mean eccentricity (above 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 spotted 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

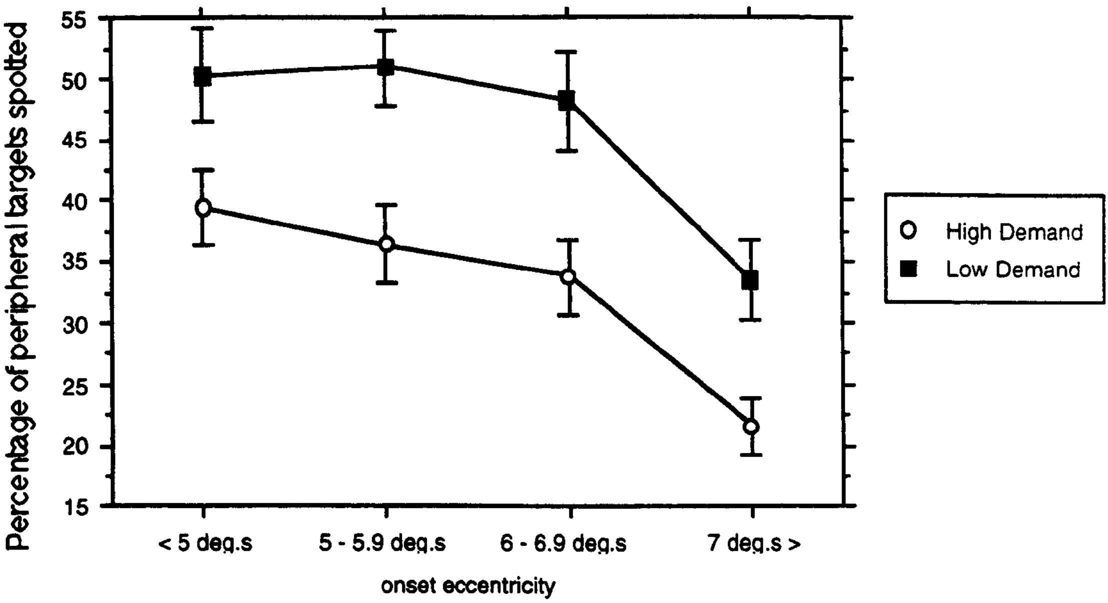

Figure 6.1 The mean hit rates for detecting peripheral targets (displayed as a percentage of those targets which were successfully presented to the participants) across the factors of demand and onset eccentricity, with standard error bars added.

8.6° if they were spotted, and 9.1° if they were missed. These figures are consistent with the equivalent means from experiment 7 (8.3° and 9.1° respectively).

A surprising result was attributed to the experience factor. It seemed that experienced drivers' average eccentricity for a target presentation over 7° was significantly 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 section 6.3.4).

The third main effect was found across the participants' varying levels of experience ($F_{(1,34)}$=5.3, p<0.05) with the learner drivers responding to significantly fewer peripheral targets than the more experienced drivers.

As with the results of experiment 7, a significant interaction was not found. It was initially suggested that the less experienced participants (in this case the learner drivers) would be significantly out-performed by more experienced drivers in the high demand portions of the test. However it seems that the learner drivers were more affected than experienced drivers by the demands of the clips even during the low demand segments where no hazards were present. The predicted interaction with eccentricity did not occur, perhaps unsurprisingly considering the failure to find Tunnel Vision. The mean hit rates across all three factors can be viewed in Table 6.1.

	Hit Rates (%)							
	High Demand				Low Demand			
	<5°	5°	6°	7°+	<5°	5°	6°	7°+
Experienced Drivers	47	42	40	26	57	54	54	38
	{15}	{19}	{21}	{14}	{22}	{15}	{24}	{19}
	[24]	[23]	[23]	[35]	[21]	[18]	[19]	[32]
Learner Drivers	32	29	27	16	44	47	41	27
	{15}	{19}	{16}	{13}	{23}	{22}	{24}	{19}
	[21]	[19]	[21]	[34]	[20]	[14]	[16]	[33]

Table 6.1. Percentage hit rates for learner and experienced drivers across demand and eccentricity {with standard deviations} and [the average no. of targets per participant].

As the same clips were used in this experiment as in experiment 7 the chance of any random response being counted as an actual response to a peripheral target was again 30%. 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.

A subsequent analysis was performed on all responses to presented targets. Because this analysis included those (unsuccessfully presented) targets that had not been assigned an onset eccentricity by the computer, the eccentricity factor had to be omitted. A main effect of demand ($F_{(1,34)}=8.0$, $p<0.01$) and experience ($F_{(1,34)}=118.9$, $p<0.01$) were found. This supports the more refined analysis that only included those peripheral targets that could be classified according to onset eccentricity.

6.3.2 The timeline of attentional degradation around the hazard response

One advantage of this experimental design over that of its predecessor is that the inclusion of hazard 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 this data has produced a precise indicator of whenever each participant felt the demands of the clip raised above the threshold for reporting a hazard in the hazard responses. 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 spotted (as a ratio of all targets presented) was calculated for 500 ms bins around the hazard response. If this had been done individually for participants, many bins would have been empty or the bin size would have had to be so large as to obscure any trends anyway. For this reason data from all learner drivers, and separately for all experienced drivers, 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 6.2.

From the distribution in Figure 6.2 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 pronounced around the −1500 to −500 ms section of the distribution. This 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 6.3).

This second distribution shows that the hit rate for both groups sinks to a similar level at only one point, approximately

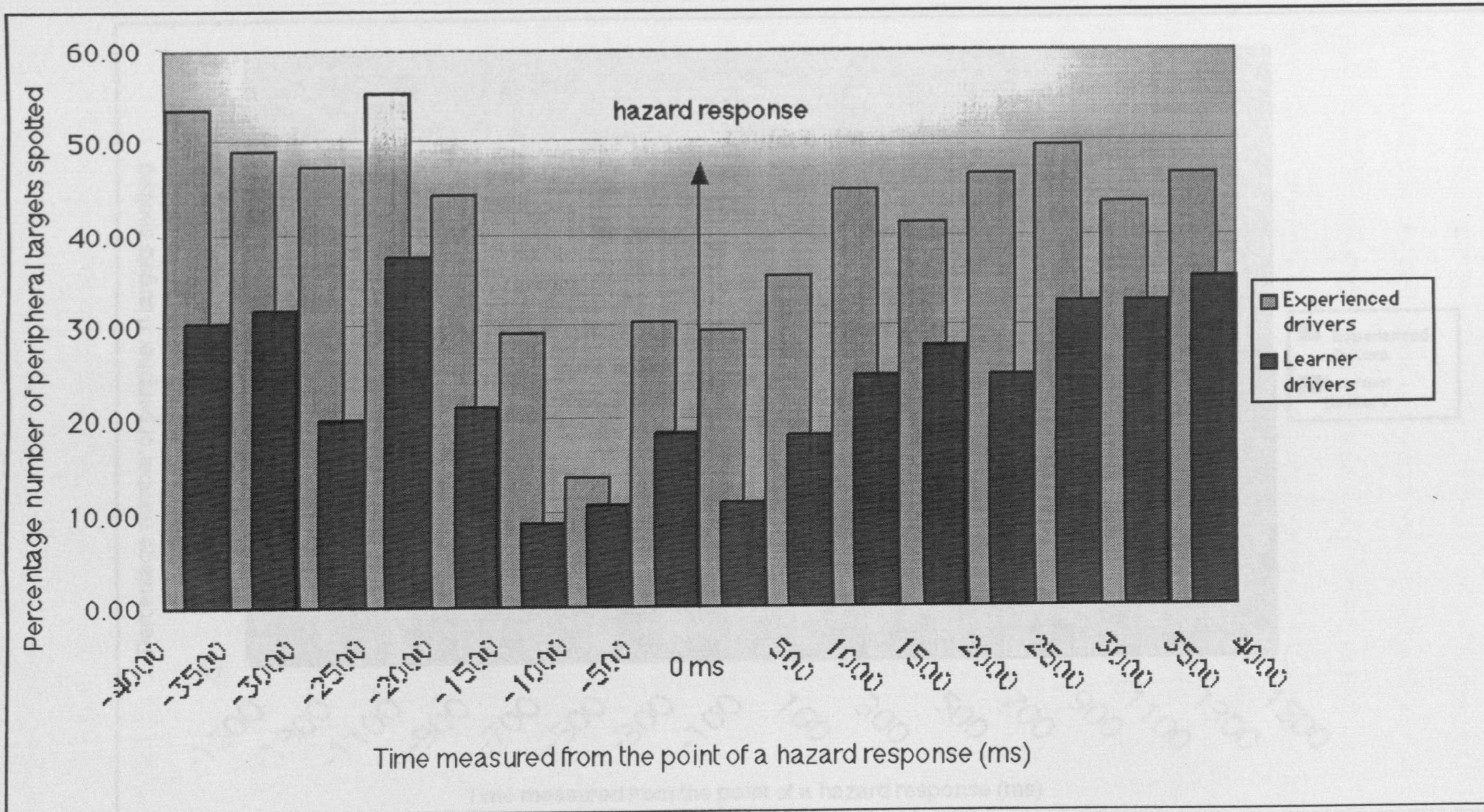

Figure 6.2. A frequency distribution of the percentage of targets that were spotted, split across 500 ms bins around the hazard response, for both novice and experienced participants.

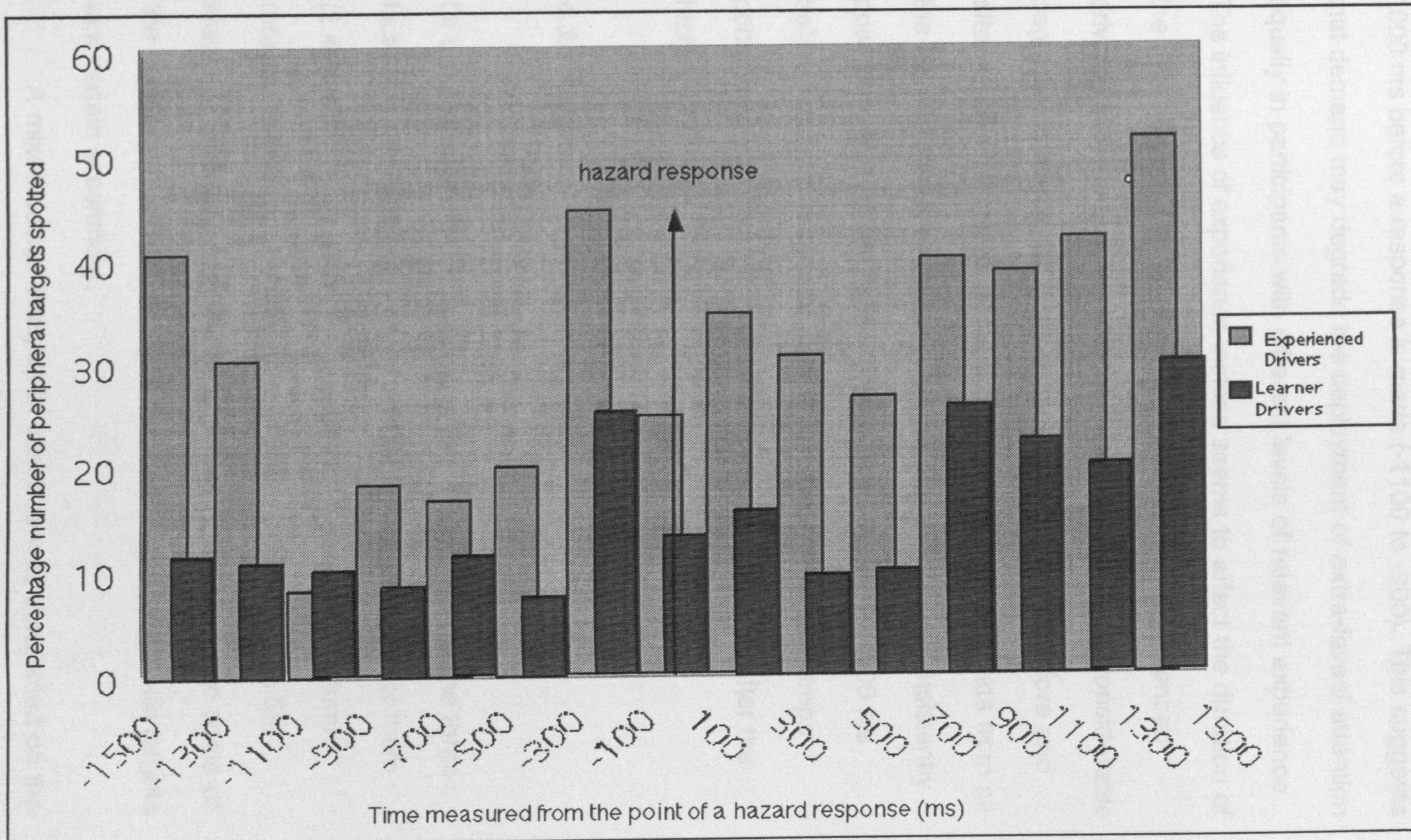

Figure 6.3. A frequency distribution of the percenmtage of targets that were spotted , split across 200 ms bins around the hazard response, for both novice and experienced participants.

1000 ms before a response is made (-1100 to -900). This suggests that demand may degrade the deployment of extra-foveal attention equally in participants with different levels of relevant experience. The influence of experience instead seems to affect the duration of the degradation. The amalgamated data across experienced drivers seems to suggest that they suffer (as a group) considerable degradation over an 800 ms period (-1100 to –300) before and after which a hit rate of about 40% is maintained. The data from all the learner drivers suggests however that they 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.

6.3.3 Peripheral target reaction times

Of the 288 cells that contributed to this design (across the three factors of demand, eccentricity and experience), seven of them (2.4%) were replaced by the average of the row and column means. The increase in the level of mean substitution in the response time data over the hit rate data occurred due to some of the novice participants failing to respond to any peripheral targets at a certain eccentricity.

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 ($F_{(1,34)}=4.0$, $p=0.053$). 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 6.2.

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

Table 6.2. Response times to peripheral targets.

6.3.4 Measures of the general search strategy of participants

The overall mean fixation duration was calculated from the mean fixation duration for each clip for each participant. Experienced drivers averaged 472 ms while learner drivers averaged 495 ms. The difference was insignificant (t_{34}=0.43). Mean fixation location was also calculated for each participant group across each meridian. As in the previous experiment, 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.

On basis of the analyses for the previous experiment, no difference was expected between the groups in regard to the spread of spread across either meridian. However, in keeping with past research (e.g. Mourant & Rockwell, 1972), yet contrary to the results of experiment 7, 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). The experienced drivers did seem to have a larger spread of search in the horizontal meridian in this experiment though not in the previous one. 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 place holders that the point of gaze is not nearest to. The variance of the fixation locations in the vertical meridian was also analysed though no differences were found (t_{34}=0.19).

The measure of Onset Fixation Durations (OFDs) proved to be of interest in experiment 7, and so they were recorded and analysed for the present experiment also. As with the analysis of the reaction times, 2.4% of cells had to be replaced by the average of the row and column means. When analysed across the three factors of demand, experience, and eccentricity, plus the additional factor of whether the target presented during the OFD was spotted or missed, only one main effect was found. This effect reflected an increase of 251 ms in OFDs when a peripheral target was spotted ($F_{(1,34)}$=25.3, p<0.01). In experiment 7 the increase in OFDs was to found to occur before the peripheral target response, therefore suggesting that long fixation durations are necessary in order to spot peripheral targets, at least at long eccentricities. A similar analysis was performed upon these data, across the factors of experience, demand and eccentricity, and the further factor of splitting of OFDs into two parts, before and after the peripheral target presentation. Despite a slight trend in the direction predicted on the basis of experiment 7, the interaction between eccentricity and the division of the OFDs into that which occurred before and after the target presentation, was not significant ($F_{(3,102)}=0.56$).

6.3.5 Results of the hazard perception test

The hazard perception test was used in this experiment as the primary task. Participants merely had to make a response when they thought a potentially hazardous event was occurring or about to occur. This is the same primary task used in experiment 3, though a foot pedal was used in this experiment to differentiate from the mouse button responses required for the peripheral target lights.

Hazard perception scores were calculated according to the method detailed in Appendix 1, though a significant difference was not found between the two groups ($t_{34}=0.27$). Simple response times to the hazards were also calculated and again failed to differentiate between the groups ($t_{34}=1.11$). Though experiment 3 noted that experienced drivers made more hazard responses than novice drivers, this difference was not found between the experienced drivers and the learner drivers in this experiment ($t_{34}=0.13$).

6.3.6 A comparison of experienced driver hit rates across experiments 7 & 8

The only difference between the two experienced driver data sets from experiment 7 and experiment 8 is the primary task that the participants were asked to focus upon while responding to the peripheral target lights. This similarity allows a comparison across these two participant groups to gauge the influence of the primary task upon secondary task performance. Comparison of hit rates across the two experienced groups produced the expected main effects of demand ($F_{(1,36)}=96.9$, $p<0.01$) and eccentricity ($F_{(3,108)}=40.4$, $p<0.01$) and a significant difference between the two groups of experienced drivers ($F_{(1,36)}=20.1$, $p<0.01$). From the graph of these means (see Figure 6.4) it can be seen that the inclusion of the requirement to respond as quickly as possible to the presence of a hazard, has increased the degradation of peripheral performance by such a magnitude that the hits rates in the low demand windows of experiment 8 are more akin to those of the high demand windows in experiment 7.

A comparison was also made of the response times to the peripheral targets of experienced drivers from both experiments. There was a main effect of the primary task between the two studies ($F_{(1,36)}=11.01$, $p<0.01$) and demand ($F_{(1,36)}=26.2$, $p<0.01$). These effects followed the same pattern perceived in the hit rates. The effect of eccentricity failed to reach significance however ($F_{(3,108)}=1.45$).

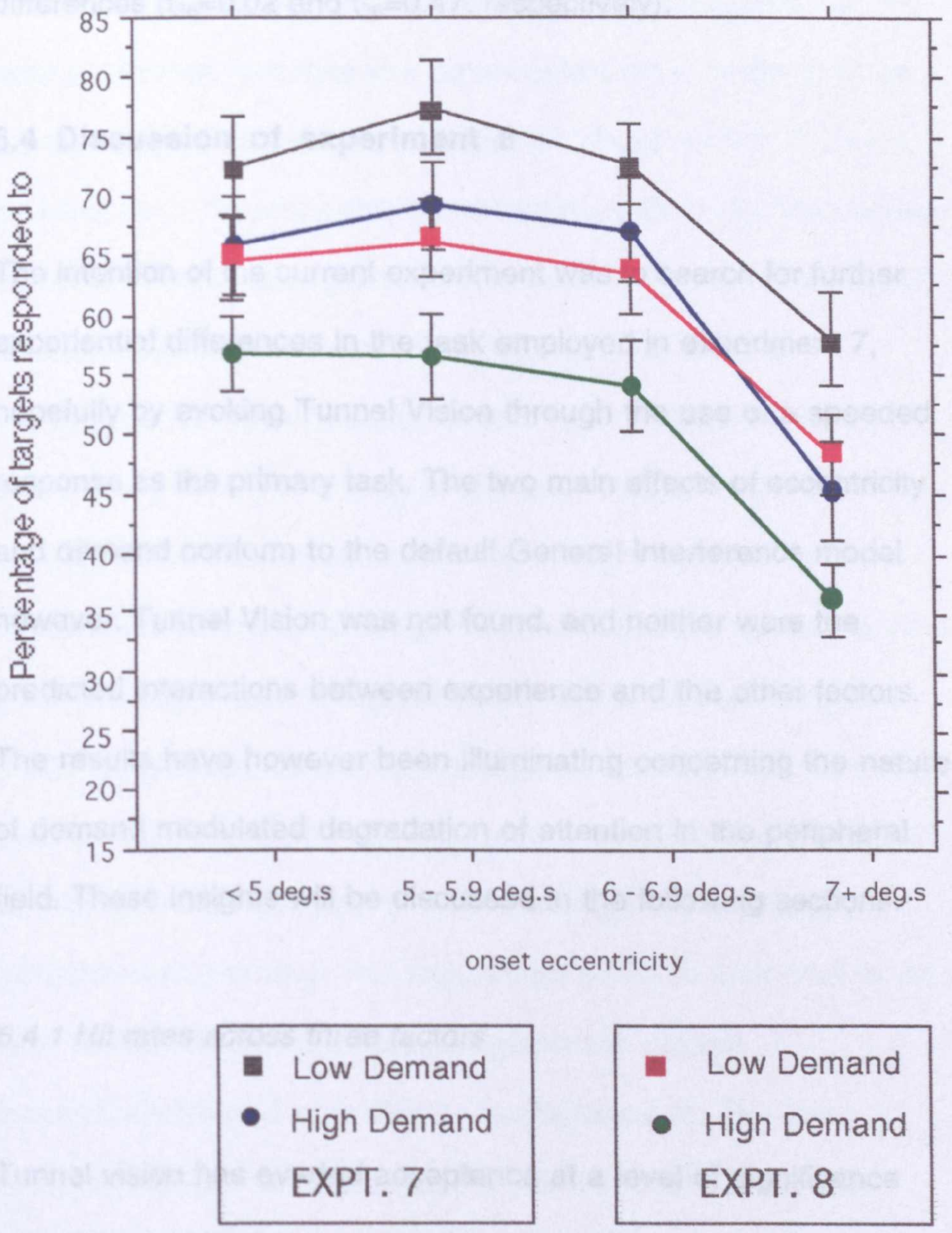

Figure 6.4. A comparison of the percentage hit rates of 20 experienced drivers from experiment 7 and 18 experienced drivers from experiment 8, across the factors of demand and eccentricity, with standard error bars added.

Due to the unexpected difference found between experienced and learner drivers in regard to the spread of search in the horizontal meridian, these data were also compared across the two experiments for experienced drivers, but no effect was found

(t_{36}=0.19). Comparisons of overall mean fixation durations and spread of search in the vertical meridian also did not reveal any differences (t_{36}=0.02 and t_{36}=0.47, respectively).

6.4 Discussion of experiment 8

The intention of the current experiment was to search for further experiential differences in the task employed in experiment 7, hopefully by evoking Tunnel Vision through the use of a speeded response as the primary task. The two main effects of eccentricity and demand conform to the default General Interference model however. Tunnel Vision was not found, and neither were the predicted interactions between experience and the other factors. 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 sections.

6.4.1 Hit rates across three factors

Tunnel vision has evaded acceptance at a level of significance once more, without even a trend to suggest it was ever there. Experiment 8 included the speeded response primarily to meet Williams' three criteria and to thus produce the sought after interaction between eccentricity and demand. The intention was then to examine any experiential differences under this new model.

One could argue that the tweaking of a paradigm to produce a certain effect will have little generalisability to the real world situations these experiments attempt to emulate. However, in this case a speeded response to a potential hazard is certainly more appropriate than the abstract ratings task of experiment 7. If real life hazardous situations produce a degradation of attention as the model of Tunnel Vision predicts, then there is little to be gained by discussing the effects according to the model of General Interference. However, despite a more appropriate primary task, and meeting the three criteria of Williams, Tunnel Vision still did not occur. The conceptualisation of a spotlight contracting to increase the resolving power at the point of gaze is not appropriate to the paradigm used in experiments 7 and 8. Lee and Triggs (1976) questioned the term 'perceptual narrowing', often used to describe demand modulated degradation of extra-foveal attention, as they too 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 conceptualisation of such attentional degradation. The few marginal results that have reported Tunnel Vision (Chan & Courtney, 1995, Williams, 1988) look increasing suspect in light of the evidence mounting against them.

Despite the lack of the predicted interaction between eccentricity and demand, and the subsequent interactions with experience, the three main effects are informative. The main effect of demand again endorses the categorisation of the clip segments on the basis of previous hazard responses from experiment 3. The main effect of eccentricity also supports the large performance drop above 7°. A comparison of the targets that were presented beyond 7° eccentricity again revealed that, on average, targets that were spotted were nearer than those that were missed. The mean eccentricities of spotted and missed targets are similar to those found in experiment 8, and are only half a degree apart. This again raises the possibility of a spatial border of attention, though as this experiment was not designed to specifically follow up this particular finding from experiment 7, any such interpretations should be followed by the same caveats. One difference with the results of experiment 7 was the finding that the hit rates at eccentricities less than five degrees, were significantly higher than those at 6-6.9°. The inclusion of the speeded response seems to have accentuated the decline in hit rates across the nearer levels of eccentricity.

The effect of experience has shown that the group of learner drivers had not achieved the same efficiency in the deployment of extra-foveal of attention as the more experienced drivers. It seems that the ability to detect peripheral targets, despite an increase in foveal demand, is not a skill that is picked up after a few hours behind the wheel. It is unfortunate that novice drivers were not included (on the practical grounds that the supply of suitable naïve participants was exhausted). It would have been interesting to see if the increased demand of a speeded response for the primary task increased the gap between the novice and experienced drivers to a level of significance.

One surprising 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 which 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 place holders 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.

6.4.2 What did the inclusion of a speeded response actually achieve?

The speeded response did not produce tunnel vision. It did however seem to make the peripheral target detection task a lot harder. Figure 6.4 suggests that the decrement in peripheral performance created by the inclusion of the foot pedal resulted in the low demand segments of experiment 8 producing similar hit rates to the high demand clip segments in experiment 7. The requirement to press the foot pedal to acknowledge hazards decreased the amount of extra-foveal attention at all eccentricities, even in the low demand windows where no hazard was present. It is possible that the participants are saving attention in readiness for the appearance of the hazard, though it may be more likely that they are merely interrogating the scene to a greater extent than in experiment 7. The ratings task of the previous experiment required an overview of the whole clip. The requirement to make a hazard response in the current experiment however requires moment to moment monitoring of the environment, and greater inspection of stimuli even within low demand segments of the clips, in case something seemingly innocuous suddenly becomes a threat.

The surprising difference between learners and experienced drivers in the spread of search in the horizontal meridian suggested that the inclusion of the hazard response task had increased the search of experienced drivers. However, a comparison between the data from the two experiments revealed this not to be the case. Instead it seems that the learner drivers have less spread of search in the horizontal meridian.

A further benefit of the foot pedal response to the appearance of a hazard is that it allows greater accuracy in pin-pointing the sudden increase in foveal demand. The results so far are based upon demand according to five second segments of clips, within which participants have previously tended to make a hazard response. The actual hazard onset may however occur at any time within the five 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 low demand conditions. A second problem lies with individual differences in the recognition of what is and what is not a hazard. The success of the demand factor in experiments 7 and 8 argues that this was not a serious problem when averaged across the participants however. Despite the success of the five second segmentation of the clips, 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 line of attentional degradation for both experienced and learner drivers. The pooling of data from all the participants precluded the use of statistics though the graphs themselves are suggestive of differential effects of foveal demand upon experienced and learner drivers. Figure 6.3 suggests that the increase in foveal demand reduced the deployment of attention in both experienced and learner drivers to a similar level on aggregate. At about 1100 to 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 fits with the drop in peripheral detection rates.

Despite this seemingly dramatic decrease in performance for the group of experienced drivers (a larger decrease than that which afflicts the pooled data of the learners), they seem to recover almost immediately, with an average doubling of the peripheral task performance in the period 900 ms to 700 ms before the hazard response is made. The learner drivers' data however suggests that they may suffer for a much longer period. Apart from a sudden peak in learner driver performance around 300 to 100 ms before the hazard response, their ability to detect peripheral targets seems to suffer from 1500 ms before the hazard response, to 700 ms after it. From this graph it seems that the experienced drivers suffer a greater magnitude of degradation on the peripheral task than the learner drivers, though the effect is relatively short lived. Learners may however suffer 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. Though no firm conclusions can be drawn from these data without the aid of inferential statistics, the distributions have provided further research questions into the underlying nature of experiential differences (i.e. why are experienced drivers better at the task?).

One definitely 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 6.3, the learner drivers' peripheral performance sinks to a consistently low level 1500 ms before the hazard response, whereas the experienced drivers suffer the 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 be reflected in a significant difference between the experienced and learner drivers on the hazard perception score, and on hazard perception response times. Neither of these results was discovered however. If the 'short sharp shock' investment of attention does reflect a strategy of the experienced drivers, is it 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 hyper-vigilance (see section 5.1.3), where an individual may become more aware of items in the peripheral field under anxiety provoking conditions?

These are 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 experiential effects in the degradation of extra-foveal attention in an applied setting such as driving.

6.4.3 Assessing the possibility of dual task interference

A further benefit of the frequency distribution graphs discussed in the previous section, is that they allow something to be said about the possible confound of dual task interference between the primary hazard response and the secondary peripheral target response. Though the former was registered through a foot pedal and the latter through the PC mouse, these are both motor responses, and it is possible that the requirement to press the foot pedal interfered with responses to the peripheral targets. Several studies have demonstrated the interference effects that occur using within-modal tasks such as these (e.g. McLeod, 1977).

In the comparison of cross- and within-modal tasks McLeod found a decrement to occur in the performance of one task that required a motor response, dependant on the temporal distance from the requirement to perform a different motor response to an abrupt onset. This decrement in his frequency distribution chart occurred between 300 and 200 ms before the interfering motor task (see Figure 6.5).

Referring to the frequency distribution graph that charts the hit rates for peripheral targets around a hazard response, one can see no such decrement around the time period that McLeod reported to reflect interference. In fact the –300 to –100 category marks a sudden though brief return to form for both groups before dropping again in the 200 ms bin around the hazard response. This second dip in performance may reflect the interference of one motor task upon the other, though it is unlikely that within-modal interference affects the detection of targets up to one and a half seconds before the foot pedal is pressed. This early decline in peripheral target detection seems to have more to do with the processing demands of the situation rather than the impulse to perform two motor tasks at the same time.

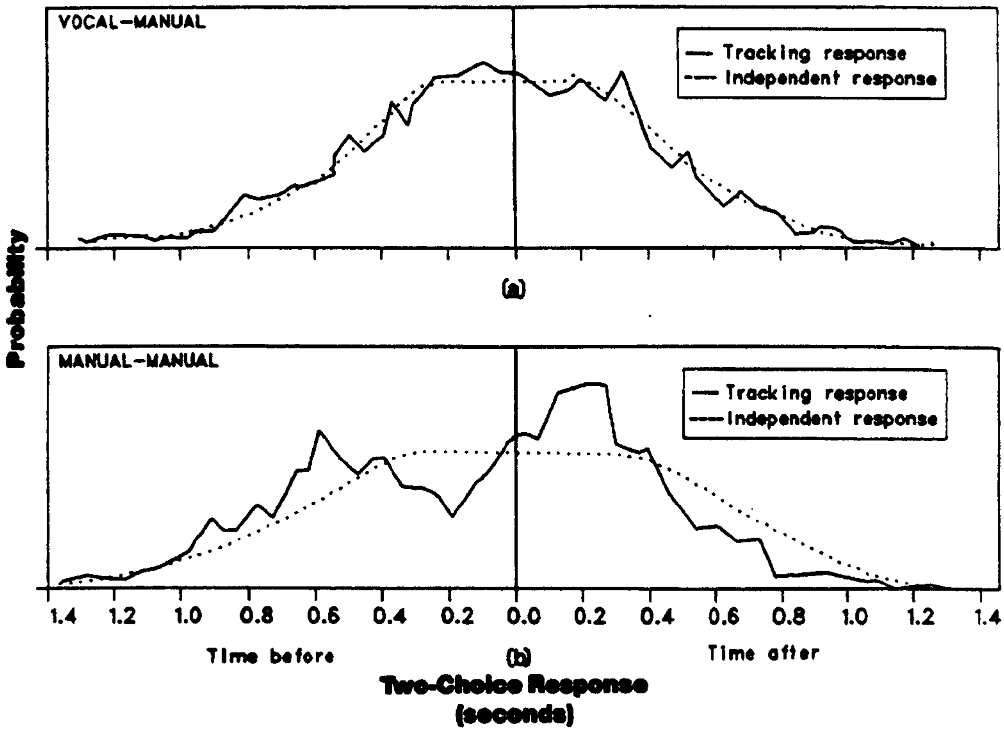

Figure 6.5. Performance on a continuous task over time compared to a single secondary motor task (McLeod, 1977).

6.4.4 The disappearance of effects

Though many of the findings of experiment 7 have been replicated and elaborated upon in the current experiment, two effects from the previous experiment have disappeared. The first of these is the effect of eccentricity upon response times. This gave a marginal significance in experiment 7. The lack of an eccentricity effect perhaps makes the most sense of the two, for if one were to see a target onset then response times should be similar regardless of eccentricity. The only time that an effect of eccentricity should influence response times is when the peripheral target remains on long enough for eye movements to confound the results. This was the argument made against Miura's (1990) use of response times as the main measure of attentional degradation. In contrast, the consistency of the effects upon hit rates support their choice as the main dependent variable.

The second effect to disappear was the explanation for the tendency of Onset Fixation Durations to be longer when targets were spotted rather than missed. Post hoc analyses performed on the data from experiment 7 revealed that this was due to the portion of the OFDs that occurred before target onset. This lead to the suggestion that long fixations were necessary to spot targets at long eccentricities (from the interaction of OFDs split into before and after the target onset, with eccentricity). In experiment 8 however, though OFDs were again longer for those targets that were spotted rather than missed, splitting the fixations into that which occurred before and after target onset revealed no further differences. If, as postulated in chapter 5, attention is deployed from the point of gaze outward as more resources become available during the on-going fixation, then the interaction noted in experiment 7 may have had some relation to the effect of eccentricity upon response times. For instance, as the stimulus at the point of gaze is mined of information, spare attention may increase the spotlight size around the fixation point. If each separate fixation produces this effect then not only would this produce the interaction between OFDs before and after target onset with the eccentricity factor, one may also expect this to delay response times to the targets at distant eccentricities. The expanding boundary of attention may only reach the farther eccentricities sometime during the 200 ms presentation of the peripheral targets, whereas a nearer target may already fall within the spotlight.

The fact that these two effects are now *both* absent cannot be used as proof of a relationship between the two, though this circumstantial evidence would have been more thoroughly discredited if one or the other effect had remained. Why either effect should disappear however is unclear. The difference between OFDs for spotted targets and those that were missed was only 251 ms for this experiment, whereas it was 405 ms for experiment 7. It is possible that the slight trend in the direction predicted from experiment 7 may have failed to reach significance due to a small effect size.

As a final remark upon the meaningfulness of the OFD differences noted previously, it should be pointed out that if expansion of the spotlight, (due to the freeing of resources from the on-going processing of the current fixation) does occur, it is not affected by demand. If this were the case an interaction between demand and eccentricity should have been noted in the hit rates. A Tunnel Vision model in this instance could be thought of as a reduction in the speed of the spotlight expansion. The failure to find tunnel vision in either experiment 7 or 8 requires a different theory. It may be possible that, under conditions of high foveal demand, the spotlight will still expand outward from the point of gaze at the same speed, though the overall attention given to this expansion is less, resulting in the same spatial coverage at the same speed, but with diluted resources.

6.4.5 Conclusions from experiment 8

Though Tunnel Vision was not produced through the inclusion of a speeded response for the primary task, important experiential effects were still discovered. The finding of a difference between learner drivers and experienced drivers shows that merely one or two hours behind the wheel is not enough experience to allow development of the optimum strategy for deploying attention in the peripheral field.

The degradation of peripheral task performance was increased by the inclusion of the foot pedal, accentuating the gradual decline effect over the nearer levels of eccentricity, though the abrupt fall off in performance was still present beyond seven degrees. In addition to these findings there is some suggestion from the frequency distributions that though experienced drivers may suffer degradation of a greater magnitude than the learners, this drop in performance is short lived. Learners however seem to suffer over a longer period. It has been suggested that this may reflect a different strategy in the deployment of attention that is developed through experience with the context.

Chapter 7. SUMMARY AND DISCUSSION: the implications for applied and theoretical research

The aim of this thesis was to identify differences between groups of participants based upon the amount of driving experience that they have. This was considered to be an important underlying factor in the excessive accident liability that is constantly reported for the 16-20 age group every year.[1] Despite the fact that experience is confounded with many other factors such as age and social norms, studies that have partialled out these other influences have revealed the role of experience in accident liability to be considerable enough on its own to warrant research (e.g. Maycock et al., 1991). Maycock's study showed that accident liability drops by 30% in the first year after passing the driving test due to experience alone, whereas age can only account for a drop of 6% in the same year.

[1] The 16-20 age band may seems a strange grouping to choose for the UK as provisional licenses are only given to people aged 17 and over. This occurs because the accident statistics are also presented for pedestrians and cyclists who can be 16 and under (see Figure 1.1).

On the basis of other studies which have shown the link between errors of visual information acquisition and accident liability (e.g. Nagayama, 1978), it was decided to look for experiential differences in the role that vision plays in driving. It was hoped that this would increase understanding of one of the elements in the model of driver accident liability outlined by Gregersen and Bjurulf (1996). A further aim of this thesis was to explain the identified differences within a theoretical framework, rather than simply providing a description of the results.

The experimental findings shall first be summarised in the following sub-sections, before the general discussion of the results in the context of their implications for both driving and attention research.

7.1 A summary of the results from the individual experiments

7.1.1 Experiment 1: testing the influence of concurrent verabalisation upon measures of eye movements

The aim of chapter 2 was to identify and hopefully resolve certain methodological issues in driving research. Before experiment 1 was reported the issue of whether driving research should be conducted in the real world or the laboratory was raised. The conclusion of the brief review of literature was that the ultimate choice between the two methodologies should be based primarily upon ethical and practical considerations. Theoretical considerations should be also be heeded in order to make sure that the choice of methodology does not influence the variables one is attempting to measure. If the decision comes down in favour of a laboratory based experiment, then there are still options open to the investigator that can render the results as close to the 'real thing' as possible. The two main options that seem to affect laboratory results are the resolution of the image (Hughes and Cole, 1986a; Staplin, 1995), and the dynamics of both the stimuli and the perceiver's viewpoint (Cohen, 1981; Koornstra, 1993). It is possible that the issue of image quality is more important than the need for interactivity. This may account for some of the different results that have been reported in the literature in regard to the requirements of motor responses (such as navigation) influencing visual search strategies (Lee & Triggs, 1976; Land & Lee, 1994).

Experiment 1 was concerned with a related issue: that of the method of collecting data on the visual search strategies of drivers. Two alternatives presented themselves, both of which have a considerable history in the driving literature, and beyond. Though the direct measurement of eye movements accounts for the larger portion of visual research in driving over the last fifteen to twenty years, the use of concurrent verbalisation was reported to offer solutions to some of the ethical, practical and theoretical problems inherent with eye tracking systems (Renge, 1980; Underwood & Everatt, 1992). Despite the promise of this cheaper, and more user-friendly method of data collection, there was the possibility that, as the act of verbalisation is essentially a secondary task, the verbal report may interfere with the actual search strategies (verbal overshadowing - Schooler & Engstler-Schooler, 1990). Furthermore such verbalisations may not even accurately represent what is being attended to (Renge, 1980). Experiment 1 was designed to test the hypothesis that the requirement to report attended stimuli may actually influence the search strategy by combining both methodologies into one study.

The results suggested that concurrent verbalisation did not affect search strategies during the hazard perception clips. Measures of visual search averaged across a residential clip revealed no differences in the overall fixation durations or the spread of search in the horizontal or vertical meridians across the three groups (the natural report condition, the restricted report condition, and a control group who did not have to verbalise). In order to assess what the participants were looking at during the clip, the scene was broken down into five categories, and total gaze durations in each category were apportioned accordingly. Only one significant difference was found; the restricted report participants tended to fixate the road ahead more often. This isolated effect was considered unlikely to be directly linked to the requirements of concurrent verbalisation as neither the restricted or the natural report groups reported the 'road ahead' An analysis of the higher-order skill of hazard perception was conducted on the reaction times to hazard onsets across the participant groups. No significant differences were found.

The one significant difference that was discovered between the participant groups (the increase in total gaze duration upon the 'road ahead' in the restricted report condition) actually goes in the opposite direction to theories of interference such as verbal overshadowing (Schooler & Engstler-Schooler, 1990). Overshadowing predicts a decrease in those stimuli that are harder to attach a verbal response to, such as the 'road ahead'.

Though the results suggest that verbalisation has little effect upon how the participants searched the scene or what they looked at, further analyses questioned whether the verbal reports actually reflected what the participants paid attention to. Correlations between verbalisations and total gaze durations in the five categories failed to reach significance. Furthermore there were more significant differences found between the percentage of verbalisations in the categories between the restricted and natural report conditions than there were amongst all three groups in regard to the total gaze durations within those categories. This not only suggests that verbal reports do not reflect search strategies, but that different instructions will produce different data sets.

It was argued in chapter 2 that the problem of fixation-without-perception (and visa versa) may be overcome by relying upon verbal reports, but the natural system of parsing eye movements into verbalisations is unknown (and seemingly changes with slight alterations in the reporting criteria), and provides an extra inscrutable layer through which one has to infer effects. It was decided that the eye tracking systems provided the most flexible approach allowing the use of acknowledged parsers from the literature (spatial and temporal fixation filters) to be applied to the data.

One of the interesting results that emerged from the eye tracking data was the reduction of fixation durations during the hazard window, when compared to a similar length window before the hazard onset. It appeared possible however that this was merely an artifact of the particular hazard as the pre-hazard fixation durations were considerably longer than the overall averages. Instead of a reduction of the fixation durations within the hazard window, it seemed that the significant difference was caused by a dramatic increase of fixation durations in the pre-hazard window, due to the specific nature of the precedent conditions. This suspicion was confirmed in experiment 3 when contradictory, though more believable, results were found from averaging across many different hazard types.

The conclusion of this chapter was that methodology should be guided by the research question. Whether choosing between the laboratory or the real word for an experimental setting, or between eye tracking and verbalisation as a method of measurement, depends on which method best suits the hypotheses. For this thesis it was decided that the laboratory and the real world could both be useful and complimentary settings (though once the choice of the laboratory has been decided upon, there are many other design decisions that must be taken). The decision between eye tracking and the used of concurrent verbalisation was more straight forward, with the former proving to be better suited to the research issues raised in chapter 1 (see chapter 2 for a full discussion of this issue).

7.1.2 Experiments 2 & 3: exploratory investigations of potential experiential differences in both the real world and a laboratory setting.

Of the previous studies that have attempted to identify differences between drivers of varying experience, they have usually had very few participants for such varying skill levels (e.g. Mourant & Rockwell, 1972; Mourant and Donahue, 1977; Cohen, 1981), and the findings often appear to be contradictory (e.g. Summala, et al., 1996; Miltenburg & Kuiken, 1991). Any use of demand manipulations are usually incomparable to previous studies, and tend to confound (though often out of necessity) visual complexity and cognitive demand (Williams, 1988). Despite these reservations, an argument was put forward in chapter 3 that manipulation of the visual demands placed upon the driver may help to locate experiential differences in the visual acquisition of information.

Building upon the findings of the previous chapter, participants were eye tracked both driving in the real world and performing a hazard perception test in the laboratory. In experiment 2 sixteen experienced drivers and sixteen novices drove a set route through three different road types; rural, suburban, and a dual carriageway. In experiment 3 thirty two novices and twenty two experienced drivers had to watch hazard perception clips (drawn from the same pool of stimuli from which experiment 1 was designed). It was predicted that participants' visual search strategies would respond differently to the increasing demands (across the road types in experiment 2, and with the appearance of a hazard in experiment 3) according to their level of driving experience.

The results from the on-road study revealed that both the number and duration of fixations changed across the road types. Both experienced and novice drivers produced the shortest (and therefore the most) fixations on the suburban road. An interaction between experience and road type revealed that the two groups of drivers differed on length of fixations for the rural road and the dual carriageway. Whereas the novices produced the longest fixations upon the dual carriageway, the more experienced drivers reduced fixation durations on this road and instead produced long fixation durations upon the rural road.

Measures of the spread of search revealed that the dual carriageway encouraged experienced drivers to increase their search in both meridians, while novices maintained a relatively short spread of search in the horizontal meridian, and a large spread in vertical meridian across all three road types.

Analyses were also conducted on a subset of data to assess any experiential differences in what the drivers looked at. Two initial differences revealed that the experienced drivers viewed the focus of expansion more than the novice drivers, while the reverse relationship was discovered for gaze durations upon the dashboard. The fixation of the focus of expansion fits with Fry's (1968) assessment of this area of the road as the optimal place to fixate in the absence of other hazardous stimuli, while the novices' preoccupation with the dashboard fits with the suggestion made in chapter 3, that inexperienced drivers may not have automatised certain functions of the car (such as changing gear at the appropriate speed without looking at the speedometer). The fact that there were no differences in the category of 'road ahead' suggests that the experienced drivers were fixating higher in the scene (so that many of their fixations on the road ahead, also fell into the category of the focus of expansion). Brown and Groeger (1988) suggested that the typical higher fixation point of experienced drivers compared to novice drivers supports the theory that, with increased experience, drivers tend to focus higher in the scene to sample steering cues. Though these data support the difference between the two groups in the average height of fixations in the scene, from these findings it would be more parsimonious to suggest that this reflects the preoccupation of the novices with the dashboard, and not their ignorance of higher-order steering cues.

Three interactions between categories and experience were also found. Experienced drivers were found to (i) look through the curve more on the rural road than novices; (ii) give more attention than novices to the vehicle in front when on rural roads, but less attention than novices to such vehicles on the suburban road; and (iii) look at the mirrors more often than novices when on the dual carriageway. All these interactions were explained in chapter 3 in regard to the effects of increased demands across roadways. In addition, the latter result seemed to explain the large increase in the search space that experienced drivers produced on the dual carriageway.

The results from experiment 3 only revealed one significant difference between the novice and experienced drivers in regard to the eye movement data. It was found that novices produced a wider search in the vertical meridian than the more experienced drivers. This was a similar effect to that found in the on-road data. The only other experiential difference was the greater amount of button responses the experienced drivers made to potential hazards.

More interestingly experiment 3 revealed an opposite effect to a findings from experiments 1 and 2, and the literature on driving. All of the latter sources suggested increased demands tended to decrease fixation durations, resulting in an increased sampling rate. Experiment 3 however revealed that the onset of a hazard *increases* fixation durations in a similar manner to a low frequency word attracting long fixation durations. Even recoding experiment 3 according to road type rather than the hazard windows, revealed significantly decreased fixation durations on roadways that are considered to be of higher demand. Furthermore, the contradictory result of experiment 1 (in which fixations decreased in length during the hazard window) was confirmed to be due to a confound related to the preceding moments before the hazard onset window. These antecedent conditions created artificially high fixation durations in the pre-hazard window. From these results it was concluded that the two demand manipulations of experiments 2 and 3 were actually eliciting opposite responses from the participants. The increased demand across the road types appears to be mainly an increase in visual complexity (more stimuli to attract attention), which thus decreases fixation durations and increases the sampling rate so that the driver can monitor the extra stimuli in the scene. The increase in demand that occurs with the onset of a hazard however, appears to require extra processing as fixations are lengthened, and search strategies restricted to a small area focused upon the hazard.

From the results of experiments 2 and 3 it was concluded that the on-road quasi-manipulation of demand (which may be more to do with visual complexity) did help to distinguish between the novices and experienced drivers. The novices applied inappropriate sampling rates to the road types (resulting in longer fixations on roads that were more cluttered and dangerous) and appeared unable to modify the spread of search according to road type. They failed to increase the horizontal spread of search upon the dual carriageway, and had an inappropriately large spread of search on the rural and suburban roads. Though experiment 3 only exhibited the one experiential difference, the main interest of the results lay with increases in fixation durations within the demand windows. Though this is contrary to the previous findings in previous studies, it was argued that the two manipulations of demand used in experiments 2 and 3 were fundamentally different, with the increase in visual complexity across road types serving to increase the sampling rate and disperse attention, while the onset of a hazard decreases the sampling rate and focuses attention.

7.1.3 Experiments 4, 5, & 6: displaying demand induced degradation of extra-foveal attention in the laboratory

The lack of experiential differences in experiment 3 was surprising. The one effect of experience (in the spread of vertical search) suggested that both the real roads and the hazard perception clips were, to a certain extent, being treated similarly by the drivers. Despite this, the appearance of a hazard did not distinguish between the two groups of drivers in either their eye movements or their responses to the hazard. Fixation durations were similar across experience, as were the participants' response times to hazard onsets. However, the accident statistics, and studies of accident causes, reported in chapter 1 clearly reveal that these very situations do discriminate between drivers of varying experience in the actual accident rates.

It was proposed that the failure of the hazard perception test to reveal differences between the driver groups may lie with the inherent problems of eye tracking summarised in chapter 2. A hypothesis was suggested that the experienced drivers may actually have more attentional resources than less experienced participants when placed in a hazardous situation, though instead of using this spare attention to speed up the processing of the hazard, they may devote spare capacity to the peripheral field. This would allow them to deal with the hazard at the same processing speed as the inexperienced driver, while also being aware of the surroundings. This extra attention to the peripheral visual field may provide a preview of any further situational complications, and may also aid the driver to maintain lane position.

Chapter 4 reviewed the evidence for demand modulated degradation of attention in the peripheral field. Experiment 4 attempted to find a loss of preview benefit with an increased foveal load, to replicate basic findings in the area. Visual complexity was maintained throughout the experiment by altering the instructions, rather than the foveal stimulus itself, in order to manipulate demand. Participants were presented with a screen with a letter at the centre and either a staggered junction or a right-bend junction presented at 4.8° to the left or right of the central stimulus. Each slide would not be presented until the computer confirmed that the participant was looking at the centre of the screen. Thus the first fixation made by the participant had to be upon the central letter. In the low demand condition the central letter could be ignored. The participant merely had to saccade to the peripheral target, and make a push button discrimination response. In the high demand condition however, the participant had to decide whether the central letter was either a consonant or a vowel. If it was a vowel the trial proceeded as per the low demand condition. If the letter was a consonant however, this acted as a catch trial and the participant had to abort the trial. The hypothesis stated that the increased processing of the central stimulus in the high demand condition would reduce the amount of attention devoted to the peripheral stimuli. Thus once a participant had made a saccade to the peripheral target in the high demand condition, their fixation durations on the traffic sign glyph should be longer than in the low demand condition.

The results supported this hypothesis. Both first fixation durations and the total gaze durations on the peripheral target were increased in the high demand condition.

In addition to this hypothesis, experiment 4 also attempted to find an experiential difference between drivers. This was undertaken on the basis of Williams' (1995) finding that the visual skills acquired by aviators generalised to context-free studies of spatial attention modulated by foveal demand. It was hoped that if novice and experienced drivers do differ in their ability to deploy extra-foveal attention, then this may become apparent in this simple laboratory design. The results however failed to support this hypothesis. It was subsequently suggested that if experienced drivers do redeploy spare attention in the peripheral visual field, and that this spare attention arises from the familiarity of the demanding foveal stimuli, then the effects would only occur within a driving context. In this study the peripheral targets were driving related, though it may have been more important to have driving related stimuli at the point of fixation.

A further problem was noted with the main effects of increased fixation durations upon the peripheral targets. It was possible that the increased durations did not occur due to the degradation of extra-foveal attention, but instead occurred due to a dual task confound in the high demand condition. It is possible that when a participant saccaded to a peripheral target after making a vowel/consonant discrimination at the centre, the fixation durations were lengthened due to post-fixation processing of the central letter. In other words, the participants' fixation durations on the peripheral target may have increased because they were still wondering whether they should have saccaded in the first place.

The next stage of research seemed to require a more driving related to setting to assess the possibility of differences between drivers groups in the deployment of extra-foveal attention. However as the results of experiment 4 did not show an unequivocal effect of foveal demand on peripheral performance, further studies were deemed necessary to validate the paradigm before applying it to a driving context.

Experiment 5 strove to remove the dual task confound by increasing the number of peripheral targets to two, and removing the catch trials. Instead of the 'go/no-go' trials of experiment 4, participants were required to decide which of two targets they should identify (the target on the left or right of centre). Participants had to make this choice in both the low and high demand conditions. In the high demand condition however the participants had to use both the colour and direction of a central arrow to decide which target to report, whereas the two low demand condition required only the orientation or the colour of the arrow to be used alone. According to Treisman and Gelade's (1980) feature integration theory, combining the colour and direction of a central arrow should require attention, whereas detection of a single feature should not reduce capacity. As eye tracking was not used, slides were only displayed for 300 ms, and required participants to report both the relevant direction indicated by the arrow and the peripheral target. As the factor of driving experience had been removed, the peripheral targets were changed form traffic signs to letters.

The results revealed a significant decrease in peripheral performance when participants were required to combine the features of the central arrow, rather than simply use the orientation. This implied that the extra attention required to interrogate the arrow in the high demand condition, degraded attention in the extra-foveal visual field.

One unexpected result was that peripheral performance using colour to identify which peripheral target to report, fell between that of the orientation condition, and the feature integration condition. This was explained in chapter 4 in terms of the lack of consistent mapping in everyday life between colour and direction.

Experiment 6 attempted to extend the research conducted so far, to include the factor of eccentricity. Through the inclusion of eccentricity it was hoped to identify whether the area of attended space was actually contracting (according to the model of tunnel vision) or whether attention was merely being diluted from the whole area (according to the default model of general interference). The model of tunnel vision is characterised by an interaction between eccentricity and foveal demand such that high eccentricities suffer more under increased foveal demands. This reflects the contracting of the area of attention. If demand affects peripheral performance at all levels then one cannot conclude that the area of spatial attention has shrunk. Instead attention may just be taken equally from all eccentricities. If these studies were to be subsequently transferred to a driving context, it was thought that knowledge of which model was evoked in these basic laboratory conditions would provide a yardstick that may ultimately help to tease out experiential differences in peripheral performance.

The design of experiment 6 was similar to experiment 5. The colour feature manipulation was dropped, and the factor of eccentricity was included. In experiment 5 the peripheral targets were only presented at 3.5°. In experiment 6 they were also presented at 7° from the central arrow.

The results failed to indicate tunnel vision. Two main effects of demand and eccentricity showed that an increase in demand at the point of fixation decreased performance equally at all eccentricities, though performance also declined as eccentricity increased.

Several conclusions were drawn from the experiments reported in chapter 4. In regard to experience it seems that such context-free experiments do not evoke experiential differences. This does not mean that such differences do not occur. Peripheral performance may increase with experience, though such improvements may only be noted in the actual context in which they're developed.

The other effects however confirmed that an increase in foveal demand (in this case, when visual complexity was held constant) does decrease the amount of attention that can be deployed in the extra-foveal visual field, as reflected in the decrease in peripheral performance. The common conception of such degradation is that the zoom lens, or field of view, contracts to increase the resolving power at the point of fixation. This however does not seem to occur in these simple laboratory studies.

The next stage of the research required the application of the findings reported in chapter 4, back to the driving context in order to search for experiential differences.

7.1.4 Experiment 7: peripheral performance in a hazard perception task

This experiment was designed to test drivers' peripheral attention while watching hazardous scenes. Experiments 4-6 had demonstrated the effects of increased foveal demand upon extra-foveal attention (and also demonstrated the inability of a context-free setting to distinguish between novice and experienced drivers), and experiment 3 had demonstrated that the appearance of hazards in a hazard perception clip tended to focus the participants' attention upon the source of the disturbance, increasing fixation durations. By combining these two findings in experiment 7 it was hoped to provide an experiment that would allow natural increases in demand to influence attention to peripheral targets, across eccentricities that changed with the natural eye movements of the individual, rather than an artificial eccentricity manipulation that is forced onto participants. This latter point required a return to the DPI eye tracker used in experiment 3.

Thirty nine clips were presented to each participant. They were told that their primary task was to view the clips as if they were the driver, and to look out for potential hazards, in order to rate each clip along the dimensions of danger and difficulty. Half of the total clip time was designated as low demand and the other half designated as high demand. This was done on the basis of the hazard perception responses made by participants in experiment 3. Those five second segments of clip that had more button presses per participant, were classed as highly demanding. In this way it was hoped to achieve a manipulation of demand based on self-reported processing load. As it is impossible to present a hazard on the screen while holding visual complexity constant, this measure of self-reported demand provides a method of avoiding the problem by only dealing with demand in terms of the judgements required to decide if something is a hazard or not. A target light was presented in each five second window, in one of four place holders. Participants were told that their secondary task was to press a button as soon as they saw one of the lights. At the same time as a peripheral light appeared, the computer recorded how far the participant's point of gaze was from the target. The percentage hit rates for peripheral target detection were then compared across the three factors of experience, the self-reported, driving-related, demand manipulation, and the categorised levels of eccentricity.

The results revealed main effects of all three factors but no interactions. The main effect of eccentricity was primarily due to the large degradation that occurred beyond 7°, though all eccentricities were degraded equally by the demand manipulation, with less targets being spotted in the presence of hazards. The effect of experience was found to lie between the non-drivers and the experienced drivers. The novice drivers fell in-between the other two groups. The effect of experience suggests a definite improvement in peripheral ability with increasing driving experience. The effects of demand and eccentricity however again failed to reflect tunnel vision. One suggestion as to why tunnel vision had been so elusive came from Williams (1988), who stated three elements of the experimental set-up that are required in order to evoke the desired interaction. These were a high central load, instructions that focus the participant on the central task, and speed stress on the primary task. Experiment 7 met the first two criteria, though the latter was lacking. It was suggested that the inclusion of a speeded response, such as the addition of the basic hazard perception response, would be closer to the actual task than merely rating the scene on a couple of dimensions, and may produce tunnel vision. If the tunnel vision interaction was discovered it was also suggested that further interactions between experience and the other factors may be found. Williams (1999) agreed that the inclusion of a speeded response in this particular paradigm should produce the typical interaction.

Onset Fixation Durations (OFDs) proved to be an interesting additional measure. OFDs are the durations of the fixations at the time of a peripheral target onset. It was found that OFDs tended to be longer for those targets that were spotted rather than those that were missed. Two explanations were possible; either fixation durations are increased by spotting a target light in the periphery, or target lights are more likely to be spotted with longer fixation durations. When the OFDs were split into the part that occurred before onset and the part that occurred after, it became clear that the latter post hoc explanation was correct, at least at the further eccentricities (reflected in an interaction between eccentricity and the partitioning of the OFDs). One possible explanation for this effect is that attention is deployed from the point of fixation outward as the continued processing of the stimulus at the point of fixation renders it less demanding over time. The failure to find tunnel vision however suggests that an increase in demand does not affect the speed at which attention is deployed from the fovea outwards, nor the spatial extent that it covers. Instead it involves the amount of attention that is dispersed.

7.1.5 Experiment 8: learner drivers and the search for tunnel vision

Experiment 8 was essentially a replication of experiment 7 though with two important modifications. The main change to the design was to introduce a primary task that required a fast response and placed the participants under speed stress. This was achieved by introducing a foot pedal to the apparatus which allowed the participants to make a speeded response to the appearance of a hazard. It was hoped that the addition of this hazard perception task, within the original peripheral light detection study, would encourage tunnel vision. It was further hoped that this may provide more insights into the experiential differences that occurred in experiment 7.

The second change to the design was the level of experience of the driver groups. A group of experienced drivers were again recruited along with a group of learner drivers at various stages in the learning process. The choice of learner drivers was motivated by a mixture of practical and theoretical reasons. Theoretically, the small differences noted between novice and experienced drivers in experiment 7 would hopefully be exaggerated by the inclusion of learner drivers. It would have been preferable to have also included a group of novice drivers, though unfortunately the pool of potential naive participants is limited, and at the time of testing that pool had run dry.

The study was run in the same manner as experiment 7, though participants were asked to try to spot hazards and respond to them as quickly as possible.

The results resembled those of experiment 7, though overall hit rates were reduced due to the increased demands of the primary task. Each of the three factors produced a main effect. Peripheral performance was degraded by eccentricity, demand and experience in the predicted directions, though no interactions were discovered. The fact that the learner drivers' hit rates differed significantly to those of the experienced drivers does suggest that peripheral performance on the light detection task does have a positive relationship with driving experience. Furthermore this relationship seems to be gradual, and not an immediate improvement in ability after a minimal amount of experience (as the non-driver, significant difference may have suggested).

The two main effects of demand and eccentricity mirrored the pattern of the earlier study. The significant difference in the factor of eccentricity again lay in the 7° and above category. Analysis of the eccentricities of targets over 7°, from both experiments 7 and 8, revealed a small but highly significant difference between the mean eccentricities of those targets that were spotted and those targets that were missed (the means for experiment 7 were 8.3° and 9.1°, and for experiment 8 they were 8.6° and 9.1°, for spotted and missed targets respectively).

The effect of increased demand in the presence of a hazard was similar in magnitude to that observed in experiment 7. The basis for this statement is the lack of an interaction between demand and eccentricity, in the comparison of the two experienced groups from experiments 7 and 8. The inclusion of the speeded primary task merely seemed to degrade performance at all levels of the other factors.

The lack of an interaction between demand and eccentricity once more prevents acceptance of the tunnel vision model. Three separate experiments have attempted to evoke the required interaction, yet none have succeeded. Each subsequent experiment modified the design in the hope that further experiential differences may be uncovered through the production of tunnel vision. In experiment 8 all of Williams' (1988) criteria were met, though to no avail. These experiments add to weight of evidence against those few marginal significant interactions (Chan & Courtney, 1993; Williams, 1988), and increase the growing suspicion that tunnel vision may not exist as a model of attentional degradation, at least under the current experimental conditions.

One advantage of the inclusion of the foot pedal response to hazards was to provide a more fine grained indicator of the sudden increase in demands. Though no statistics were permitted on the aggregated data, hit rates were combined across participants to produce a time line of degradation (Figures 6.2 and 6.3). These graphs provided suggestive evidence that degradation of extra-foveal attention affects inexperienced drivers sooner than experienced drivers, and though the latter group may actually suffer a greater drop in absolute hits, this occurs for a shorter period than the protracted effects that the learner drivers suffered from. This also argues against any claim of dual task confound, as any interference is unlikely to affect performance up to one and a half seconds before the foot pedal is pressed. The interpretation of these graphs suggest that more experienced drivers have a different approach to dealing with sudden increases in demand than learner drivers. It seems that they prefer a short, sharp shock to the attentional system, rather than devoting attention away from the peripheral field for up to 2300 ms as the learner drivers seemed to.

The Onset Fixation Durations failed to reveal the significant interaction found in experiment 7 between the partialling of the fixation into that which occurred before and after hazard onset, and the eccentricity factor. Though the trend of the durations in experiment 8 tended to the same direction, it failed to be recognised at an acceptable level of significance. This is possibly due to the smaller increase in OFDs for those peripheral targets that were spotted.

The final conclusion from experiment 8 was that demand induced degradation of attention deployed outside the foveal region can distinguish between groups of drivers on the basis of experience. This may therefore be a contributing factor to the increased accident liability of drivers between the ages of 17 and 19.

7.2 A brief synopsis of all the results

The aim of this thesis was to identify experiential differences in visual information acquisition during driving. A secondary aim was to achieve such results through a combination of theoretical and applied research. The exploratory research was conducted in experiments 2 and 3. This revealed interesting differences between novice and experienced drivers on the road, but little of interest in the laboratory. It also demonstrated the different effects that an increase in demand due to a change of roadway can produce, compared to the appearance of a hazard. These differences were interpreted as reactions to an increase of visual complexity in the former case, and an increase in processing demand in the latter. The lack of experiential differences in the hazard perception test provoked further research into the effects of increased processing demand, rather than visual complexity. The latter issue seemed to be more a matter of knowing where to look (or being sensitised to certain areas of visual information), whereas a more interesting theory of demand induced degradation of attention could be applied to the appearance of a hazard. This theory was suggested on the basis that experiential differences in the response to hazards must occur (to reflect the increased accident rates of inexperienced drivers), and on the basis of the literature that suggested the importance of peripheral vision (e.g. Land & Horwood, 1995; Lee & Triggs, 1976; Mourant & Rockwell, 1972; Miura, 1990; Summala, et al., 1996). Furthermore chapter 2 had highlighted the possibility of factors that eye tracking alone could not account for. If experiential differences had occurred in extra-foveal attention in experiment 3, the results may not have shown up in a standard eye tracking experiment.

The basic hypothesis, that demand at the fovea could reduce attention to peripheral stimuli, was tested in experiments 4-6. The hypothesis was upheld as reductions in peripheral performance were noted as demand at the point of fixation increased. No experiential effects were discovered however, despite Williams' (1995) claim that abilities developed in a specific context, which increase attention in the extra-foveal visual field, are transferable to a context free setting.

The final stage of the research returned to the driving context in order to evoke experiential differences in peripheral performance. Both experiments 7 and 8 produced results which suggest that more attention can be devoted outside the fovea with increasing driving experience.

7.3 An assessment of the approach adopted in this thesis

Without considering the actual findings of the experiments reported here, a number of successes and limitations can be attributed to the research as a whole. These highs and lows of the current research shall be highlighted in this section, before the following sections report on the implications of the findings to current and future research.

7.3.1 Areas in which this thesis has succeeded

One of the aims of this thesis was to incorporate both applied and theoretical research, culminating in not only the description of an experiential difference between driver groups, but also some understanding about the processes involved. This has been achieved through two separate strands of research. Experiments 2 & 3 represented the exploratory phase in which differences (or the lack of them) were identified. Experiments 4-6 reflected the theoretical approach. These experiments were able to verify the basic phenomena underlying the hypothesis of experiential differences in degradation of extra-foveal attention. Finally, the results of the exploratory experiments were combined with the theory and findings of chapter 4, to produce the final two experiments.

This is a process that that is rarely undertaken in driving research. It has often been the case that findings of exploratory studies are merely described (e.g. Mourant & Rockwell, 1972; Miltenburg & Kuiken, 1990), and any attempts to understand the differences have been superficial, and rarely related back to the relevant psychological literature. This is not to say that any driving research that is incestuous and isolated from previous theoretical work is necessarily a bad thing. Once again this depends on the hypotheses under scrutiny. If one wishes to test the visibility of certain traffic signs under certain conditions, the best sign can be easily selected by experimentation, with little need to explain the results within a theoretical framework. However, if all driving research were to forsake its theoretical roots then this would be a loss for the field in general. There is some driving research that is heavily based upon theoretical research. For instance Sauvan (1998) reported research upon the visual control of self motion, drawing evidence from a wide range of neuropsychological sources. The number of publications in the area of experiential differences that relate their findings back to the theory is however limited. This current research is an example of this kind that would hopefully be of interest to researchers from both applied and more theoretical fields.

A number of other improvements over contemporary research were included in the design of the experiments. The number of participants in the average driving study is particularly limited. However the complexity of driving argues that the variance in performance of certain skills will be extremely large. Despite this fact a number of studies persist in comparisons of individual participants (though sometimes over an extensive number of trials), or in comparisons of very small groups of drivers, which often stretch the limits of the statistical techniques employed. Again this does not render these studies invalid or useless, though one should be careful when interpreting such statistics. Many of the studies in this thesis have employed large numbers of participants, and where ever statistical conventions have been stretched, the reader has been made aware of the fact. A related issue is the amount of missing data that several driving experiments have to endure. One of the most notable is the study by Miltenburg & Kuiken (1990), discussed in chapter 3. In the current research every effort was made to obtain complete data for as many participants as possible. The poorest completion rate occurred during experiment 8, in which two participants had to excluded from the analysis owing to data loss. The number of cells that had to be replaced by group means never rose above 3%.

A final success of the methodology of this research lies with the manipulation of demand used in experiments 7 and 8. The index of demand for these experiments was based on the hazard responses of experiment 3. This provides a comparable measure across different experimental designs and different stimuli (once submitted to a hazard perception test). The use of self reported demand also avoids the problem of trying to quantify the comparison between qualitatively different stimuli.

7.3.2 Areas in which future research should attempt to succeed

Despite the large numbers of participants used in many of the studies, inexperienced drivers are not easy to find. The Department of the Environment, Transport and the Regions have provided invaluable help in obtaining novice drivers, with their permission to distribution questionnaires through driving test centres asking for paid volunteers. Despite these methods of recruitment, drivers who have just passed the driving test are understandably reticent about participating in a study of their driving abilities. Learner drivers, it seems, are even less inclined to volunteer, and non-drivers (of a legal age to drive) are almost non-existent. A further problem with all inexperienced and non-drivers is their lack of mobility which often precludes willing people from taking part if they live too far from the laboratory.

These problems tend to affect the running of the experiments, but need not affect the results once all the potential participants have been tested. The one exception to this is the lack of a novice group of drivers in experiment 8. When the pool of local, naïve novices has been repopulated, it may be of interest to test another batch under the methodology of experiment 8.

In regard to the hazard perception stimuli, the heterogeneous nature of the clips may well hide other subtle differences between groups behind large variances. Though this issue was effectively side-stepped in experiments 7 and 8, further research may be illuminated by an items analysis of the clips.

Another issue is the lack of interactivity involved in all of the experiments (except for experiment 2). Unfortunately without a full scale simulator one could not achieve the complete level of interaction that critics may suggest is needed, and the safety issue of presenting hazardous events precludes an on-road study. Chapter 2 presented an argument against the necessity of full interaction. On the basis of this the results are believed to stand without the inclusion of full interactivity. Certainly the addition of the foot pedal in experiment 9 (though not truly interactive, as it did not affect the display) did not change the pattern of degradation, but merely increased the magnitude of the effect.

The presentation of the hazard clips also raises the question of whether the non-veridical display has influenced the results. The angles of the display were compressed and as such the rate of visual motion is biased. These issues relate to the discussion in chapter 2, in regard to the medium in which driving stimuli should be presented. Unfortunately, knowledge of the correct procedure does not necessarily entail the ability to follow that procedure. In this instance, the results can be compared across several experiments that used the same compression rate. Future experiments on different stimuli and different media can be compared through the use of the index of demand.

7.4 Implications of the findings to driving research, and future extensions

The primary aim of the reported research was to identify differences in visual information acquisition that varied according to driving experience. The interpretation and implications of these findings will be discussed in this section. Additional driving-related results will also be discussed in subsequent sub-sections.

7.4.1 Experience and the deployment of extra-foveal attention

The search for experiential differences culminated in the findings that experience modulates the deployment of extra-foveal attention. Foveal attention does not seem to differ in absolute terms between drivers of differing experience (at least between learner, novice and experienced drivers). This latter point is demonstrated by the lack of experiential differences that occurred between the driver groups in regard to the hazard responses and fixation durations within the hazard windows. If drivers of all levels of experience can process demanding stimuli with the same speed of processing, any significant difference between the groups had to lie outside the fovea. This difference was found in the deployment of extra-foveal attention.

On the basis of Figures 6.2 and 6.3 the benefit of experience seems to delay the investment of attention at the fovea for several hundred milliseconds, before nearly all attention is devoted to the foveal stimulus for a very short period of time. This strategy is distinct from the learner drivers in experiment 8 where peripheral performance was degraded for over two seconds. The difference in the speeds of these two strategies may relate to accident liability in a hazardous situation. Inexperienced drivers are involved in more accidents than experienced drivers and one of the reasons may be that they concentrate too much on the locus of the hazard and fail to take into account the rest of the world. This concentration upon the hazard does not take up too much attention, but rather it captures attention for too long a period compared to the more experienced drivers.

How might such an effect contribute to accident liability? It has already been reported that lane maintenance relies heavily upon peripheral vision. If information from lane control markers can no longer be taken in then this may cause the driver to veer to one side of the lane or the other, possibly resulting in a collision with pedestrians or the kerb on one side, or oncoming traffic on the other. Any subsequent sudden events or hazardous stimuli may not be noticed until it is too late to react. Furthermore any attempt to avoid the potentially hazardous event that has captured attention may place the inexperienced driver at further risk, as emergency manoeuvres may not be preceded by necessary visual checks (e.g. to see if the on-coming lane is empty before overtaking a car in front that suddenly brakes). Though demand was not found to interact with the degradation suffered by inexperienced drivers, it is in high demand situations that such degradation is likely to produce an accident.

The stimulus that captures attention need not be a potential hazard however. The only comparisons that have been made in terms of demand manipulations have been between road types and hazard onsets. It is more likely however that a complex road sign will produce behaviour similar to an increase in demand due to the appearance of a hazard, rather than the demand (or the increase in visual complexity) that occurs between road types. This provides an obvious extension to the current research; to what extent is peripheral performance degraded with less threatening (yet still localised) demanding stimuli. For instance one could propose that the same degradation of peripheral performance may occur as the driver views a complex road sign. If the same pattern of degradation is expected in regard to complex road signs, then one may predict that experienced drivers may invest attention in the signs later than their less experienced counterparts, though any speeded discrimination response should be similar for both groups. This may even reveal itself in the actual time taken to fixate the road sign, with experienced drivers taking longer to fixate the sign, though once it is fixated they should be able to finish processing at the same time as the less experienced drivers, or perhaps even sooner.

How can these results help drivers? Perhaps inexperienced drivers could be trained to deploy their attention at the same time as experienced drivers? Unfortunately the history of training new or inexperienced drivers is not a hugely successful one. Published research suggests that the availability of such training merely encourages teenagers to take up driving at an earlier age

(Raymond, Jolly, Risk & Shaoul, 1973). This earlier exposure to risk may actually be counterproductive in attempts to reduce accident liability (Brown, 1997). Training specific to eye movements appears to have had even less success. Zwahlen's (1993) review of eye movement instructions to drivers found little validation of many of the guidelines when compared to actual results. Instead of set rules for viewing the road, Zwahlen emphasised the lack of pattern in eye movements and the need for flexibility in search strategies. Though the evidence of experiment 2 strongly suggests that some patterns exist, the results also supported the flexibility of search strategies across road types. This was an approach that the experienced drivers took, while the strategies of the novices' remained inflexible across the different road types.

With the many problems associated with the training of eye movements, the possibility of training the deployment of attention (an altogether more intangible concept to teach) seems more remote. One further problem with teaching eye movements or attentional deployment is that teaching learners or novices to emulate the search strategies of more experienced drivers may place them in a riskier situation. For instance, if novice drivers need to fixate lane markers because they cannot take in such information through peripheral vision as the experienced drivers do, then training these drivers to not focus on the lane markers will not improve their driving ability as they will still not be able to acquire lane maintenance information through peripheral vision. Similarly, training an inexperienced driver to disperse their attention across the driving scene so as to be aware of peripheral stimuli, may divert vital resources from the point of fixation. If training is to be undertaken one needs to understand the reasons that experiential differences occur. In the case of the deployment of extra-foveal attention, it seems that training inexperienced drivers to process foveal items would improve the spread of attention in the periphery without degrading foveal performance.

Another approach to improving driver safety is through road design. If future research confirms the hypothesis that peripheral degradation also occurs with complex road signs as well as the appearance of hazards, then road designers should be advised not to place such signs at locations where peripheral information is of vital importance, such as in bends or where the lane narrows, both of which are areas of the road where lane maintenance information is required.

7.4.2 Experiential differences across road types

The results of experiment 2 also suggested some basic differences between novice and experienced drivers in regard to where and what they look at. The dual carriageway especially differentiated between the two groups. From these results it would be tempting to suggest that inexperienced drivers should increase their spread of search and decrease their fixation durations on certain road types, though again the issue of training is dogged by the question of why these differences exist. If the differences occur because the inexperienced driver knows no better, then it should be a 'simple' matter of telling drivers where to look. However if the novice drivers are not accomplished enough in the skills of visual information acquisition, teaching them to look in certain places that do not give them enough information, or that provide them with cues that they cannot yet use, will not improve their accident liability. The results discussed in the previous section have permitted certain suggestions to be put forward as to how training should be undertaken in regard to increases in processing demand (by focusing upon reducing the foveal load, rather than influencing peripheral detection rates). However, the increases in visual complexity that correspond to a change in road types need to be investigated as a separate topic before any such suggestions could be ventured. The differences noted in experiment 2 provide an interesting starting point for investigating increases in visual complexity, and its differential effects upon drivers of varying experience. The two dimensions of visual complexity and processing demand have been noted to be inseparable (though they vary in different quantities depending on the demand manipulation). Future research should focus upon the possible interactions that may occur between these two factors in relation to driving.

7.4.3 The hazard perception test

Research on previous hazard perception tests has related performance to accident liability (Quimby, Maycock, Carter, Dixon & Wall, 1986). The current hazard perception test clips used in experiments 1, 3, 7, and 8 designed by NFER were based upon the prototype test studied by McKenna and Crick (1994). They found clear differences in hazard perception performance between drivers of varying levels of experience. These differences were not found in experiments 3 and 8. It seems that something was lost in the transition from McKenna and Crick's original version to the version designed by NFER. The main change between the two versions of the hazard perception test was the inclusion of a wider range of hazardous situations. It is possible that hazard perception ability is dependant on the specific type of hazard used (rather than the inclusion of any potentially hazardous event - Quimby & Watts, 1981). If this is the case then the generalisability of the hazard perception test to real life situations must be suspect. If this is not the case, then the few published results that link hazard perception ability to accident liability must be questioned. The most likely explanation of the two is that the hazard perception test does not transfer very well across different driving situations. This must certainly be the case for the stimuli used for the current studies.

The inability of the hazard perception test to distinguish between driver groups (especially considering its pedigree) due to the increased variation in hazardous events, makes the differences noted in the peripheral target detection paradigm seem all that more impressive.

7.4.4 What drivers look at

The category analysis results of experiment 2 have also provided some interesting data that relate to theories in the driving literature. One of the findings of previous research has been that though novice drivers tend to have a greater vertical spread of search, their average fixation location in the road ahead is lower than that of more experienced drivers (Mourant & Rockwell, 1972; Brown & Groeger, 1988). This finding was replicated in the subset of participants' included in the category analysis. Though novice and experienced drivers fixated the road ahead for a similar amount of time, the experienced drivers spent more of this time fixating at the focus of expansion, which is the farthest point on the road ahead. Mclean and Hoffman (1971) suggested that this may represent the experienced drivers use of higher order steering cues obtained from the focus of expansion (such as the offset of the visible expansion point from the 'true' expansion when driving through a curve). They proposed that less experienced drivers were unaware of the value of these cues or were unable to use them, and therefore tended to fixate lower in the visual scene.

An alternative explanation is that the novices are so preoccupied with the dashboard, that eye movements may remain closer to the car, not because they fail to recognise the use of steering cues at the focus of expansion, but in an attempt to minimise the angle through which the eyes must move from viewing the road to checking dashboard instruments. The greater the angle that the fovea must traverse, the greater the likelihood that an eye movement needs to be accompanied by a head movement. Head movements are considerably slower than ballistic saccades, and as such, viewing the road ahead at a shorter preview distance than experienced drivers may overall give a better preview than the focus of expansion. If a hazard suddenly appeared at the focus of expansion while the driver is fixated at this point, then reactions to the hazard may be faster than those of drivers who are fixating lower in the scene. However, the responses of these latter drivers will most certainly be faster than any inexperienced drivers who have to make both an eye movement and a head movement from the dashboard back to the road ahead. Again, this highlights the problems of prescribing eye movement training without understanding why such experiential differences exist.

The experienced drivers' lack of concern with the dashboard supports an assumption that was made in chapter 4. It was suggested that experienced drivers may have more spare attentional capacity than novices due to their familiarity with the situations and stimuli. One possible explanation for increased spare attention is that experienced drivers may automatise certain features of the driving task. In this example it seems that the dashboard is a largely redundant source of information for the experienced drivers. It is possible that the experienced drivers have learned to extract dashboard information (primarily speed) from the visual scene (through the expansion rate of the scene) or auditory cues (such as the sound of the engine). The second main reason to view the dashboard is for spatial information about the position of various instrument switches and buttons (e.g. confirming which side of the steering column the indicator switch is on). The motor routine of turning on an indicator is a simple task that could feasibly be automatised with a mixture of general driving experience, and specific experience of a certain make of car. Future research may be designed to assess the affect that experience has upon certain driving sub-tasks (such as changing gear) and the effect that this may have upon where drivers look, and how they do so. For instance, if gear changing is automatic then experienced drivers may not need to alter the position of their point of gaze or the durations of their fixations, when changing from one gear to another. A comparison with inexperienced drivers may distinguish between the groups, perhaps suggesting a development of automatised behaviour with experience. This would identify whether inexperience in gear changing causes the pre-occupation of inexperienced drivers with the dashboard. Comparisons across manual and automatic cars would also reveal whether experienced drivers differ at all in their visual search behaviour under the same sort of visual conditions that prompt a gear change (Shinar, Meir & BenShoham, 1999).

A separate issue that was identified in this analysis, is whether the tangent point is an important source of information for curve negotiation. The analyses of experiment 2 support the suggestions of Land and Lee (1994) that this is the case, though fixations through the bend seem more important judging by the comparison of percentage of gaze durations in these two locations. While supporting the research of Land and Lee (1994), this result also emphasises the need to test hypotheses in different locations under different conditions, as the particular nature of a certain road or road feature can lead to confounds, or in the case of Land and Lee an over-exaggeration of the importance of one source of information. Specific research should address the relative importance of different sources of information during certain driving tasks (such as curve negotiation), on a range of different roads that provide information from the many sources in differing quantities.

7.5 Implications of the findings to attention research, and future extensions

Before discussing the implications of this work for future research in the theoretical field of attention, a caveat should be reported. The majority of the studies in this thesis report applied experiments which attempted to measure things that happen in the real world, using realistic stimuli. As such, these experiments (excluding experiments 4-6) did not set out to test particular theories of attention to the satisfaction of theoretical research. The use of realistic stimuli introduces many potential confounds that may obscure results. The implications of these studies to theoretical attention research are not clear cut. However, the suggestions that these experiments raise can be tested under less realistic circumstances where the issue of driving experience is not important to the hypotheses. It is on this basis that these implications for future research are offered.

7.4.1 The search for tunnel vision

Three separate experiments reported in this thesis have failed to find the required interaction that would support the tunnel vision model of degradation of extra-foveal attention due to increased demands at the fovea. Neither peripheral discrimination, nor mere target detection have shown the predicted results, even with the three criteria of Williams (1988). It seems that the limited evidence for tunnel vision (Chan & Courtney, 1993; Williams, 1988) cannot be improved.

Increases in foveal demand *do* require a redeployment of attention to the point of fixation, which supports the notion of a limited capacity model of attention, and furthermore, this degradation cannot be solely attributed to dual task interference. However instead of a contracting spatial area of attention that zooms in on stimuli that are harder to process, it seems that attention is drained from all eccentricities with equal effect. This latter pattern of results has been recorded with more consistency, over many similar field and laboratory experiments, than the former pattern (e.g. Holmes et al., 1977; Lee & Triggs, 1976; Williams, 1982, 1995).

These results do not, however, accord with the many experiments that have been reported to demonstrate the zoom lens affect (Broadbent, 1982: Eriksen & Murphy, 1987; LaBerge, 1983). For instance, LaBerge (1983) required participants to either categorise the central letter in a five letter string, or categorise the whole five letter word. After this response a probe would indicate one of the five letters to report. LaBerge found that when the beam was set wide (reporting the whole word) response times were similar for all five letters. However when the beam was given a narrow setting (reporting the central letter), response times outside the beam were slowed in relation to the central letter. This was interpreted as the effect of a variable width beam of attention.

An alternative manipulation of the beam width was employed initially by Eriksen & Murphy (1987). They found flanker incompatibility interference when they presented two letters (one target and one distracter) together on a screen. This interference disappeared however when the appearance of both target and flanker was preceded by a spatial pre-cue. Eriksen and Murphy argued that this reflected the contraction of the zoom lens due to the appearance of the pre-cue. This shrinkage of the beam left the flanker outside the area of spatial attention and therefore unable to interfere with the categorisation of the target.

Both of these studies, and many similar ones, suggest that the area of attention does contract. However, attempts to shrink the attended region with increases in foveal demand suggest that such contraction does not occur. How can these two different results be accommodated in a single theory of attention?

First it should be noted that there is a qualitative difference between the manipulations of LaBerge (1983) and Eriksen and Murphy (1987), and demand induced degradation of extra-foveal attention. The manipulation of LaBerge for instance sets an artificial width of the hypothesised zoom lens. Participants are told, in essence if not literally, how wide the beam of attention should be set according to a particular task. In contrast, demand induced degradation is a more naturalistic reduction in peripheral performance, in which the attentional system itself reallocates attention away from extra-foveal regions. The LaBerge study may represent an artificial contraction of the beam due to the interference of some form of central executive, which occurs in the absence of any other reason to maintain a wide spread of attention. Without explicit instructions to focus attention on one part of a visual display, a natural redeployment of attention may degrade all eccentricities equally in order to maintain a rudimentary awareness of the environment. This may especially be the case when watching the hazard perception test, as the dynamic background to the hazard also needs to be monitored. More research needs to be undertaken to identify the natural degradation of extra-foveal attention, rather than artificially setting the beam to a certain width. Lavie's (1995) study may have aided the understanding of this process if the factor of eccentricity had been included. Unfortunately this was not the case.

If this argument is reversed however one could suggest that the artificiality of abrupt-onset peripheral targets deters any contraction of spatial. Even the requirement to report any peripheral object may persuade the spotlight to retain a wide spread. The balancing of these two artificial elements of such studies is a problem that future research should consider.

A further problem with the manipulation of the spotlight width used in LaBerge's (1983) study is that the response times may have merely reflected how much attention had already been given to the letters during the initial categorisation task of either the central letter of the whole word. If the participant had to categorise the whole word then some attention must have been paid to all five letters in the string. If the categorisation merely involved the central letter then the participant had no previous need to pay attention to the other four letters. If attention has already been paid to all the letters in the string then any response to an individual letter should require the same time regardless of which letter. This could just be a case of repetitive priming, which may not occur after the central letter categorisation task due to the lack of attention previously paid to the other letters, or simply the lack of memory for unprocessed flankers.

The manipulation used by Eriksen and Murphy (1987) and Lavie and Driver (1996) seems at first not to be dogged by such confounds. The use of a pre-cue is a less artificial manipulation of the beam width, and also does not raise problems with memory or the level of processing conducted on parafoveal flankers. The abrupt onset of a target has been noted to have special importance within the attentional system (Egeth & Yantis, 1997), and seems to have an exceptional ability for capturing attention. Again however one could argue that abrupt onsets are still somewhat artificial. Rarely in real life will stimuli pop into existence out of thin air. The appearance of a hazard in the hazard perception clips, and certainly in the real world, is rarely an abrupt onset, but instead often involves an element already within the scene which becomes hazardous (such as a pedestrian on the pavement who only becomes hazardous once they step into the road in front of the participants perceived vehicle).

The evidence from experiments such as those by LaBerge (1983) and Eriksen and Murphy (1987) suggest that the beam can be reduced in diameter, though the experiments that have failed to find tunnel vision suggest that this may be an artificial manipulation of beam width. Certainly in the experiments presented in this thesis there is no evidence for a contracting area of spatial attention with an increase in demand at the point of fixation. Though this does not undermine the possibility of a variable width beam of attention, it certainly does not support the assumption that this beam may contract in order to increase the resolving power at the point of fixation.

7.4.2 Is degradation of extra-foveal attention space or object-based?

It was noted in chapter 4 that though evidence of tunnel vision would support the space-based theories of attention, a pattern of results indicating general interference would not distinguish between spatial attention or object-based attention. The majority of this chapter has discussed the results within the framework of spatial attention, despite the earlier admission that general interference would not preclude object-based attention.

The sudden decline in performance over seven degrees of eccentricity has been suggested to represent a catastrophic degradation perhaps indicative of a boundary of spatial attention.

While no such firm conclusions can be drawn due to the caveats mentioned in chapter 5, it does argue for further investigation of the larger eccentricities in future research.

Even if a spatial boundary was strongly supported on the basis of these data, there is a further confound that would prevent that conclusion. The place holders may have been viewed as objects themselves, and as such we cannot clearly discriminate between the two theories. In fact Lavie and Driver (1996) would suggest that the placeholders would be viewed as objects, but only within the spatial area of attention. Their theory states that as the zoom lens contracts, objects that do not remain wholly within the beam of attention will no longer be attended to as objects. Their study used a pre-cue to reduce the beam width and then measured the benefits of object-based attention against spatial attention at similar eccentricities. Performance on their target matching task was improved with object-based stimuli, providing the spotlight was still set on a wide focus. The pre-cue reduced the beam diameter and removed the object-based benefits.

One problem with the interpretation of this study is that if the pre-cue really reduced the diameter of the beam to such an extent, then correct responses to targets at eccentricities outside the area of spatial attention should have only reached the level of chance, as the participants could not attend to them. This was not the case however. Instead it seems that object-based attention contracted with the pre-cue, but nothing can be said about the extent or nature of attention to the extra-foveal features in the peripheral matching task.

Lavie and Driver (1996) assumed that the extent of object-based attention is controlled by the extent of spatial attention. An alternative explanation is that spatial attention only constrains the maximum spread of object-based attention. If this was the only link between the two systems then object based attention would be free to contract with a pre-cue, whilst leaving spatial attention on a wide setting. The advantage of this would be that the spread of attention should still be able to detect sudden onsets, and perhaps even single feature changes in the rest of the attended field, while object-based attention to particular stimuli is reduced to a small region. This could also apply to natural degradation of attention due to a demand increase at the point of fixation. For instance in experiments 7 and 8 object-based attention may contract upon the cause of the hazard, while spatial attention remains at a wide setting in case of an abrupt onset. The degradation that occurs in the detection of peripheral targets suggests a further relationship between these two systems: attentional resources are still taken from spatial attention to fund the contraction of object based attention despite no actual shrinkage in the width of the beam.

The advantage of this tentative theory is that it could provide a bridge between the differing results of the zoom lens theorists (such as Eriksen & Murphy, 1987) and the results presented in this thesis and elsewhere that suggest attention does not shrink with a natural increase in processing demand. Eriksen and Murphy's design used flanker interference with a target task. If one assumes that object-based attention is required for semantic processing then a contraction effect may occur with a corresponding reduction in inference during pre-cued trials. In many of the attempts to assess demand induced degradation the peripheral task has tended to be either detection of an abrupt onset (e.g. Lee & Triggs, 1976; Miura, 1990) or detection of single features (e.g. Holmes, et al., 1977; Williams, 1982). If spatial attention is equal to these tasks (a weaker form of Treisman and Gelade's, 1980, argument that single features are available for processing at any point in the visual field), and it does not contract with object-based attention, then the default pattern of general interference may be expected.

It was not the aim of this thesis to test new twists on attentional theories, and as such the experiments reported here were not designed to verify attentional hypotheses. However, the results have raised some interesting hypotheses in the attempts to rationalise the contradictory effects of several paradigms. These hypotheses may form the basis of future theoretical work in the field of attention. If future work were to support these fledgling hypotheses then the prospect of finding (object-based) Tunnel Vision may rise once more.

7.5 Conclusions

The deployment of extra-foveal attention during driving differentiates between participants of the basis of driving experience. This element of experience can feed into models of driver accident liability and hopefully provides another link in the attempt to understand why inexperienced drivers are over-represented in the accident statistics. The methodological pincer movement, combining previous research from both theoretical and applied areas, has been successful in identifying this experiential difference, and also in understanding something of its nature. Though experienced drivers still suffer degradation in the peripheral field due to increased demands at the fovea, it seems they have developed a different strategy in regard to *when* they invest attention. In addition to achieving the initial aims of this thesis set out in chapter 1, a number of suggestions for future research have arisen from the findings, again in both theoretical and applied areas of research.

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Appendix 1 - Details of the hazard perception clips

The hazard perception clips used in experiments 1, 3, 7 and 8 were designed by the National Foundation of Education and Research (NFER) who were commissioned to film the clips for the Department of Transport (now the Department of Transport, the Environment and the Regions). The original intent for these clips was their use in a hazard perception test that could be easily administered to learner drivers as part of the driving test procedure. In order to achieve this NFER developed a simple scoring system that gave participants a hazard perception score at the end of the test.

The clips were filmed in and around Cambridge with each containing between one and four hazardous or potentially hazardous events. A typical clip lasts for an average 43 seconds (clip length varies between 18 and 72 seconds) and falls into one of seven initial categories that NFER defined. These categories were (a) rural lanes; (b) suburban roads; (c) busy urban roads; (d) residential areas; (e) single carriageway (main routes); and (f) dual carriageways. The letters in the clip names refer to these initial categories. Where analysis was performed across road types however, the classification system of Chapman and Underwood (1998) was used instead.

The table (Table A1) below details the number of hazardous events in each clip, a description of each hazard, the time of the hazard onset (in mille seconds) from the start of the clip. The last two columns refer to the hazard perception scoring system. The column 'Scoring Interval' is the period after the hazard onset during which the participant must make a response to score the maximum five points. There are five scoring intervals of the same duration for each hazard, with the hazard perception score decreasing by one point for each subsequent interval from the hazard onset. Any response that occurs after five scoring intervals receives no score. The 'Mean Score' column refers to the average score that participants obtained in tests conducted by NFER.

Table A1. A list of the hazard descriptions, onset times and scoring intervals for the 39 clips used in experiments 2, 3, 7 & 8.

Clip no.	Number of hazards	Description of hazard(s)	Time of hazard onset	Scoring Inteval	Mean score (NFER)
a1	1	A horse appears in the road ahead	16200	600	2.10
a3	1	The driver has to avoid a jogger in the road ahead	22000	400	2.09
a4	1	A horse appears in the road ahead	21000	500	1.52
a7	1	The driver has to avoid a parked van and an on-coming cyclist	30000	800	1.79
a9	1	An attempt to over take a horse is complicated by an on-coming car	29200	800	1.72
a11	1	An attempt to over take a jogger is complicated by an on-coming car	24500	800	2.32
b4	3	A pedestrian steps onto a zebra crossing in the road ahead. Two other pedestrians at later intervals.	1400 13000 22800	1000 700 700	1.70 1.95 2.24
b5	11	A pedestrian steps onto a zebra crossing in the road ahead.	32800	500	3.18

b6	3	A parked lorry and a selection of on-coming vehicals create three hazardous events	6700 16300 20300	400 600 600	2.62 1.58 2.54
b8	1	An attempt to over take a parked car is complicated by an on-coming car	12100	700	1.86
b10	2	Multiple hazards	5400 13000	500 500	2.28 2.59
b11	1	A car reverses into the road ahead	20200	400	2.39
c5	2	Pelican crossing light turns red. Later an elderly pedestrian steps into the road.	13500 24000	500 600	2.49 2.02
c9	1	A cyclist suddenly emerges from a side road to the left	21500	300	2.46
c10	4	Car emerges from the left (and other hazards).	11000 21300 30000 43300	500 500 800 300	1.30 3.15 1.55 1.72
c12	4	Several pedestrians step into the road at separate times.	24600 29600 35100 39800	500 300 700 800	2.81 2.55 2.09 1.47
c13	3	Several pedestrians step into the road at separate times.	10500 19000 25700	300 900 200	2.90 2.19 3.14
c15	2	A motor bike enters suddenly form the left. Later traffic ahead brakes.	14700 20200	700 400	1.98 2.49

d4	1	An attempt to over take parked vans is complicated by an on-coming car	1700	300	1.46
d5	1	A parked car reverses suddenly into the road ahead	26400	400	2.59
d6	1	A cyclist suddenly emerges from a side road to the left	16400	300	2.83
d7	1	A car suddenly emerges from the left	15300	300	2.96
d8	2	The car ahead brakes suddenly	3700 23500	1200 400	2.71 1.83
d10	1	A pedestrian steps into the road ahead from between two parked cars	17000	400	2.55
d11	1	A pedestrian steps into the road ahead from between two parked cars	19200	500	2.53
d14	2	The car ahead brakes suddenly. A pedestrian crosses the road	16000 40800	900 1000	1.16 1.93
d15	1	A children's ball is kicked into the road from a nearby football match	33000	900	2.66
e3	3	A man with a bicycle moves to the centre of the road. Later a car enters suddenly from the right. Later still, an on-coming bus overtakes a parked van.	14500 26300 40500	600 600 800	2.76 1.93 1.32
e6	1	Single hazard	13000	600	2.26

e7	2	Multiple hazards	17400 20300	300 400	2.28 0.97
e9	2	Multiple hazards	13000 39000	1400 1400	1.79 2.10
e11	2	Multiple hazards	11500 24600	600 600	2.61 2.88
e12	1	An on-coming car cuts across the lane at a set of traffic lights	20300	300	2.66
e13	1	An on-coming motor cycle cuts across the lane at a set of traffic lights	19300	700	1.80
e14	2	Multiple hazards	16500 36000	400 700	2.55 2.39
e16	1	The door of a parked lorry opens during overtaking	30000	600	2.31
f7	1	Car enters from slip road to the left	9500	1400	1.68
f10	1	Car ahead changes lanes	21100	600	2.53
f11	1	The door of a parked lorry opens during overtaking	9500	1400	3.13

Appendix 2 - Analysis of Variance tables

The following tables are presented in the order that they appear in chapters 2 to 6. Preceding the list of tables is a key to the factor names (Table A2).

Table A2. Key to the factor names.

The Factors	*Description*
Dem.	Level of demand placed upon the participants.
Ecc.	The distance between peripheral targets and the central fixation cross in expt 6.
Expt.7 vs Expt.8	A comparison of hit rates between the two experiments. The only difference between the two experiments is the type of primary task used.
Exp.	Participant groups of differing driving experience (Expt.s 2, 3, & 4, experienced and novice drivers; Expt. 7, experienced, novice and non-drivers; Expt. 8, experienced and learner drivers).
hit/miss	The act of responding (or failing to respond) to a peripheral target (expts 7 & 8).
Meridian	The axes of the display (X & Y).
O E	Onset eccentricity - the distance from the point of fixation and the position of a target at time of oset (expts 7 & 8).
Ratings	The scores taken from two Likert dimensions that assessed the participants' judgements of danger and difficulty of hazard perception clips (expt. 7).
Report Condition	Experiment 1 had three verbal report conditions: natural report, restricted report and a control condition which did not require the participants to report what they were attending to.

Table A2 cont.

The Factors	*Description*
Response	Participants could either respond Yes or No to the targets in expt 4. This was included as a factor in the analyses.
Roadway	The type of roads that were driven or viewed by the participants.
Sac. Dist.	The distance between two fixations.
Window	Segments of the hazard perception clips defined as either high or low demand, on the basis of whether a hazard falls within them (expts 1 & 3) or on the basis of participants' button presses to perceived hazards (expts 7 & 8).

EXPERIMENT 1:

Comparison of mean response times to the hazards across all clips

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
report condition	2	322802	161401	.820	.4418
Residual	27	5317572	196947		

Comparison of mean fixation durations across the report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
report condition	2	24198	12099	1.156	.3299
Residual	27	282650	10469		

Comparison of mean fixation durations in the hazard window and in the pre-hazard window

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
report condition	2	239652	119826	.632	.5391
Subj. (Group)	27	5117224	189528		
window	1	1694770	1694770	6.294	.0184
window * report condition	2	294436	147218	.547	.5851
window * Subj. (Group)	27	7269943	269257		

Comparison of the variance of fixation locations across the horizontal and vertical meridians

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	17.62	8.8	.160	.8528
Subj. (Group)	27	1486	55		
Meridian	1	7337	7337	183.8.0001	
Subj. (Group) * Report condition	2	194	97	2.439.1063	
window * Subj. (Group)	27	1078	40		

Comparison of the gaze durations on the road ahead across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	228	114	3.672	.0389
Error	27	837 31			

Comparison of the gaze durations on the car in front across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	605	303	1.951	.1616
Error	27	4188	155		

Comparison of the gaze durations on the cyclist across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	8.3	4.2	.442	.6470
Error	27	253 9.4			

Comparison of the gaze durations on the oncoming traffic across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	27.27	13.66	.152	.8595
Error	27	241890			

Comparison of the gaze durations on the general surroundings across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	2	129	64.5	.579	.5673
Error	27	3008	111		

Comparison of the verbalisations on the car in front across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	1	10229	10229	15.856	.0006
Error	22	14192	645		

Comparison of the verbalisations on the cyclist across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	1	44834483	9.291	.0059	
Error	22	10614	482		

Comparison of the verbalisations on the oncoming traffic across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	1	382	382	1.561	.2247
Error	22	5392	245		

Comparison of the verbalisations on the general surroundings across report conditions

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Report condition	1	214	214	.519	.4787
Error	22	9062	412		

EXPERIMENT 2:

Mean fixation durations across roadway and level of experience

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	.004	.004	.149	.7018
Subj.(Group)	30	.850	.028		
Roadway	2	.040	.020	7.955	.0009
Roadway * Exp.	2	.016	.008	3.140	.0505
Roadway * Subj.(Group)	60	.150	.002		

The number of fixations across roadway and level of experience

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	882	882	.584	.4509
Subj.(Group)	30	45351	1512		
Roadway	2	3173	1586	9.728	.0002
Roadway * Exp.	2	105	53	.323	.7254
Roadway * Subj.(Group)	60	9785	163		

The spread of search along the horizontal meridian across roadway and level of experience (variance of fixation locations)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	2984	2984	1.395	.2469
Subj.(Group)	30	64193	2140		
Roadway	2	9167	4583	7.760	.0010
Roadway * Exp.	2	7812	3906	6.613	.0025
Roadway * Subj.(Group)	60	35440	591		

The spread of search along the vertical meridian across roadway and level of experience (variance of fixation locations)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	966	966	3.495	.0713
Subj.(Group)	30	8295	276		
Roadway	2	1053	526	4.018	.0230
Roadway * Exp.	2	443	221	1.690	.1932
Roadway * Subj.(Group)	60	7859	131		

Selected tables from the category analysis of Experiment 2 (across the factors of experience and road type):

Gaze duration upon the focus of expansion

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	1.026E9	1.026E9	7.217	.0276
Subj.(Group)	8	1.137E9	1.421E8		
Roadway	2	1.147E8	5.735E7	1.589	.2348
Roadway * Exp.	2	1.664E7	8.324E6	.231	.7967
Roadway * Subj.(Group)	16	5.776E8	3.61E7		

Gaze duration upon the dash board

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	1.159E8	1.159E8	6.598	.0332
Subj.(Group)	8	1.405E8	1.757E7		
Roadway	2	1.215E8	6.077E7	1.843	.1904
Roadway * Exp.	2	2.02E7	1.01E7	.306	.6289
Roadway * Subj.(Group)	16	5.275E8	3.297E7		

Gaze duration upon the road ahead through the corner

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
experience	1	5.871E7	5.871E7	5.915	.0411
Subj.(Group)	8	7.939E7	9.924E6		
Roadway	1	4.108E7	4.109E7	4.285	.0722
Roadway * Exp.	1	5.577E7	5.578E7	5.817	.0424
Roadway * Subj.(Group)	8	7.670E7	9.588E6		

Gaze duration upon the mirrors

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	1.259E7	1.259E7	1.154	.3141
Subj.(Group)	8	8.729E7	1.091E7		
Roadway	2	4.073E7	2.036E7	9.099	.0023
Roadway * Exp.	2	1.812E7	9.06E6	4.048	.0378
Roadway * Subj.(Group)	16	3.581E7	2.238E6		

EXPERIMENT 3:

Comparison of mean fixation durations across the three hazard windows

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	59174	59174	1528 .2219	
Subj.(Group)	52	2013496	38721		
Wndow	2	1351658	675829	52.387	.0001
Window * Exp.	2	46844	23422	1.816	.1679
Wndow * Subj.(Group)	104	1341665	12901		

Comparison of zero order measures of saccade distance across the three hazard windows

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	33	33	.054	.8168
Subj.(Group)	52	31647	609		
Wndow	2	2176 1088		7.551.0009	
Window * Exp.	2	184	92	.639	.5297
Wndow * Subj.(Group)	104	14986	144		

t-test performed upon the Mean Fixation Durations averaged across each whole clip for each participant

	Exp'd	*Novices*
Mean	410.73	438.81
Variance	4056.87	5560.93
Observations	22	32
Pooled Variance	4953.52	
df	52	
t Stat	1.44	

Saccadic distance (d_0, d_1, d_2) across experience

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	132	132	.292	.5913
Subj.(Group)	52	23560	453		
Sac. dist.	2	7856	3928	149.2	.0001
Sac. dist. * Exp.	2	65	33	1.236	.2948
Sac. dist. * Subj.(Group)	104	2737	26		

t-test comparison of the variance of fixation locations across the horizontal meridian (degrees)

	Exp'd	*Novices*
Mean	5.86	6.57
Variance	0.83	6.8
Observations	22	32
df	52	
t Stat	1.1	

t-test comparison of the variance of fixation locations across the vertical meridian (degrees)

	Exp'd	*Novices*
Mean	0.26	0.51
Variance	0.33	0.64
Observations	22	32
df	52	
t Stat	2.88	

t-test comparison of hazard perception scores across experience

	Exp'd	Novices
Mean	41.6	40.7
Variance	151.7	125.7
Observations	22	32
df	52	
t Stat	0.29	

t-test comparison of responses per hazard across experience

	Exp'd	Novices
Mean	2.1	1.6
Variance	0.96	0.32
Observations	22	32
df	52	
t Stat	2.43	

t-test comparison of time taken to fixate a hazard from onset (ms)

	Exp'd	Novices
Mean	612	663
Variance	95571	184707
Observations	22	31
df	51	
t Stat	2.47	

t-test comparison of response fixation durations (the fixations which straddle the hazard response, in ms):

	Exp'd	*Novices*
Mean	970	1069
Variance	153648	93844
Observations	22	31
df	51	
t Stat	1.03	

Comparison of the portion of response fixation durations that occur before the hazard response with the portion that occur after the response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	62697	62697	1.059	.3084
Subj. (group)	51	3.01 E6	59229		
B/A the resp.	1	32743	32743	1.2	.2785
B/A the resp. * Exp.	1	6638	6638	.243	.624
B/A the resp. * Subj. (group)	51	1.39 E6	27284		

Mean fixation durations across roadway and level of experience

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	24654	24654	1.64	.2063
Subj.(Group)	50	751703	15034		
Roadway	2	52128	26064	24.8	.0001
Roadway * Exp.	2	3117	1559	1.49	.2314
Roadway * Subj.(Group)	100	104943	1049		

The spread of search along the horizontal meridian across roadway and level of experience (variance of fixation locations)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	.002	.002	4.15 E-4	.9838
Subj.(Group)	50	190.9	3.8		
Roadway	2	130.9	65.4	64.3	.0001
Roadway * Exp.	2	3.5	1.7	1.7	.1848
Roadway * Subj.(Group)	100	101.8	1.02		

The spread of search along the vertical meridian across roadway and level of experience (variance of fixation locations)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	2.26	2.26	8.987	.0042
Subj.(Group)	50	12.57	.251		
Roadway	2	.507	.253	2.194	.1168
Roadway * Exp.	2	.339	.170	1.469	.2352
Roadway * Subj.(Group)	100	11.56	.116		

Saccadic distance (d_0, d_1, d_2) across roadway and experience

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	580.4	580.4	.441	.5096
Subj.(Group)	50	65768	1315		
Sac. Dist.	2	23241	11620.5	158	.0001
Sac. Dist. * Exp.	2	132.8	66.4	.903	.4086
Sac. Dist.* Subj.(Group)	100	7353	73.53		
Roadway	2	28376	14188	90.6	.0001
Road Type * Exp.	2	590	295	1.89	.1572
Road Type * Subj.(Group)	100	15665	156.7		
Sac. Dist. * Roadway	4	342	85.5	1.87	.1180
Sac. Dist. * Roadway * Exp.	4	175	44	.954	.4339
Sac. Dist. * Roadway * Subj.(Group)	200	9173	45.9		

EXPERIMENT 4:

Comparison of saccade latencies across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	90099	90099	3.605	.0680
Subj. (Group)	28	699775	24992		
Dem.	1	3233262	3233262	165.	.0001
Dem. * Exp.	1	3917	3917	.201	.6573
Dem. * Subj.(Group)	28	545552	19484		
Response	1	11195	11195	1.038	.3170
Response * Exp.	1	8482.214	8482.214	.787	.3827
Response * Subj.(Group)	28	301915	10783		
Dem. * Response	1	5542	5542	.528	.4734
Dem. * Response * Exp.	1	7489.306	7489.306	.714	.4053
Dem. * Response * Subj.(Group)	28	293759	10491		

Comparison of mean saccadic inaccuracy across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	2.990	2.990	.305	.5851
Subj. (Group)	28	274.53	9.805		
Dem.	1	.022	.022	.005	.9414
Dem. * Exp.	1	.390	.390	.098	.7560
Dem. * Subj.(Group)	28	110.97	3.963		
Response	1	.192	.192	.092	.7641
Response * Exp.	1	.912	.912	.437	.5139
Response * Subj.(Group)	28	58.435	2.087		
Dem. * Response	1	.696	.696	.532	.4719
Dem. * Response * Exp.	1	.381	.381	.291	.5936
Dem. * Response * Subj.(Group)	28	36.620	1.308		

Comparison of Pre-Target Fixation probabilities across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	.119	.119	2.472	.1271
Subj. (Group)	28	1.347	.048		
Dem.	1	.011	.011	.479	.4944
Dem. * Exp.	1	.009	.009	.369	.5485
Dem. * Subj.(Group)	28	.647	.023		
Response	1	.002	.002	.089	.7675
Response * Exp.	1	.037	.037	1.570	.2205
Response * Subj.(Group)	28	.660	.024		
Dem. * Response	1	.025	.025	1.732	.1988
Dem. * Response * Exp.	1	.007	.007	.495	.4877
Dem. * Response * Subj.(Group)	28	.404	.014		

Comparison of First Fixation Durations across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	4969	4969	.221	.6421
Subj. (Group)	28	630214	22508		
Dem.	1	285162	285162	31.933	.0001
Dem. * Exp.	1	15756	15756	1.764	.1948
Dem. * Subj.(Group)	28	250044	8930		
Response	1	4182	4182	.475	.4964
Response * Exp.	1	24808	24808	2.817	.1044
Response * Subj.(Group)	28	246556	8806		
Dem. * Response	1	23155	23155	3.056	.0914
Dem. * Response * Exp.	1	10222	10222	1.349	.2553
Dem. * Response * Subj.(Group)	28	212154	7577		

Comparison of Gaze Durations across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	30106	30106	.265	.6109
Subj. (Group)	28	3183980	113714		
Dem.	1	1036799	1036799	17.985	.0002
Dem. * Exp.	1	148301	148301	2.573	.1200
Dem. * Subj.(Group)	28	1614134	57648		
Response	1	844	844	.095	.7596
Response * Exp.	1	3239	3239	.366	.5499
Response * Subj.(Group)	28	247679	8846		
Dem. * Response	1	13074	13074	.771	.3875
Dem. * Response * Exp.	1	1439	1439	.085	.7730
Dem. * Response * Subj.(Group)	28	474999	16964		

Comparison of Response Times across demand, experience and response

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	329575	329575	1.119	.2992
Subj. (Group)	28	8247533	294555		
Dem.	1	1.33 E7	1.33 E7	90.617	.0001
Dem. * Exp.	1	367505	367505	2.512	.1242
Dem. * Subj.(Group)	28	4096037	146287		
Response	1	20320.	20320	.755	.3924
Response * Exp.	1	13830	13830	.514	.4795
Response * Subj.(Group)	28	753962	26927		
Dem. * Response	1	12166	12166	.260	.6142
Dem. * Response * Exp.	1	3858	3858	.082	.7762
Dem. * Response * Subj.(Group)	28	1311144	46827		

EXPERIMENT 5:

Comparison of peripheral accuracy across three levels of central demand

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Dem.	2	1662	831	5.207	.0092
Dem. * Subj.(Group)	46	7343	160		

EXPERIMENT 6:

Comparison of peripheral accuracy across central demand and eccentricity

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Subject	9	1684.063	187.118		
Dem.	1	2641.167	2641.167	21.418	.0012
Dem. * Subject	9	1109.854	123.317		
Ecc.	1	2506.417	2506.417	42.479	.0001
Ecc. * Subject	9	531.035	59.004		
Dem. * Ecc.	1	1.753	1.753	.027	.8736
Dem. * Ecc. * Subject	9	588.546	65.394		

EXPERIMENT 7:

Peripheral target hit rates

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	18032	9016	4.531	.0149
Subj. (Group)	57	113430	1990		
Dem.	1	10122	10122	95.8	.0001
Dem. * Exp.	2	84.321	42.161	.399	.6728
Dem. * Subj.(Group)	57	6022	105.643		
OE	3	34110	11370	81.364	.0001
OE * Exp.	6	1757	293	2.096	.0561
OE * Subj. (Group)	171	23896	140		
Dem.* OE	3	507	169	1.429	.2360
Dem.* OE * Exp.	36	1032	172	1.455	.1965
Dem. * OE * Subj.(Group)	171	20216	118		

Peripheral target hit rates (including unsucessfully presented targets)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	3536	1768	3.579	.0343
Subj. (Group)	57	28159	494		
Dem.	1	2588	2588	136.5	.0001
Dem. * Exp.	2	7.523	3.761	.198	.8206
Dem. * Subj.(Group)	57	1081	18.959		

Peripheral target response times

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	729606	364803	4.112	.0215
Subj. (Group)	57	5057232	88723		
Dem.	1	144682	144682	31.025	.0001
Dem. * Exp.	2	1432.586	716	.154	.8580
Dem. * Subj.(Group)	57	265814	4663		
OE	3	50117	16706	3.110	.0279
OE * Exp.	6	13038	2173	.404	.8754
OE * Subj. (Group)	171	918691	5372		
Dem.* OE	3	4954	1651	.406	.7492
Dem.* OE * Exp.	6	32634	5439	1.336	.2438
Dem. * OE * Subj.(Group)	171	696280	4072		

Analysis of the Danger and Difficulty ratings

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	1.217	.609	.400	.6720
Subj. (Group)	57	86.645	1.520		
Ratings	1	5.619	5.619	56.724	.0001
Ratings * Exp.	2	.353	.177	1.784	.1772
Ratings * Subj. (Group)	57	5.646	.099		

Analysis of Mean Fixation Durations

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	74021	37010	1.548	.2215
Error	57	1362988	23912		

Analysis of Mean Fixation Locations across the horizontal meridian

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	2520	1260	.956	.3906
Error	57	75143	1318		

Analysis of Mean Fixation Locations across the horizontal meridian

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	108	54	.103	.9025
Error	57	29929	525		

Analysis of the variance of fixation locations in the horizontal meridian

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	1.36	.680	.090	.9137
Error	57	429	7.528		

Analysis of the variance of fixation locations in the vertical meridian

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	2.996	1.498	.313	.7326
Error	57	272.987	4.789		

Analysis of the Onset Fixation Durations

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	9864185	4.93 E6	2.692	.0763
Subj. (Group)	57	1.044E8	1.83 E6		
hit/miss	1	3.95 E7	3.945E7	71.720	.0001
hit/miss * Exp.	2	1.35 E6	673784	1.225	.3014
hit/miss * Subj. (Group)	57	3.14 E7	550119		
Dem.	1	303	303	.001	.9699
Dem. * Exp.	2	108451	54226	.258	.7734
Dem. * Subj. (Group)	57	1.20 E7	210095		
OE	3	986604	328868	2.570	.0560
OE * Exp.	6	642422	107070	.837	.5432
OE * Subj. (Group)	171	2.19 E7	127982		
hit/miss * Dem.	1	165296	165296	1.179	.2821
hit/miss * Dem.* Exp.	2	206918	103459	.738	.4825
hit/miss * Dem. * Subj. (Group)	57	7.99 E6	140171		
hit/miss * OE	3	221297	73766	.554	.6462
hit/miss * OE * Exp.	6	1065806	177634	1.334	.2447
hit/miss * OE * Subj. (Group)	171	2.28 E7	133187		
demand * OE	3	32449	10816	.079	.9713
demand * OE * Exp.	6	675096	112515	.822	.5543
demand * OE * Subj. (Group)	171	2.34 E7	136892		
hit/miss * Dem. * OE	3	742143	247381	1.838	.1422
hit/miss * Dem. * OE * Exp.	6	764651	127442	.947	.4632
hit/miss * Dem. * OE *Subj. (Group)	171	2.30 E7	134614		

Comparison of target hits and misses over 7° from fixation

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	2	.675	.337	.69	.5055
Subj. (Group)	57	27.9	.489		
OE	1	17.0	16.986	169	.0001
OE * Exp.	2	.457	.229	2.28	.1119
OE * Subj. (Group)	57	5.7	.100		

EXPERIMENT 8:

Peripheral target hit rates

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	9986.142	9986.142	5.279	.0279
Subj. (Group)	34	64314.810	1891.612		
Dem.	1	11842.862	11842.862	87.509	.0001
Dem. * Exp.	1	75.256	75.256	.556	.4610
Dem. * Subj.(Group)	34	4601.335	135.333		
OE	3	14769.940	4923.313	30.528	.0001
OE * Exp.	3	138.614	46.205	.287	.8350
OE * Subj. (Group)	102	16449.654	161.271		
Dem.* OE	3	216.791	72.264	.531	.6620
Dem.* OE * Exp.	3	109.277	36.426	.268	.8486
Dem. * OE * Subj.(Group)	102	13880.588	136.084		

Comparison of target hits and misses over 7° from fixation

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	4.391	4.391	6.992	.0123
Subj. (Group)	34	21.350	.628		
Hit/miss	1	4.105	4.105	15.133	.0004
Hit/miss * Exp.	1	.017	.017	.062	.8050
Hit/miss * Subj. (Group)	34	9.223	.271		

Peripheral target hit rates (including unsucessfully presented targets)

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	3271	3271	8.010	.0078
Subj. (Group)	34	13885	408.369		
Dem.	1	3042	3042	119	.0001
Dem.* Exp.	1	4.9	4.948	.193	.6629
Dem.* Subj. (Group)	34	870	25.56		

Hit rates across all participants according to 500 ms bins

Bin	*Exp'd*	*Learners*
-4000	53.76	30.38
-3500	49.14	32.17
-3000	47.46	20.00
-2500	55.46	37.60
-2000	44.20	21.54
-1500	29.25	8.89
-1000	13.85	11.18
-500	30.53	18.75
500	29.49	11.26
1000	35.58	18.57
1500	44.67	24.83
2000	41.22	28.03
2500	46.73	25.00
3000	49.57	32.82
3500	43.33	32.69
4000	46.67	35.29

Hit rates across all participants according to 200 ms bins

Bin	*Exp'd*	*Learners*
-1500	40.63	11.76
-1300	30.43	10.91
-1100	8.33	9.80
-900	18.00	8.70
-700	16.95	11.29
-500	20.00	7.55
-300	44.44	25.30
-100	24.53	13.11
100	34.48	15.69
300	30.51	9.52
700	26.79	10.00
900	40.00	25.81
1100	38.81	22.41
1300	41.94	19.67
1500	51.72	29.63

Response times to peripheral target lights

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	245177	245177	4.015	.0531
Subj. (Group)	34	2076070	61061		
Dem.	1	73144	73144	5.526	.0247
Dem. * Exp.	1	23560	2360	.178	.6755
Dem. * Subj.(Group)	34	449993	13235		
OE	3	29817	9939	1.090	.3567
OE* Exp.	3	2941	980	.108	.9555
OE*Subj. (Group)	102	929691	9115		
Dem.* OE	3	55760	18587	2.217	.0907
Dem.* OE*Exp.	3	12349	4116	.491	.6893
Dem. * OE * Subj.(Group)	102	855110	8383.432		

t-test performed upon the Mean Fixation Durations

	Exp'd	*Learners*
Mean	472.43	495.01
Variance	26918.59	22073.54
Observations	18	18
Pooled Variance	24496.06	
df	34	
t Stat	-0.43	

t-test performed upon the mean fixation locations in the horizontal meridian

	Exp'd	*Learners*
Mean	297.00	305.26
Variance	2517.10	2172.22
Observations	18.00	18.00
Pooled Variance	2344.66	
df	34.00	
t Stat	-0.51	

t-test performed upon the mean fixation locations in the vertical meridian

	Exp'd	Learners
Mean	266.37	258.83
Variance	576.28	359.56
Observations	18.00	18.00
Pooled Variance	467.92	
df	34.00	
t Stat	1.05	

t-test performed upon the variance of fixation locations in the horizontal meridian

	Exp'd	Learners
Mean	7.91	6.38
Variance	6.71	4.39
Observations	18.00	18.00
Pooled Variance	5.55	
df	34.00	
t Stat	1.95	

t-test performed upon the variance of fixation locations in the vertical meridian

	Exp'd	Learners
Mean	2.19	2.03
Variance	2.22	8.46
Observations	18.00	18.00
Pooled Variance	5.34	
df	34.00	
t Stat	0.19	

Analysis of the Onset Fixation Durations

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Exp.	1	91179	91179	.035	.8525
Subj. (Group)	34	8.83 E7	2.60 E6		
hit/miss	1	9.07 E6	9.08 E6	25.336	.0001
hit/miss * Exp.	1	4.02 E5	4.02 E5	1.122	.2970
hit/miss * Subj. (Group)	34	1.22 E7	3.59 E5		
Dem.	1	110694	1.15	.354	.5556
Dem. * Exp.	1	376944	376944	1.207	.2797
Dem. * Subj. (Group)	34	1.06 E7	312383		
OE	3	979767	326589	2.122	.1021
OE * Exp.	3	64978	21659	.141	.9354
OE * Subj. (Group)	102	1.57 E7	153940		
hit/miss * Dem.	1	320403	320403	2.166	.1503
hit/miss * Dem.* Exp.	1	772	772	.005	.9428
hit/miss * Dem. * Subj. (Group)	34	5.03 E6	147929		
hit/miss * OE	3	203729	67907	.555	.6456
hit/miss * OE * Exp.	3	938660	312887	2.559	.0592
hit/miss * OE * Subj. (Group)	102	1.25 E7	122255		
demand * OE	3	419726	139909	1.054	.3724
demand * OE * Exp.	3	70396	23465	.177	.9120
demand * OE * Subj. (Group)	102	1.35 E7	132803		
hit/miss * Dem. * OE	3	111623	37208	.397	.7554
hit/miss * Dem. * OE * Exp.	3	121446	40482	.432	.7306
hit/miss * Dem. * OE *Subj. (Group)	102	9559110	93717		

t-test performed upon the Hazard Perception Scores

	Exp'd	Learners
Mean	43.80	44.75
Variance	83.02	149.60
Observations	18.00	18.00
Pooled Variance	116.31	
df	34.00	
t Stat	-0.27	

t-test performed upon the Hazard Perception Response Times

	Exp'd	Learners
Mean	1405.19	1502.28
Variance	59986.17	78951.41
Observations	18.00	18.00
Pooled Variance	69468.79	
df	34.00	
t Stat	-1.11	

t-test performed upon the number of Hazard Perception Responses

	Exp'd	Learners
Mean	82.22	84.33
Variance	1483.01	2757.76
Observations	18.00	18.00
Pooled Variance	2120.39	
df	34.00	
t Stat	-0.14	

Comparison of the experienced driver groups from experiments 7 and 8

Source	*df*	*SS*	*MS*	*F-Value*	*P-Value*
Expt.7 vs Expt.8	1	34558	34558	20.140	.0001
Subj. (Group)	36	61771	1716		
Dem.	1	7521	7521	96.911	.0001
Dem. * Expt.7 vs Expt.8	1	235	235	3.032	.0902
Dem. * Subj. (Group)	36	2794	77.608		
OE	3	19129	6376	40.393	.0001
OE * Expt.7 vs Expt.8	3	617	206	1.303	.2774
OE * Subject(Group)	108	17049	158		
Dem. * OE	3	157	52	.392	.7586
Dem. * OE * Expt.7 vs Expt.8	3	232	77	.580	.6292
Dem. * OE * Subj. (Group)	108	14362	133		

Appendix 3 – Instructions to participants

This appendix details the specific instructions given to the participants in each experiment.

Experiment 1: Concurrent verbalisation and hazard detection

You are going to be shown a total of 13 video clips which have been taken from the driver's perspective. Each clip lasts less than a minute though it will contain at least one *potential hazard*. We define a potential hazard as anything you see that would make you consider taking evasive action, such as braking or steering to avoid something. For example potential hazards could include a car emerging suddenly from a side road, or the vehicle that you are following suddenly braking.

You should watch these video clips as if you are the driver, looking for these potential hazards. When you see a potential hazard you should press the mouse button in front of you as quickly as possible. The computer will beep to let you know that the response has been recorded. There is no limit to how many times you can press the mouse button but please try to judge whether things in the video clips are hazardous, rather than just pressing all the time.

A). While you watch the clips we will monitor your eye movements with an eye tracker. In addition you should report verbally anything in the visual scene that you look at or that attracts your attention. You don't have to report things all the time, but when you realise that you are paying attention to something please tell us what it is by speaking into the microphone in front of you.

B). While you watch the clips we will monitor your eye movements with an eye tracker. In addition you should report verbally anything in the visual scene that you look at or that attracts your attention. You don't have to report things all the time, but when you realise that you are paying attention to something please tell us what it is by speaking into the microphone in front of you. When you do report items in the visual scene try to limit your utterances to one or two words rather than in sentences.

C). While you watch the clips we will monitor your eye movements with an eye tracker.

Before we calibrate the eye tracker you can press the mouse button to view a practice clip.

(You have the right to withdraw from this study at any point.)

[A practice clip of a cyclist emerging from a hidden side road is shown to all participants. They were also encouraged to verbalise if they belonged to group A or B. After the clip the participants were told that the cyclist was the hazard.]

Experiment 2: On-road measurement of eye movements

[Read to the participants by the experimenter sat in the back seat of the instrumented vehicle]

This drive will take roughly an hour to complete. You should drive in your normal manner while observing legal restrictions imposed by road signs. I will sit in the back of the car throughout the experiment and will tell you where to turn at roughly the same time you would see the appropriate traffic sign. The first twenty minutes of the drive are classed as a familiarisation drive. This gives you a chance to get used to the car and to the instructions. After the familiarisation I will ask you to stop at a certain point. At this half way point you will be calibrated on the head mounted eye tracker, and then asked to return to the university via a different route according to my instructions. At all times you should try to drive just as you would do normally.

If at any time you wish to stop the study for whatever reason, please indicate and pull over when safe to do so.

Experiment 3: In-lab measurement of eye movements

You are going to be shown a total of 13 video clips which have been taken from the driver's perspective. Each clip lasts less than a minute though it will contain at least one *potential hazard*. We define a potential hazard as anything you see that would make you consider taking evasive action, such as braking or steering to avoid something. For example potential hazards could include a car emerging suddenly from a side road, or the vehicle that you are following suddenly braking.

You should watch these video clips as if you are the driver, looking for these potential hazards. When you see a potential hazard you should press the mouse button in front of you as quickly as possible. The computer will beep to let you know that the response has been recorded. There is no limit to how many times you can press the mouse button but please try to judge whether things in the video clips are hazardous, rather than just pressing all the time.

While you are watching the clips your eye movements will be monitored by an eye tracker. This requires you to place your head in a chin rest. Velcro straps will secure your head in position. Before the clips you will undergo a calibration on the eye tracker. During calibration you should follow the instructions on the experimenter in the room.

Try to keep your head as still as possible while being eye tracked. Any movements can result in lost data.

You have the right to withdraw from this study at any point.

Experiment 4: An initial attempt to reduce attention to extra-foveal stimuli due to an increase in the cognitive demand of a foveal stimulus

[These instructions were presented on three slides on the computer along with examples of the stimuli].

High Demand Block

This part of the experiment will display 30 slides. Before each slide is presented you must stare at the cross at the centre of the screen. The next slide will only be displayed if the computer is sure you are staring at the centre. Each consists of two red triangle warning signs – one at the centre of the screen and the second either to the left or to the right of the centre. The centre sign will contain one six letters: either a consonant (R, F, V) or a vowel (A, E, U). If the letter in the centre is a consonant you should press the "N" button as quickly as possible. This aborts that slide and moves on to the next. If the central letter is a vowel you should then move your eyes to the second sign either to the left or right of centre. This sign will either contain a staggered junction sign or a right hand bend sign [samples of all stimuli are shown to participants on the screen]. If it is the staggered junction then you should press "Y" as quickly as possible. If it is the right hand bend junction then you should press "N" as quickly as possible. After this you will return to the fixation cross. Once the computer is sure that you are looking at the centre once again then the next slide will be presented.

While you are watching the clips your eye movements will be monitored by an eye tracker. This requires you to place your head in a chin rest. Velcro straps will secure your head in position. Before the clips you will undergo a calibration on the eye tracker. During calibration you should follow the instructions on the experimenter in the room.

Try to keep your head as still as possible while being eye tracked. Any movements can result in lost data.

You have the right to withdraw from this study at any point.

Low Demand Block

This part of the experiment will display 30 slides. Before each slide is presented you must stare at the cross at the centre of the screen. The next slide will only be displayed if the computer is sure you are staring at the centre. Each consists of two red triangle warning signs – one at the centre of the screen and the second either to the left or to the right of the centre. The centre sign will contain one six letters (A, E, F, R, U, V). Ignoring the letter, you should move your eyes to the second sign either to the left or right of centre. Try to always move your eyes in the correct direction. Do not move your eyes left if the second sign is to the right of centre. This second sign will either contain a staggered junction sign or a right hand bend sign [samples of all stimuli are shown to participants on the screen]. If it is the staggered junction then you should press "Y" as quickly as possible. If it is the right hand bend junction then you should press

"N" as quickly as possible. After this you will return to the fixation cross. Once the computer is sure that you are looking at the centre once again then the next slide will be presented.

While you are watching the clips your eye movements will be monitored by an eye tracker. This requires you to place your head in a chin rest. Velcro straps will secure your head in position. Before the clips you will undergo a calibration on the eye tracker. During calibration you should follow the instructions on the experimenter in the room.

Try to keep your head as still as possible while being eye tracked. Any movements can result in lost data.

You have the right to withdraw from this study at any point.

Experiment 5: Manipulating foveal load with two extra-foveal stimuli

[These instructions were presented on screen with relevant stimuli (see Fig. 4.3). The three blocks were **A)**. orientation detection, **B)**. colour detection, and **C)**. feature integration].

This part of the experiment will display30 triplets of slides. The first of the slides is a fixation cross that you should stare at. When this disappears the second slide of the triplet will be presented for a very short amount of time. You will not have time to move your eyes during the presentation of the second slide so please keep your eyes at the centre of the screen. The second slide contains three placeholders – one in the centre, one to the left and one to the right of centre. The centre placeholder contains either a red or green arrow head pointing toward the left or the right. The other two placeholders will contain one of six letters (A, E, G, K, P, U). The second slide will be quickly replace by the third slide which will ask you what you saw in the second slide. You should tell the experimenter...

A). which direction the arrow was pointing to (left or right) and what letter is pointing to;

B). what colour the arrow was (red or green) and the letter to the left (if the arrow was green) or to the right (if the arrow was red);

C). what direction the arrow was pointing to (if the arrow was green) or the opposite direction (if the arrow was red), and what letter the arrow was pointing to (if the arrow was green) or was not pointing to (if the arrow was red).

Experiment 6: Investigating the influence of eccentricity

[The instructions were the same as those for experiment 5, though the colour detection condition was dropped and an eccentricity factor was included].

Experiment 7: The effect of experience upon detecting peripheral targets during a driving related task

[Given to participants to read prior to the experiment]

You are going to be shown a total of 39 video clips which have been taken from the driver's perspective. Each of these clips contains at least one *potential hazard*. We define a potential hazard as anything you see that would make you consider taking evasive action, such as braking or steering to avoid something.

You should watch these video clips as if you are the driver, looking for these potential hazards. At the end of each clip you will be asked how DANGEROUS you think it would be to drive though that particular (that is, what risk of accident or injury?) and how DIFFICULT it would be to drive through (that is, regardless of the likelihood of an accident, how hard would you have to concentrate to navigate the clip in real life). The appearances of the hazards should help you in this assessment so keep an eye open for them.

[Participants were provided with practice on the rating system displayed between the clips. This was a simple Likert scale with a cursor controlled by the PC mouse].

Overlaid on the driving scene are four red boxes each with a smaller box inside. You will notice, from time to time, a brief white flash will appear in one of the smaller boxes. When you see a white flash you should press the Y button on the mouse in front of you. The white lights will usually be spotted out of the corner of your eye. Please don't stare at one of the red boxes waiting for a white light, or just move your eyes from box to box hoping to catch one; the main aim of this study is that you *search for the hazards* and respond to them as quickly as possible with the foot pedal, but any lights you *do* see should be responded to with the Y button.

The clips will be shown to you in four blocks, with a brief break in-between blocks. Once the first clip of a block has finished the screen will display a message asking you to press a button to continue. The next clip will not start until you have pressed the button.

While being eye tracked it is important to keep your head as still as possible throughout the block. Please try not to speak during the experiment as this may disrupt calibration. If you have any questions please ask the experimenter now.

Experiment 8: An attempt to produce Tunnel Vision through the inclusion of a speeded response as the primary task

[Given to participants to read prior to the experiment]

You are going to be shown a total of 39 video clips which have been taken from the driver's perspective. Each of these clips contains at least one *potential hazard*. We define a potential hazard as anything you see that would make you consider taking evasive action, such as braking or steering to avoid something.

You should watch these video clips as if you are the driver, looking for these potential hazards. When you see a potential hazard you should press the foot pedal as quickly as possible. You will know when the foot pedal is depressed as the computer will beep. Your foot should normally rest at the side of the foot pedal, and you do not need to hold the pedal down when you notice a hazard; just tap the pedal to acknowledge the hazard. There is no limit to how many times you can press the foot pedal but please try to judge whether things in the video clips are hazardous, rather than just pressing all the time.

Overlaid on the driving scene are four red boxes each with a smaller box inside. You will notice, from time to time, a brief white flash will appear in one of the smaller boxes. When you see a white flash you should press the Y button on the mouse in front of you. The white lights will usually be spotted out of the corner of your eye. Please don't stare at one of the red boxes waiting for a white light, or just move your eyes from box to box hoping to catch one; the main aim of this study is that you *search for the hazards* and respond to them as quickly as possible with the foot pedal, but any lights you *do* see should be responded to with the Y button.

The clips will be shown to you in four blocks, with a brief break in-between blocks. Once the first clip of a block has finished the screen will display a message asking you to press a button to continue. The next clip will not start until you have pressed the button.

While being eye tracked it is important to keep your head as still as possible throughout the block. Please try not to speak during the experiment as this may disrupt calibration. If you have any questions please ask the experimenter now.