Investigating drivers' visual search strategies: Towards an efficient training intervention.

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Abstract

Road crashes are the main cause of death of young people in the developed world. The factors that cause traffic crashes are numerous; however, most researchers agree that a lack of driving experience is a major contributing factor. Another reason that has been reported for the increased crashes is that novice drivers have not developed the optimum visual search strategies of their more experienced counterparts. Although several training interventions have tried to improve scanning of novice drivers, they have limited success. The aims of this Thesis are to identify some parameters that influence visual search and to develop an efficient training intervention that will improve drivers' visual skills. In Experiment 1 an image-based questionnaire was used to assess driving instructors' and novice drivers' priority ratings to different areas of the driving scene. Results showed that for both groups the opinions regarding visual field prioritisation were highly consistent when compared to chance. Despite the rating consistencies, group differences were found, across all scenarios with "Rear View Mirrors" being the visual field with the most frequent observed group differences. Certain categories ("Road Ahead" and "Mirrors") were highly ranked across all scenarios, while other categories were more scenario specific. In Experiments 2 & 3 a novel experimental paradigm was used to investigate the interaction bottom-up and top-down influences upon drivers' visual attention. Analysis showed that participants' fixation locations had a stronger relationship with where participants clicked (top down) than with saliency peaks (bottom up). In Experiments 4 & 5 the difference in eye movements between driving instructors and learner drivers was examined during simulated driving. Results showed that driving instructors had an increased sampling rate, shorter processing time and broader scanning of the road than learner drivers. Scenario-specific analysis showed that instructors fixated more than learners on side mirrors while learners showed higher visual allocation to the rear view mirror. It was also found that poor visibility conditions and especially rain decrease the effectiveness of drivers' visual search. Finally in Experiments 6, 7 & 8 we asked how we can improve learner drivers' visual skills. Results from Experiments 6 & 7 demonstrated that the ability to distinguish between the eye movements of learner drivers and driving instructors improved as the number of objective differences between the two groups increased across specific scenarios. In Experiment 8 a pilot study showed that a scenario specific training intervention can improve certain aspects of learner drivers' visual skills. The findings of this Thesis have both theoretical and practical implications regarding drivers' visual search.

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It was one of my dreams to do a PhD and conduct scientific research at this level and now that the journey has ended I can really state that reality has exceeded my expectations. During my PhD I had some memorable experiences and met some individuals that inspired me and supported me.

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Μακριά απ΄τη λοιμική της πολιτείας, ονειρεύτηκα στο πλάι της μιαν ερημιά, όπου το δάκρυ να μην έχει νόημα, κι όπου το μόνο φως να ΄ναι από την πυρά που κατατρέγει όλα μου τα υπάρχοντα.

Ώμο τον ώμο οι δυο μαζί ν΄αντέχουμε το βάρος από τα μελλούμενα, ορκισμένοι στην άκρα σιγαλιά και στη συμβασιλεία των άστρων.

Σαν να μην κάτεχα, ο αγράμματος, πως είναι ΄κει ακριβώς, μέσα στην άκρα σιγαλιά, που ακούγονται οι πιο αποτρόπαιοι κρότοι.

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Οδυσσέας Ελύτης

Chapter 1: Literature Review

1.1 Introduction

1.1.1 Driving in everyday life

Driving has become an everyday task and the ability to drive is considered as a necessity. Despite the development of public transport systems, it seems that during the last decade, citizens of the developed world used their cars as the favoured method of transportation (Ball, Owsley, Sloane, Roenker, & Bruni, 1993). Usually the successful completion of the driving task is taken as granted. However, it is a well known and bitter fact that driving accidents occur.

1.1.2 Traffic crashes

The number of traffic crashes has decreased over the last decade both in USA and Europe (Eurostat, 2007; NHTSA, 2006). This decrease could be attributed to many factors, amongst which are the development of new approaches to drivers' training; such as the graduated driver licensing, (Hedlund, 2007) or the technological advancement of cars (Reimer, D'Ambrosio, & Coughlin, 2007). However, despite this reduction, traffic crashes are still the most common cause of death for people aged less than 40 in the developed world (Plainis, Murray, & Pallikaris, 2006). Based on this disappointing statistic, it is evident that more efficient traffic education programmes need to be developed (Mayhew, 2007). In addition, further investigation and understanding of accident causes seems essential.

1.1.3 Psychology and driving

Several organisations around the world are concerned with the development of safer and accident free driving environments. The discipline of psychology has offered a plethora of insights (Ranney, 1994; Trick, Enns, Mills, & Vavrik, 2004) especially about the cognitive processes and limitations of drivers. The fields of cognitive and applied psychology have developed some experimental paradigms in order to investigate the role of human behaviour and cognition upon driving. However, this attempt to explore and explain driver's behaviour has not yet produced a consistent methodology and unified findings. Ranney (1994) concluded that "it has never been clear whether theories should explain everyday driving, or accident – causing behaviours, or both" (p. 733). Due to this differentiation of methods many questions still remain unanswered and will be raised later in this Thesis.

The aim of driving research should not be only to describe the attributes and processes during driving. New approaches and methodologies need to be developed in order to improve drivers' understanding and driving behaviour. Indeed it was suggested (Crundall, 2005; Deery, 1999) that new training interventions are necessary for young novice drivers to develop better attentional strategies regarding hazard perception.

1.1.4 Chapter overview

The purpose of this Chapter is to review and discuss the literature related to driving research. The relevant theories will be linked to experimental driving research in order to bring together both the theoretical and applied aspects of the field. The implications of the most influential theories and methodologies would be described and discussed. Also some training attempts related to drivers' visual search will be presented. The research questions that will form the focus of this Thesis will then be mentioned. Finally the structure of the Thesis will be outlined.

1.2 Driving Experience

1.2.1 Traffic accident causes

Since driving is such a complex task (Groeger & Banks, 2007) the explanations for the occurrence of traffic accidents are numerous and include a wide range of variables (Reimer et al., 2007). Some factors that affect driving performance and may therefore impact upon crash liability include, risky behaviour (Clarke, Ward, & Truman, 2005), type of road (Crundall & Underwood, 1998), cognitive load (Lee, Lee, & Boyle, 2007), time of day (Lenné, Triggs, & Redman, 1997), weather conditions (Edwards, 1998), age (Twisk & Stacey, 2007), driving experience (Crundall, Underwood, & Chapman, 1999), visual attention (Ball et al., 1993), gender (Laapotti & Keskinen, 1998), lifestyle (Chliaoutakis, Koukouli, Lajunen, & Tzamalouka, 2005) and nationality (Ozkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). Hence, the potential number of factors makes the explanation of traffic accidents far from straightforward and it is beyond the scope of the Thesis to cover all these factors. This Chapter will focus more on the experiential differences in visual attention and the conditions that can influence this link.

1.2.2 Young novice drivers

Despite the aforementioned variation in traffic accident causes most researchers agree that the major contributors to traffic safety is driving experience and age, with young novice drivers having up to nine times higher crashing rate than more experienced drivers (Pradhan et al., 2005). It is indeed a fact that novice drivers are overrepresented into road accidents data (Deery, 1999; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). Some researchers (Clarke et al., 2005) suggested that this increased accident liability of young drivers is a result of their risk taking behaviour. Yet a large body of research throughout the literature (Crundall & Underwood, 1998; Deery, 1999; Underwood, Chapman, Bowden, & Crundall, 2002b) suggests that novice drivers have not yet developed an adequate attentional model in order to guide their visual search onto potential hazards and other important information for drivers.

1.2.3 Driving elements

On this line it could be said that when social and attitudinal factors are accounted for there are at least two main elements necessary in order to complete driving with safety; motor skills and cognitive elements (Deery, 1999). In regards to the importance of motor skills in driving it has been claimed that car handling skills can be acquired after 15 hours of practice (Hall & West, 1996) hence they might not be as crucial as other factors. Indeed, many researchers have been more concerned with the cognitive aspects of driving (Lee, 2008) with findings stating that attention (and distraction) are major causes of traffic accidents (Ball et al., 1993; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Trick et al., 2004).

1.3 Visual attention

1.3.1 Theories of attention and driving

It is not within the scope of the Thesis in general and of this Chapter in particular, to present an exhaustive review of attentional theories and driving (for a review see: Driver, 2001; Trick et al., 2004). One reason that there is a difficulty in dealing with attentional aspects of driving is stated by Trick et al., "the research on attention is fragmented, and the applied research on driving and attention is further split between three largely independent traditions: the experimental research, the differential crash rate research, and the automation research" (p. 385). In addition the number of published papers related to attention and visual search has increased dramatically the last 25 years (Nothdurft, 2006). In order to overcome those difficulties this section will try to be accurate by presenting only the very basic aspects of attentional theories related to experimental driving research.

1.3.2 Visual attention and evolution

Before the presentation of the link between visual attention and driving it is essential to mention some theoretical perspectives of visual attention. Visual attention is a necessity for survival since the neurophysiology and anatomy of the primate visual system and brain functions does not allow the processing of all the available information. This behavioural restriction led to the evolution of attention. Visual attention allows a step by step processing of the given stimuli. In evolutionary terms it has been proposed (Treue, 2001) that visual attention is a mechanism that controls the flow of information into the sensory system. Possible reasons for this control mechanism are the inability of the system to process all the available visual information (Kahneman, 1973) and moreover to filter out behaviourally irrelevant information.

1.3.3 Attentional spotlight

According to Trick et al (2004) one source of debate regarding attention is the assumption that attention is unified with awareness. In this Thesis, the view that attention is different from awareness (Lamme, 2003) would be considered as prominent. The most common analogy about attention is the “spotlight” metaphor (Eriksen & Eriksen, 1974). It was proposed that attention moves like a spotlight and attends to a certain area in a scene. Inside that area visual information is processed in more detail in relation to visual stimuli outside this area. The “spotlight” moves in accordance with eye movements (more about eye-movements methodology and measures will be presented in Chapter 2) and attends the selected area. This is called overt attention (Itti & Koch, 2000). However, attention is possible without eye movements (Itti & Koch, 2001) and this process is called covert attention. Initially it was believed that this spotlight was space based, meaning that it had only spatial properties. Other findings proposed that attention can be object based (Driver, 2001). That means that attention shifts in relation to the objects of interest or to the objects that attract attention. Nevertheless, many researchers suggested that object and space based attention reintegrate (Lavie & Driver, 1996; Logan, 1996).

1.3.4 Change and inattentional blindness

In contrast with the initial theoretical aspects of the "spotlight" metaphor there are research findings that investigated what happens outside the locus of attention and it has been suggested that it is possible to neglect stimuli outside the "spotlight". This has been demonstrated by two types of inattention, change and inattentional blindness. Change blindness occurs when someone is unable to identify changes between two similar pictures after a medium, such as a flicker screen, has intervened. In order to investigate the relation of change blindness and driving one study (Galpin, Underwood, & Crundall, 2009) showed participants a road picture for 1s. After that a blue screen flashed and the road picture was presented again with a change (e.g. lane markings were missing). Participants had difficulties to spot the change in relation to the original image. However, research on that field and the precise effects on driving need further exploration before any safe conclusions can be drawn.

Inattentional blindness is the condition that someone is focused on a particular task while at the same time neglects surrounding stimuli again, outside the "spotlight". Research (Crundall, Shenton, & Underwood, 2004) investigated whether inattentional blindness can cause attentional narrowing on a driving related task. The experimenters recruited 15 participants and they recorded their eye movements while they were playing a computer game. During control trials subjects had to free-drive through a simulated city, while during the experimental trials they had also to follow a car. Results showed that during intentional car-following participants produced less horizontal search, they had longer fixations, they neglected pedestrians, and they made more traffic violations and had more crashes. Crundall et al. concluded that it is beyond doubt that car following narrows attention. Participants neglected the majority of visual information while they focussed on the car in front even when the amount of time that a lead vehicle was ahead was controlled. The authors suggested that this attentional capture might be the explanation for crashes during police pursuits or related driving situations and the most likely explanation for these results is inattentional blindness. However, one has to be cautions when interpreting these results since the experimental methodology involved a commercial driving game that does not provide certain aspect of experimental control.

1.3.5 Useful field of view

So far some theories that describe the operation of visual attention have been described together with some experimental work that is related with aspects of driving. Yet it is not well defined how attention with its mechanisms is linked with driving and how it influences drivers' performance. As mentioned before, visual attention is considered a major contributing factor in road accidents (Recarte & Nunes, 2003; Trick et al., 2004). Also visual attention effectiveness during driving can influence either the successfulness or the failure of the driving task.

Despite the fact the driving is a highly visual task; the attentional demands of this task might play a more crucial role in effectively performing this task than the sensory properties of vision. Of course the ideal is for both cognitive and sensory systems to work in a harmonised way. Researchers (Ball et al., 1993) emphasised that although driving is a highly visual task there is a low correlation between driving accidents and visual impairments. However, they found a significant correlation between the “useful field of view” (UFOV) and crash rates at an elderly population. By UFOV they meant the measurement of the area that someone can have a state of alertness and respond to stimuli (i.e. the extent of functional peripheral vision). They concluded that a visual test that underlines more the cognitive components of vision is a more appropriate tool to predict crash rates, in other words in order to prevent more accidents we need to make sure that the driving population is attentionally fit. One may say that undoubtedly that vision corrected to normal is an influencing factor. However, the major elements that contribute to safe driving are the attentional elements of vision.

1.3.6 Summary on visual attention

Summarising the findings from this section it could be said that there is a strong link between visual attention and driving performance. However, there are some theoretical and practical implications in regards to the ways that visual attention operates and affects driving. In regards to the “spotlight” it could be said that its size varies and can be associated with the UFOV that has been shown to be closely related with driving performance. Also, as it was presented above it is possible to neglect changes outside the field of view. Despite the fact that visual attention theories and experimental methodologies have offered some insight in regards to driving it seems that there must an interaction with another factor that can better explain driving characteristics and mechanisms.

1.4 Driving experience and visual attention

1.4.1 Experience and visual search

So far driving experience and visual attention were described separately and they are considered to be major contributing factors to traffic accidents. However, they are far from distinct and their link has been clearly demonstrated both on theoretical and applied research findings. Cognitive processes in the form of visual attention and eye movements affect the control of everyday tasks (Land, 2006). Visual search properties are not consistent across tasks even when the visual array remains the same and they depend on the nature of the intended action (Yarbus, 1967). In addition it has been suggested that task-related visual search patterns are learned and adequate learning results in a pro-active behaviour of visual allocation (Hayhoe & Ballard, 2005). Although the link between attention and performance is not always clear (Pashler, Johnston, & Ruthruff, 2001) usually task-experience results in more efficient visual search patterns.

The effects of experience and expertise on visual attention and visual search patterns have been demonstrated in a variety of tasks. For example differences have been found in visual search between experts and intermediate chess players with experts having a more efficient search than intermediates (Charness, Reingold, Pomplun, & Stampe, 2001). More recently a similar methodology found that this difference in chess players is greater when the pieces on the chess board are positioned in a semantically meaningful pattern rather than a random pattern (Brockmole, Hambrick, Windisch, & Henderson, 2008). Also Land and McLeod (2000) found that "good" cricket batsmen had smaller saccade latencies than "poor" batsmen or non-players.

1.4.2 Driving experience and visual search

In regards to driving it could be said that proficient visual attention allocation has been linked with better driving safety (Ball et al., 1993) and failures of attention can have adverse effects such as traffic crashes (Trick et al., 2004). It has been proposed that novice drivers have not developed the efficient visual search strategies of their more experienced counterparts (Crundall & Underwood, 1998). Crundall and Underwood found that experienced drivers have an increased sampling rate of the visual scene compared to novice drivers, with a greater number of shorter fixations. In addition they found increased horizontal scanning of the road for experienced drivers on certain roadways. Chapman and Underwood (1998) showed that novice drivers had longer fixations while watching driving video clips compared to experienced drivers suggesting increased processing time. Novices' mean fixation duration became even longer during dangerous driving situations.

In addition to general eye movement differences, specific regions of the driving scene have been found to attract attention differently depending on driving experience and road type. Recarte and Nunes (2000) reported that participants who drove on both motorways and urban roads produced more fixations on in-car controls than in the nearside mirror and rear view mirror. Also they found that the nearside mirror attracted more fixations than the rear view mirror. Regarding experience Underwood, Crundall and Chapman (2002a) have shown that novice drivers have a greater number of fixations on the rear view mirror than experienced drivers while experienced drivers fixate more on the nearside mirror than novice drivers. Furthermore inexperienced drivers tend to direct their attention more to in-car objects than experienced drivers

1.4.3 Driving experience and peripheral field of view

Crundall et al (1999) investigated the interaction of driving experience and peripheral field of view. They used three groups of participants with variable driving experience (20 experienced, 20 novices and 20 non drivers). Participants watched some driving videos which contained at least one hazardous event. The primary task was to evaluate how hazardous each clip was. On the presentation screen there were four placeholders at the top-middle, left-middle, right-middle and bottom-middle of the edges of the screen. During the video small lights would randomly appear within the placeholders. The secondary task was to press a response key when this light was detected by participants. Results showed that experienced drivers had the most correct identifications of peripheral targets with non drivers being the worst. Again driving experience played a major role in attending to visual targets even outside the central field. This indicates that the functional field of view becomes greater with driving experience since experienced participants identified more targets. Despite the plausible explanations of the results there are some issues that need further discussion. One criticism might be the viewing conditions because participants had their head on a chin rest so that might be a restriction of visual strategies and ecological validity issues.

1.4.4 Summary on driving experience and visual attention

The research presented here clearly demonstrated that experience produces a different visual search than novice drivers and we tend to assume that experienced drivers have more effective visual skills because they have fewer accidents. However, it remains unclear if this "expertise" can be transferred through training (i.e. bypass experience built up over years with more explicit training). This raises the further question about whether their skills can be learnt explicitly.

1.5 Training

1.5.1 Current drivers' training

As it was mentioned above (see section 1.1.2) the disappointing crash statistics of young novice drivers, have generated some concerns about the efficiency of current training systems (Fisher, Pollatsek, & Pradhan, 2006; Mayhew, 2007). Although there is variability between drivers' training systems across different European countries (Twisk & Stacey, 2007) as well as within the USA (Hedlund, 2007) there is no hard evidence to suggest that current training systems produce safe drivers. By acknowledging the limitations of current systems some corrective actions, like the extended pre-licensing practice in Sweden (Gregersen et al., 2000) and the graduated driver licensing (GDL) in USA (Shope & Molnar, 2002), have been implemented with some success. GDL in particular has managed to reduce the traffic crashes of young novice drivers (Hedlund, 2007) but it has been proposed that further developments are necessary since there might be some aspects of driving that cannot be developed under restricted driving (Foss, 2007).

1.5.2 Training interventions

Although there are training systems that target the development of various skills and attributes of driving, here we will describe some interventions that aimed to affect the cognitive factors of driving and more specifically visual attention. Based on these reports, there have been some attempts to develop training interventions that can improve drivers' visual attention. Probably the most well known addition to the UK' formal driver training is hazard perception which was included into the driving test in 2002 and is based on the work of McKenna and Crick (1994) in which they found that experienced drivers respond faster to video-based driving hazards. However, the hazard perception test has received some criticism regarding its effectiveness (Underwood, 2007).

More recently a pragmatic and ecologically valid methodology has been used to enhance drivers' knowledge, skills and attitudes (Stanton, Walker, Young, Kazi, & Salmon, 2007). Stanton et al used an advanced coaching system in order to achieve better overall driving performance. The training included a combination of methods such as car control, individualised coaching and insight training. Results showed that participants that received the training had better situation awareness, driving skills and less external locus of controls in comparison to the control groups. However, the duration and the extent of this enhancement are not clear yet. Also, the extent of the training would make it too costly for it to become widespread. Finally, advanced coaching systems address the improvement of current drivers while the high risk of newly qualified drivers cannot be assisted by such training.

1.5.3 Eye movement training

Despite the popularity of eye movements' research it is only relatively recently that training interventions have targeted drivers' eye movements. In one experimental methodology, visual feedback was used in order to provide drivers with an indication of their off-road glances (Donmez, Boyle, & Lee, 2007). During simulated driving participants received a visual warning that informed them in regards to their off-road glances. When participants inspected off-road areas above a certain threshold point a visual warning was displayed into two locations; either vehicle-centred or though an in-car information system display. The results of this study showed that with feedback, independently of location, drivers reduced their off-road glances. Although there is a debate in regard to the appropriate algorithm that calculates off-road distraction (Kircher, 2007), these results show potential in helping drivers keep their eyes on the road, but it cannot tell you where to look on the road to stay safe.

However, this methodology is still at the initial phase and needs to be further replicated in a more realistic driving situation.

In regards to hazard perception and visual search training there are some promising research findings (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006). Pollatsek et al recruited young novice drivers and gave them 10 top-down views of driving scenarios and participants had to indicate the points they would look at if they were driving in that situation. After this, audiovisual feedback was provided to participants to indicate the most efficient visual search pattern in the given scenario. Following this feedback some questions were given to participants in order to reinforce the knowledge elements of each scenario. Results showed that correct responses after the training were significantly higher than at pre-test, indicating an efficiency of the programme at least for similar types of scenarios and stimuli. Immediately after this training the trained group was compared to a control (untrained) group on a driving simulator in driving scenarios that were either very similar to the top-down views or novel to both groups of novices. Results showed that trained novices inspected the location of potential risk more than untrained drivers in both types of scenario.

Overall it was found that training via top-down images had some transferability to a dynamic driving environment and improved participants' hazard perception skill as indicated by eye movements. However, the simulated driving was delivered immediately after the training and it is not clear whether this effect lasts long enough to influence real driving. Interestingly, the researchers did not find any change in the behavioural measures, which suggests that visual search strategies are developed independently of car control skills. Finally there is the possibility that training simply increased the overall scanning of novices and they may therefore have attended to the potential hazard location as a result of simply sampling more objects in the visual field at more disparate locations, rather than actually using knowledge to guide them to target object. Despite these unanswered questions and possible methodological sensitivities, Pollatsek et al have developed a methodology that apparently enhances novices' visual search strategies. More importantly this methodology can initiate future training intervention improvements that may be beneficial to the traffic safety of novice drivers.

Another study that attempted to train novices' eye movements and improve their visual search strategies was delivered by Chapman, Underwood and Roberts (2002). The training intervention consisted of a series of driving video clips with dangerous situations. Audiovisual feedback was given to the trained group and participants were guided either to look for specific hazards or they were prompted to scan across the scene. The visual search cues that were used to guide participants were extracted by the eye movements of experienced drivers that were shown the same clips previously. After the guidance procedure novice drivers showed wider visual scanning patters on a hazard perception test and also on real roads in an instrumented vehicle when compared to an untrained control group. The aim of the training was to develop the knowledge, the scanning and the anticipation of participants. However it is not clear if the aim was achieved since it is possible that this scanning behaviour is a mechanistic and reflexive general behaviour that was generated by training rather than a result of deeper understanding of the driving situation. Also there is a possibility that the training group scanned more because this was reinforced by the training intervention and not because they were aware of the demands of the driving situation. This is quite possible since trained novices showed increased scanning in both safe and hazardous video clips, whereas Chapman et al anticipated that scanning would only occur in the hazardous clips, as it does with their more experienced counterparts who change their visual search patterns as a factor of road type (Crundall & Underwood, 1998) and hazardous situations (Chapman & Underwood, 1998).

1.5.4 Summary on training

Previous training interventions raised several issues and offered useful methodologies that can help novice drivers to develop a more efficient visual search. However, a common question that remains unanswered is whether people that receive the training are aware of patterns that are involved. Also it is far from clear for how long these interventions are effective. Finally, the parameters that constitute efficient cognitive training are yet to be determined.

1.6 Research questions – Thesis structure

The aims of this Thesis are to identify some parameters that influence visual search and to develop an efficient training intervention that will improve drivers' visual skills. In order to reach these aims there are several objectives that must be tackled and will be examined in the following Chapters of this Thesis.

From the brief review of the literature it is obvious that several methodologies are used to collect experimental data. In order to clarify some practical and methodological issues Chapter 2 will review some of the methodologies that will be used in this Thesis.

Throughout this Chapter it has been acknowledge many times that novice drivers are at greater risk of an accident and that one reason that has been reported for this is that they do not have as effective visual search strategies as experienced drivers. One might expect that new drivers might be taught the appropriate visual skills while learning to drive, though this requires driving instructors to have introspection into their own visual skills before they can be passed on to the student. In addition novice drivers should be able to acquire the visual skills from explicit instruction for training to be effective. These questions will be addressed in Chapter 3.

Overt visual attention is guided by top-down and bottom-up mechanisms. However, it is not clear which of these mechanisms have greatest influence on visual search in driving. In Chapter 4 two experiments used a novel experimental paradigm to investigate the interaction of those influences upon drivers' visual attention.

Despite the fact that visual search strategies of experienced drivers have been investigated in depth, the visual search patterns of driving instructors have not been examined yet. Also previous research has focused more on the global eye movements (e.g. spread of search) while any effects of scenario specific micro-level visual search have not be examined with few exceptions (e.g. Land & Lee, 1994). In Chapter 5 an experiment is reported that investigated the difference in eye movements between driving instructors and learner drivers while they drove a virtual route in a driving simulator. Also the eye movement of drivers were examined on scenario specific situations.

It has been demonstrated that environmental factors such as driving during night and rain increases the risk of a crash. Both of these factors may be related to drivers' visual search strategies that become more efficient with increased experience. The second experiment of Chapter 5 will explore the difference of eye movements between driving instructors and learner drivers while they drive on three virtual routes that included day, night and rain routes.

In section 1.5 it was shown that further additions in the formal drivers' training that will enhance the performance of newly qualified drivers might be necessary. One aspect that is related with traffic safety and can be the basis of training interventions is visual attention and eye movements. The aim Chapter 6 is to identify the parameters of an efficient training package by investigating drivers' ability to classify the eye movements of other drivers. In addition at experiment 8 a pilot study will attempt to identify the effectiveness of a scenario specific training intervention.

Finally Chapter 7 will summarise all the major findings of the whole Thesis and present a general discussion of the findings with their implications and the future research questions.

Chapter 2: Methodology

2.1 Introduction

As it was mentioned in Chapter 1 there are several methods that someone can use in order to collect data related to driving research. Since in this Thesis a combination of eye-tracking, observational methods and driving simulators is used, it is necessary to describe some important methodological issues. For this reason this Chapter will provide some theoretical background about eye-tracking, observational methods and driving simulators. Also the definition of these terms will make the reading of subsequent Chapters easier as well as the interpretation of the research findings.

2.2 Eye Tracking Methodology

2.2.1 Introduction

Eye tracking methodologies are being used more and more in a wide variety of research areas (Duchowski, 2003; Richardson & Spivey, 2004a). Eye trackers can record human eye movements and estimate the point of regard on a given visual scene. The first question that arises is why this technique is used? What are the advantages and what insights eye tracking can offer to researchers? An in depth answer will of course depend on the specific area that the methodology is applied. For example research on bilingual language processing might be interested on how participants' eye movements are altered when looking words on different languages (Kaushanskaya & Marian, 2007). Developmental psychology might be interested on infants gaze allocation (Aslin & McMurray, 2004). However, the main reason that the eye tracking is primarily used is the fact that in most cases eye movements are closely related to visual attention (Duchowski, 2003; Parkhurst, Law, & Niebur, 2002; Rayner, 1998).

Another factor that should be mentioned here is the variety of eye tracking hardware and software configurations used throughout the literature (Rayner, 1998). So another question arises. Is there a standard methodology to be used in every experimental situation? Are there any particular advantages or disadvantages by using different methods? Since the list of eye tracking applications is endless and for the interests of brevity here we will discuss the cognitive and applied psychological research and in particular drivers' eye movements as an indication of an application of eye tracking. The analysis and discussion of eye tracking issues will be done in reference to driving research.

2.2.2 Eye movements

As mentioned above, visual attention plays an important role in the driving task. It has been suggested (Itti & Koch, 2001; Richardson & Spivey, 2004a; Velichkovsky et al., 2003) that eye movements and visual attention are closely related. It is necessary to present here some physiological properties of the eye together with the methods to record them since this presentation will clarify further discussion.

The combination of five types of eye movements (saccades, vergence, vestibular and smooth pursuits) are of great importance in order to change gaze allocation (Duchowski, 2003). For the purpose of this Thesis two eye characteristics will be discussed in more detail, saccades and fixations (see Figure 2.1).

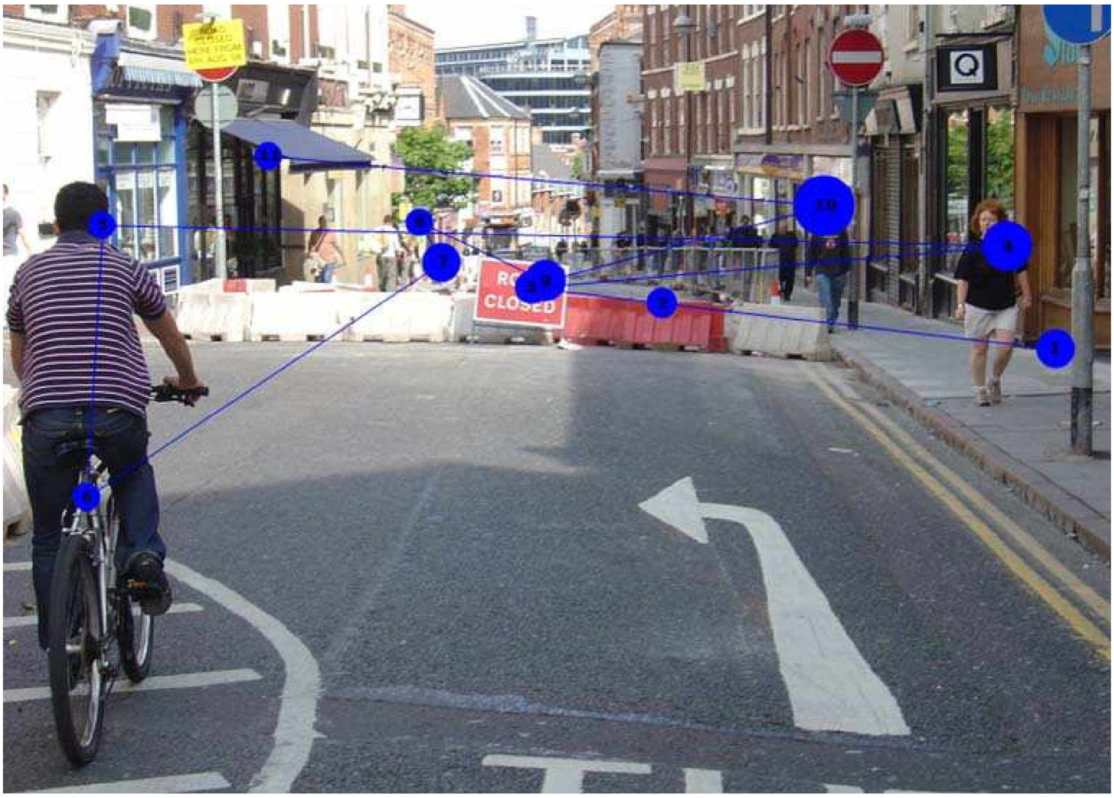

Figure 2.1. The Figure illustrates a sequence of fixations and saccades while scanning a picture. The circles represent the fixations and the lines the saccades. The numbers indicate the order of the sequence and the circle diameter is relative to the duration of fixations

The first movement is called saccade. A saccade is a fast and rapid movement of the eye. Saccadic movements vary in duration from 10ms to 100ms (Duchowski, 2003). It is believed that during a saccade the perceptual input from the scene is decreased and this phenomenon is called saccadic suppression (Rayner, 1998). Maybe this is due to motion blur occurs during the saccadic movement. Whether the perceived stimuli remains in visual memory or is completely unprocessed is not clear. Interestingly, Duchowski stated that during saccadic suppression the perceptual system might become blind. The perceptual system uses saccades to direct the eye from one point of interest to another. This movement has been characterised as ballistic, in a sense that since it is initiated cannot be altered. Probably because saccades are rapid and very fast movements there is not enough feedback to the visual system to alter the saccade after it has started.

The second eye movement of interest is called fixation. A fixation occurs when the eye gaze is directed and is usually representative of processing. Fixation durations vary and they are task dependent. For example the mean fixation duration on a reading task is 225ms while at scene perception is 330ms (Rayner, 1998). Duchowski (2003) stated that during a fixation the eye is not completely still but, there are tremor drifts and microsaccades during fixation. There is not an agreed minimum or maximum fixation duration throughout the literature but Duchowski claimed that fixation duration varies from 150ms to 600ms, although there are cases that fixations as short as 50ms appear during reading (Rayner, 1998), and also that during visual inspection 90% of the time the eyes are fixating.

After the presentation of eye movements it could be asked how those movements can assist researchers to understand better driver's behaviour. Research (Velichkovsky et al., 2003) investigated the appropriateness of using eye movements' analysis in order to identify drivers' hazard perception. The researchers concluded that the eye tracking technique is appropriate to bring to light the attentional strategies of drivers. Furthermore they suggested that eye movements can offer valuable information regarding the development of driving training modules. By measuring those values we can develop conclusions regarding attention allocation and change. However, as mentioned many times above conclusions should be carefully stated when referring to the interaction between attention and eye movements.

2.2.3 Eye movement recording

There is a variety of methods that one can use in order to record eye movements (Rayner, 1998). Duchowski (2003) reports four major categories of eye

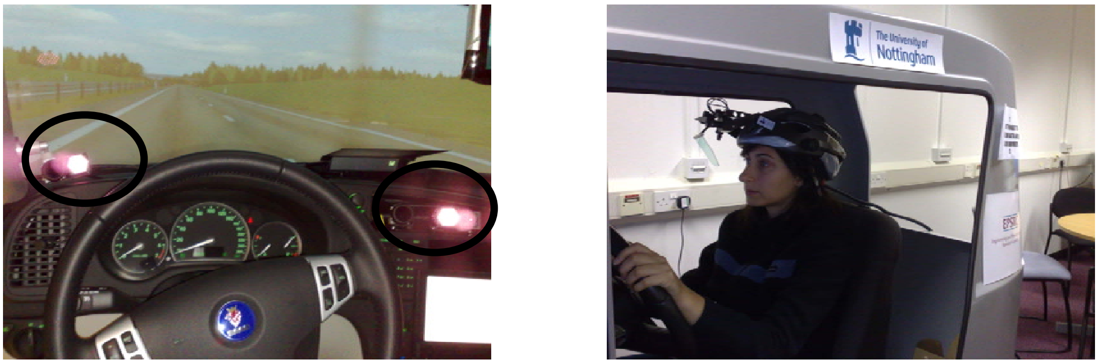

Figure 2.2. The left picture demonstrates 2 remote trackers (inside circles), while the right picture shows a participant in a simulator wearing a head-mounted eye-tracker.

tracking methods. Electro – Oculography, Scleral Contact Lens / Search Coil, Video Oculography, and Video Based Combined Pupil / Corneal Reflection (pupil – CR). Here we will focus on the latter (for more information see: Duchowski, 2003; Jacob & Karn, 2003) and the following information will refer to pupil – CR eye trackers. Corneal reflection systems transmit a light source (infra-red) to the eye and they calculate the reflection of the cornea in relation to the pupil centre. The method to extract the point of regard was clearly explained by Richardson and Spivey (2004b): “since the position of the corneal reflection remains constant during head transition, but moves with eye rotation, point of regard can be extrapolated” (p. 578) if device is head-mounted.

2.2.3.1 Eye tracking types

There are four types of pupil – CR eye trackers; fixed position, remote, portable and head mounted (see Figure 2.2). Usually the fixed position trackers have the best resolution up to 1250 Hz. On the negative side it can be said that they lack ecological validity. This is because they cannot accommodate head movements and participants must have their heads stabilised. Also usually the higher the resolution the more expensive the tracker is.

Portable and remote eye trackers have less resolution than fixed position ones around

50 / 60 Hz. However, in the case of the portable tracker it is a very useful that it can be moved outside the laboratory. Also it has a usability feature since it can be used to test people with disabilities and infants (Aslin & McMurray, 2004). Portable and remote eye trackers can tolerate minor head movements but the head movement is somehow limited since the accuracy of eye movements is decreased with intensive head movements (Morimoto & Mimica, 2005). Usually participants use a chin rest to view the experimental stimuli when these trackers are used.

A head mounted eye tracker has almost the same resolution as the portable and remote trackers and is around 50 / 60 Hz. Its greatest strength as research tool is the calculation of head movements. Usually head mounted tracker is attached to a helmet and uses two cameras. One camera records the eye movements while the second monitors participant's field of view. Head mounted eye trackers have been used often at driving research (Crundall & Underwood, 1998) since they allow participants to drive (real car or simulator) in a natural way. Of course by saying natural someone should not neglect the fact that participants have to wear the helmet with the eye tracker. This helmet might somehow restrict head movement and decrease the ecological validity of the tool (Jacob & Karn, 2003).

2.2.3.2 Eye tracking calibration

Every pupil CR tracker comes with software that performs at least two basic functions, calibration and data collection. The calibration process usually includes 9 or 5 points on the screen that the participant has to look at. The software then is able to calculate where participants gaze is located. In theory calibration process is a very easy process. In practice calibration demands a certain skill (Schnipke & Todd, 2000) and careful step by step planning because is the most crucial procedure in data collection. If the calibration of the eye tracker is not successful then the data would be problematic. During long testing sessions it is often necessary to recalibrate the participant. This can be frustrating for both the experimenter and the participant and makes the experiment lengthier.

In theory everyone can be calibrated and be tested with modern eye trackers. Practice shows that is not always the case (Jacob & Karn, 2003) and several techniques have been suggested to improve calibration efficiency (Morimoto & Mimica, 2005). Also there is possible that the size and colour of pupil could affect calibration and tracking (Aslin & McMurray, 2004; Schnipke & Todd, 2000). Unfortunately those things cannot be a priori determined so this could lead to extra money for paying participants without even testing them. In general it can be said that it is almost impossible to have a 100% data from all the participants, especially on driving research where head movements are necessary. It needs careful planning to incorporate those difficulties in order to complete an applied experiment.

2.2.3.3 Eye tracking data

One of the first steps in data analysis is de-noising (Duchowski, 2003). Irrelevant data might include blinks or eye movements outside the calibration area and should be removed from the dataset. Data output can be analysed and viewed by using specialist software. Usually the software provided with the eye tracker, calculates fixations and saccades though it is possible to calculate these from raw x and y coordinates. The data output can provide the x and y position of the gaze. The built in algorithm and the method used to calculate those values may vary across different software (Jacob & Karn, 2003). There are two major techniques to detect fixations and saccades. The first is called proximity analysis and it calculates fixations and saccades by the way the gaze changes its position across the area. For example large gaze dispersion results a saccade while a small dispersion indicates a fixation. It should be mentioned that the dispersion area does not have a standard value across all algorithms. The second detection method is velocity-based and calculates the values according to the speed of the eye movements. Data analysis usually requires a lot of time and effort and is not flawless (Aslin & McMurray, 2004; Jacob & Karn, 2003). Sometimes it is necessary for research groups to develop their own calculating algorithms.

2.2.4 Eye tracking in action: Driving research

The eye tracking method is widely used in driving research. In Chapter 1 several studies that used eye tracking have been described so any additional presentation is not necessary. In general those studies outlined how eye tracking methodologies can be used in an applied research field. Eye movement recording lets the researchers draw conclusions about the differences between experienced and novice drivers. Also eye movement analysis has provided an insight of the most useful points of regard under specific driving situations. The results from those studies and from driving research in general could indicate how experienced drivers behave in terms of eye movements and try to develop intervention schemes to train novices' eye movements.

2.2.5 Summary of eye tracking

As it was made clear throughout this Chapter when we refer to eye trackers we must acknowledge the variety of methods used. This variation might generate some methodological issues when trying to compare different findings. However, Rayner (1998) claimed that despite those difficulties most of the results are easily replicable across different methods. Regardless of the comparability of research findings there is a necessity for more standardisation of eye tracking methods (Jacob & Karn, 2003).

From a usability point of view data acquisition and calibration techniques should be simplified more in order to allow eye tracking to be used with less effort. In relation to accuracy and resolution of eye movements, future systems should accommodate natural head movements without compromising resolution and without significant increases in cost.

The methodological sensitivities mentioned cannot hide the recent progress on eye tracking. Although eye tracking techniques have been developed many decades ago it was not possible until recently to have a reliable and valid tool that many researchers can use. As was mentioned, modern eye tracking devices can account for eye and head movements as well as identifying the attended point of regard. Several attentional mechanisms have been explored with the aid of eye tracking. Based on the analysis of this section, eye tracking methodology will be considered as a major research tool in this Thesis in order to investigate the interaction of visual attention and driving experience.

2.3 Observational Methodology

2.3.1 Introduction

Since there are several experimental methods careful consideration is necessary for the selection of the appropriate method to answer a research question. However, there is no golden selection rule or a perfect method. Every method has both advantages and disadvantages (Wilkinson, 1999). This section will discuss how observational methods can be used for driving research data analysis.

Observational methods have been used to answer a wide range of research questions. Various research studies used observational analysis to investigate topics such as: children's' social play and theory of mind (Tan-Niam, Wood, & O'Malley, 2000), occupational risk factors (David, 2005), the level of interaction between patients and their therapist during music therapy (Raglio, Traficante, & Oasi, 2006), and the activity of rugby referees (Martin, Smith, Tolfrey, & Jones, 2001). The above studies provide just an indication of the research areas investigated using observational methods. Due to the limited space here the discussion will be focused around applied psychology and in particular driving research and studies that investigated drivers' eye movements. There are many ways to apply observational analysis, from pen and paper notes to modern software. Since the focus of this section is on recent driving research the term observational analysis will be related to video observation.

One of the greatest advantages of observational analysis is the in depth analysis that can be achieved with this method. Observational methods can reveal the dynamic conditions under investigation. It is an adequate research tool and can provide experimenters with several insights on topics that quantitative and qualitative methods cannot.

2.3.2 Observational methods in driving research

This section will present some driving studies form the field of applied psychology. This is a necessary step prior to any discussion regarding observational methodology. The focus here will be on the description of the methodology rather than the discussion of the actual results. So despite any repetition of any key studies of the field the emphasis and discussion here will be only at a methodological level. As mentioned before the research methods will be related to drivers' eye movements. However, in order to clarify the methodological issues regarding observational analysis a coding example will be provided. A more detailed coding example from

Experiment 4 (Chapter 5) will give the reader better understanding of the methodologies that will be discussed later.

2.3.2.1 Coding example from driving research

Participants drove in a virtual environment while their eye movements were recorded. The eye tracker had two attached cameras. One camera recorded eye movements while the other recorded what the participants were looking at. The eye tracker's software produced a video file for each participant that showed the route driven with a moving circle overlaid that represented the eye movements of the drivers. The total video duration for each participant was approximately 5 minutes. Every route and video had three types of driving situations (parked cars, stop sign and traffic lights). There were two groups of participants, driving instructors and learner drivers. A 15 second sample from each participant was selected (5 second for each situation). The selection was made in a way that all participants drove on the same route. The coding was performed in the software Observer (Noldus, Trienes, Hendriksen, Jansen, & Jansen, 2000). The coding scheme consisted of 8 mutual exclusive and exhaustive categories. Also a miscellaneous category was added for no data or data outside the predetermined visual fields of interest. A unique key was assigned to each code category. Recorded videos were reproduced through the software frame by frame. On every frame the observed category was registered by pressing the assigned key. At this study we examined eye fixations. Video frequency was 25 frames per second (40ms per frame) and in order for a successful fixation to be registered two consequent frames were necessary. When the eye movement was stationary on a predetermined category for two or more frames the eye movement was registered as a fixation. After the coding the software produced a summary of the data with total duration fixation, mean fixation duration and number of fixations. Data coding had taken into account the different groups (instructors and learners) and were exported for additional analysis.

This is a typical but not the only way to conduct frame by frame observational analysis. The above example describes the precise steps that are used in the decoding of video footage from eye tracking software. Further discussion on this data will occur in Chapter 5.

2.3.3 Driving Research

After the description of a typical procedure, some studies that have used observational methods in order to examine drivers' visual allocation are outlined in this section. Prior to this it needs to be clarified that observation methods allow a categorical analysis of eye movements in contrast with the general eye movements parameters (spread of search, saccade amplitude, etc). One study used categorical analysis of eye movements in order to explore drivers' visual inspection on internal and external mirrors (Underwood et al., 2002a). Observational analysis involved a 15 second sampling period. During this period mirror inspections of participants were recorded. A subsequent analysis of those data (Underwood et al., 2003) investigated drivers' visual allocation across 11 non overlapping items. Those 11 visual items were coded prior to the analysis. On this study a 1 minute video with eye-movements was analysed for each participant. Frame by frame analysis revealed the most inspected categories, and patterns of movement between categories.

Researchers (Crundall, Van Loon, & Underwood, 2006) recorded the eye movements of participants while they were watching some driving videos. The aim of the study was to identify road visual inspection of road advertisements. Frame by frame analysis of the eye movements identified the frequency and duration of advertisement inspection.

In another experiment the experimenters (Pastor, Tejero, Choliz, & Roca, 2006) investigated drivers' rear view mirror inspection. An observational analysis was performed to identify the rear view mirror inspection. The analysis was done by time sampling since the video was divided into 45 time intervals. The coding was performed every minute. During each time interval the experimenter coded whether each participant was looking at the rear view mirror or not. Analysis involved the total fixations at the rear view mirror.

2.3.4. Observational methodological issues

After the description of some driving research studies that used observational methods we will discuss some specific issues regarding the coding and analysis.

2.3.4.1 Observational Coding

One of the most important issues on observational method is the coding procedure (Bakeman & Gottman, 1997). This has to be performed prior to analysis since if there is a missing code that records an important behaviour that behaviour either will be lost or the analysis should be repeated. An example will illustrate this point. In section 2.3.3 it was mentioned that in the Underwood et al (2003) study they had coded 11 visual categories. If the coding scheme was not complete and not carefully planned then there is a possibility that one important visual field might be neglected and coded as other behaviour or as a miscellaneous item. As a conclusion it can be said that careful planning and coding in an observational study is the first step of successful analysis.

2.3.4.2 Observational Sampling

Usually when investigating driver's eye movements we are interested in the duration of the visual inspection. This method is called event sampling. Event sampling allows the coding of the duration of the observed behaviour. Event sampling needs the coding categories to be defined in advance. Also it might add extra time for coding. Another technique is time sampling. The observation time is divided into time intervals and the observer codes at the change of each interval. Time sampling has been applied to driving research as well (Pastor et al., 2006). A possible methodological issue with time sampling is the fact that an interesting and rare behaviour might not be coded if occurred outside the interval. The usage of either event or time sampling depends on the research question (Bakeman & Gottman, 1997).

2.3.4.3 Observational method reliability

One of the issues that experimenters are concerned with when conducting observational analysis is the issue of reliability (Jansen, Wiertz, Meyer, & Noldus, 2002). It is a matter of discussion whether different observers record the same behaviours on the same data. This is a valid point especially when considering coding schemes based on social attributes (Bakeman & Gottman, 1997). Still there are some methods that can measure inter and intra observer reliability. The most common methods for reliability calculation are: Cohen's k, Pearson's r and percentage agreement (Jansen et al.). Regarding the coding of eye movements things are simpler. This is because the eye movements' positioning can be clearly identified without much misinterpretation and the only thing that needs to be identified is how close does the point of regard needs to be to be included in a particular category.

2.3.5 Summary on observational methods

It was shown that driving research has used observational methods in many cases. The advantages of observational analysis makes possible for researchers to draw conclusions about what drivers look at rather than just making conclusions about general visual strategies (e.g. spread of search). Data from observation can also be used in subsequent analysis and provide a better understanding on drivers' visual allocation. Observational software has evolved and offers a quicker and more reliable coding and analysis. Despite the development of modern technology that can assist researchers, cautious consideration is still needed prior to data analysis environment. This consideration should focus on the creation of an appropriate coding scheme. Observational methods are not without disadvantages. Time consumption and reliability are two key issues that the researchers should be aware of. When combined with the other research techniques that are used they can offer a clear understanding on driving topics. As a conclusion it could be said that observation analysis is an invaluable tool for driving research and it will be used at the data analysis of Experiments 4 and 5.

2.4 Driving Simulators

2.4.1 Introduction

Although the two methods that are mentioned above refer to the way the data are collected and analysed there are some issues with the usage of the testing environment. The research findings discussed so far, derive from a variety of testing environments including in-car experiments, video clip presentations and driving simulators (see Figure 2.3). Indeed it seems that driving research has employed various methodologies which make comparison of results difficult (Crundall & Underwood, 1998). Driving simulators are increasingly being used as a methodology to investigate drivers' visual skills and perception (Kemeny & Panerai, 2003).

Figure 2.3. This photo portrays a state of the art driving simulator installed at VTI, Sweden.

2.4.2 Advantages of driving simulators

Regarding the effect of experience on drivers' visual attention there are some reasons why an on-road study is problematic. An on-road study might generate some safety and ethical issues and lack of experimental control. It would also be expensive to run. However, there is a research tool that, in most cases, will minimise these methodological and financial issues. Indeed, it has been suggested that safety, cost and experimental control are three of the advantages of using driving simulators (Reed & Green, 1999). Moreover it was claimed that driving simulators can generate driving conditions that are relatively similar to on-road studies (Tornros, 1998). So it seems that in general driving simulators can be the middle ground between naturalistic on-road studies and accident data analysis studies and bridge any existing research gap between these methodologies. This may be one of the reasons that driving simulators are used increasingly and more specifically to investigate drivers' visual skills and perception (Kemeny & Panerai, 2003). In addition simulators allow uncommon experiences (e.g. hazards) to be temporally condensed.

2.4.3 Validity of driving simulators

Despite any advantages in using a driving simulator there are some methodological considerations. One of the major methodological issues with driving simulators is the fact that drivers' behaviour may be different when risk factors (i.e. there is no cost in a virtual collision) are absent (Reimer, D'Ambrosio, Coughun, Kafrissen, & Biederman, 2006). Another factor associated with the criticism of using simulators is validity. In other words how comparable is simulated driving to actual driving. The term validity can be divided into absolute and relative validity (Tornros, 1998). Absolute validity refers to the relationship between on road and simulated measures (e.g. the relationship between speed or lane position while on-road and while driving in a simulator). Relative validity refers more to the direction of the results rather than the actual values. For example if the speed of the car increases on dual carriageway driving both for on-road and simulator driving there is relative validity despite any variation of the absolute speed values between methodologies.

2.4.4 Summary of driving simulators.

Despite any methodological and ecological validity issues, driving simulators could be considered as the best alternative to on-road driving (Reimer et al., 2006). Based on the number of advantages that mentioned above, the virtual environment of a driving simulator will be used in this Thesis in order to explore drivers' visual attention. Also the issue of validity will be examined when possible in order to make sure that the data from the virtual environment have some validity and the findings allow the extraction of conclusions.

As a final remark of this Chapter it can be said that there is not one perfect methodology and all have advantages and disadvantages. The approach of this Thesis is to use multiple methodologies (including eye-tracking, observational methods and driving simulators) that allow a convergence of data in an attempt to understand drivers visual search strategies.

Chapter 3: Exploring drivers' self-report visual priorities in a range of driving scenarios

3.1 Experiment 1

3.1.1 Introduction

In Chapter 1 it was mentioned that novice drivers' visual search inefficiency might result in a reduced awareness of potential hazards and important driving operations and may partly explain the high accident involvement of novice drivers. One of the fundamental functions of visual attention is to select areas of the scene to process, which in turn requires a prioritisation hierarchy. It has been suggested that since the environment contains an enormous amount of information evolution has developed a step by step intake of this information by allocating the gaze and attention to particular parts of the scene that are of interest (Itti & Koch, 2000; Treue, 2001). In driving terms it could be said that since most traffic conditions contain a large number of visual stimuli the drivers have to prioritise and deploy their cognitive resources with efficiency. Considering the fact that it is only over the last 100 years that we have began to move through the environment at such speed, prioritisation and selection has become probably the most important aspect of vision in driving.

An additional point of interest is how current driving training curricula assist the development of efficient visual search strategies of drivers. In regards to the curriculum used in the UK there are some references to visual search. However, the strategies involved to make drivers more visual aware are somewhat general. Phrases like "look well ahead", "keep the eyes moving" and "get the big picture" are used to encourage effective visual search (Miller & Stacey, 2006 p.76). Despite any effect that those techniques might have it needs to be acknowledged that they are very general therefore might not be as effective as one might hope.

It seems that although there are positive developments in drivers' training further improvements are essential. For ideal driver training, driving instructors (DIs) should be able to guide learner drivers and train their visual attention and eye movements. This requires a consensus among DIs about an optimum prioritisation hierarchy, in other words, there needs to be a "right way" of deploying attention. Furthermore DIs should have introspection into this prioritisation which will allow them to pass on this information explicitly to learners. Regarding novice drivers (NDs) it is important to investigate whether they have adopted the explicit visual priorities of the DIs as this would suggest that NDs have successfully learned this prioritisation either implicitly or explicitly.

Unfortunately no previous research has addressed this issue. Although previous questionnaire based studies (e.g. Ozkan, Lajunen, & Summala, 2006) have explored drivers' self-reported behaviours and attitudes towards driving or safety there has not been any attempt to measure introspection into visual field prioritisation. Though behavioural and eye movement driving research has demonstrated clear experiential differences, we do not know whether the underlying strategies differ due to a lack of NDs explicit understanding or it is just a failure to implement these strategies.

There are some possible reasons why NDs have not as efficient visual search strategies as more experienced drivers. One possible explanation is that the cognitive demands of the driving situation are so high that they are not able to prioritise the appropriate visual field due to cognitive overload. However, this explanation is not so likely since previous research has shown that there are visual search differences between experienced drivers and NDs even when watching low cognitive demand stimuli like driving videos (Underwood et al., 2002b). So an alternative suggestion regarding NDs reduced visual search effect might be the lack of visual priority-specific knowledge. Since learners acquire knowledge from DIs this might be a possible broken link in driving training. Do DIs know what to teach in relation to visual prioritisation? In order to answer that question we need to assess DIs' knowledge by measuring their introspection. If ranking of priorities is consistent amongst DIs then we can conclude that there is a shared knowledge base amongst instructors. The existence of agreement between DIs will rule out the knowledge explanation and will indicate a problematic transfer of knowledge to NDs. This problematic knowledge will result in NDs not to have similar prioritisations as DIs. The aim of this experiment is to investigate the above by using a questionnaire that will address those issues.

The Driver Prioritisation Questionnaire (DPQ) is an exploratory questionnaire study that uses representations of driving scenarios. Participants have to provide rankings of the visual fields for each given driving scenario. First, we predict that DIs will show consistency in their prioritisation hierarchies, suggesting that as a group they have access to the optimum hierarchies for optimal scenarios. Secondly, DIs priority hierarchies will differ to those of NDs. It is predicted that if NDs lack explicit knowledge of where to look in specific scenarios, then group differences will be noted. Finally we predict that, at least for DIs, that some aspects of this visual scene will be prioritised above other aspects, when compared to chance. This will demonstrate that prioritisation, rather than random selection, is actually occurring.

3.1.2 Method

3.1.2.1 Participants

Eighty-eight driving instructors (DIs) took part in this study (22 females). The DIs' mean age was 42.9 years. The mean driving experience was 24.2 years. On average they had 6.4 years as driving instructors. Instructors were practicing their profession across the UK. The second experimental group consisted of 70 novice drivers (NDs) with 47 females in that group. The mean age was 23.7 years. The average driving experience was 0.9 years. Twenty eight of these were still learner drivers at the time of their participation. Recruitment of participants was done electronically so the chance of a DI being the trainer of a ND was minimal.

3.1.2.2 Stimuli and apparatus

The Driver Prioritisation Questionnaire (DPQ) consisted of nine different driving scenarios. The scenarios included: two "Pulling Away" scenarios ("Urban" and "Suburban"), two "Dealing with Junctions" scenarios ("Give Way" and "Right of Way"), two "Changing Lanes" scenarios ("Urban" and "Dual Carriageway") and three "General Driving" scenarios ("Urban", "Dual Carriageway" and "Motorway"). Each driving scenario was represented by a photograph (see Figure 3.1 for an example, while the full questionnaire can be found at Appendix A). Each photograph was accompanied with short instructions of what behaviour the driver would be planning in that scenario.

Some photographs were taken from a personal database while others were taken from the Sabre website (http://www.sabre-roads.org.uk/) with the society's permission. The motivation of using photographs was that they can represent a variety of driving scenarios with certain clarity. The selection of the photographs was done after consultation of driving experts and DIs. Each of the nine photographs reflected a specific driving scenario.

1) PULLING AWAY - URBAN ROAD

Scenario Description: The driver is inside the parked car (circled) and has to pull away and continue on the road ahead.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
1a) Road Ahead	
1b) Side Roads	
1c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
1d) Side Mirrors	
1e) Rear View Mirror	
1f) Blind Spot	
1g) Contraflow Lane / On Coming Traffic	
1h) In Car Controls (e.g. speedometer)	

Figure 3.1. Pulling away - urban road driving scenario.

The DPQ was administered in two forms; paper and on-line. The on-line version of the DPQ was advertised at various web-based DIs' and learner drivers' forums. The hard copy of the DPQ was printed and distributed through BSM centres to DIs while all NDs completed the online version. Approximately half of the NDs were recruited from a single online learner forum (www.2pass.co.uk).

3.1.2.3 Procedure

The first part of the DPQ asked participants to enter their demographic data. Demographic questions included sex, age, years of driving experience, years of experience as a driving instructor or number of lessons as learner. The second part of DPQ presented nine driving scenarios. Each scenario was represented by a separate photograph, followed by eight visual field categories including “Road Ahead”, “Side Roads / Adjoining Lane", "Off-Road Task-Relevant Information", “Side Mirrors”, “Rear View Mirror”, “Blind Spot”, “Contraflow Lane / On coming Traffic” and “In-Car Controls”. The selection of the visual fields was reviewed by driving experts and DIs (who did not take part in the study themselves) prior to inclusion in the questionnaire. It was concluded that those visual fields provide an adequate representation of the generic visual fields that the driver was likely to choose between in each scenario.

Participants had to rate the visual fields by giving a number from 1 to 8. Number 8 represented the visual field that the driver thought he/she should look the most in the given driving scenario, while number 1 represented the visual field that the driver should look the least. Instructions made it explicitly clear that they should not give the same ranking twice. The same procedure was identical across all 9 driving scenarios.

3.1.2.4 Statistical Analysis

The first analysis explored whether DIs and NDs were consistent with their ratings within their groups. Kendall's coefficient of concordance (W) was used to measure agreement (Field, 2005) for the rankings of DIs and NDs on visual fields. A significant Kendall's W implies that ranking was consistent within group. Also Kendall's coefficient can be used to measure effect size (APA, 2001). Kendall's W was calculated for all the scenarios both for DIs and NDs separately.

The second statistical analysis compared DIs ratings to NDs ratings for each individual field within a scenario. Since the data were ordinal, group differences within each scenario were tested by using the non parametric between subjects Mann – Whitney test (Cooligan, 2004). On each scenario eight comparisons were performed, one for each visual field hence giving the Bonferroni corrected p value of 0.006.

Another analysis was performed on the separate driver groups to investigate whether there was a significant variation in the ranking of the visual fields within a scenario compared to chance. For this purpose a non parametric Friedman test was performed for each group at every scenario in order to explore any differences between the visual fields (Howell, 2007). Following any significant Friedman test, post hoc comparisons (Wilcoxon signed-rank test) were performed separately for DIs and NDs at each scenario. Each pair compared two visual fields and in order to compare all possible combinations 28 pairs were entered per group on each scenario. This was done in order to explore further which visual fields were ranked significantly differently in comparison to the others. The p value was Bonferroni corrected to 0.001.

3.1.3 Results

The results of each scenario will be discussed separately. However the choice of stimuli allows the clustering of the scenarios into four more general categories, “Pulling Away”, “Dealing with Junctions”, “Changing Lanes” and “General Driving”. The following sections will report analyses of the individual scenarios within these categories. The graphical representation for the ranking across scenarios can be found in Figure 3.2 and Figure 3.3. Post hoc comparisons results for DIs are shown in Table 3.1 and Table 3.2 shows the results for NDs and can be found at the end of the Chapter. In order to further clarify the results section it should be mentioned that the term scenario refers to a driving situation (e.g. perform a pulling away manoeuvre) while the term category refers to the visual fields that participants ranked (e.g. road ahead).

3.1.3.1 “Pulling Away”

The first two scenarios represented a pulling away manoeuvre, either in an urban or suburban setting. For both scenarios the consistency of DIs and NDs rankings was found to be significant and Kendall’s W for the urban scenarios was 0.563 ($p < 0.001$) and 0.468 ($p < 0.001$) for DIs and NDs respectively. For the suburban scenario W for DIs was 0.570 ($p < 0.001$) and for NDs 0.471 ($p < 0.001$). This suggests that both DIs and NDs agreed amongst themselves about rankings.

To explore whether there are any differences between the rankings of the DIs and NDs, rankings for each category were compared across groups using Mann-Whitney. For both scenarios the only significant group difference was found for the “Road Ahead” visual field. The mean ranking of the “Road Ahead” visual field was higher for DIs for both the urban (mean rank DIs = 6.5, NDs = 5.3, $U = 1987$, $p < .001$) and suburban scenario (mean rank DIs = 5.9, NDs = 4.9, $U = 2025$, $p < .001$).

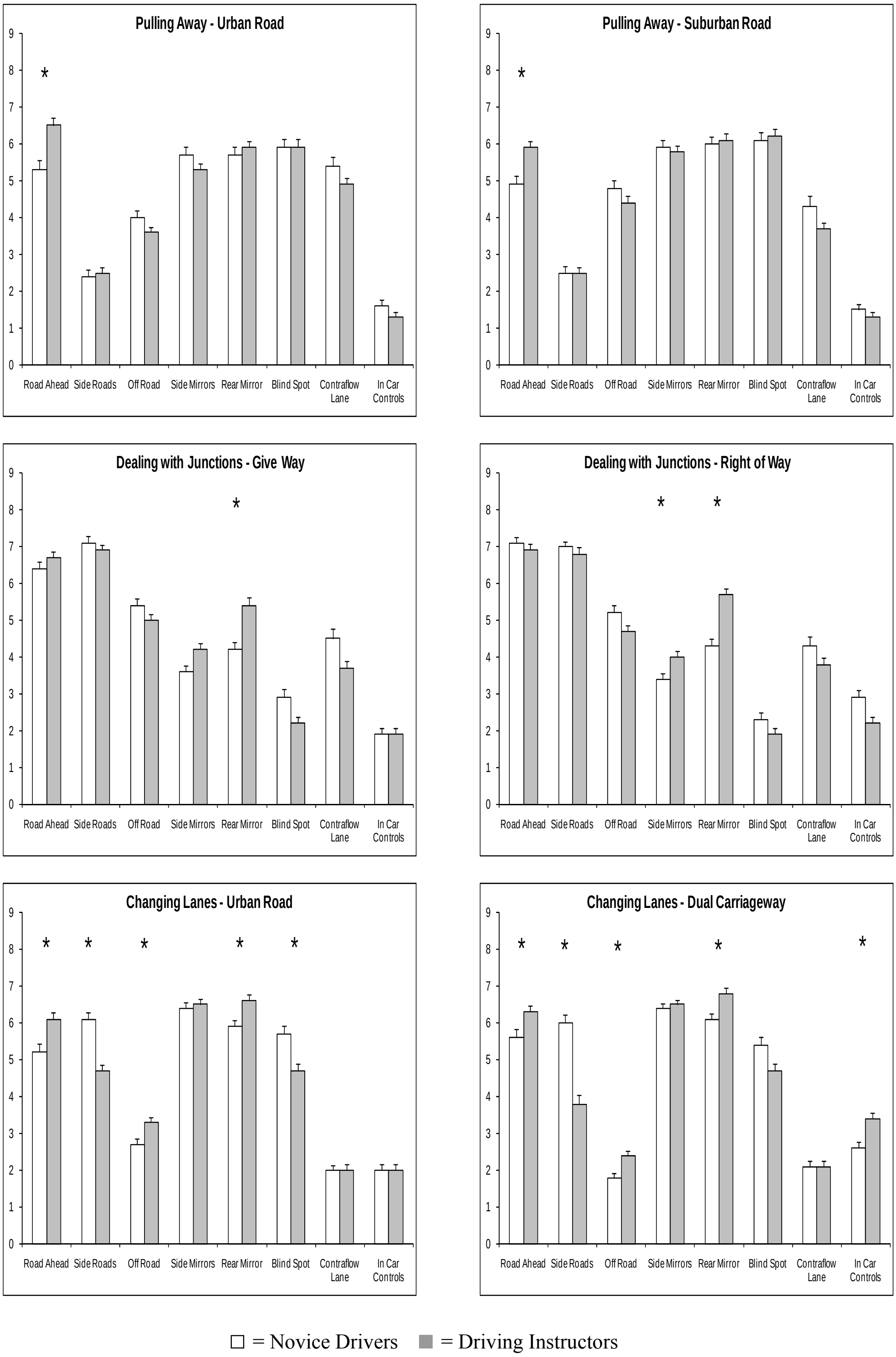

Figure 3.2. Mean rankings with standard error of the mean for all visual field categories across 6 scenarios. * denotes a significant group difference at p < 0.006.

A third analysis checked to see whether the rankings of DIs and NDs formed a pattern that was significantly altered from chance. Friedman tests indicated a significant variation in the ranking of the visual fields for both groups for both the urban scenario (DIs: χ^2 (7) = 342, p <0.001; NDs: χ^2 (7) = 229, p<0.001) and the suburban scenario (DIs: χ^2 (7) = 351, p <0.001; NDs: χ^2 (7) = 230, p<0.001)

In order to assess which visual fields differed in prioritisation a series of post hoc Wilcoxon tests were performed for each scenario, with a corrected alpha level of p = 0.001. When differences were not found between two or more visual fields they are considered to form a cluster of equal priority categories. The first notable cluster for both scenarios includes “Road Ahead”, “Side Mirrors”, “Rear View Mirrors” and “Blind Spot” could be clustered together and have been ranked higher than the rest of the fields. While the remaining visual fields were at the low end of the ranking with “Side Roads / Adjoining Lane” and “In-Car Controls” ranked the lowest forming another cluster. In addition to the findings described above there are unique characteristics for each of the two scenarios. In regard to the urban scenario DIs ranked “Rear View Mirrors” significantly higher than “Side Mirrors” while NDs did not. Also DIs ranked “Contraflow Lane / On Coming Traffic” significantly lower than “Rear View Mirror” while those fields did not differ significantly in NDs ranks. One final difference in the urban scenario was the higher ranking of “Blind Spot” than “Contraflow Lane / On Coming Traffic” as it was scored by DIs while NDs considered those fields to have the same priority. Regarding the suburban road only one difference was noted with DIs ranking “Side Mirrors” significantly higher than “Off Road Information” while NDs ranked those visual fields statistically the same.

3.1.3.2 “Dealing with Junctions”

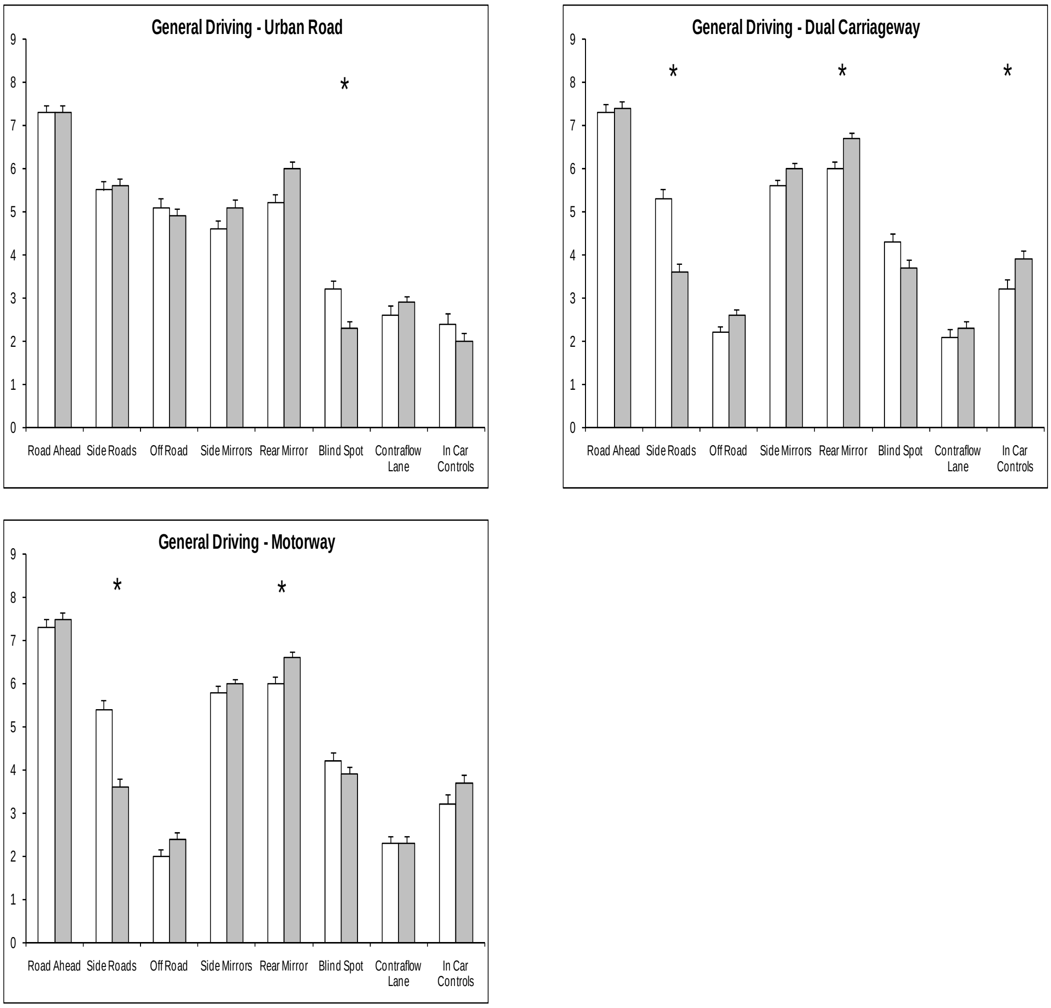

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Figure 3.3. Mean rankings with standard error of the mean for all visual field categories across the 3 general driving scenarios. * denotes a significant group difference at $p < 0.006$.

As it was mentioned there were two "Dealing with Junctions" scenarios, one represented a "Give Way" junction while the second a "Right of Way" junction. For both scenarios ranking consistency was found to be significant and Kendall's W for the "Give Way" scenarios was 0.573 ($p < 0.001$) and 0.501 ($p < 0.001$) for DIs and NDs respectively. For the "Right of Way" scenario W for DIs was 0.6 ($p < 0.001$) and NDs 0.582 ($p < 0.001$).

Regarding the group differences in the rankings for both scenarios, DIs ranked "Rear View Mirror" higher than NDs, for "Give Way" (mean rank DIs = 5.4, NDs = 4.2, U = 2701, $p < .001$) and "Right of Way" (mean rank DIs = 5.7, NDs = 4.3, U = 1504, $p < .001$).

Friedman tests indicated a significant variation in the ranking of the visual fields for both groups for both the "Give Way" scenario (DIs: $\chi^2 (7) = 353$, $p <0.001$; NDs: $\chi^2 (7) = 245$, $p<0.001$) and the "Right of Way" scenario (DIs: $\chi^2 (7) = 361$, $p <0.001$; NDs: $\chi^2 (7) = 277$, $p<0.001$).

For both groups the post hoc comparisons showed that for both scenarios "Road Ahead" and "Side Roads / Adjoining Lane" formed a cluster as they were both ranked significantly higher than all the other categories though they did not differ from each other. "In -Car Controls" and "Blind Spot" were significantly lower in all comparisons forming a cluster at the lower end of the scale. Different patterns were also noted for DIs and NDs. DIs did not differentiate their priorities between "Off Road Information" and "Rear View Mirror" while NDs scored "Rear View Mirror" significantly lower. DIs ranked "Off Road Information" higher than "Contraflow Lane / On coming Traffic" while NDs ranked these fields the same in statistical terms. DIs considered the "Rear View Mirror" to have higher priority than "Contraflow Lane / On coming Traffic" while NDs did not differentiate significantly between these categories in these average rankings.

In regards to the "Give Way" scenario specifically, it was found that DIs ranked "Side Mirrors" significantly lower than "Rear View Mirror" and higher than "Blind Spot". In opposition NDs prioritise "Side Mirrors" to an equal extent as the "Rear View Mirror" and "Blind Spot".

In the "Right of Way" scenario DIs ranked "Side Mirrors" (mean rank DIs = 4, NDs = 3.4, U = 2213, $p < .006$) higher than NDs. Post hoc comparisons for this scenario showed that DIs did not differentiate statistically their priorities between "Off Road Information" and "Rear View Mirror" while ND scored "Rear View Mirror" significantly lower. DIs scored "Off Road Information" higher than "Contraflow Lane / On coming Traffic" while NDs ranked those fields statistically similarly. Also DIs considered the "Rear View Mirror" to have higher priority than "Contraflow Lane / On coming Traffic" while NDs did not significantly differentiate between them.

3.1.3.3 "Changing Lanes"

The next two scenarios represented a situation on which drivers have to change lanes either on an urban road or in a dual carriageway. For both scenarios ranking consistency was found to be significant and Kendall's W for the urban scenario was 0.583 ($p < 0.001$) and 0.631 ($p < 0.001$) for DIs and NDs respectively. For the dual carriageway scenario W for DIs was 0.578 ($p < 0.001$) and NDs 0.625 ($p < 0.001$).

Regarding the investigation of any group differences on the rankings, Mann – Whitney showed that for both scenarios, DIs ranked "Road Ahead" higher than NDs, in the urban scenario (mean rank DIs = 6.1, NDs = 5.2, U = 2236, $p < .006$) and dual carriageway (mean rank DIs = 6.3, NDs = 5.6, U = 2314, $p < .006$). DIs ranked "Side Roads / Adjoining Lane" lower than NDs for both the urban (mean rank DIs = 4.7, NDs = 6.1, U = 1577, $p < .001$) and the dual carriageway (mean rank DIs = 3.8, NDs = 6, U = 1367, $p < .001$). "Off Road Information" was ranked higher by DIs than NDs in the urban scenario (mean rank DIs = 3.3, NDs = 2.7, U = 2174, $p = .001$) and dual carriageway (mean rank DIs = 2.4, NDs = 1.8, U = 2080, $p = .001$). The ranking for "Rear View Mirror" was significantly higher for DIs than NDs for both urban scenario (mean rank DIs = 6.6, NDs = 5.9, U = 2220, $p < .006$) and dual carriageway (mean rank DIs = 6.8, NDs = 6.1, U = 1998, $p < .001$) scenario.

Friedman tests indicated a significant variation in the ranking of the visual fields for both groups for both the urban scenario (DIs: χ^2 (7) = 359, $p <0.001$; NDs: χ^2 (7) = 309, $p<0.001$) and the dual carriageway scenario (DIs: χ^2 (7) = 355, $p <0.001$; NDs: χ^2 (7) = 306, $p<0.001$)

For both scenarios "Rear View Mirror", "Side Mirrors", "Blind Spot", "Road Ahead" and "Side Roads / Adjoining Lane" clustered together scored higher according to all participants, than the remaining three fields. Pairwise comparisons showed that DIs ranked both "Side Mirror" and "Rear View Mirror" significantly higher than "Side Roads / Adjoining Lane" while NDs prioritised "Side Roads / Adjoining Lane", "Side Mirrors" and "Rear View Mirrors" to an equal extent in statistical terms. DIs prioritised "Rear View Mirror" higher than "Blind Spot" while NDs did not rank "Rear View Mirror" and "Blind Spot" significantly different.

In regards to the urban scenario an additional group difference was found with the "Blind Spot" visual field ranked significantly lower by DIs than NDs (mean rank DIs = 4.7, NDs = 5.7, U = 2102, $p = .001$). Post hoc comparisons in the urban scenario showed that DIs ranked "Side Mirrors" higher than "Blind Spot" while NDs' ranking showed no statistical difference between these fields. DIs ranked "Road Ahead" higher than "Blind Spot" while those fields were ranked statistically the same by NDs. DIs did not ranked differently "Road Ahead" with "Side Mirrors" while NDs ranked "Side Mirrors" higher.

Regarding the dual carriageway scenario the "In-Car Controls" visual field was ranked significantly higher by DIs (mean rank DIs = 3.4, NDs = 2.6, U = 2135, p

= .001) than NDs. Wilcoxon Signed Ranks Test for the dual carriageway scenario showed that DIs had no significant difference between “Side Roads / Adjoining Lane” and In-Car Controls” while NDs ranked “In car Controls” lower than “Side Roads / Adjoining Lane”. As a consequence of the low ranking of “In-Car Controls” by NDs no significant difference was found with “Contraflow Lane / On coming Traffic” while DIs ranked “In-Car Controls” higher. DIs ranked “Side Roads / Adjoining Lane” lower than “Road Ahead” although NDs showed no statistical difference. DIs ranked “Road Ahead” significantly higher than “Side Roads / Adjoining Lane” and NDs showed no significant difference. NDs ranked side mirror higher than road ahead while these fields were ranked statistically the same by DIs.

3.1.3.4 “General Driving”

General driving scenarios presented a photo of an urban, dual carriageway or motorway driving situation with moderate traffic. Observation of the results showed that the general driving does not provide a common framework for all three scenarios since the urban road scenario has a different pattern of results. Despite the variation in the results across scenarios there was a significant ranking consistency. For the urban scenario W was 0.592 ($p < 0.001$) and 0.469 ($p < 0.001$) for DIs and NDs respectively. For the dual carriageway scenario W for DIs was 0.619 ($p < 0.001$) and NDs 0.586 ($p < 0.001$). Finally for the motorway scenario values were 0.641 ($p < 0.001$) and 0.59 ($p < 0.001$) for DIs and NDs respectively.

Friedman tests indicated a significant variation in the ranking of the visual fields for both groups for the urban scenario (DIs: χ^2 (7) = 364, $p <0.001$; NDs: χ^2 (7) = 229, $p<0.001$), the dual carriageway scenario (DIs: χ^2 (7) = 381, $p <0.001$; NDs: χ^2 (7) = 287, $p<0.001$) and the motorway scenario (DIs: χ^2 (7) = 395, $p <0.001$; NDs: χ^2 (7) = 289, $p<0.001$).

In the urban scenario the only group difference was found at the "Blind Spot" visual field, with DIs ranking this lower than NDs (mean rank DIs = 2.3, NDs = 3.2; $U = 2011$, $p < .001$). Pairwise comparisons for the urban scenario showed that "Road Ahead" was significantly highest in all comparisons for both groups. DIs ranked "Side Roads / Adjoining Lane" and "Rear View Mirror" higher than "Off Road Information" while NDs did not differentiate significantly between these categories. DIs ranked "Rear View Mirror" higher than "Side Mirrors" while NDs did not differentiate statistically between "Side Mirrors" and "Rear View Mirror". Finally, DIs ranked higher "Contraflow Lane / On coming Traffic" than "In-Car Controls while NDs did not shown significant difference between "Contraflow Lane / On coming Traffic" and "In-Car Controls".

For dual carriageway and motorway scenarios some specific group differences were found. DIs ranked "Side Roads / Adjoining Lane" field lower than NDs in dual carriageway (mean rank DIs = 3.6, NDs = 5.3; $U = 1492$, $p < .001$) and motorway scenario (mean rank DIs = 3.6, NDs = 5.4; $U = 1391$, $p < 0.001$). The "Rear View Mirror" was ranked by DIs higher than NDs for both dual carriageway (mean rank DIs = 6.7, NDs = 6; $U = 2043$, $p < 0.001$) and motorway scenario (mean rank DIs = 6.6, NDs = 6; $U = 2075$, $p < 0.001$).

Post hoc comparisons showed that "Road Ahead" was significantly higher than the other items for both groups and scenarios. It was also revealed that "Contraflow Lane / On coming Traffic" and "Off – Road Task – Information" ranked significantly lower than any other item.

For both dual carriageway and motorway scenarios DIs ranked "Rear View Mirror" higher than "Side Mirrors" while NDs did not rank "Side Mirrors" and "Rear View Mirrors" significantly different. Also the "Side Roads / Adjoining Lane" did not differ significantly from “Side Mirrors” and “Rear View Mirror” for NDs while “Rear View Mirror” was significantly higher for DIs. DIs ranked “Side Roads / Adjoining Lane” statistically the same with “Blind Spot” and “In Car Control”, while NDs ranked “Side Roads / Adjoining Lane” higher in both scenarios.

Regarding the dual carriageway scenario the “In-Car Control” category was ranked higher by DIs than NDs (mean rank DIs = 3.9, NDs = 3.2; $U = 2295$, $p < 0.006$). Wilcoxon comparisons showed that for the for the dual carriageway scenario DIs ranked “Contraflow Lane / On coming Traffic” lower than “In-Car Controls” while NDs did not differentiate significantly between these two fields.

3.1.4 Discussion

3.1.4.1 Consistency

The first question addressed by this research was whether DIs and NDs will show a ranking consistency. Rather than selecting “correct” areas of the visual scene a priori we allowed participants to choose their own areas of prioritisation and judged the “correctness” of their knowledge via the consistency of the ratings across the group. This is based on the assumption that if DIs show consistency within group then we can assume that they select the optimum priority for each scenario. One might argue that group consistency does not necessarily reflect efficient strategies. However, as inexperienced drivers have a greater crash liability, it is highly likely that DIs are behaving in a way that contributes to their safety. One still might argue however that group consistency could still reflect a consistent error of insight on the DIs part: while they may perform behaviours x, y and z to stay safe, a systematic failure of insight may lead them all to believe that they perform the behaviours a, b and c. While this is an unlikely scenario, it can still be ruled out by comparing the ratings of DIs to actual observed behaviour in previous studies of eye tracking while driving. This link between eye tracking studies and the present findings will be discussed below.

In terms of the results Kendall's coefficient of concordance showed that there was an overall consistency across DIs. Surprisingly NDs' results showed similar levels of group consistency to that of the DIs indicating that NDs do agree with each other regarding where they should look, though this agreement does not mean that they choose the same categories as DIs. In fact, as the later results show there are considerable differences between DIs and NDs. The high consistency of DIs rankings suggest that DIs have sufficient introspection into the optimum visual strategies for specific scenarios, which should provide them with the knowledge base which they can then pass on to their students. Regarding NDs the present findings show that they possess a sort of a common knowledge regarding visual field prioritisation which possibly derived from their driving training.

3.1.4.2 Group Differences

Group differences were explored by using Mann – Whitney tests. Results showed that most group differences occurred in both "Changing Lanes" scenarios with 5 visual fields found to be significantly different between groups. One possible explanation for the numerous differences in the "Changing Lanes" scenarios might be the fact that NDs have not had such experience on the road because the scenarios involved changing lanes on multiple lane roads. Novice drivers are typically more likely to be overtaken on these roads than to be making an overtaking manoeuvre themselves. Thus, they might not be aware of the optimum prioritisations required for those particular scenarios. The remaining scenarios found differences between DIs and NDs in one, two or three categories.

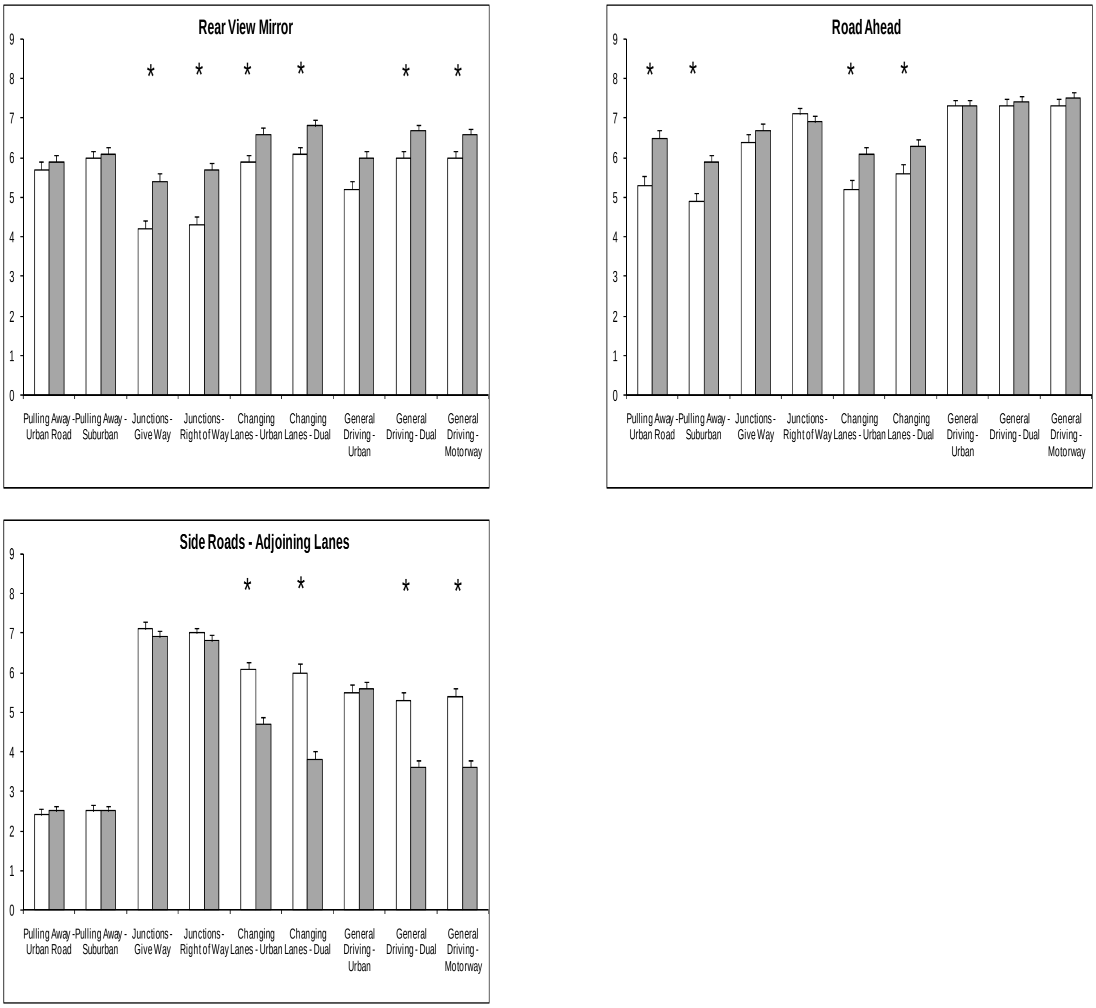

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Figure 3.4. Mean rankings with standard error of the mean for 3 visual field categories across the 9 scenarios. * denotes a significant group difference at $p < 0.006$.

An alternative way to look at group differences is to sum the frequency of the differences between DIs and NDs for each visual field across the 9 scenarios. It was found that DIs ranked “Rear View Mirror” higher than NDs across 6 scenarios (Figure 3.4 illustrates group differences across 3 visual categories). “Side Roads / Adjoining Lane” and “Road Ahead” were found to be different between groups in 4 scenarios. Interestingly the results showed a very consistent pattern as DIs ranked “Rear View Mirror” higher on all the scenarios that this group difference was found. The results suggest that DIs did not pass to NDs their knowledge regarding the prioritisation of mirrors. Also DIs had a higher ranking on all scenarios for “Road Ahead” compared to NDs. Finally, “Side Roads / Adjoining Lane” was ranked differently between groups with DIs ranking this lower than NDs. These group differences inform the debate as to why NDs have improvised visual search (Crundall & Underwood, 1998). The results suggest that NDs lack the same priorities as DIs, suggesting a lack of explicit knowledge. This fits with previous research which showed that NDs poor visual search was not due to the demands of having to control the car, but instead stems from a lack of understanding of where to look in certain scenarios (Underwood et al., 2002b).

3.1.4.3 Scenarios

In addition to group differences, a variation of prioritisation between categories was observed within all the scenarios. In statistical terms the Friedman test clearly demonstrated that within all scenarios the priority ratings differed significantly compared to chance, suggesting that certain categories were favoured over others dependent on the particular scenario. The Wilcoxon comparisons revealed the subsequent differences between the visual field categories on each scenario.

The results for the “Pulling Away” scenarios indicated a specific prioritisation pattern. DI’s think “Road Ahead” is a more important region to look at when the driver is pulling away compared to NDs. The NDs however, cluster the “Road Ahead” category with other visual fields in contrast with DI’s rankings. This difference on those two scenarios might be explained by the fact that the usual driving mnemonics for a pulling away manoeuvre refer to mirror, signal and manoeuvre. This explicit teaching tool may lead NDs to under prioritise the road ahead.

For “Dealing with Junctions” scenarios participants provided prioritisation rankings that are clearly understandable in the context. It seems sensible that “Road

Ahead" and "Side Roads / Adjoining Lane" are the most critical locations when approaching a junction. The "Blind Spot" possibly received a very low ranking because the photographs represented a single lane carriageway, with limited possibility of a vehicle overtaking from behind. Also the drivers in these scenarios are not likely to change lanes, hence the low ranking of "Blind Spot". Post hoc comparisons for both scenarios revealed that the main difference between groups is that NDs in general had lower rankings than DIs for "Rear View Mirror" failing to differentiate from "Side Mirrors". Results suggest that DIs inspect and prioritise "Rear View Mirror" differently than "Side Mirrors" depending on context. However this optimum prioritisation has not been transferred to NDs since they seem not to distinguish significantly between these two categories even when there is no cognitive demand like the filling of DPQ.

For scenarios involving "Changing Lanes" the explanation for the low ranking of the "Contraflow Lane / On coming Traffic" item can be attributed to the fact that the opposing lane was separated from the driver's lane by a central reservation. This is standard for motorways, and is increasingly common with multiple lane carriageways. The high ranking of both "Side Mirrors" and "Rear View Mirror" is task specific. The safety of changing lanes is highly dependent on the driver knowing what other road users are immediately to the rear or side of the vehicle. As it was mentioned above those two scenarios have the most group differences indicating an unfamiliar context for NDs. Also a similar pattern of results was found in the post hoc comparisons regarding "Rear View Mirror" and "Side Mirrors" with DIs having higher rankings than NDs.

The final three scenarios represented general driving across urban roads, dual carriageways, and motorways. According to all participants the "Road Ahead" location is the most important when driving along urban roads. In contrast "In-Car Controls" should be the least looked-at location. For the dual carriageway and motorway scenarios the low ranking of "Contraflow Lane / On coming Traffic" and "Off – Road Task – Relevant Information" might have occurred because motorways do not usually have pedestrians and there is a central reservation between lanes of opposite direction. In most other scenarios the "In-Car Controls" category had the lowest prioritisation. That was not the case for the dual carriageway and motorway scenarios which had much higher prioritisation. This is possibly due to the greater speed on these roads requiring more frequent speed checks. Observation of the results showed that both DIs and NDs clearly distinguished their priorities between urban driving and driving on both high speed roads. Both groups ranked lower "Side Mirrors", "Rear View Mirror", "Blind Spot" and "In Car Controls" in the "General Driving – Urban" than the other two scenarios.

Overall the results showed that "Road Ahead", "Side Mirror" and "Rear View Mirrors" were in most cases significantly higher than the rest of the given visual categories. Also those visual fields produced the most group differences and significant comparisons. "In-Car Controls" was the lowest ranked with the exception of the scenarios that involved driving on high speed roads. While the "In-Car Controls" category did not distinguish the speedometer from other in-car controls, this result ostensibly suggests that all drivers recognise the need for speed management on higher speed roads. "Off -Road Task-Relevant information" item was ranked low but it was probably due to the fact that photos of DPQ did not contain any immediately threatening off-road stimuli such as pedestrians. The low ranking of those visual fields could be explained by previous research findings indicating that certain locations becoming visually important according to task demands. "Side Roads / Adjoining

Lane" and "Blind Spot" items were usually in the middle of the ratings dependent on the scenario.

3.1.4.4 General Discussion

Results showed that DIs are consistent and choose patterns of prioritisation that differ from chance and are scenario specific. This suggests that DIs have explicit shared knowledge of the optimum visual search. Whether this agreement is based entirely in explicit knowledge or the DPQ acted as a knowledge elicitation tool is not clear. Previous research has shown that rating tasks elicit knowledge from experts and moreover they showed differences between experts and novices (Hoffman, Shadbolt, Burton, & Klein, 1995). Hence it is possible that the DPQ acted as a cue for DIs to externalise their existing knowledge.

NDs are also consistent and have patterns that diverge from chance but have many differences with DIs. This suggests that in some cases they all agree to look in different places than DIs. They must all be following the same guidelines – either an incorrect informed model (based on DIs advice, but this result in wrong prioritisations – mirror, signal manoeuvre) or they are using a "naïve model" to guide their priorities. In other words, when pulling away, even non drivers will realise that it is important to use mirrors and look over the shoulder etc. A naïve model will not include the less obvious priorities however. It is likely that reality involves a mixture of these problems.

DIs and NDs differ and since NDs are under no demands when completing the DPQ it suggests that although DIs have this knowledge NDs are not benefiting. This suggests that driving training is not enough to transfer knowledge from DIs to NDs. This might be due to failing of DIs to choose the appropriate technique or maybe due to resource limitations of the NDs when in the learning situation. It is possible that learning during on-road lessons might be problematic due to poor encoding. For example when a learner is performing a pulling away manoeuvre and the DI will instruct the mirror, signal, manoeuvre directions it is possible that the learner will concentrate more in performing the task rather than encoding any specific directions. A possible solution to this problem might be some classroom instruction.

Our results are consistent with previous research findings (Underwood et al., 2003). They found no road type difference between rural, suburban and dual carriageway between “Road Near Ahead”, “Road Mid Ahead” and “Road Far Ahead” as calculated by mean fixation duration. Overall they found that “Road Far Ahead” and “Road Mid Ahead” visual fields had the more fixations than the rest of their defined fields. This is the case for our results since the “Road Ahead” category was significantly amongst the highest ranked categories in most scenarios.

Underwood et al (2003) reported increased mirror fixations on dual carriageways than rural and suburban roads. Again both mirror visual fields where highly rated by both DIs and NDs. Although as it was mentioned NDs rated significantly “Rear View Mirror” significantly lower in 6 scenarios. Another study investigated the relationship between state of alertness and mirror inspection (Pastor et al., 2006). Their most interesting finding in relation to our results is the mirror inspection between motorway and one lane road driving where they found a higher frequency of mirror inspection on motorways than roads. The results of those studies match the results of the present study where we found that “Side Mirror” and “Rear View Mirror” were significantly higher at “Dual Carriageway” and “Motorway” general driving scenarios than “Urban” general driving.

On the experimental level it is proposed that future driving training interventions should consider the preference on “Road Ahead”, “Side Mirrors” and

"Rear View Mirrors". It is believed that the consequence of that will increase both horizontal and vertical scanning as well as increase the level of alertness (Pastor et al., 2006). In applied terms DIs themselves could benefit by the results of the DPQ. Regardless of the efficiency of the existing training system, DIs could enhance their teaching strategies by considering the findings of DPQ. For example DIs could teach alternative ways of speed estimation without inspection of in-car controls. It seems that certain visual fields priorities knowledge has not been transferred to NDs by DIs during training. It would be beneficial if DIs focus more on their explicit instructions to those areas. At last it could be said that by involving DIs into the experimental psychological research we might increase their awareness regarding the cognitive aspects of visual search. Also by comparing DIs and NDs, the two extremes of driving experience have been explored.

DIs have knowledge regarding visual search priorities but NDs do not have same knowledge. This discrepancy indicates failure of DIs to transfer this specific knowledge. Perhaps classroom teaching without driving demands might resolve part of the problem. Training of specific scenarios would benefit from our findings such as further emphasising use of mirrors, encouraging NDs to reduce time of in-car controls and highlighting the need to pay attention to the road ahead even when performing a pulling away manoeuvre.

Despite the relatively low number of participants it can be argued that the exploratory scope of the questionnaire has been achieved. Hopefully future studies with the DPQ will replicate these effects on larger sample. Another way of investigating further the topic would be the measurement of eye movements of DIs and NDs. Eye movements could reveal a different pattern in relation to other studies that used experienced drivers. Moreover, a more dynamic experimental methodology might provide insight regarding the influence of the attentional mechanisms that affect visual search. Also it would be a point of interest to compare participants' opinions between a theoretical questionnaire and behavioural data from simulated driving or by using an instrumented vehicle. As a final remark it should be mentioned that the involvement of driving instructors in applied driving research is an avenue that should be explored further as not only will the expert nature of these drivers enlighten the skill development in driving, but they are a vital part in the training process that has been neglected by researchers.

Significant Comparisons Table - Driving Instructors

Scenario	Visual Field	Road Ahead	Side Roads	Off Road Task	Side Mirrors	Rear View Mirror	Blind Spot	Contraflow Lane
Pulling Away - Urban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	X	*	*	*			
	Blind Spot	X	*	*	X	X		
	Contraflow Lane	*	*	*	X	*	*	
	In-Car Controls	*	*	*	*	*	*	*
Pulling Away - Subrban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	X	*	*				
	Rear View Mirror	X	*	*	X			
	Blind Spot	X	*	*	X	X		
	Contraflow Lane	*	*	X	*	*	*	
	In-Car Controls	*	*	*	*	*	*	*
Dealing with Junctions - Give Way	Side Roads	X						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	X	*			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	*	X	*	*	
	In-Car Controls	*	*	*	*	*	X	*
Dealing with Junctions - Right of Way	Side Roads	X						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	*	*			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	*	X	*	*	
	In-Car Controls	*	*	*	*	*	X	*
Changing Lane - Urban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	X	*	*				
	Rear View Mirror	X	*	*	X			
	Blind Spot	*	X	*	*	*		
	Contraflow Lane	*	*	*	*	*	*	
	In-Car Controls	*	*	*	*	*	*	X
Changing Lane - Dual Carriageway	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	X	*	*	X			
	Blind Spot	X	X	*	*	*		
	Contraflow Lane	*	*	X	*	*	*	
	In-Car Controls	*	X	*	*	*	*	*
General Driving - Urban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	X	X				
	Rear View Mirror	*	X	*	*			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	*	*	*	X	
	In-Car Controls	*	*	*	*	*	X	*
General Driving - Dual Carriageway	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	*	*			
	Blind Spot	*	X	*	*	*		
	Contraflow Lane	*	*	X	*	*	*	
	In-Car Controls	*	X	*	*	*	X	*
General Driving - Motorway	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	*	*			
	Blind Spot	*	X	*	*	*		
	Contraflow Lane	*	*	X	*	*	*	
	In-Car Controls	*	X	*	*	*	X	*

* = significant, p<.001

Table 3.1. Wilcoxon Signed – Pair Test comparisons for Visual Field rankings of Driving Instructors within scenario.

Significant Comparisons Table - Novice Drivers

Scenario	Visual Field	Road Ahead	Side Roads	Off Road Task	Side Mirrors	Rear View Mirror	Blind Spot	Contraflow Lane
Pulling Away - Urban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	x	*	*				
	Rear View Mirror	x	*	*	x			
	Blind Spot	x	*	*	x	x		
	Contraflow Lane	x	*	*	x	x	x	
	In-Car Controls	*	*	*	*	*	*	*
Pulling Away - Subrban Road	Side Roads	*						
	Off Road Task	x	*					
	Side Mirrors	x	*	x				
	Rear View Mirror	x	*	*	x			
	Blind Spot	*	*	*	x	x		
	Contraflow Lane	x	*	x	*	*	*	
	In-Car Controls	*	*	*	*	*	*	*
Dealing with Junctions - Give Way	Side Roads	x						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	*	x			
	Blind Spot	*	*	*	x	*		
	Contraflow Lane	*	*	x	x	x	*	
	In-Car Controls	*	*	*	*	*	x	*
Dealing with Junctions - Right of Way	Side Roads	x						
	Off Road Task	*	*					
	Side Mirrors	*	*	*				
	Rear View Mirror	*	*	x	*			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	x	x	x	*	
	In-Car Controls	*	*	*	*	*	x	*
Changing Lane - Urban Road	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	x	*				
	Rear View Mirror	x	x	*	x			
	Blind Spot	x	x	*	x	x		
	Contraflow Lane	*	*	*	*	*	*	
	In-Car Controls	*	*	*	*	*	*	x
Changing Lane - Dual Carriageway	Side Roads	x						
	Off Road Task	*	*					
	Side Mirrors	x	x	*				
	Rear View Mirror	x	x	*	x			
	Blind Spot	x	x	*	*	x		
	Contraflow Lane	*	*	x	*	*	*	
	In-Car Controls	*	*	*	*	*	*	x
General Driving - Urban Road	Side Roads	*						
	Off Road Task	*	x					
	Side Mirrors	*	x	x				
	Rear View Mirror	*	x	x	x			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	*	*	*	x	
	In-Car Controls	*	*	*	*	*	x	x
General Driving - Dual Carriageway	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	x	*				
	Rear View Mirror	*	x	*	x			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	x	*	*	*	
	In-Car Controls	*	*	*	*	*	x	*
General Driving - Motorway	Side Roads	*						
	Off Road Task	*	*					
	Side Mirrors	*	x	*				
	Rear View Mirror	*	x	*	x			
	Blind Spot	*	*	*	*	*		
	Contraflow Lane	*	*	x	*	*	*	
	In-Car Controls	*	*	*	*	*	x	x

* = significant, p<.001

Table 3.2. Wilcoxon Signed – Pair Test comparisons for Visual Field rankings of Novice Drivers within scenario.

Chapter 4: Investigating the interaction of top-down and bottom up influences upon drivers' visual attention

4.1 Summary of previous findings

In experiment 1 it was found that driving instructors (DIs) and novice drivers (NDs) have different priorities in regards to visual allocation when driving. In addition consistency was found in the opinions within each group. It was proposed that both groups have different knowledge schemes regarding visual search priorities. However, it is not clear yet whether these differences in explicit priorities are only detectable at a pen and paper theoretical level or whether similar differences can be found in actual eye movements. Although previous research has clearly demonstrated behavioural differences on visual attention some questions remain unanswered. One issue that needs further clarification is they way that attentional mechanisms influence visual search strategies. In the two Experiments of this Chapter a novel experimental paradigm will be used to investigate the interaction of top-down and bottom-up influences upon drivers' visual attention.

4.2 Experiment 2

4.2.1 Introduction

In the literature review in Chapter 1 (see section 1.4) the link between visual attention and driving experience was considered critical for driving safety. In general it has been demonstrated that more experienced drivers have more efficient visual search strategies. In more specific terms it has been found that expert drivers have more frequent and shorter fixations than less experienced drivers and also they have greater spread of search in the horizontal axis (Chapman & Underwood, 1998). Moreover experienced drivers tend to fixate on different regions than novices

(Underwood et al., 2002a). However, there is more than one mechanism that controls the allocation of attention and the way that those mechanisms interact while driving is not clear yet.

4.2.2 Bottom-up and top-down influences

There are two main approaches that try to explain human eye movement control; the first is a bottom-up, salient-driven hypothesis while the second is a top-down cognitive hypothesis (Henderson, Brockmole, Castelhano, & Mack, 2007). The first approach proposes that attention is directed by a bottom-up mechanism (Itti & Koch, 2000). This bottom-up process drives attention in relation to the properties of the stimuli available and it favours the inspection of points that stand out in relation to the surroundings (Parkhurst et al., 2002). Based on this bottom-up approach a computation model has been developed that predicts attentional allocation (for a detailed view of the model see: Itti & Koch, 2001). Briefly described, the model breaks down a picture into three separate maps (colour, intensity, orientation) and after the separate calculation of the salient points in each map it constructs an overall saliency map. The overall saliency map contains a winner-take-all point that is assumed to attract attention. Subsequent points of attention are calculated after the target point is moderated by inhibition of return (Klein, 2000). Based on this computational model of bottom-up attention software has been developed that calculates the most salient points of pictures and predicts the focus of attention (saliency toolbox; Walther & Koch, 2006).

In order to demonstrate the applicability of the theoretical concept described above Parkhurst et al (2002) conducted an experiment. In their experiment they showed pictures from four categories to participants. They asked participants to free view the pictures for five seconds while they recorded their eye movements. The calculated the saliency values based on the computational model and they correlated the salient points with the fixated points. They concluded that fixations are influenced by saliency. They also proposed that under normal viewing condition eye movements are guided by the properties of the stimuli. Although the results are convincing there are some points that might have influenced the findings. First, it must be said that the strongest correlations where found for the first fixations on pictures and most salient points, while the correlations became weaker after each fixation, which suggests that top down influences became stronger during the presentation of a picture. Secondly, the highest influence of saliency on visual search was found for fractal pictures which lack semantic value and therefore have limited top down knowledge associated with them. Finally, it is not clear how saliency influences visual allocation when the task requires more demanding visual search and whether this model can incorporate top down influences upon attention.

It is quite possible that when the complexity of the image increases (see Figure 4.1) some of the predictions of the bottom-up model might not be so realistic. For example a driver might want to scan the road for any potential hazard rather than looking at a salient, but not semantically important, bright spot at a behaviourally irrelevant place. Indeed there are many cases where visual saliency cannot accurately predict the attended location, as with instances where there are inconsistent changes in natural scenes (Stirk & Underwood, 2007). Stirk and Underwood conducted an experiment in order to explore whether the saliency of stimuli influences more than high level scene knowledge. They used a change blindness paradigm (see section 1.3.5) and they changed some scene objects either with high or low salient objects or with scene consistent or inconsistent objects (e.g. a toilet roll in the shower). They found that participants were faster and more accurate to detect inconsistent objects

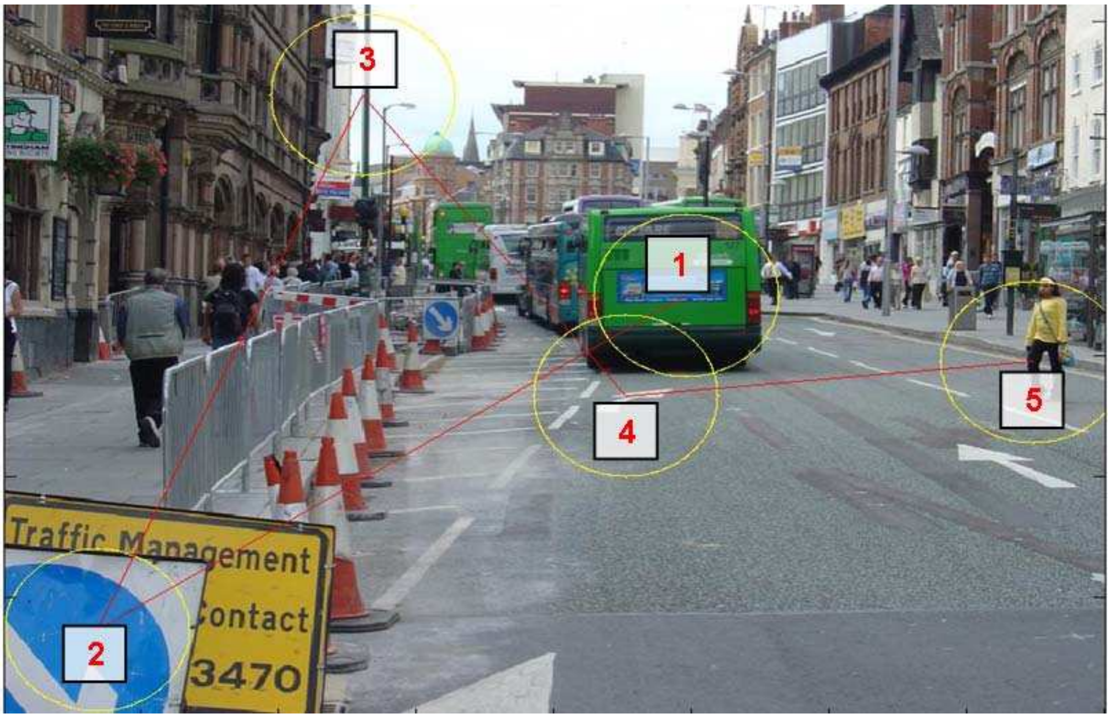

Figure 4.1. Figure represents a saliency scanpath as predicted by the algorithm and the numbers indicate the order of the attended locations. For demonstration purposes the field of attention size was modified to 2^o.

than consistent ones and, moreover, there was no effect of saliency. They suggested that detection was influenced more by top-down factors than by low-level factors such as saliency.

Furthermore it would make no evolutionary sense to have an attentional system if processing was entirely bottom-up (Desimone & Duncan, 1995). So it seems that maybe there is something more in the eye movement control than just bottom-up factors. This is proposed by the top-down approach which suggests that eye movements in scene perception are affected by cognitive factors such as episodic memory, scene-schema or task related knowledge (Henderson, 2003; Yarbus, 1967). More studies related to this topic have been mentioned in Chapter 1 (see section 1.4). In the driving context an often used surrogate measure for increases in schema strength or knowledge is driving experience.

There are many studies that have investigated the interaction between bottom-up and top-down influences on visual search (Henderson, 2007). However, it is not so clear which of the two mechanisms contribute more in controlling the movement of the eyes and the locus of attention (Chen & Zelinsky, 2006). In anatomical terms things are no clearer since the terms bottom-up and top-down usually refer to cognitive modules and conceptual principles rather than to distinct anatomical features (Sarter, Givens, & Bruno, 2001). However, recent findings suggest that there is a neuroanatomical dissociation between bottom-up and top-down processes of visuospatial selective attention (Hahn, Ross, & Stein, 2006). In addition, Buschman and Miller (2007) compared neural activity during bottom-up and top down functioning of monkeys. It was found that bottom-up and top-down signals originate from different brain areas. However, further replication is necessary and it remains unanswered whether these results could be extended into attentional processes in general or they are limited to particular aspects.

In addition to the lack of conclusive remarks on the interaction of bottom-up and top-down factors there are some methodological issues that need to be addressed. The most common methodology used to generate the bottom-up salient locations in a natural scene is Itti and Koch's (2000, 2001) computational model (Foulsham & Underwood, 2008). In contrast, there is no methodological consistency to the manipulation of the stimuli and the methodology that can generate top-down activation.

4.2.3 Present Study

There are both theoretical and practical motivations in the investigation of the top-down and bottom-up interactions upon drivers' visual attention. On the theoretical level it would be important to know how drivers' visual attention is affected and whether it is influenced by top-down knowledge of the given scene or it is driven mainly by the properties of the driving situation. Furthermore it is a point of great interest to know whether this interaction remains stable across time. On the practical level by knowing the mechanisms that drive visual attention it would be possible to develop specific aspects of drivers' training, for example if bottom-up factors affect to drivers' attention to a great extent, a training intervention that neglects the visual properties of the driving scene will not be as efficient.

There are three main questions that drive the current experiment. First, we would like to explore how the horizontal and vertical scanning of participants is affected during visual search. Since previous driving studies have shown that more experienced drivers have greater spread of horizontal search (Chapman & Underwood, 1998) the hypothesis here is that experienced drivers will have greater spread of search than novices. Secondly, the interaction between top-down and bottom-up factors is explored and we hypothesise that experienced drivers' (EDs) visual attention will be influenced mainly by top-down due to their high task-related knowledge while NDs may be affected less by top-down factors since their lack of experience precludes the same strength of scene-schema or task-related knowledge. Finally it needs to be clear whether any interaction between these factors is stable through visual allocation or it reaches any peaks during visual search.

One methodological issue in the present study is the manipulation of the top-down factor. Previously, different methods have been used to control top-down influence such as target preview (Buschman & Miller, 2007; Chen & Zelinsky, 2006), experts' definition of high semantic areas (Henderson et al., 2007) and manipulation of verbal instructions (Mosimann, Felblinger, Colloby, & Muri, 2004) amongst others. Our novel methodology allowed participants to define their own top-down preferences. This was necessary in order to allow us to draw conclusion both about their top-down knowledge on the scene as well as their introspection into their own visual search. Another important element in our methodology will be the absence of a time limit in the top-down condition which will minimise any pre-attentive bottom-up influences. The absence of time limits is important when one considers studies that show that fixations are more likely to deviate from saliency predictions the longer a picture is presented for (Foulsham & Underwood, 2008; Parkhurst et al., 2002). Finally the recruitment of two groups of participants with diverse driving experience should show whether experience changes the relationship between top down and bottom up factors in influencing eye movements. Hence we used experienced drivers (EDs) and novice drivers (NDs). In regards to the bottom-up calculation the commonly used saliency toolbox will be employed in order to predict the attended locations.

4.2.4 Method

4.2.4.1 Participants

Fourteen experienced drivers (EDs, 9 females) were recruited for this experiment with a mean age of 26.3 years (SD 3.7). Their mean driving experience was 8.1 years (SD 3.2) since passing their driving test. The other group consisted of 15 novice drivers (NDs, 8 females) with mean age of 20.7 years (SD 2.3). Their driving experience was on average 0.5 years (SD 0.7) since passing their driving test.

4.2.4.2 Stimuli and apparatus

Fifty pictures were used as stimuli. The pictures represented a variety of road conditions and they were taken from the drivers' perspective. The conditions that were represented in the pictures included rural roads, suburban roads and motorways. Stimuli were presented on a 19 inch monitor. Each picture was presented at 1024 x

768 pixels, producing a visual angle of 30^o x 24^o at a distance of 70cm. A chin rest was used in order to ensure the viewing angle was the same for all participants and the eye movements were recorded by using an SMI Remote Eye-tracking Device (RED). The salient points on each picture were calculated by the saliency toolbox 2.1 (Walther & Koch, 2006) employing the default values. The first fixation was removed since participants had to fixate at the centre of the screen prior to picture onset.

4.2.4.3 Procedure

After participants completed a questionnaire with some demographic questions they were seated in front of the screen at 70 cm. Their head movements were restricted by using a chin rest. The experiment was consisted of two tasks, *looking* and *clicking*. All the participants performed the looking task before the clicking task; this specific order was followed to make sure that the top-down selection, required in the clicking task, did not affect the eye movements of the participants. For the looking task participants were asked to imagine they were driving in the conditions that the pictures represent and to look at the scene as they would do normally. Prior to picture presentation a fixation cross appeared for 1 second at the centre of the screen and participants were asked to fixate the cross before the scanning the picture. This was done to ensure that all participants had the same starting point of visual search. Every picture was presented for four seconds in a random order. During the four seconds of the presentation participants' eye movements were recorded.

For the clicking task, participants viewed the same pictures as before, in a new random order. Participants were instructed to click with a mouse on five points in the picture that they thought they should look at if they were driving through that situation. It was explained that the first click should represent the most important visual point while the subsequent clicks representing the second, third, fourth and fifth most important point. There was no time limit for each click and a new picture was presented after the participant clicked for the fifth time.

4.2.5 Results

Three categories of analyses were performed in order to explore bottom-up and top-down influences on visual attention. The first analysis was performed to investigate any differences in the distribution of fixations and clicks. The second was done to identify how eye movements were affected by cognitive factors or saliency of the stimuli. Finally in order to look closer at the processes over time we conducted a point by point analysis, comparing each fixation to each click and each salient point.

4.2.5.1 Spread of search

The first step of the analysis was to investigate any differences between NDs and EDs in the spread of search and for that reason the horizontal and vertical spread of the fixations and clicks were examined. In regards to the spread of fixations and clicks in the horizontal axis a 2x2 mixed design ANOVA was conducted with the particular behavioural measure (fixation locations / click locations) as the within groups factor, and driving experience as the between groups factor with EDs and NDs as levels. The standard deviations of x and y coordinates of fixations and clicks were averaged across the first five points and then across the 50 photos. Hence, each participant had one value for the horizontal spread of fixations and one for the horizontal spread of clicks. Standard deviations were calculated in degrees. The behavioural measure factor was significant, $F(1, 27) = 52.1$, $MSE = 0.5$, $p < 0.001$, with both EDs and NDs having less spread in their fixations (mean = 5.28^{o}) than their clicks (mean = 6.64^{o}). The average spread of salient points was nine degrees. There

Figure 4.2. Figure illustrates an example of a sequence of fixations (scanpath) by one participant in one picture. The numbers indicate the order of fixations while the circle diameter illustrates the fixation duration.

was no effect of group, $F (1, 27) = 0.5$, $MSE = 1.17$, $p = 0.47$, and no interaction was found between measure and group, $F (1, 27) = 0.04$, $MSE = 0.5$, $p = 0.84$.

The same statistical analysis as above was performed for the vertical axis. The behavioural measure factor was again significant, $F (1, 27) = 382$, $MSE = 0.17$, $p < 0.001$, with both groups having less spread in their fixations (mean = 2^{o}) than their clicks (mean = 4.12^{o}). The average spread of salient points was 4.6 degrees. No group effect was found, $F (1, 27) = 0.37$, $MSE = 0.27$, $p = 0.55$, and no interaction was found between measure and group, $F (1, 27) = 1.19$, $MSE = 0.17$, $p = 0.30$.

4.2.5.2 Scanpath analysis

Three sequences or scanpaths were available for further analysis. These were the fixation location, clicking location and the saliency peak scanpaths, each containing 5 sequential instances of each measure. The fixation scanpath is the sequence of fixations made in any picture (see Figure 4.2). The clicking scanpath was

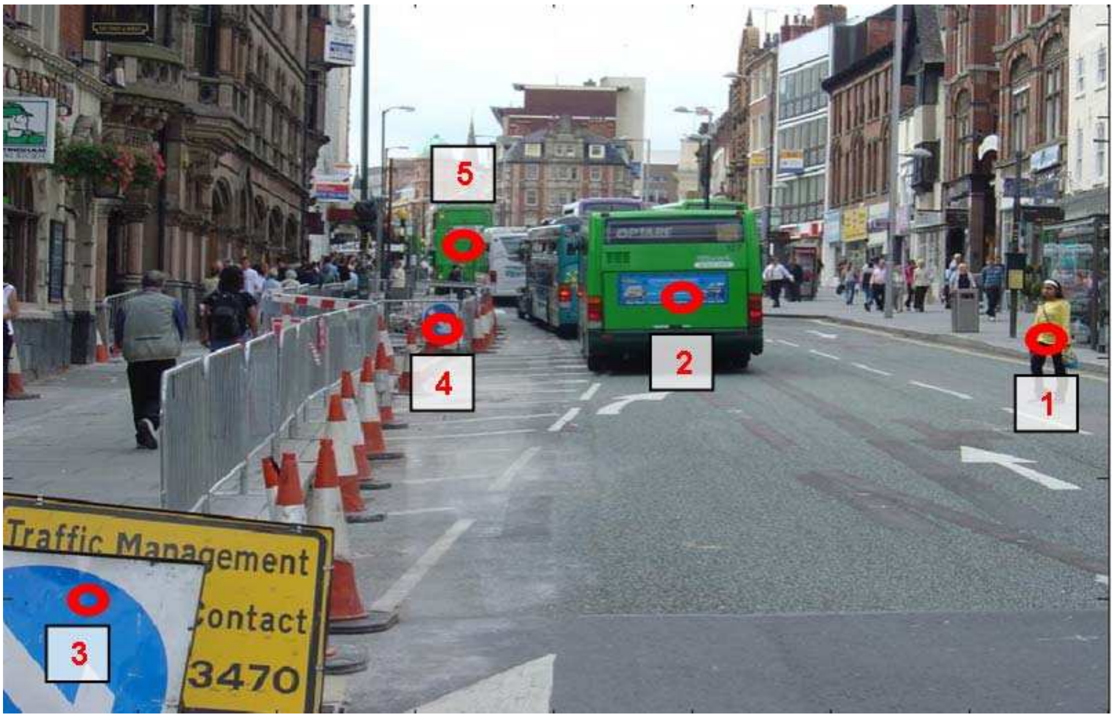

Figure 4.3. Figure includes a sequence of clicks by one participant in one picture and numbers indicate the order of the clicks.

the sequence of clicks that the participants made on each picture and it represented the most important visual information as judged by the participants (see Figure 4.3). Finally for each picture the saliency toolbox predicted the locations of attention in any picture based on the physical properties of the stimuli (see Figure 4.1). Based on these scanpaths there are three possible paired comparisons: a comparison of a particular fixation location with the corresponding saliency peak; a comparison of a particular fixation location with the sequentially corresponding click location; and a comparison of click locations to the sequentially ordered corresponding saliency peaks.

In order to obtain a value of similarity for our compared scanpaths we used the Mannan similarity index (Mannan, Ruddock, & Wooding, 1995) which compares two scanpaths and returns similarity values from 0 to 100, with 100 being the value for identical scanpaths. Also it is possible to get negative values for scanpaths that differ systematically. Mannan similarity was employed since has been used before in

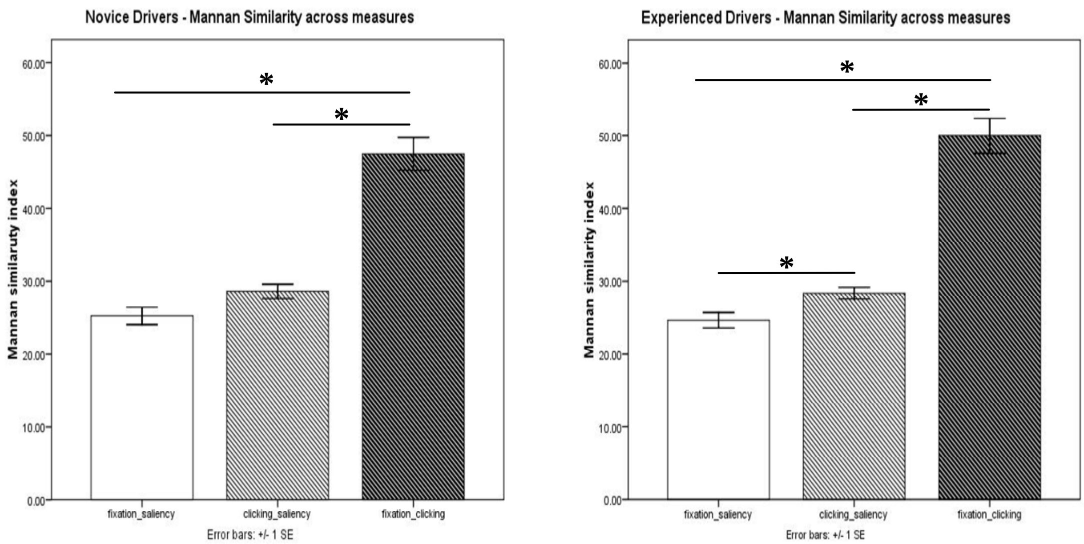

Figure 4.4. Left bar is the similarity between fixation and saliency and indicates how eye movements are influenced by bottom-up factors. Middle bar is the similarity between clicking and saliency which will give us an estimation of how similar participants' explicit reports are to bottom-up influences of saliency. Finally the third bar represents how similar participants' reports are to the eye movements they produced and represents how accurate their introspection is into their eye movement patterns

scanpath comparison analysis (Henderson et al., 2007). In order to perform scanpath comparison analysis a Java based programme available on-line was used (Foulsham & Underwood, 2008).

Since we had three comparisons and two groups of participants a 3x2 ANOVA would seem appropriate however this will violate the assumption of independence. Hence a non parametric test is more suitable for this case. However, since there is considerable difficulty conducting a mixed design non-parametric test (Brunner & Puri, 2001), we analysed EDs and NDs separately using the Friedman test which is the non-parametric equivalent to one-way repeated ANOVA. For the post-hoc comparisons we used Wilcoxon signed-rank tests corrected with the Bonferroni method.

Results for both groups are demonstrated in Figure 4.4. The bars in Figure 4.4 represent the similarity index for the three scanpath comparisons. The first bar is the similarity between fixation and saliency which will indicate how eye movements are influenced by bottom-up factors. The second bar is the similarity between clicking and saliency which will give us an estimation of how similar are the top-down and bottom-up factors. Finally the third bar represents how close the top-down factor is to the eye movements since this bar shows how similar the fixation and clicking scanpaths are.

In regards to NDs, the Friedman test was significant, χ^2 (2) = 25.2, $p < 0.001$, and the post-hoc tests showed that the fixation-clicking comparison (mean = 47.48) was significantly higher than fixation-saliency (mean = 25.24, T = 0, $p < 0.001$) and clicking-saliency (mean = 28.60, T = 0, $p < 0.001$). Finally, clicking-saliency was not found to be significantly higher than fixation-saliency.

For EDs the Friedman test was also significant, χ^2 (2) = 26.14, $p < 0.001$, and the post-hoc tests showed that the fixation-clicking comparison (mean = 49.98) was significantly higher than fixation-saliency (mean = 24.64, T = 0, p = 0.001) and clicking-saliency (mean = 28.36, T = 0, p = 0.001). Also a difference was found between fixation-saliency and clicking-saliency (T = 12, p = 0.011).

4.2.5.3 Point by point analysis

In order to look closer within each comparison pair we performed a point by point analysis. For example at the fixation-saliency comparison we compared the first fixation with the first salient point, the second fixation with the second salient point and so on. A 5x2 mixed ANOVA was performed for every comparison with the number of points as the within factor and the group as the between. Pairwise comparisons with Bonferroni corrections explored any significant differences between the points.

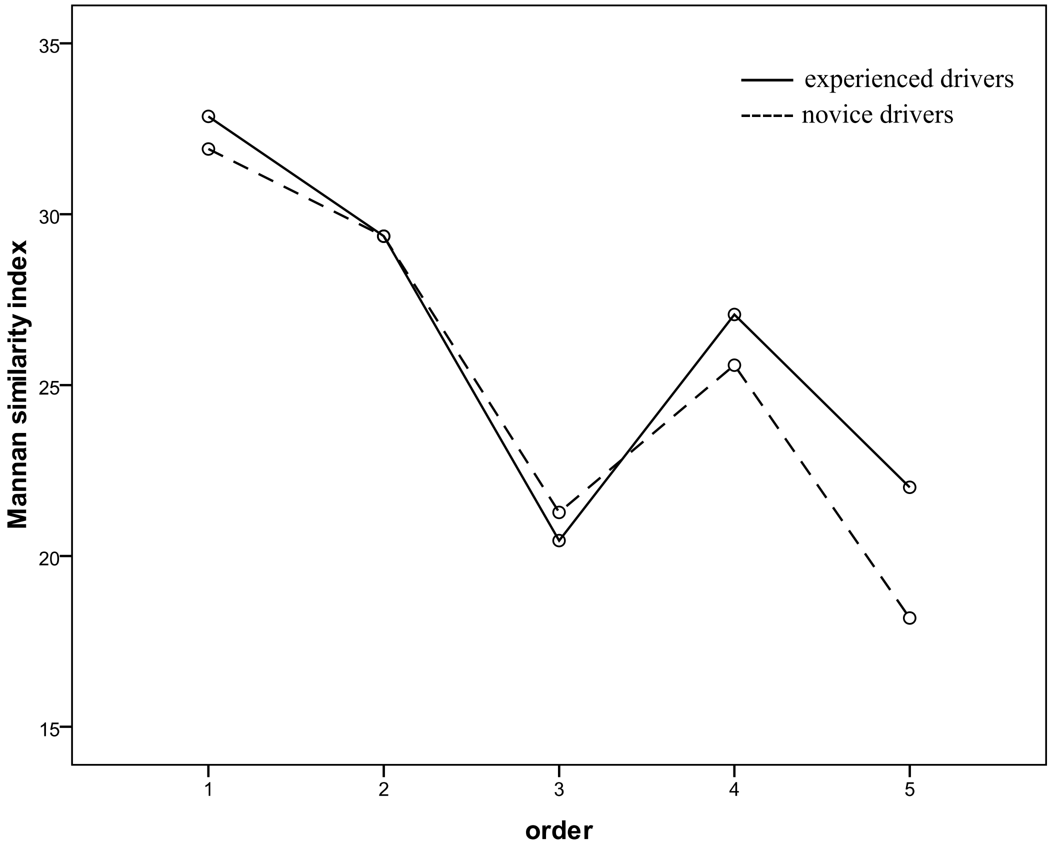

Figure 4.5. This figure demonstrates the point by point similarity between fixations and saliency.

For the fixation-saliency analysis an overall effect of order was found, F (4, 108) = 28.83, MSE = 28.43, p < 0.001 (see Figure 4.5), with the first fixation-saliency point (mean = 32.39) having significantly higher similarity than all the other points apart from the second point (mean = 29.36). The similarity was even lower for the third point (mean = 20.86) but it was significantly increased at the fourth point (mean = 26.32, p < 0.001) and then by the fifth point (mean = 20.1) the level of similarity became similar to the third point. No group effect was found, F (1, 27) = 0.71, MSE = 12.13, p = 0.41. Finally, no interaction between order and group was found, F (4, 108) = 0.79, MSE = 28.43, p = 0.53.

For the clicking-saliency analysis an overall effect of order was found, F (4, 108) = 14.06, MSE = 30.88, p < 0.001 (see Figure 4.6), with the second clicking-saliency point having significantly higher similarity than the rest of the points. The

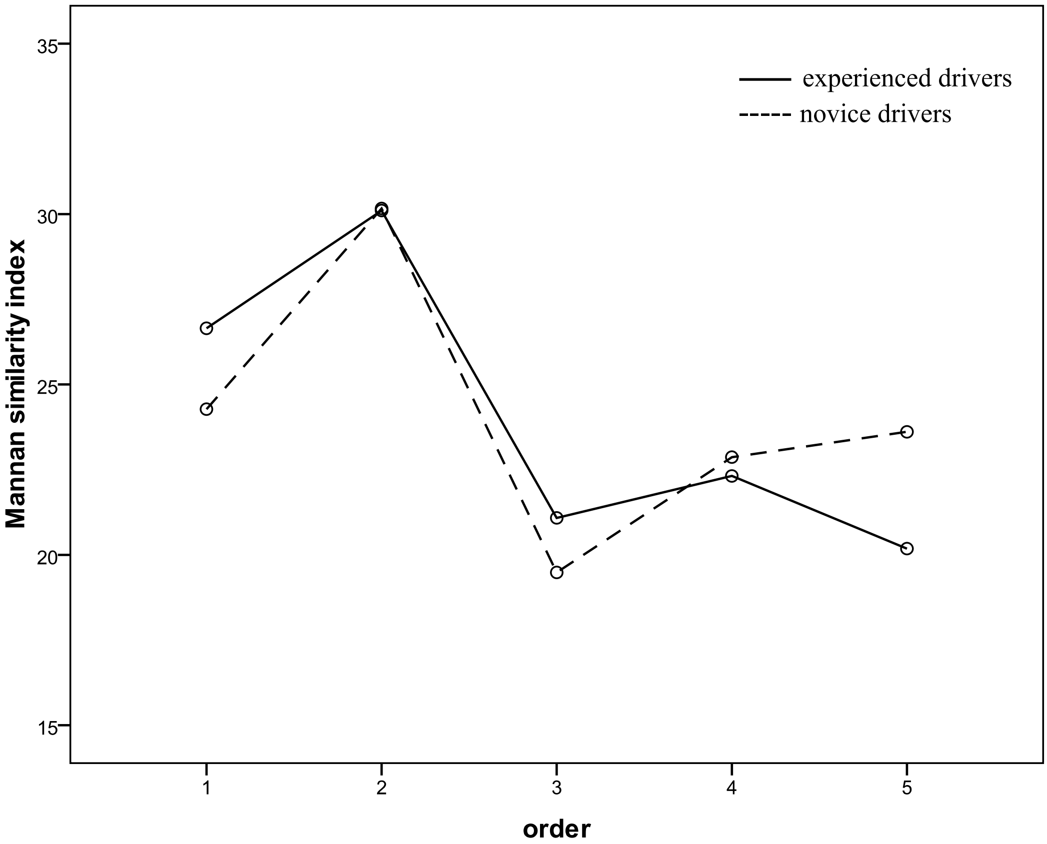

Figure 4.6. This figure demonstrates the point by point similarity between clicking and saliency.

similarity level increased significantly from the first point (mean = 25.46), to the second (mean = 30.13, $p < 0.001$) and then decreased significantly to the third point (mean = 20.28, $p < 0.001$). After the third point the similarity between clicking and saliency remained at the similar levels with the fourth (mean = 22.59) and fifth points (mean = 21.89) not being significantly different than the third point. No group effect was found, $F(1, 27) < 0.001$, MSE = 15.89, $p = 0.99$. Finally, no interaction between order and group was found, $F(4, 108) = 1.19$, MSE = 30.88, $p = 0.32$.

For the fixation-clicking analysis an overall effect of order was found, $F(4, 108) = 15.71$, MSE = 56.82, $p < 0.001$ (see Figure 4.7), with the first fixation-clicking point (mean = 52.14) having significantly higher similarity than the remaining points. After the first point the similarity was significantly decreased to the second point (mean = 42.07, $p < 0.001$) and then remained the same since there was no any

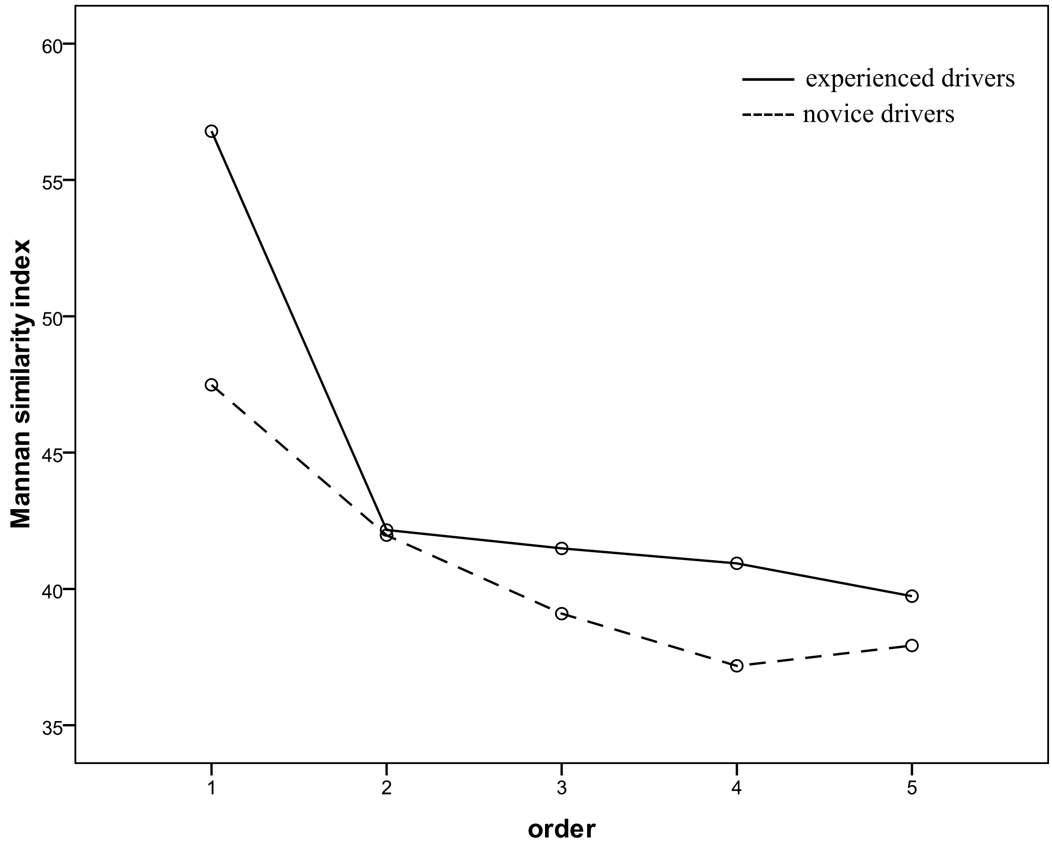

Figure 4.7. This figure demonstrates the point by point similarity between clicking and fixations.

significant difference between the second point and the third (mean = 40.29), fourth (mean = 39.06) and fifth point (mean = 38.83). No group effect was found, F (1, 27) = 1.81, MSE = 48.76, p = 0.19. Finally, no interaction between order and group was found, F (4, 108) = 1.56, MSE = 56.82, p = 0.19.

4.2.6 Discussion

4.2.6.1 Spread of search

In regards to the spread of clicks for both the horizontal and vertical axes it was found that clicking had larger horizontal and vertical spread than fixations. There is a possibility that participants seem aware for the need to sample widely but do not do so when viewing the scene, possibly because the time constraints of real time eye movements do not allow them to prioritise the top-down locations soon enough to receive one of the first 5 fixations. This result might provide indirect evidence that the top-down manipulation has been achieved by this specific methodology.

Surprisingly no group effect was found for the spread of fixations or clicks. This result is not in agreement with previous findings from the driving literature on which experiential differences were detected (Crundall & Underwood, 1998). However, there is a possible explanation for these results. Maybe the two groups that were used here are not sufficiently distinct and the difference in their years of driving experience is not enough to elicit different behaviour in this task (Horswill & McKenna, 2004). Also previous research has shown that driving experience in years does not automatically result in expertise (Duncan, Williams, & Brown, 1991), so it is possible that more diverse groups are necessary to reveal any differences in spread of search under this experimental conditions.

4.2.6.2 Scanpath analysis

In regards to the scanpath comparison analyses it was found that EDs and NDs had similar patterns which imply that under static stimuli the visual search mechanisms operate similarly despite the variation of driving experience. Although a direct comparison has not been performed due to the difficulty of running non-parametric mixed design analysis the findings had very similar outputs. Again one could argue that the two groups are not diverse enough to allow any potential differences to be revealed.

In terms of the three scanpath comparisons it was found that visual search was more closely related to top-down influences rather than bottom-up factors as indicated by the high similarity between fixation and clicking. For both groups the similarity between fixation and clicking was significantly higher than the other two categories. This is in agreement with previous studies (Chen & Zelinsky, 2006; Henderson et al.,

2007) on which they found that top-down factors affected visual search. Underwood and Foulsham (2006) found that saliency affects visual search when free viewing however they used general natural scenes while we used driving pictures which in themselves involve semantic structure likely to invoke additional top-down elements.

For NDs fixations and clicks were affected to equal extents by saliency since the post hoc test was not significant. This result indicates that saliency had little effect for both clicks and fixations. Similar similarity values using the Mannan index have been obtained before when saliency points were compared to fixations (Henderson et al., 2007). However, EDs also showed significant difference between fixation / saliency similarity and clicking / saliency similarity indicating that saliency affected EDs clicks to the greater extent than fixations. This implies that saliency has a greater relationship with where EDs think they should look, than where they actually look. This is a little bit surprising because one might expect the opposite result, that the less experienced drivers will be affected more by saliency. There is the possibility however that some semantically important locations were also highly salient at the same time. Furthermore it is possible that EDs clicking was affected by saliency. Nevertheless EDs high similarity between fixation and clicking shows high levels of introspection between where they should look and where they actually look.

4.2.6.3 Point by point analysis

After the analysis between scanpath comparisons we will try to look closer within each comparison to explore further the processes that take place.

The first point by point analysis investigated how saliency affected the sequence of five fixations. For the fixation / saliency comparison results showed that the similarity between salient locations and fixation locations was significantly greater for the first point compared to the second and third point. Similarity then increased slightly at the fourth point but by the fifth point the similarity returned again to the levels of the third point. This shows that the effect of saliency upon fixations takes place primarily at the initial stages of deploying attention. This is consistent with previous research in which it was found that saliency affects early fixations more than later ones (Foulsham & Underwood, 2008; Parkhurst et al., 2002). Again driving experience did not affect this interaction as there were no group differences.

The second point by point analysis explored how saliency affected participants' click locations. For the clicking / saliency comparison it was shown that the second point had significantly greater similarity than all the other points. This pattern shows that the bottom-up influence of salience at the second point has the greatest relationship with clicking, before it reaches the lowest value at the third point and then remains stable over the fourth and fifth point. This is somehow difficult to interpret since someone might expect the first click to be influenced more however it is possible that at the first point introspection in terms of top-down influence affected the first click to a greater extent since it represented the most important information.

The third and final point by point analysis looked at how knowledge affects fixation allocation. For the fixation / clicking comparison it was found that the similarity at the first point was significantly greater than all the other points which had the same level of similarity up to the fifth point. So it seems that knowledge and top-down factors also have maximum influence at the initial fixations and this effect declines with subsequent fixations (yet remains relatively high compared to the salience / fixation relationship). As in all the other interactions no effect of driving experience was found.

4.2.6.4 Research questions

The first question that derives from the results of all three analyses is why the driving experience variation of the groups did not affect any of the results. There are two strong candidates that can explain this pattern of results. It is possible that the experimental conditions do not allow such differences to be explored. Maybe any task- related knowledge that is required for this task has already been acquired even from novice drivers while any additional task-related knowledge of the EDs does not provide any further benefit due to a ceiling effect. On the other hand it is very possible that the distinction between novice and experienced drivers in this experiment are not great enough to produce differences in visual search strategies. This issue can be addressed by using from more extreme location on the driving experience.

The second main finding of Experiment 2 was that participants' visual search was influenced more by top-down factors than bottom-up. For both groups the similarity between looking and clicking was significantly higher than the other comparisons. Thus when all participants scanned the picture to acquire information they did not scan it randomly instead used conscious knowledge to guide their fixations. Of course there is the question of whether the same interaction will occur in different groups of participants.

The point by point analysis showed that any significant effects and influence of either bottom-up or top-down factor on visual search occurs at the initial stage of the visual search and after the third click or the third fixation in most cases any influence effects remain stable.

4.3 Experiment 3

4.3.1 Introduction

In order to answer the questions that generated after the discussion of the results in Experiment 2 it is necessary to modify some methodological aspects in Experiment 3. Since the most surprising outcome of Experiment 2 was the fact that driving experience did not result in any major differences, alternative groups that have more diverse characteristics should be used. The usage of groups that have a greater difference in terms of expertise than in Experiment 2 will provide better insight to the interpretation of the results. For this reason we will use driving instructors (DIs) and learner drivers (LDs) in experiment 3. DIs were chosen since they combine driving experience and high levels of introspection since they need to teach visual search strategies amongst other skills. On the other hand LDs are less likely to have developed any strategies yet due to their lack of experience.

In Experiment 3 the same three main questions as in Experiment 2 will be examined. In terms of spread of search the hypothesis is that DIs will have greater spread of search than LDs. In regards to the interaction between top-down and bottom-up factors we can assume that DIs' visual attention will be influenced mainly by top-down due to their driving experience and understanding of the driving task while LDs could be more prone to bottom-up influences due to their lack of experience. Finally, in regards to the point by point analysis the hypothesis is that it will be similar to the pattern of Experiment 2 but possibly with group differences.

4.3.2 Method

4.3.2.1 Participants

Twenty driving instructors (DIs, 3 females) were recruited for this experiment with mean age of 51 years (SD 11). The mean driving experience was 31.9 years (SD 12) since passing their driving test and the average years as instructor was 16 years (SD 12). The other group consisted of 20 learner drivers (LDs, 13 females) with mean age of 23.8 years (SD 12). They had undertaken a mean of 24 hours of driving lessons.

4.3.2.2 Stimuli and apparatus.

The same stimuli as in Experiment 2 were used. However in order to be able to test DIs it was necessary to move outside the laboratory so a portable eye tracker was used. Stimuli were presented on a 17 inch screen with an integrated Tobii D10 portable eye tracker. Each picture was presented at 1024 x 768, producing a visual angle of approximately 30^o x 24^o at a distance of 60cm. The eye movements were recorded with a Tobii D10 eye tracker.

4.3.2.3 Procedure

The same procedure as Experiment 2 was used with the following variations. Due to the nature of the eye tracker slight head movements may have led to small variations in the distance from the screen. Participants were instructed to click with a mouse three (instead of five, see section 4.3.3) points in the picture that they would look at if they were driving into that situation. It was explained that the first click should represent the first most important visual point while the third click the third most important point. There was no time limit for each click and a new picture was presented after the participant clicked for the third time.

4.3.3 Results

The same analyses as in Experiment 2 were performed. The findings of Experiment 2 showed that most significant changes in the point by point analysis

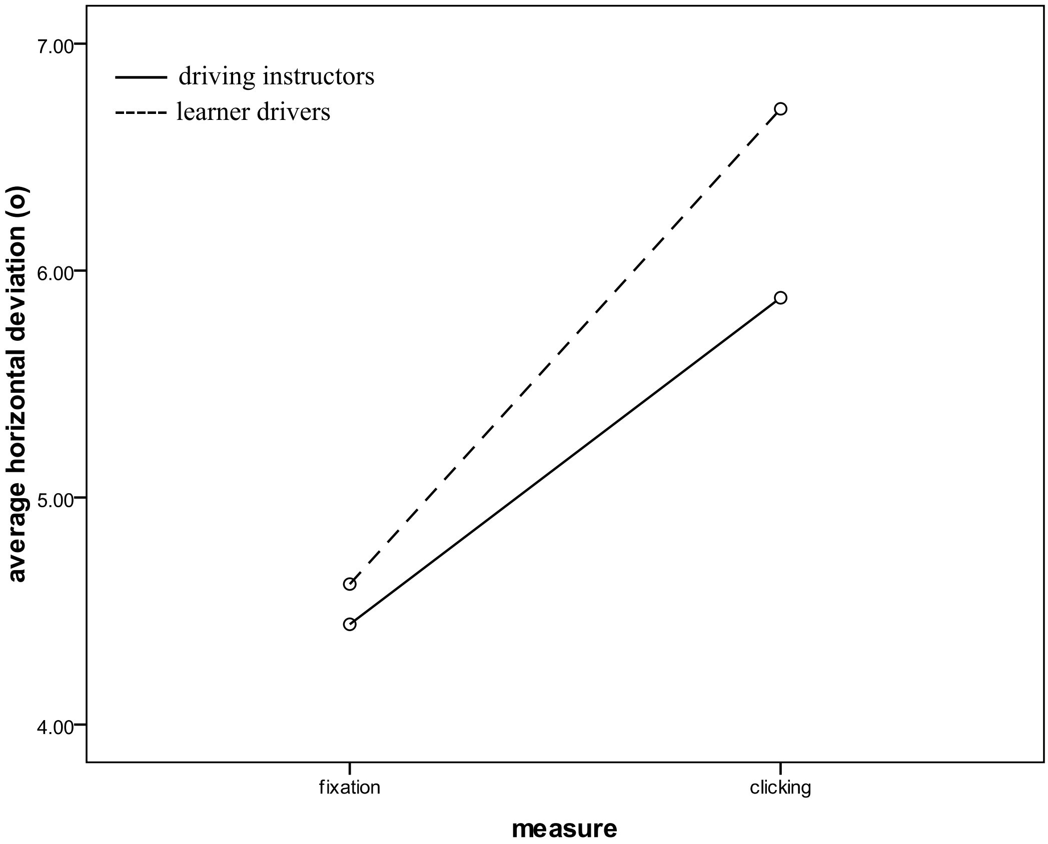

Figure 4.8. This figure demonstrates the horizontal spread of fixations and clicks.

occur during the first 3 fixations or clicks. Hence, for practical statistical reasons as well as for the easier interpretation of the results we trimmed all our fixation and clicking sequences together with the saliency output to the first three points. As a consequence the subsequent analysis will involve only the trimmed scanpaths.

4.3.3.1 Spread of search

In regards to the spread of fixations and clicks in the horizontal axis a 2x2 mixed design ANOVA was conducted with the particular behavioural measure (fixation locations / click locations) as the within groups factor, and driving experience as the between groups factor with LDs and DIs as levels (see Figure 4.8). The behavioural measure factor was significant, $F(1, 38) = 91.76$, $MSE = 25.84$, $p < 0.001$, with both DIs and LDs having less spread in their fixations (mean = 4.53o, DIs = 4.44 o, LDs = 4.62 o) than their clicks (mean = 6.29 o, DIs = 5.88 o, LDs = 6.71 o).

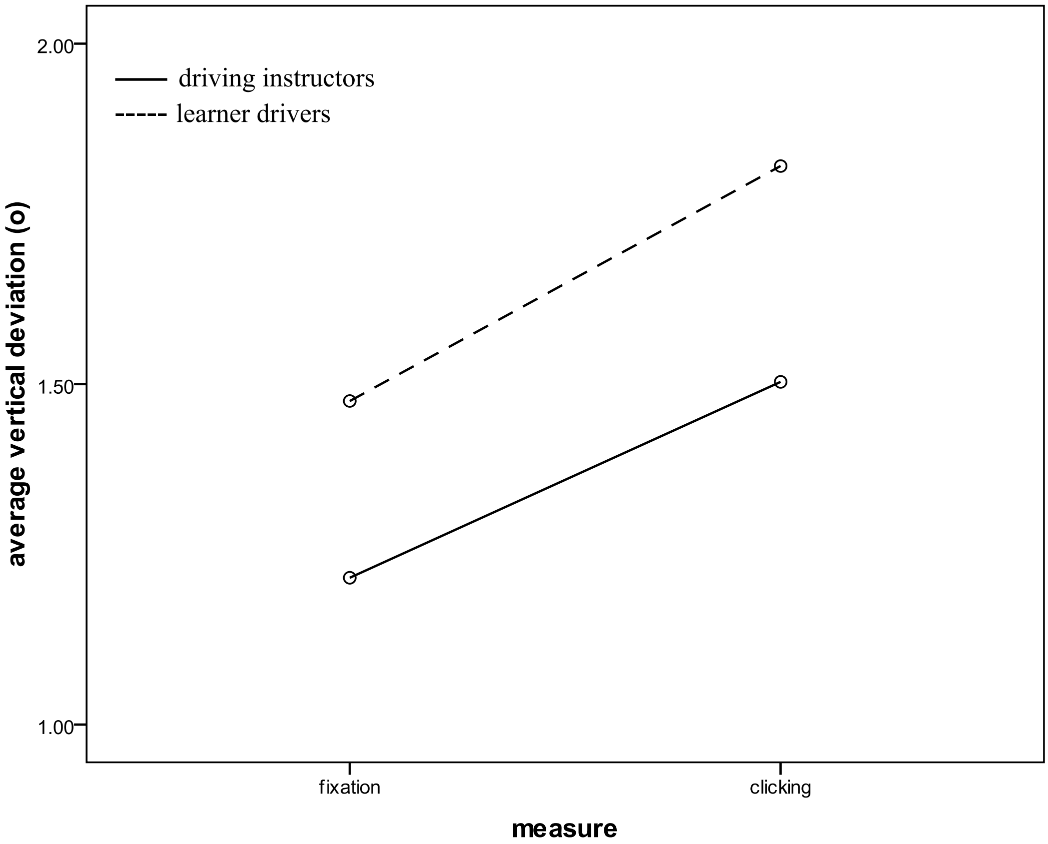

Figure 4.9. This figure demonstrates the vertical spread of fixations and clicks.

Post hoc independent t-test (Bonferroni corrected) showed that there was no difference at the fixation spread, t (38) = - 0.64, p = 0.5, however a difference was found at the clicking spread, t (38) = - 2.61, p < 0.025. The average spread of salient points was nine degrees. Also a group effect was found, F (1, 38) = 4.62, MSE = 1.10, p < 0.05, with LDs (mean = 5.67 ^{o}) having higher spread than DIs (mean = 5.16 ^{o}). Finally no interaction was found between measure and group, F (1, 38) = 3.15, MSE = 25.84, p = 0.08.

The same statistical analysis as above was performed for the vertical axis (see Figure 4.9). The behavioural measure factor was significant, F (1, 38) = 25.53, MSE = 2.98, p < 0.001, with both groups having less spread in their fixations (mean = 1.35^{o}, DIs = 1.22 ^{o}, LDs = 1.48 ^{o}) than their clicks (mean = 1.66 ^{o}, DIs = 1.50 ^{o}, LDs = 1.82 ^{o}). Post hoc independent t-test (Bonferroni corrected) showed that LDs had higher spread both for the fixations , t (38) = - 2.98, $p < 0.025$, and clicks, t (38) = - 2.99, $p < 0.025$. The average spread of salient points was four degrees Also a group effect was found, F (1, 38) = 15.20, MSE = 2.08, $p < 0.001$, with LDs (mean = 1.65 ^{o}) having higher spread than DIs (mean = 1.36 ^{o}). Finally no interaction was found between measure and group, F (1, 38) = 0.21, MSE = 2.98, p = 0.65.

4.3.3.2 Scanpath analysis

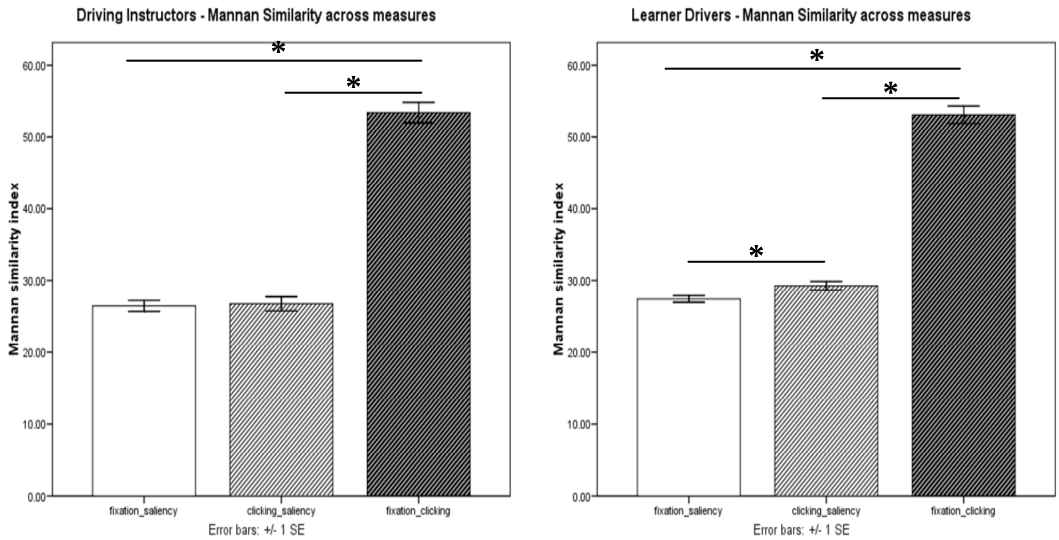

Figure 4.10. This Figure demonstrates the results of Experiment 3 for the scanpath analysis. The bars represent the same comparisons as the ones described in Figure 4.4.

For the scanpath analysis of this experiment the same methodology as in Experiment 2 was used. Results for both groups are demonstrated in Figure 4.10.

For DIs the Friedman test was significant, χ^2 (2) = 30.61, $p < 0.001$, and the post-hoc tests showed that the fixation-clicking comparison (mean = 53.41) was significantly higher than fixation-saliency (mean = 26.43, T = 0, $p < 0.001$) and clicking-saliency (mean = 26.72, T = 0, $p < 0.001$). No difference was found between fixation-saliency and clicking-saliency (T = 79, p = 0.52).

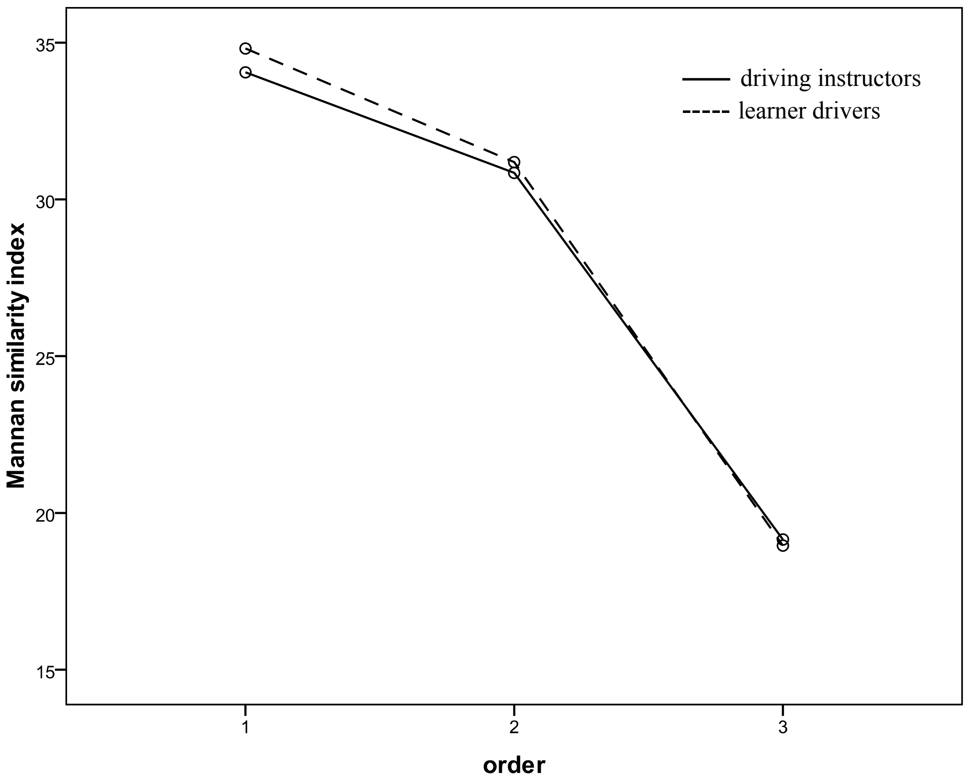

Figure 4.11. This figure demonstrates the point by point similarity between fixations and saliency.

In regards to LDs, Friedman test was significant, χ^2 (2) = 33.60, p < 0.001, and the post-hoc tests showed that the fixation-clicking comparison (mean = 53.12) was significantly higher than fixation-saliency (mean = 27.40, T = 0, p < 0.001) and clicking-saliency (mean = 29.24, T = 0, p < 0.001). Finally, clicking-fixation was found to be significantly higher than fixation-saliency and clicking-saliency (T = 40, p < 0.017).

4.3.3.3 Point by point analysis

For the fixation-saliency analysis an overall effect of order was found, F (2, 76) = 115, MSE = 22.70, p < 0.001 (see Figure 4.11), with the first fixation-saliency point (mean = 34.44) having significantly higher similarity than the second (mean = 31.02, p < 0.05) and the third (mean = 19.05, p < 0.001). Also the second point was significantly higher than the third (p < 0.001). No group effect was found, F (1, 38) =

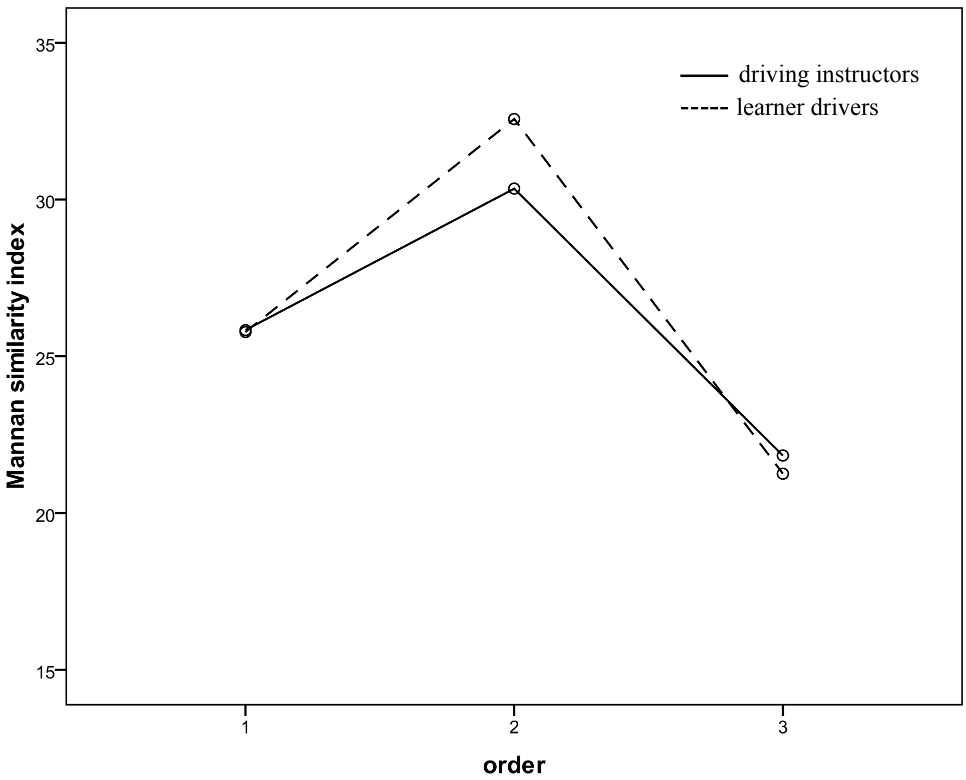

Figure 4.12. This figure demonstrates the point by point similarity between clicking and saliency.

0.09, MSE = 10.45, p = 0.77. Finally, no interaction between order and group was found, F (2, 76) = 0.10, MSE = 22.70, p = 0.91.

For the clicking-saliency analysis an overall effect of order was found, F (2, 76) = 38.43, MSE = 25.74, p < 0.001 (see Figure 4.12), with the second fixation-saliency point (mean = 31.46) having significantly higher similarity than the first (mean = 25.81, p < 0.001) and the third (mean = 21.55, p < 0.05). Also the first point was significantly higher than the third (p < 0.001). No group effect was found, F (1, 38) = 0.20, MSE = 13.92, p = 0.66. Finally, no interaction between order and group was found, F (2, 76) = 0.86, MSE = 25.74, p = 0.43.

For the fixation-clicking analysis an overall effect of order was found, F (2, 76) = 55.53, MSE = 33.16, p < 0.001 (see Figure 4.13), with the first fixation-saliency point (mean = 54.30) having significantly higher similarity than the second (mean = 46.02, p < 0.001) and the third (mean = 40.85, p < 0.001). Also the second point was

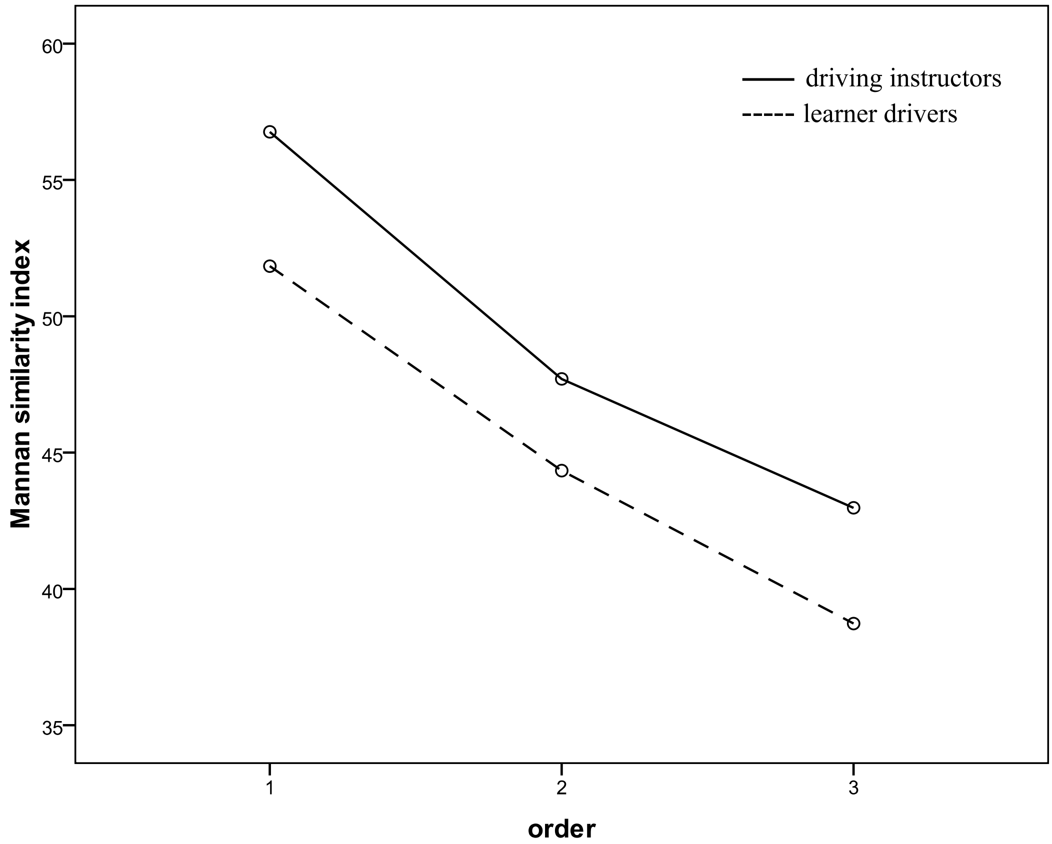

Figure 4.13. This figure demonstrates the point by point similarity between clicking and fixations.

significantly higher than the third (p < 0.001). A marginal group effect was found, F (1, 38) = 3.87, MSE = 45.08, p = 0.056. Finally, no interaction between order and group was found, F (2, 76) = 0.19, MSE = 33.16, p = 0.83.

4.3.4 Discussion

4.3.4.1 Spread of search

In regards to the distribution of fixations and clicks, the results were similar to Experiment 2 and it was found that clicks had larger horizontal and vertical spread than fixations. Again this can be explained by the lack of time limits which allowed participants to scan the picture more thoroughly and click at their point of interest without any restrictions while during the fixation scanning a certain level of fixation proximity is expected.

Surprisingly enough it was found that LDs had a broader spread than DIs. This is contrary to our hypothesis and findings in the literature but could have some explanations. It is possible that LDs were affected by the high spread of salient locations hence their clicks had higher spread than DIs. Also, it seems probable that LDs may have the explicit understanding that implies broader visual search scanning. While this knowledge certainly exists in DIs as well, it is possible that LDs' recent training might have exaggerated the spread of their visual search pattern. This explanation is not so unlikely since LDs share some driving mental models (Konstantopoulos & Crundall, 2008) and it is possible that their DIs have transferred some general instructions like "look ahead", and "keep the eye moving" as is suggested in one DIs handbook (Miller & Stacey, 2006, p.79).

4.3.4.2 Scanpath analysis

Similar to the results of Experiment 2 both groups had high similarity between fixation and clicks indicating strong top-down influence in visual search. For DIs fixations and clicks were affected to an equal extent by saliency. In contrast LDs results revealed a significant difference between fixation / saliency and clicking / saliency indicating that saliency was related to LDs clicks to a greater extent than fixations. This is the opposite pattern from what was found in Experiment 2, where the more experienced drivers had significantly higher click / saliency similarity than fixation / saliency. However, again we can assume that some important locations were highly salient and participants clicked on them. Despite the difficulty in fully interpreting this result the main finding here remains quite robust and it is the fact that all participants in both experiments had high fixation / click similarity which implies high introspection between where they thought they should look and where they actually look.

4.3.4.3 Point by point analysis

The fixation / saliency point by point analysis showed the same results as in Experiment 2 with the first point having significantly higher similarity than the second and third. This replicates the results and again shows that the effect of saliency upon fixations takes place at the initial stages of attention.

The second point by point analysis explored how saliency affected participants' clicking. In Experiment 2 the clicking / saliency comparison showed that the second point was affected significantly more than the first and third. Unexpectedly this pattern of results appeared again in Experiment 3 which suggests that the second clicked was influenced more by the properties of the stimuli while it is possible that introspection influenced more the first clicking location.

Finally, the fixation / clicking point by point analysis showed that the knowledge of where they should look influenced the first fixation to the greatest extent. After that initial high level of introspection this relationship decreases at subsequent points. A marginal group effect was found with DIs having higher similarity between fixation and clicking than LDs indicating a possible better task-related knowledge or level of introspection.

4.3.5 Conclusions – Future research

Some general conclusions for the findings of both experiments are that although EDs' fixation and clicking spread was no different than NDs', LDs' showed higher spread of search than DIs' in both axes. For the horizontal axis this difference was mainly due to LDs' higher spread of fixations while for the vertical axis both LDs fixations and clicks had higher spread than DIs'. One possible explanation for this pattern of results might be LDs recent training that encourages broad scanning and LDs were able to apply these instructions under static images. Also, all groups of participants showed high similarity between looking and clicking indicating a strong top down element. Also point by point analysis showed that the influence of saliency upon fixations decreased with fixation order. In the case of clicking, however saliency influenced the second point more than the rest. Finally the similarity between fixations and clicks decreases across the sequential order indicating that introspection is greatest at the initial stages. In regards to group differences the marginally significant value was found between DIs and LDs in the comparison of fixation and clicking across the 3 points indicating that in this context driving experience had a small effect. It seems that all groups have knowledge of where they should look. However, it is very important to notice that it is not clear if the different groups of participants look at similar locations or they just differ systematically.

There are some future methodological improvements that might include area of interest analysis in order to identify where participants looked. Also, future methodologies could include picture manipulation in order to examine the effect of different driving scenarios or hazardous situations. Finally, non-drivers might be included to determine whether the lack of group differences was because of similar cognitive processes or just because the task-related knowledge threshold in driving pictures is so low that even LDs possess sufficient knowledge to perform similarly to more experienced groups.

In relation to the theoretical implications of the findings it could be said that the present results are consistent with the view that cognitive top-down factors affect visual search more than bottom-up attributes. In addition we added a new paradigm that allowed participants to define their top-down points. This permits a more direct comparisons between top-down and bottom-up influences. Potential practical implications of the results might enhance future training interventions by illustrating the fact that under static conditions the visual search of both LDs and DIs influenced majorly by top-down factors. Finally future exploration in more dynamic environments such as driving simulators will provide a better understanding of the ways that visual search operates under more realistic conditions.

Chapter 5: The effects of driving experience and visibility conditions in visual search and attention allocation

5.1 Summary of previous findings

So far in Experiment 1 it was shown that different groups of drivers have different knowledge about the priorities of visual search. However, these findings were based on a questionnaire which on one hand might be an appropriate method to extract knowledge but on the other hand it is possible that actual visual search differs from this explicit and abstracted approach. In order to examine visual search more directly yet still under highly controlled conditions Experiments 2 and 3 were conducted. The findings of these Experiments showed that drivers' eye movement and visual search under static conditions are guided more by top-down influences that bottom-up. However, apart from the differences in spread of search, the results did not show any great experiential differences despite the diversity of the groups used. So the main question that has arisen is whether this lack of group difference was due to the nature of the stimuli and the limited attentional requirements of the task or due to the fact that the mechanisms and strategies that affect visual search do not differ with experience. Another question is related to the fact that it is not clear if these different groups of drivers attend to similar areas of the driving scene or whether they attend different areas. This question still remains unanswered since the methodology used in previous experiments did not provide such answers.

In this Chapter we will try to tackle these questions as well as generating some additional research questions. It is necessary to explore experiential differences on visual attention under more dynamic and realistic driving situations. Also we need to identify to what stimuli different groups of drivers allocate their attention, and this necessitates a categorical analysis of fixations. In addition some driving conditions that have been associated with increased traffic crashes will be implemented in the methodology in order to examine visual search patterns under these conditions. Finally, since the experimental procedure in this Chapter will include a driving simulator it is essential to test its validity in order to be able to generalise some of the findings, as it was mentioned in Chapter 2.

5.2 Experiment 4

5.2.1 Introduction

The aim of this Experiment is to identify any differences in visual attention, as expressed by eye movements, between driving instructors (DIs) and learner drivers (LDs). Again it seems that the usage of DIs is appropriate as they are more than just experienced drivers because they provide explicit feedback and directions regarding visual search strategies everyday as part of their profession. Furthermore previous research findings have shown that years of driving experience do not necessarily result in driving expertise (Duncan et al., 1991) so using just experienced drivers might hide any potential experiential differences.

Previous work on scanning differences has taken relatively large portions of time while here we would like also to examine whether differences can be found at the micro-level of particular driving situations. Hence it is necessary to maximise the possibility of getting a difference by comparing the two extremes of DIs and LDs.

The experimental hypothesis is that DIs will have wider horizontal scanning and less processing time of the visual scene than LDs. In addition we will investigate whether any differences in eye movements are equally distributed across the driven route or whether they are scenario specific. For that purpose some short-duration, scenario-specific sections of the simulated routes will be further analysed frame by frame. Since previous research (Crundall & Underwood, 1998) has found that visual search is road type dependent we predict a variation of eye movement differences across scenarios. Also, video analysis of these scenarios will indicate experiential differences in visual allocation to specific regions. Based on previous research findings (Underwood et al., 2002a) we predict that DIs would fixate more on side mirrors than LDs. Regarding the remaining visual regions and due to the difference of the scenarios used here it is not possible to predict a priori any specific regions that might produce differences based on experience or scenario.

Finally, the validity of the driving simulator will be assessed by comparing the results with similar research findings that have previously used an on-road methodology (Crundall & Underwood, 1998) and video presentations (Underwood et al., 2002b).

5.2.2 Method

5.2.2.1 Participants

Thirty participants were recruited for this experiment. The data for 5 subjects were excluded from further analysis due to technical failure of the recording apparatus. The remaining participants formed two groups. The first group consisted of 14 driving instructors (DIs), 1 female, with mean age of 49 years (SD = 9). The mean driving experience for this group was 30 years (SD = 9). Their experience as driving instructor was on average 9.5 years (SD = 10). The other group consisted of 11 learners (LDs), of which 5 were female, with a mean age of 20 years (SD = 2). Their driving experience was measured in number of lessons with a mean of 20 lessons (SD = 13).

5.2.2.2 Stimuli and apparatus

Figure 5.1. Inside view of the driving simulator

Participants drove a predetermined route on a Faros GB3 driving simulator comprising an enclosed cab with steering wheel, dashboard and pedals modelled on a Vauxhall Corsa (see Figure 5.1). An urban road with moderate traffic that included traffic lights, right and left turns, intersections, etc was generated. The dynamic environment was presented on three 19’’ LCD monitors (380mm x 300mm). Eye movements were recorded by using a head mounted SMI iView XTM HED, 50 Hz video based / corneal reflection tracker.

5.2.2.3 Procedure

First, all participants completed a questionnaire asking demographic questions. After the completion of the questionnaire they sat in the simulator. The experimenter made clear that participants could adjust the driving seat so they could feel comfortable and reach the driving wheel and pedals. All participants drove a practice route in order to familiarise themselves with the simulated environment and car control. Then the calibration of the eye tracker took place by using a 13 point calibration screen. After the calibration participants drove on the test drive. An experimenter gave driving directions while the participants were driving. The duration of the route was approximately 5 minutes. Participants were warned electronically by the software and orally by the experimenter if they exceeded 30 miles per hour.

5.2.2.4 Global eye movement analysis

For the purpose of the eye movement analysis a 2 minute window was taken from every drive. The starting point for the window was the same for all participants as it was defined geographically (e.g. when the car passed a specific traffic light). However, each driver encountered varying driving conditions during the 2 minute route due to the interactive nature of the simulator. This meant that some drivers drove further than others in the 2 minute window but the variations across participants were minor. Within each window the number of fixations and their mean duration was measured and the standard deviations of the horizontal and vertical fixation locations were calculated. These latter measures were considered indicative of the drivers' spread of search (Crundall, Chapman, Phelps, & Underwood, 2003).

5.2.2.5 Scenario – specific eye movement analysis

Each clip was taken from the scene camera attached to head-mounted eye tracker. Clips presented an in-car view of drivers interacting with simulated traffic. The eye movements of participants were overlaid on the video and were represented by an orange circle. Each scenario lasted 5 seconds. Since we would like to examine the effect of scenario specific driving we chose parts of the videos that represented some particular driving situations. The first scenario represented a driving situation in which the driver had to encounter a route with parked cars on the left (see Figure 5.2A), the second scenario represented a situation that the car approached a stop sign junction and had to turn right (see Figure 5.2B) and the last scenario had the driver passing through a green traffic light in which the driver had to wait for a gap in the oncoming traffic to turn right (see Figure 5.2C).

Figure 5.2A

Figure 5.2B

Figure 5.2C

Figure 5.2. Example screenshots to demonstrate the different driving scenarios. 5.2A illustrates "Parked Cars", 5.2B "Stop Sign" and 5.2C "Traffic Lights" scenarios.

In order to perform a frame by frame analysis 3 scenarios from the video of each participant's drive were used as stimuli. These clips were taken from the 5 minute simulated drive described above. While the scenarios themselves were chosen a priori; each participant's inclusion into the analysis was based on the clarity of the eye trace over each 5 second clip. In total, 3 clips were taken from 10 DIs and 10 LDs thus making 60 videos.

Prior to frame by frame analysis we defined some non-overlapping regions that drivers had inspected while driving. The defined gaze-regions were the following: parked cars at the left, parked cars at the right, car ahead in the same lane, car ahead in a different lane, car ahead in an ongoing lane, road ahead, rear view mirror, side mirrors, car on the left, car on the right, stop sign, traffic lights, side road left, side road right and miscellaneous. The frame by frame analysis was conducted to investigate fixations on these regions. Clips were 25 frames per second, hence one frame was 40 ms. The fixation was registered by the coder when the orange circle was at a specific region for at least three consecutive frames. Most of the gaze-regions had the same exposure time with the exception of some scenario specific regions (e.g. Car left). As mentioned above there was variability of traffic across conditions, however this variability should be randomised across participants and any exposure differences of regions should be minor. Three eye measurements were analysed for each visual region; number of fixations, mean fixation duration and percentage of fixations in that region in relation to all fixations in that scenario.

5.2.2.6 Simulator Validity Analysis

The experimental methodology of the present study does not allow absolute validity to be explored hence only the relative validity will be examined. One of the methods to assess simulator output is the "comparison of physical and / or mental

Measurements	Drivers	
	Driving Instructors	Learner Drivers
Number of Fixations	211 (35)	185 (25)
Mean Duration Fixation (ms)	473 (86)	552 (92)
Horizontal Deviation (^{o})	15 (3)	12 (1.6)
Vertical Deviation (^{o})	3.7 (.8)	3.7 (.5)

Table 5.1. Means for eye movement measurements across driving groups for the 2 minute window. Standard deviations shown in brackets.

loading by analysis of physiological variables" (Reed & Green, 1999, p.1016). Based on that method we will examine the relative validity of the simulator by comparing the direction of physiological measures, as reflected by eye movements, between the present simulator data and findings from similar studies using either on-road or laboratory methodologies. The relative validity will be observed by the direction of the data when the experimental sample is manipulated for experience. The eye movement measurement that will be compared will be the mean fixation duration. Since previous studies have used different road types we consider the simulated route as an urban route.

5.2.3 Results

5.2.3.1 Global eye movement analysis

Descriptive statistics for all four eye movement measures are shown in Table 5.1. DIs produced a greater number of fixations than LDs as shown by an independent samples t-test ($t(23) = 2.09$, $p < 0.05$), and mean fixation durations were shorter for DIs than LDs ($t(23) = 2.23$, $p < 0.05$).

As mentioned the driving stimuli were displayed across three screens. The horizontal standard deviation was calculated as the standard deviation of all fixations across the angle subtended by the three screens. Results showed that DIs had a greater horizontal spread of fixations than LDs ($t(23) = 3.31$, $p < 0.005$). An example of this greater horizontal search for DIs is shown in Figure 5.3. This figure represents all the

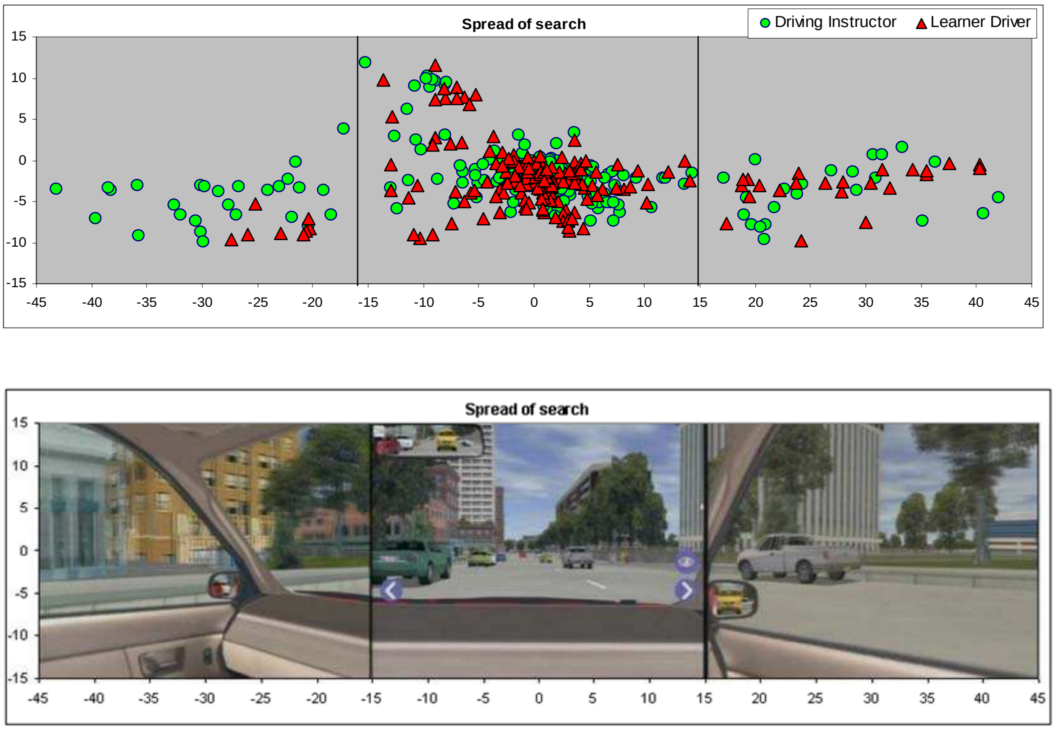

Figure 5.3. Upper image represents an example of spread of search between one driving instructor and one learner driver. Both axes represent visual angle measured in degrees. Lower picture is for demonstration purposes to indicate where the illustrated fixations might be allocated in the driving scene. Fixations off the 3 screens (e.g. on the speedometer) are not included.

fixations for one DI and one LD during two minutes in the simulator. As can be seen the DI fixations are spread more widely in the horizontal axis. Finally, the standard deviation of fixation locations along the y axis was calculated. No significance was found between groups for this comparison ($t\ (23) = .18$, $p = 0.9$).

5.2.3.2 Video Analysis of three scenarios

In order to investigate whether the scenarios had any effect on general eye movements a 2x3 ANOVA (video type and scenario) was conducted for the total number of fixations. The dependent variable was the sum of all fixations at the predefined categories. A main effect was found for video type, $F\ (1, 18) = 4.5$, $MSE = 22.7$, $p < 0.05$, with DIs (mean = 14) producing more fixations than LDs (mean = 11). No effect of scenario, $F\ (2, 36) = 2.0$, $MSE = 14.6$, $p = 0.14$, or any interaction, $F\ (2, 36) = 2.1$, $MSE = 14.6$, $p = 0.14$, was detected.

Scenario:	Parked Cars		Stop Sign		Traffic Light	
Group:	DIs	LDs	DIs	LDs	DIs	LDs
			Number of Fixations			
Side Mirrors	***0.5 (0.5)***	***0.1 (0.3)***	0.5 (0.8)	0.4 (0.7)	0.1 (0.3)	0.3 (0.5)
Car Ahead Different Lane	**1.4 (1.1)**	**0.6 (0.5)**	0.5 (1.1)	0.4 (0.7)	0 (0)	0.1 (0.3)
Rear View Mirror	1 (0.9)	0.6 (1)	**0 (0)**	**0.5 (0.5)**	0.1 (0.3)	0.2 (0.4)
Car Right	0 (0)	0 (0)	**1.2 (1.2)**	**0.2 (0.4)**	0.1 (0.3)	0 (0)
			Mean Fixation Duration (seconds)			
Side Mirrors	***0.2 (0.3)***	***0.02 (0.1)***	0.2 (0.3)	0.1 (0.1)	0.01 (0.04)	0.04 (0.1)
Rear View Mirror	0.2 (0.2)	0.1 (0.2)	**0 (0)**	**0.1 (0.2)**	0.04 (0.1)	0.1 (0.2)
Parked Car Left	***0.2 (0.3)***	***0.04 (0.1)***	0 (0)	0 (0)	0 (0)	0 (0)
			Percentage of Fixations			
Side Mirrors	***4.7 (6)***	***0.5 (1.5)***	5.8 (12)	2.5 (4.6)	0.2 (0.8)	0.7 (1.3)
Road Fixation	37 (21)	37 (31)	19 (12)	18 (17)	**17 (19)**	**33 (12)**

Table 5.2. Means and standard deviations of fixations, mean fixation durations and percentage of fixations in gaze-regions. Each value represents the group average for each region at every scenario. Values in bold denote a significant comparison, of p < 0.05 and in italics a p-value of 0.059.

In regards to the mean fixation duration a similar type of analysis was performed, on mean fixation durations. Mauchly's test showed that the assumption of sphericity was violated, χ^2 (2) = 38.6, $p < 0.05$; hence the more conservative Greenhouse-Geisser (ε = 0.5) was used to correct degrees of freedom. No effect was found for video type, F (1, 18) = 1.6, MSE = 0.4, p = 0.2, scenario, F (1.1, 19) = 1.6, MSE = 0.7, p = 0.2, or interaction, F (1.1, 19) = 1.1, MSE = 0.7, p = 0.3.

For the remaining analysis it was necessary to analyse scenarios separately since many of the regions are scenario dependent. Means and standard deviations of the eye movements can be seen at Table 5.2. When Levene's test was significant equal variances were not assumed and the corresponding p value was reported. Regarding the "Parked Cars" scenario there was a trend towards more frequent fixations on the side mirrors by DIs than LDs (mean DI = 0.5, LD = 0.1; t (14.7) = 2,

$p = 0.059$). Also, if there was a vehicle ahead, travelling in the same direction as the participant but not in the same lane, DIs looked at this more frequently than LDs (mean DI = 1.4, LD = .6; $t(12.9) = 2.1$, $p = 0.05$) with DIs producing more fixations than LDs. The mean fixation durations were almost significantly higher for DIs than LDs for parked cars at the left (mean DI = .22, LD = .04; $t(10.9) = 2.1$, $p = 0.059$), and side mirrors (mean DI = .23, LD = .02; $t(10.1) = 2.1$, $p = 0.059$). Finally, there was a further trend towards the side mirrors region with DIs having a larger percentage of fixation than LDs, (mean DI = 4.7, LD = .5; $t(10.1) = 2.1$, $p = 0.059$).

In regards to the "Stop Sign" scenario, an independent t-test revealed that DIs made fewer fixations than LDs at the rear view mirror (mean DI = 0, LD = 0.5; $t(18) = 3$, $p < 0.05$). At car at the right region DIs fixated more frequently than LDs (mean DI = 1.2, LD = 0.2; $t(11.1) = 2.4$, $p < 0.05$). The mean fixation duration was shorter for DIs than LDs on the rear view mirror, (mean DI = 0, LD = 0.14; $t(9) = 2.3$, $p < 0.05$). DIs had a significantly lower percentage of fixations than LDs on the rear view mirror (mean DI = 0, LD = 2.9; $t(9) = 2.3$, $p < 0.05$). Finally the "Traffic Light" scenario only produced one difference between the driver group with DIs devoting a shorter percentage of their time to road ahead than LDs (mean DI = 16.8, LD = 33.1; $t(18) = 2.2$, $p < 0.05$).

5.2.4 Discussion

5.2.4.1 Global eye movements

The experimental hypothesis regarding global eye movement differences was confirmed. With the exception of the vertical standard deviation, all the eye movement measures were significantly different between DIs and LDs. In term of visual search efficiency it appeared that DIs had a higher sampling rate of the driving virtual environment than LDs reflected in a greater number of shorter fixations spread over a wider distance. Similar findings have been reported by Crundall and Underwood (1998) regarding experiential differences in eye movements. They found increased number of fixations for experienced drivers compared to novices (within a year of passing their tests) in an on-road experiment. However, this difference was road type dependent and it was found only on a dual carriageway. It seems that the present methodology created the necessary conditions to generate similar experiential differences in a route that can be classified as urban. Perhaps this is due to the greater experiential difference between the current groups which allowed differences with similar direction to be found in an urban route.

Results also showed that DIs produced lower mean fixation duration than LDs. Mean fixation duration has been considered as a strong indicator of processing time due to complexity. This notion has been supported by findings in driving studies (Chapman & Underwood, 1998) as well as natural scene perception (Underwood & Foulsham, 2006). In addition research found experienced drivers to have faster processing time than novices during hazardous situations (Chapman & Underwood, 1998). As a consequence it could be said that DIs showed faster processing speed than LDs as the analysis of mean fixation duration revealed. Again it seems that the simulated driving route had the necessary properties and characteristics to reveal differences in processing time between DIs and LDs. Although the driving route did not include any staged hazardous situations or great variation in road type, LDs required more time than DIs to process the complexity of the given virtual environment.

Finally DIs showed greater spread of search along the horizontal axes than LDs as measured by the horizontal standard deviation of fixations locations. Again these findings are consistent with previous research (Crundall & Underwood, 1998).

In regards to the vertical spread of search the lack of difference can be attributed to the importance of observation of in-car controls. It can be said that participants did not devote any significant attentional resources to in-car controls since the available information was not of critical importance to control the car or to complete the simulated route and they were informed if they were driving too fast.

There are several possible explanations for the obtained differences in global eye movements between groups. First, it could be said that visual search differences are due to increased mental load that LDs experience when driving in the simulator. It seems reasonable to suggest that LDs could not cope with the mental workload of the driving condition and they narrowed their visual search in order to have more resources for the remaining task demands. However, research showed that eye movement differences exist even at situations when the demands of actual driving are removed (Underwood et al., 2002b). They found that experienced drivers had broader scanning patterns than novice drivers when watching driving videos. This finding suggests that the difference in visual search might be due at least in part to factors other than mental workload imposed by the physical act of driving.

Another possible explanation for the results might be the effectiveness of peripheral vision (see also section 1.4.3). Indeed previous research has shown that the functional field of view is affected by experience (Crundall et al., 1999; Crundall, Underwood, & Chapman, 2002). They found that experienced drivers had a higher detection rate of peripheral targets than novice and learner drivers. The efficiency of functional field of view affects both the number of fixations and the spread of search as a larger field of view allows more information from the inspected scene to enter the perceptual system. This flow of information will generate saccadic movements of the observer. With a larger field of view peripheral information may trigger saccades from greater eccentricities resulting in wider scanning of the scene. The precise mechanism that allows the development of functional field of view is not so clear however, but behavioural data link it with driving experience.

Also, Summala, Nieminen and Punto (1996) showed that with some 50,000 km of experience drivers have learned to keep the car within the lane markings while still being able to look at the speedometer level, (20-25 deg below the vanishing point), which is a strong indication of efficient peripheral vision. However, at higher eccentricities (e.g. with a target in the middle of the console) even the experienced drivers had difficulties maintaining the car in the lane. Although these results confirm that experience influences the functional field of view in driving, they also underline some limitations regarding the efficiency of peripheral vision. A major implication of experience and functional field of view efficiency is the ability to detect the braking of a car in front while looking away from it, most probably due to reduced retinal peripheral resolution (Summala, Lamble, & Laakso, 1998). Combining the above it could be said that successful use of the peripheral vision while driving is highly task dependent. Nevertheless, driving experience results a more efficient visual search as it was found in the present results and has been demonstrated in numerous studies as mentioned above.

A third possibility is that DIs' strategies are not influenced only by driving experience but by their in-depth knowledge of driving demands due to their profession. DIs' knowledge could have been a contributing factor for the present findings due to the generation of greater situation awareness than LDs. It is plausible to suggest that DIs have developed more efficient search than LDs through training and practice. Indeed we have found that DIs and novice drivers have different priorities regarding what they think they should look at while driving (Konstantopoulos & Crundall, 2008).

5.2.4.2 Video Analysis

In regards to the “Parked Cars” scenario the general hypothesis that DIs will fixate more than LDs in side mirrors was partially supported, since the differences were almost significant. However, in the light of the exploratory nature of this work and the difficulties in testing and recruiting such a difficult sample with such a complex methodology it was considered fair to report such trends as an indication of potential differences in the population. The fact that the comparison across DIs and LDs of side mirrors was almost significant for this scenario in all three measurements (number of fixation, mean fixation duration and percentage of fixations) indicates the consistency of this difference. Also the scenario-specific region of ‘parked car at the left’ was found significant with DIs allocating more resources than LDs. The side mirrors inspection supports previous findings, and in conjunction with the finding at the parked car at the left region, confirms the suggestion that the increased horizontal scanning of experienced drivers is due to the inspection of specific locations (Underwood et al., 2002b). In regards to the “Stop Sign” scenario the results showed a very similar pattern to the “Parked Cars” scenario. Regarding the direction of the difference it was found that LDs spent more time than DIs at looking the rear view mirror. Also the region “car on the right” was found to be significant with DIs inspecting this region more than LDs. It is possible that LDs look more at the rear view mirror because they have less horizontal spread and focus more in the central part of the driving scene. These results are again in line with Underwood et al study. Finally in the “Traffic Light” scenario only the road ahead region showed significance with DIs devoting a smaller percentage of their total fixations to this region than LDs.

In general the results of the video analysis showed that despite the short duration of the videos there are behavioural differences in visual allocation in some highly specific scenarios. Although no scenario effect was found on general eye movement analysis, the pattern of the video analysis indicates variable scanning across scenarios. Most differences were found in the "Parked Cars" scenario, followed by the "Stop Sign" scenario and finally the "Traffic Light" scenario showed the least differences with only one region showing group difference in visual allocation. The global eye movement analysis that has been used by previous studies has assumed general differences in scanning strategies with only coarse manipulations to guide our interpretations (e.g. road type). Here we have demonstrated that general eye movement differences do not translate into differences in every specific scenario, and the results suggest that future eye movements' driving studies should examine this micro-level further. Certainly the results provide some insight into the topic and generate further questions like: Why do DIs not look in the mirror when approaching a stop sign? While the current data may not provide a detailed answer to this, (and we can only speculate) a global analysis would not have even raised the question.

There are some theoretical explanations for the results of the video analysis. The most prominent are the effects of experience interacting with the scenarios employed. The notion that visual search is experience dependent has been demonstrated also in other fields than driving. For example differences in eye movement patterns have been found when expert and intermediate chess players had to perform a chess related task (Charness et al., 2001). In regards to task dependence and eye movements one of the most famous works in this field has been conducted by Yarbus (1967). He showed that participants altered their eye movements when task instructions changed when they inspected a picture. Subsequent studies have also replicated and extended the effects of task in eye movements (Hayhoe & Ballard, 2005; Land, 2006).

5.2.3.3 Simulator Validity

It seems that the direction of results can support the hypothesis that the driving simulator used here is a valid driving research tool. The pattern of results (greater experience produces shorter and more frequent fixations and a greater spread of search of horizontal search) has been reported in other studies (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Underwood et al., 2002b). Hence it can be concluded, with the necessary precaution, that the simulator has good relative validity.

It has been suggested that driving simulators might exaggerate experiential differences (Reed & Green, 1999). However, there is no reason to believe that DIs are more familiar to virtual environments than LDs. Nevertheless the pattern of results still remains similar despite the different testing methodologies.

Despite the observed relative validity there are some sensitive issues regarding the simulator. One consideration comes from the suggestion that in order to have good speed perception a horizontal field of view of about 120^{o} is needed (Kemeny & Panerai, 2003). The visual angle in our simulator is dependent on the seat position but in general varies between 80^{o} – 90^{o} of the horizontal visual field. This might be a possible restriction of visual fidelity and something that future research in this simulator should take into consideration.

5.2.5 Conclusions – Future research

The notion that driving experience affects the effectiveness of visual search has been replicated by this Experiment. Furthermore, we showed that DIs visual search efficiency in relation to LDs is of such a magnitude that allows the differences to be identified even under low demand (urban road, no hazards) situations. In regards to the inspected regions the general outcome is that DIs allocated more attentional resources to the side mirrors while LDs spent more time at the rear view mirror. Both results can be attributed to wider horizontal scanning of the DIs in comparison to LDs. Also, video analysis showed that there are driving scenario specific inspected regions. Finally the driving simulator shows good signs of relative validity in regards to experiential differences in visual search. However, it is suggested that further validation should take place in order to explore any absolute validity issues.

Finally it should be considered essential to link the experiential differences in driving with ways of improving LDs' training. Future training interventions should take into account that differences in visual search are scenario specific. Also future training implementations should take into account that different driving situations require different attentional allocation patterns as was demonstrated by the present findings.

Previous attempts to train eye movements have been very generic and have used simple strategies such as telling novice and learner drivers to scan more widely (Chapman et al., 2002). The current results however demonstrate that eye movement differences can occur in highly specific situations, and it is perhaps these more concrete examples of eye movements that should form the basic unit of eye movement training interventions in the future.

5.3 Experiment 5

5.3.1 Introduction

The previous Experiment showed that there are experiential differences in visual attention, consistent with many findings in the literature, in drivers' eye movements during simulated driving according to their level of experience. The novel result of Experiment 4 was the fact that there are eye movement differences at the micro-level of a driving scenario within a very short duration. These differences are mainly due to the fact that different areas of interest are fixated by different driving groups and this occurred despite the fact that no general eye movement differences were found. Finally, the driving simulator as a research tool was validated and showed relative validity when compared with previous research findings.

Since Experiment 4 showed that the methodology and driving groups used were appropriate it was considered suitable to extend this methodology to underline any differences. The simulated environment in Experiment 4 was day time driving. Since, there are more extreme driving conditions that are related to increased traffic crashes but drivers' visual attention under those conditions is not fully understood we decided to explore drivers' attention during extreme visibility conditions. Hence we will focus on the experiential differences in visual attention and more specifically at the interaction of different visibility conditions with driving experience and visual attention.

5.3.2 Night Driving

The visibility conditions of interest in the current experiment are night driving and driving under rainy conditions. It has been shown that time of day influences both the severity and the rate of crashes (Clarke, Ward, Bartle, & Truman, 2006).

Moreover it has been shown that there is an increased crash risk during night driving (Williams, 2003). It has been suggested that any increase in road crashes during night time is partly due to voluntary risk taking of the drivers (Clarke et al., 2005). Another possibility is that those types of crashes are due to sleepiness (Akerstedt, Kecklund, & Horte, 2001). There is however evidence that a high number of crashes during night are primarily due to visual problems associated with low luminance conditions leading to an increase in reaction times (Plainis & Murray, 2002). More specifically it has been suggested by Leibowitz and Owens (Leibowitz & Owens, 1977) that although night driving conditions have little effect on peripheral vision, "focal" vision is degraded and this might cause neglect of low luminance objects during night driving.

5.3.3 Rain Driving

Another factor that affects driving crashes is weather. Despite the fact that the link between weather conditions and traffic crashes is far from clear (Edwards, 1998)there are some common findings and suggestions. In regards to driving in rainy conditions it has been shown that there is an increased risk of a crash in wet rather than dry weather (Brodsky & Hakkert, 1988). Rain conditions obviously make driving more dangerous due to decreased friction's impact on stopping distances and handling. However, Brodsky and Hakkert claimed that as well as problems created by the loss of friction, visibility in rainy conditions may also play a significant role. Also, certain types of collisions, such as hitting objects, have been associated with driving in rain (Golob & Recker, 2003).

5.3.4 Self-regulation

In addition to statistical analysis of crash records about night and rain driving there are studies that explore self-regulation in driving. Additional support that night driving is perceived as more difficult and demanding comes from self-report studies in which older drivers stated they self-regulate night driving (Reimer et al., 2007). In addition it has been shown that driving at night with rain is a situation that older drivers especially try to avoid (Baldock, Mathias, McLean, & Berndt, 2006; Ball et al., 1998). Finally, there are findings to suggest that older drivers with age-related maculopathy regulate their driving under night and rain (DeCarlo, Scilley, Wells, & Owsley, 2003). It seems that both accident data analysis and self-reported methods show that night and rain driving have increased crash risk and they are perceived to be more demanding for the driver. However, it seems that more experienced drivers are not affected in the same way as novices, since accident involvement (at-fault) drops around 6% per year of holding a driving licence (Clarke et al., 2006).

5.3.5 Present experiment

In the present study driving instructors (DIs) and learner drivers (LDs) drove under day, night and rainy conditions in a simulator while their eye movements were recorded. Based on the experimental findings mentioned above regarding driving experience we assume that DIs' eye movements will reveal shorter but more frequent fixations, reflecting reduced processing time, and a higher sampling rate of the visual scene compared to LDs. They should also show broader scanning than LDs. In addition, on the basis of the increased accident rates during night and rain driving reported in the literature, we hypothesise that drivers' eye movement patterns will be less efficient under night and rain driving than day driving (e.g. longer fixations, narrower spread of search). Also an interaction between driving experience and visibility is expected with LDs' visual search strategies degraded more than DIs' under night and rain driving. Finally, in addition to the validation in Experiment 4, the relative validity of the driving simulator will be examined further under different conditions, by comparing eye movements between similar studies since the comparison of physiological measures is considered acceptable for validation purposes (Reed & Green, 1999).

5.3.6 Method

5.3.6.1 Design

A mixed design was employed for this study. The between factor was driving experience with driving instructors (DIs) and learner drivers (LDs) as levels. The within factor was condition with day, night and rain as levels. The dependent variables were the number of fixations, as a measure of sampling rate; mean fixation durations as an indication of processing time; horizontal and vertical deviation (average standard deviations on x and y axis) as a measure of spread of search. In addition frame by frame analysis was conducted in order to identify participants' attention allocation on mirrors. In order to investigate how often the speedometer was inspected by the participants, the speedometer was defined as one area of interest and only the fixations that fell within this area were calculated automatically on the basis of X and Y coordinates. In the later analysis the independent variable were again visibility and group and the dependent variables were the number of fixations on the left, right and rear view mirror as well as the speedometer.

5.3.6.2 Participants

Twenty four participants were recruited for this experiment. The data for 3 participants were excluded from further analysis due to technical failure of the recording apparatus. The remaining participants formed two groups. The first group consisted of 10 DIs, 2 females, with mean age of 51 years (SD = 11). The mean

Figure 5.4A

Figure 5.4B

Figure 5.4C

Figure 5.4. Example screenshots to demonstrate simulated conditions. 5.4A illustrates "Day", 5.4B "Night" and 5.4C "Rain" driving conditions.

driving experience for this group was 34 years (SD = 11). Their experience as driving instructors was on average 9.2 years (SD = 9). The other group consisted of 11 LDs, of which 7 were females, with a mean age of 21 years (SD = 2). Their driving experience was measured in hours of driving lessons with a mean of 24 hours (SD = 11). Their driving lessons included practical training and verbal instructions according to UK common practice (some examples of instructions about visual scanning can be found in Miller and Stacey (2006, p.79).

5.3.6.3 Stimuli and apparatus

The same apparatus was used as in Experiment 4 (see section 5.2.2.2). However, for the purpose of this experiment there were some modifications on the driving route as mentioned below.

Participants drove three predetermined routes on the driving simulator. The driving routes were geographically the same and the only difference between routes was visibility with the employment of three conditions day, night and rain (see Figure 5.4). The starting point for each route was the same for all participants as it was defined geographically (e.g. when the car passed a certain point of the route). No extra processing was done for the finish point of the route since this was done automatically by the software when the cars passed a certain point.

During the route, participants had to encounter variable driving conditions due to the interactive nature of the simulator (e.g. some participants stopped in a red light while others encounter a green light at the same point). All three routes incorporated a 4-lane (2-lanes per direction) urban road with moderate traffic that included traffic lights, right and left turns, intersections, etc. The driving conditions comprised other road users that moved normally on the road by obeying traffic laws and it was possible for them to overtake the driver on some occasions. We did not implement any hazards during the routes in order to focus on visibility issues.

5.3.6.4 Procedure

Condition:	Day		Night		Rain	
Group:	DIs	LDs	DIs	LDs	DIs	LDs
Driving Time (min)	5.3 (0.4)	5.2 (0.4)	5 (0.4)	5.4 (0.6)	5.2 (0.4)	4.9 (0.9)
Number of Fixations	673 (89)	556 (114)	620 (80)	551 (148)	608 (96)	449 (155)
Mean Fixation Durations	413 (58)	519 (102)	424 (31)	539 (138)	457 (54)	644 (235)
Horizontal Deviation (^{o})	11 (1.9)	6.2 (1.1)	10 (1.9)	5.9 (1.1)	11 (2.0)	6.6 (1.9)
Vertical deviation (^{o})	3.2 (0.6)	3.3 (0.7)	3.4 (0.6)	3.5 (0.4)	3.1 (0.5)	3.1 (0.7)
Pupil diameter (px)	45 (6.7)	56 (11.5)	55 (11)	69 (12.3)	46 (7.7)	57 (10.6)

Table 5.3. Means and standard deviations for eye movement measurements for DIs and LDs across visibility conditions.

A similar procedure as in Experiment 4 was used apart from the following. Participants drove all three routes in a counterbalanced order in order to minimise any effects of route familiarity, however the possibility that the drivers could have different fixation patterns as their familiarity improved (Mourant, Rockwell, & Rackoff, 1969) should be taken into account. Participants were instructed to drive as they would do normally and follow the traffic regulations. The directions of the driving route were presented by arrows at the bottom of the screen and auditory instructions. The duration of each route was approximately 5 minutes. Participants were warned by a sign and a recorded message to slow down when exceeded 30 miles per hour.

Condition:	Day		Night		Rain	
Group:	DIs	LDs	DIs	LDs	DIs	LDs
Left Mirror	3.1 (3.1)	0.1 (0.4)	1.8 (1.9)	0.1 (0.4)	2 (2)	0 (0)
Right Mirror	12.1 (7.3)	1.6 (1.3)	11.2 (6.3)	3.1 (2.4)	12.3 (6.8)	1.5 (1.8)
Rear View Mirror	17.1 (9.7)	17.3 (4.5)	17.1 (8.6)	11 (4.8)	12.3 (8.2)	12.6 (7.6)
Speedometer	3.4 (7.3)	15.3 (16.2)	3.6 (6.6)	17.5 (17)	3 (7.1)	8.3 (6.4)

Table 5.4. Means and standard deviations of the fixations for the category analysis.

5.3.7 Results

Four eye movement measures are reported, number of fixations, mean duration fixation, standard deviations of the horizontal and vertical fixation locations. Also, the pupil diameter will be examined across the three visibility conditions. The means and standard deviations for all measurements can be seen in Table 5.3.

Moreover, in order to define the direction of visual search during driving a category analysis was performed. The categories were the left, right and rear view mirrors and the speedometer. This selection was made based on previous research findings suggesting that group differences on vertical and horizontal spread of search is possibly due to mirror inspection (Underwood et al., 2002a). The means and standard deviations for the fixations on these categories can be seen in Table 5.4.

For every significant main effect orthogonal pre planned contrasts with the Helmert method were performed. In the first level “Day” condition was compared with the average of “Night” and “Rain”, while in the second level “Night” was compared to “Rain” condition.

5.3.7.1 Number of Fixations

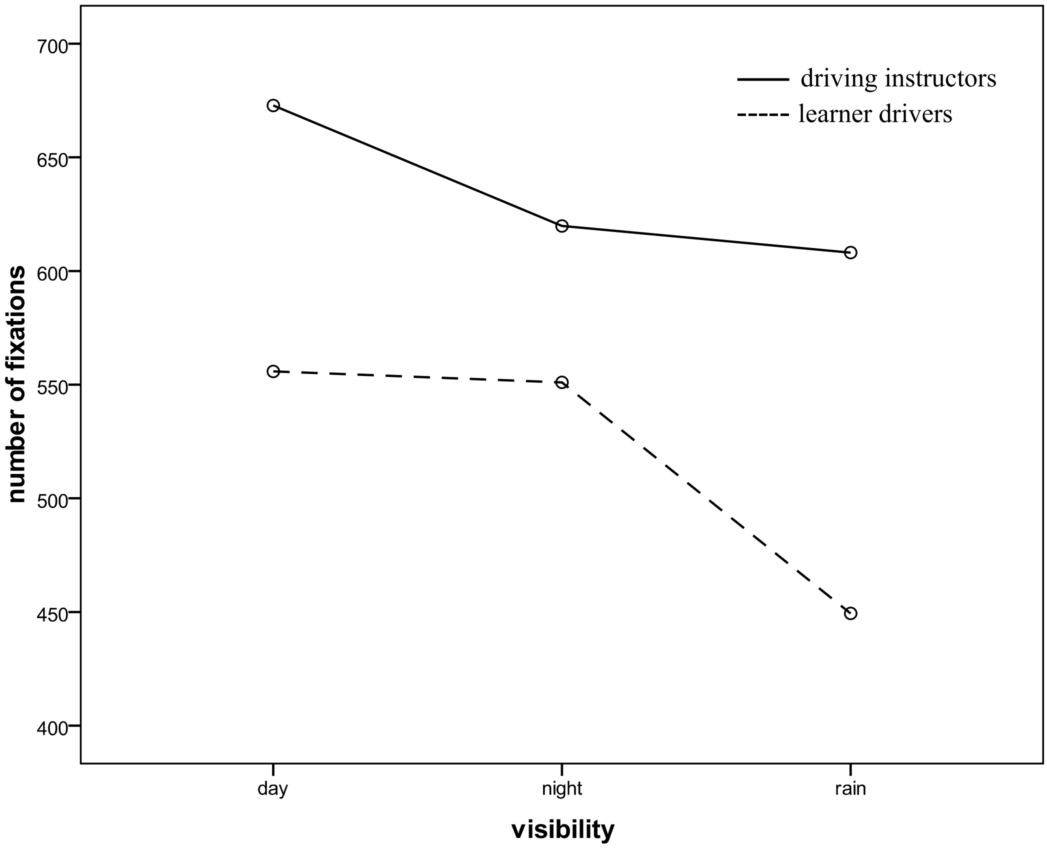

Table 5.5. This Figure illustrates the number of fixations across visibility conditions.

As participants had to encounter variable driving conditions the time of driving was not the same for everyone (e.g. some participants stopped in a red light while others encounter a green light at the same point). This could lead to methodological issues especially when concerning the number of fixations measure. For that reason an analysis was performed for driving time between groups and across visibility conditions. Mauchly's test showed that the assumption of sphericity was violated, χ^2 (2) = 15.5, $p < 0.05$; hence the more conservative Greenhouse-Geisser (ε = 0.6) was used to correct degrees of freedom. No main effect of visibility was found, F (1.3, 24.1) = 0.93, MSE = 0.39, p = 0.37, and the group main effect was not significant, F (1, 19) = 0.01, MSE = 0.15, p = 0.99. Finally no interaction between group and visibility was detected, F (1.3, 24.1) = 2.55, MSE = 0.39, p = 0.12.

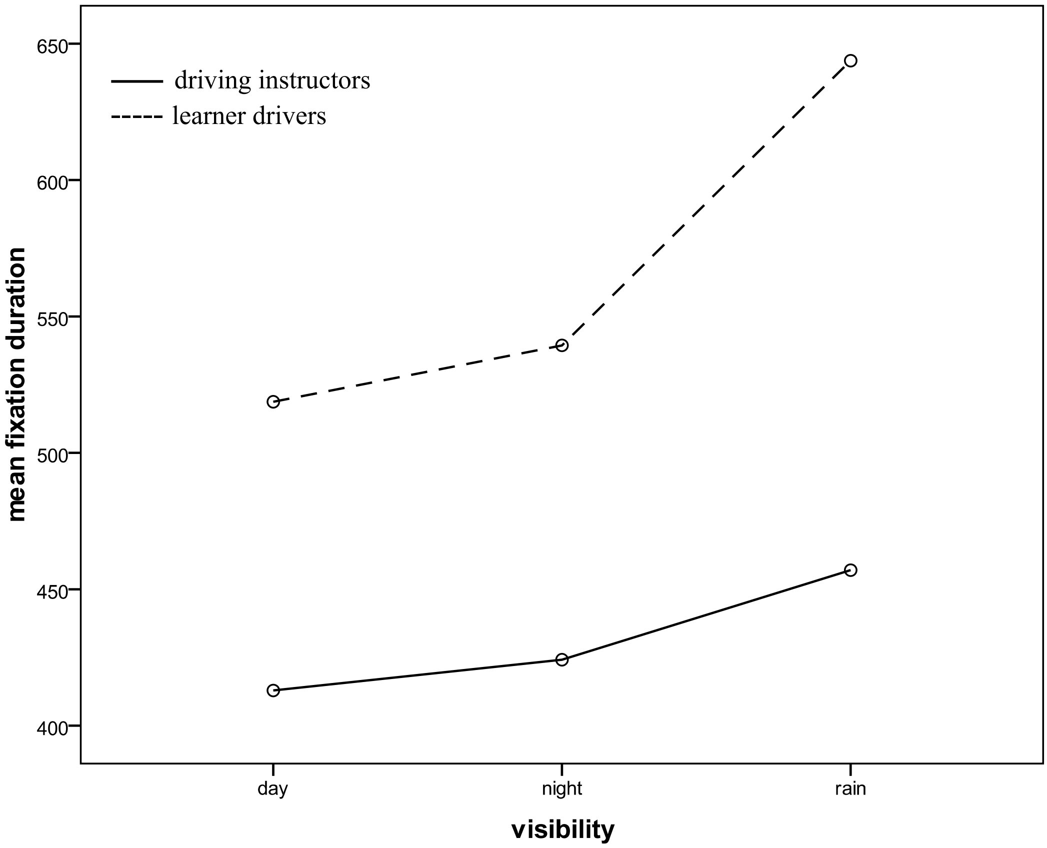

Table 5.6. This Figure illustrates the mean fixation durations across visibility conditions.

In regards to the number of fixations all the fixations during the 5 minute route were analysed. There was a main effect of visibility, F (2, 38) = 9.82, MSE = 4 044, p < 0.001 (see Figure 5.5). Pre planned contrasts showed that drivers had more fixations in the “Day” (mean = 614) route than in the other two routes (mean = 557, F (1, 19) = 16.97, MSE = 4 046, p < 0.01) and also that they produced significantly greater number of fixations in “Night” (mean = 585) than “Rain” (mean = 529, F (1, 19) = 6.24, MSE = 10 782, p < 0.05). There was a main effect for group, F (1, 19) = 6.07, MSE = 11 376, p < 0.05 with DIs (mean = 634) having greater number of fixations than LDs (mean = 519). Finally no interaction was found between visibility and group for number of fixations, F (2, 38) = 2.62, MSE = 4 044, p = 0.09.

5.3.7.2 Mean Fixation Durations

Mauchly's test showed that the assumption of sphericity was violated, χ^2 (2) = 15.6, $p < 0.05$; hence the more conservative Greenhouse-Geisser ($\varepsilon = 0.6$) was used to correct degrees of freedom. Regarding mean fixation durations there was a main effect of visibility, F (1.3, 24) = 5.24, MSE = 12 763, $p < 0.05$ (see Figure 5.6). Pre planned comparisons showed that drivers had shorter fixation durations in the "Day" (mean = 466ms) route than in the other two routes (mean = 516ms, F (1, 19) = 5.63, $p < 0.05$) and also that they produced significantly shorter fixation durations in the "Night" (mean = 482ms) route than the "Rain" one (mean = 550ms, F (1, 19) = 4.99, $p < 0.05$). There was a main effect for group, F (1, 19) = 9.09, MSE = 10 648, $p < 0.05$ with DIs (mean = 431ms) having shorter fixation durations than LDs (mean = 567ms). Finally no interaction was found between visibility and group for mean fixation durations, F (1.3, 24) = 1.27, MSE = 12 763, p = 0.28.

5.3.7.3 Horizontal Spread of Search

Mauchly's test showed that the assumption of sphericity was violated, χ^2 (2) = 6.5, $p < 0.05$; hence the more conservative Greenhouse-Geisser ($\varepsilon = 0.8$) was used to correct degrees of freedom. In regards to the standard deviations of the fixation locations in the horizontal axis no effect was found for visibility, F (1.5, 29) = 1.06, MSE = 0.96, p = 0.34. There was a main effect for group, F (1, 19) = 40.27, MSE = 2.41, $p < 0.001$ with DIs (mean = 10.6^o) having broader spread of search in the horizontal axes than LDs (mean = 6.2^o). Finally no interaction was found between visibility and group for horizontal deviation of fixations, F (1.5, 29) = 0.59, MSE = 0.96, p = 0.52.

5.3.7.4 Vertical Spread of Search

In regards to the vertical deviations there was a main effect of visibility, F (2, 38) = 3.50, MSE = 0.13, $p < 0.05$. Pre planned comparisons showed that drivers did not have significantly different vertical spread of search between “Day” (mean = 3.2°) and the average of the other two routes (mean = 3.3 °, F (1, 19) = 0.25, MSE = 0.23, p = 0.62). However, drivers had broader vertical scanning in the “Night” (mean = 3.4 °) route than during “Rain” (mean = 3.1 °, F (1, 19) = 8.44, MSE = 0.20, p < 0.05). There was not a main group effect, F (1, 19) = 0.07, MSE = 0.27, p = 0.80. Finally no interaction was found between visibility and group for vertical deviation of fixations, F (2, 38) = 0.13, MSE = 0.13, p = 0.88.

5.3.7.6 Pupil Diameter

Mauchly’s test showed that the assumption of sphericity was violated, χ^2 (2) = 15.5, p < 0.05; hence the more conservative Greenhouse-Geisser (ε = 0.6) was used to correct degrees of freedom. In regards to the pupil diameter there was a main effect of visibility, F (1.3, 24) = 141, MSE = 9.57, p < 0.001. Pre-planned comparisons showed that participants had smaller pupil diameter during the “Day” (mean = 51px) route than the other two routes (mean = 57px, F (1, 19) = 82.66, MSE = 9.20, p < 0.001). In addition contrasts revealed that participants’ pupil diameter was significantly wider during the “Night” route (mean 62px) than “Rain” (mean = 51, F (1, 19) = 200.63, MSE = 12.00, p < 0.001). There was a group effect, F (1, 19) = 7.91, MSE = 100.95, p < 0.05 with DIs (mean = 48px) having smaller diameter than LDs (mean = 61px).

5.3.7.7 Category analysis

For the fixations on the left mirror Mauchly’s test showed that the assumption of sphericity was violated, χ^2 (2) = 8.5, p < 0.05; hence the more conservative Greenhouse-Geisser (ε = 0.7) was used to correct degrees of freedom. No effect of visibility was found, F (1.4, 20.7) = 1.6, MSE = 2.1, p = 0.2, and no significant interaction, F (1.4, 20.7) = 1.4, MSE = 2.1, p = 0.3. A group effect was found, F (1,

15) = 10.2, MSE = 2, $p < 0.05$, with DIs having significantly more fixations (mean = 2.3) than LDs (mean = 0.1) at the left mirror.

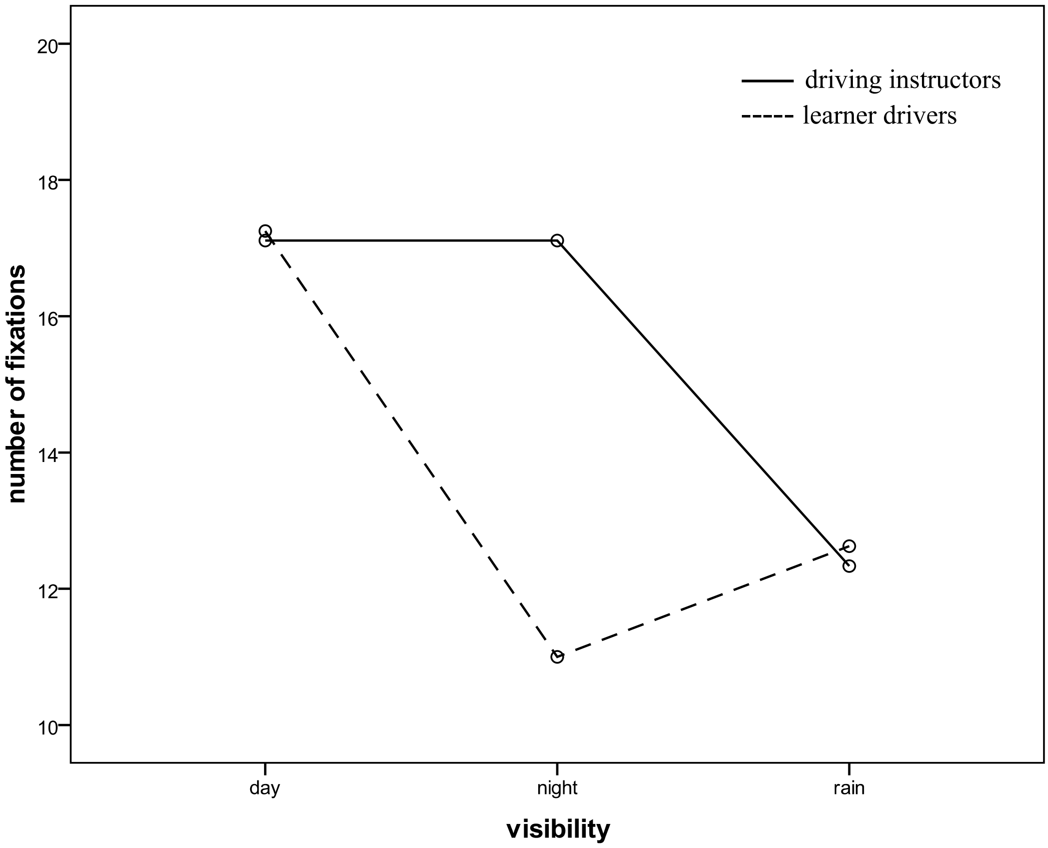

Table 5.7. This Figure illustrates the number of fixations at the rear view mirror across visibility conditions.

For the fixations on the right mirror no effect of visibility was found, F (2, 30) = 0.1, MSE = 7.5, p = 0.9, nor a significant interaction, F (2, 30) = 1.2, MSE = 7.5, p = 0.3. A group effect was found, F (1, 15) = 19.2, MSE = 2, p = 0.001, with DIs having significantly more fixations (mean = 11.9) than LDs (mean = 2.1) at the right mirror.

For the fixations on the rear view mirror a visibility effect was found, F (2, 30) = 6.3, MSE = 15.3, $p < 0.05$ (see Figure 5.7). Pre-planned contrasts showed that participants fixated the rear view mirror significantly more on the day route (mean = 17.2) than at the average of night and rain route (mean = 13), F (1, 15) = 13.5, MSE =

19.2, $p < 0.05$. No group effect was found for this analysis, $F(1, 15) = 0.3$, MSE = 47.4, $p = 0.6$. Finally a significant interaction was found, $F(2, 30) = 3.7$, MSE = 15.3, $p < 0.05$, and pre-planned contrasts showed that the interaction occurred between night and rain levels with DIs having fewer fixations on their rear view mirror in the rain condition (mean = 12.3) relative to the night condition (mean = 17) while LDs had relatively similar rear view inspection pattern during night (mean = 11) and rain (mean = 12.6).

The analysis at the speedometer fixations showed an effect of visibility, $F(2, 40) = 3.5$, MSE = 40.5, $p < 0.05$. Pre-planned comparisons showed that participants made more speedometer inspections during the night (mean = 10.6) than the rain condition (mean = 5.7). A group effect was found, $F(1, 20) = 5.6$, MSE = 104.8, $p < 0.05$, with DIs (mean = 3.3) fixating the speedometer significantly less than LDs (mean = 13.7). No significant interaction was found, $F(2, 40) = 2.7$, MSE = 40.5, $p = 0.08$.

5.3.8 Discussion

The purpose of the Experiment was to identify how drivers' visual attention is affected by both driving experience and different visibility conditions. Two groups with different driving experience (DIs and LDs) were participated into this experiment. Also in order to generate and manipulate different visibility conditions (day, rain, night) a driving simulator was used. Eye movements were used as the behavioural aspect of visual attention and the fixation allocation on certain areas of interest (mirrors, speedometer) was used as indication of visual search.

5.3.8.1 Driving Experience

The hypothesis that DIs will differ significantly from LDs was supported for all eye movement measures apart from vertical deviation of fixations. In general DIs had a greater number of shorter fixations distributed more widely across the driving scene. DIs had a higher sampling rate of the driving scene across all three visibility conditions. These result shows that DIs were able to collect more information of the scene by employing more fixations. This result confirms previous findings which showed a similar pattern of results (Chapman & Underwood, 1998; Crundall & Underwood, 1998).

Moreover DIs needed less processing time as indicated by shorter mean fixation durations. DIs were able to move their overt locus of attention more frequently than LDs independently of the visibility condition. The present findings are consistent with previous results (Chapman & Underwood, 1998) since it has been found that more experienced drivers need less processing time as demonstrated by shorter mean fixation durations. DIs' strategy of deploying frequent short fixations can be considered crucial in hazardous situations when the driver has to be able to anticipate dangerous on-road behaviours by maintaining vigilance for many potential sources of hazard without becoming overly focused on anyone source.

DIs spread their fixations on the horizontal axis significantly wider than LDs irrespective of the visibility of driving conditions. This result could be attributed in part to the significantly higher number of fixations to both side mirrors that DIs had in relation to LDs. Similar findings come from previous video analysis studies which have shown that experienced drivers inspect their side mirrors more than novices (Underwood et al., 2002a). It seems that LDs have restricted their fixation allocation to the scene more directly in front of them which results a significantly narrower allocation of fixations than DIs. Experiment 1 showed that novice drivers' infrequent inspection of side mirrors might not be due the demands of the driving situation but due to different prioritisation strategies that novices have in relation to DIs. Finally, in agreement with other findings (Crundall & Underwood, 1998) no group differences were found for vertical deviation. The lack of group differences in vertical deviation might be explained by the fact that groups did not differ at the rear view mirror inspection. In contrast there was a significant group difference at the speedometer inspection but this difference was not enough to reveal any variability between groups in the vertical spread of fixations.

5.3.8.2 Visibility Conditions

In general, visibility conditions affected drivers' eye movements. Drivers had lower sampling rates and longer fixations when driving a route with decreased visibility in comparison to day driving. Both weather conditions resulted in reduced fixations with rain condition producing the fewest fixations overall. A similar pattern of results was found for the mean fixation durations. Drivers' had longer fixation durations when driving at night and rain in comparison with the day route on which drivers' had the shortest fixation durations. Hence the decreased visibility conditions resulted increased processing time and lower sampling rate. For LDs the results are not so surprising since they are expected to have decreased performance in such situations since they might not have the experience under those conditions. Surprisingly DIs were also affected by rain and were not be able to maintain their high daytime sampling rate across all conditions. Also, DIs needed longer to process information in the driving scene under decreased visibility conditions, especially during "Rain".

In regards to horizontal spread of search no effect of visibility was detected. It seems that both DIs and LDs did not change their horizontal allocation of fixations according to visibility conditions (although DIs had significantly broader horizontal scanning than LDs). If the spread of search was partly dictated by peripheral stimuli attracting attention one might expect poor visibility to reduce the possibility that such cues might be spotted and therefore reduce the spread of search. The fact that this does not happen suggests that drivers' horizontal spread of search could be influenced by top-down strategies. In addition, another interesting finding is that the number of fixations and mean fixation durations are affected by visibility while horizontal spread of search is not. So processing time and sampling rate are affected by degradation of bottom-up information while the deployment of visual attention in the horizontal axis, is not affected by such bottom-up influences to such an extent. These findings might generate some questions about top-down and bottom-up influences upon different parameters of eye movements; however, such speculation needs further investigation.

Finally vertical deviation of fixations was affected by the visibility of the driving route. The orthogonal pre planned contrasts showed that both DIs and LDs on the night route had significantly increased vertical deviation of fixations compared to the other two driving routes. One possible explanation for these results is that speedometer was inspected at night more often because this condition removed peripheral information vital for speed estimation which is consistent with the category analysis.

5.3.8.3 Interaction between driving experience and visibility

Interestingly no interaction was found between driving experience and visibility, apart from the number of fixations at the rear view mirror. The results showed that group differences remained constant despite visibility conditions. Since certain aspects of eye movements for both driving groups were affected by visibility it seems possible to suggest that some elements of visual search are developed through general driving experience independently of the driving condition. The present results might provide additional support for the efficacy of graduated driver licensing (GDL) since it does not allow novices to drive in risky driving conditions (Hedlund, 2007) while at the same time it is possible for novices to develop some essential visual search skills by driving in less demanding situations. Hence GDL might allow a less risky transition from novice to more experienced driver without any restrictions on the development of general visual search strategies.

5.3.8.4 Eye tracking

The present findings rely mostly on eye movements as measured by an eye tracker. Although eye trackers are useful tools they only measure foveal vision and do not provide any measure of peripheral vision or useful field of view directly (Duchowski, 2003). This might be a potential methodological problem when using eye tracking and driving since it has been stated that peripheral vision is involved in a great degree when driving (Plainis, Murray, & Charman, 2005) and may indeed play a role in these findings. In order to accommodate these limitations of eye trackers some researchers have used indirect measures such as reaction times (braking) to calculate whether some areas of interest were perceived by subjects (Shinoda, Hayhoe, & Shrivastava, 2001). Although this is a very useful technique it underlines a reflexive behaviour and does not provide a great detail of insight regarding the strategies that the driver follows. Despite the fact that some elements of driving are automated there are some goal directed aspects of visual search (top-down elements) that cannot be revealed by peripheral vision only or reaction times.

5.3.8.5 Simulator Validity

The relative validity of the simulator can be examined by comparing the eye movement results of the present studies with similar results from other environments. Regarding the experiential differences, the present findings replicate previous results (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Mourant & Rockwell, 1972). Although it has been suggested that there is a possibility that driving simulators exaggerate experiential differences (Blaauw, 1982) there is no reason to believe that DIs would be more comfortable in a simulated environment than LDs. So it is reasonable to suggest that the driving simulator has relative validity as a research tool to investigate experiential differences in driving.

In regards to the visibility effects that they found here the validation procedure might be less clear than group effects. Day driving in this particular simulator could be considered having relative validity since the outcome in day driving is comparable to on-road studies and it replicates the findings of Experiment 4. Regarding night driving one question that someone might ask is if the night driving is really simulates night driving conditions. In absolute terms this issue is unknown since no luminance measurements were taken and there was no calibration of the screen or of the stimuli due to the dynamic nature of the simulator. However we have indirect evidence from pupil diameter that night driving was relatively darker than the other conditions. The pupillary light reflex will adjust its diameter according to the available illumination (Wyatt & Musselman, 1981), with the pupil becoming larger when there is less light available in order to accommodate for the low luminance conditions. The present results indicate pupil diameter was significantly larger in night condition than the other two. In regards to the group effect in pupil size that we found it can be explained by the age difference of the groups. It has been found that age affects pupil size and older adults have smaller pupil size than younger individuals (Winn, Whitaker, Elliott, & Phillips, 1994). Hence our results regarding pupil dilation fit with previous findings and indicate that the night route was darker in comparison to other two routes. However, it has been suggested (Recarte & Nunes, 2000) that pupil diameter is linked to attentional workload hence the results regarding pupil diameter might have been affected by the workload in the night condition. Nonetheless, it seems that the present findings are affected more by light reflex than mental workload due to large decrease in pupil diameter in the night condition only.

Driving under rain conditions also had an effect on drivers' visual search patterns. Whether this effect is a simulator-specific finding is not clear. Kemeny and Panerai (2003) have suggested that for visibility testing it is necessary to have absolute fidelity of the simulator. However, due to the novelty of the results, not only is it not possible to test absolute validity, but furthermore it is very difficult to examine the relative validity because there are no similar studies available to compare the results to. While it is acknowledged that simulating rain is very difficult (Rokita, 1997) since it was shown that the other two conditions have relative validity it is more likely that the rain condition has also satisfied the relative validity criterion. Despite that indication further research on this topic is necessary.

5.3.8.6 Theoretical explanations

There are some possible explanations that can account for both group and visibility results. One reason that might explain part of the present results is the visual properties of the stimuli. Plainis and Murray (Plainis & Murray, 2002) have shown that stimuli that simulate night driving (low luminance) result in slower reaction times. Consequently it could be argued that visual properties of night and rain driving might have affected visual search of the drivers. However, with such a simplistic explanation it is difficult to account for why the rain condition has affected visual search more than the night condition and why in some instances night performance did not differ from day. Nevertheless it seems that rain driving affected visual search possibly due to decreased contrast. So it seems that in addition to risky driving or wet road conditions there are some visual aspects in rain driving. This could be supported by the finding that there is increased accident risk during rainfall but this risk returns to normal after rain has stopped despite the continuing wet road conditions (Andrey & Yagar, 1993). This finding suggests that for a reason that is not so clear at present the combination of wipers and raindrops reduce considerably the visibility of the driver and lead to increased accident risk. In fact one possible explanation might come from the field of change blindness (Rensink, O'Regan, & Clark, 2000). Rensink et al found that achromatic "patches" that were presented on-screen affected participants' reaction times to identify changes. Applying this finding to the present results it could be argued that virtual rain disturbed participants' visual search. Also it could be said that after the wipers cleaned the windscreen the new raindrops affected the visual search pattern of the drivers. This is plausible as it has been found that new objects attract attention even if there is not luminance change (Yantis, 1993).

Other possible explanations for the results come from mental workload research. Previous studies have demonstrated that mental workload affects driving performance (Lee et al., 2007; Recarte & Nunes, 2003). Applying that to the current results it could be said that the driving task is very demanding for the LDs because of the novelty of the task. Following the same rationale it could be said that driving during rain increased the workload of all the participants hence it increased their processing time. Despite the fact that mental workload undoubtedly plays a role in driving performance it does not entirely explain the processes that underline driving. It has been shown that experiential differences in visual search patterns are present even when drivers are watching driving videos which consist of considerable less workload than actual or simulated driving (Underwood et al., 2002b).

5.3.9 Conclusions – Future research

The fact that driving experience influences visual search is replicated in this Experiment. Furthermore it was demonstrated that visibility conditions affect the eye movements of drivers. In particular rain driving was found to significantly affect the sampling rate and the processing time. The lack of interaction between driving experience and visibility conditions can provide some interesting theoretical implications about top-down and bottom-up influences. An additional point of interest might be the frequency of traffic violations while driving at different visibility conditions. Another future research question might be the identification of the differences in behavioural data, such as speed and steering deviation, during different visibility conditions. All the findings in the present study derive from a methodology that used a driving simulator and in general the driving simulator used here showed relative validity when compared with similar studies. However, there are some specific issues, like rain driving, that require further validation.

Although the effect of driving experience has been demonstrated before, the present study is original because it investigates the effects of visibility as a factor of driving experience and visual attention. In addition we supported the notion that there is an attentional element to driving performance across visibility conditions and expand the rationale that any high crash rate is due to driving style or risky behaviour.

Some additional practical implications of the present findings might include the development of training interventions for more efficient visual search strategies. Maybe one of the reasons that as mentioned before previous training was short lived was the fact that it was very general. Future training should consider the fragmentation and adoption of different visual allocation under different conditions. This expansion could be achieved by creating training interventions that take into account the fact that drivers have different sampling rates and processing time under different visibility conditions, and a training intervention should try to accommodate that knowledge when trying to influence drivers' visual search. Also the possibility that some eye movements (e.g. horizontal spread of search) are affected more by top-down influences than others should be taken into account. Finally the present results suggest that horizontal visual search does not vary as a factor of different driving conditions but is developed with general driving experience. Future studies that aim to train drivers' eye movements should take into account the present findings and consider the attentional allocation of drivers as a function of both driving experience and visibility.

Chapter 6: Identifying the parameters for an efficient training intervention

6.1 Summary of previous findings

In the previous Experiments the findings indicated some parameters that influence drivers' visual attention. In Experiment 1, drivers' visual attention priorities were explored in a theoretical level with the driver prioritisation questionnaire. It was found that drivers with different driving experience have different priorities regarding visual search. It was also revealed that certain visual categories (e.g. rear view mirror) are scenario dependent.

In order to examine visual search more directly in Experiments 2 and 3 the influences of top down and bottom up factors and the effects on visual search were examined. The findings from these two Experiments showed that all four driving groups that were recruited were influenced more by top-down factors. However, in opposition to the original hypothesis no group effects were found indicating that during the inspection of driving scenes the same attentional mechanisms operate. One element that was not clear from these Experiments is whether drivers with different experience look at similar areas of interest in the driving scene.

In Experiments 4 and 5 drivers tested on a driving simulator in order to answer some of the questions that have been raised in previous Experiments. The results from these two Experiments showed that there are experiential differences in visual search, both at the global level of eye movements as well as at the micro level of specific scenarios. In addition it was found that different visibility conditions affect some aspects of visual search. Finally it was noted that the simulator produced data in line with other studies using on-road and video-based methodologies suggesting a degree of relative validity.

Gathering all the findings from the previous five Experiments in this Chapter we will try to further identify which are the factors that are necessary in order to develop an efficient way to train drivers' eye movements. Finally at Experiment 8 a pilot study will put theory into practice and investigate the effects of some training interventions.

6.2 Experiment 6

6.2.1 Introduction

How can we improve learner drivers' visual skills? Much research has demonstrated that learner drivers have an impoverished spread of search during driving and that this is partly due to lack of knowledge of where and when to look, rather than simply an issue of cognitive load. Several training interventions have tried to improve scanning in these drivers with limited success. We propose that exposing drivers to examples of good and bad scanning behaviour may prove to be a useful tool in training visual search. The success of this approach however requires drivers to be able to distinguish between examples of good and bad scanning. To this end, two studies were undertaken where video clips of simulated driving with an overlaid eye movement trace were presented to participants who had to judge whether the eye movements belonged to a learner driver or a driving instructor.

As mentioned above there are many benefits that training interventions could potentially offer. It has been argued that we do not have insight to our eye movements (Chapman et al., 2002) and although this assumption is plausible there have been no studies in the driving field that have attempted to challenge this notion. It is important to understand if novices have understanding and introspection in regards to visual search strategies and eye movements. Simply increasing scanning without importing an understanding of why it is necessary it could be dangerous. “Blindscanning” could actually lead to some hazards been actively missed. Another question whether experienced drivers’ appreciation of eye movements is greater due to their experience, or whether eye movements remain difficult to understand despite such driving experience.

In this Experiment novice drivers (NDs) and experienced drivers (EDs) were recruited. The aim of this Experiment was to investigate whether short video clips of eye movements’ overlaid on a simulated drive can be identified by participants as belonging to either a driving instructor (DIs) or learner driver (LDs). It is hypothesised that more EDs will be able to identify more video clips than NDs. Also it is assumed that since eye movements are so fast the video speed will have an effect on the detection of the videos.

6.2.2 Method

6.2.2.1 Stimuli – Design

One hundred and twenty (60 normal speed, 60 half speed) short videos were used as stimuli. The original 60 videos were taken from a previous Experiment 4 and the additional 60 were produced by reducing the videos to half speed. The duration of the normal speed videos was five seconds and 10 seconds was the duration of the half-speed videos. All the videos presented an in-car view of a driver while driving on a virtual route and were taken from the head camera of the SMI head-mounted eye tracker. The eye movements of the drivers were displayed on the video as a moving orange circle. In half of the videos the driver was a driving instructor (DI) while in the remaining videos the driver was a learner driver (LD) though there was no information available to participants in the current study to discriminate between them other than what they saw on the screen. One third of the videos presented a “Parked

Cars" scenario, one third presented a "Stop Sign" scenario and the last third presented a "Stop Sign" scenario (for examples of these scenarios see Figure 5.2, page 109). The "Parked Cars" scenario showed a car driving on a one-way two-lane road with cars parked on both sides, the "Stop Sign" scenario showed a car approaching to a stop sign junction and turning right and the "Traffic Light" scenario demonstrated a car waiting at a green traffic light in order to turn right while on-coming traffic from the contraflow lane was coming. In all scenarios the traffic was moderate. Previous frame by frame videos analysis in Experiment 4 has shown that there are actual differences between the eye movements of DIs and LDs on these scenarios (see also Table 5.2, page 113).

Before the outline of the design it is necessary to define some terms because the experimental design involves drivers as participants and videos of drivers as stimuli which might be rather confusing. Hence in the statistical analysis the term driving experience will refer to the differences between the driving experience of the viewers and the term video type will refer to the differences between DIs' and LDs' videos.

A 2x3x2x2 ANOVA was used and the between subject variable was driving experience of the viewers and the within factors were: video type (instructor and learner), scenario type ("Parked Cars", "Stop Sign" and "Traffic Lights") and video speed (normal 25fps and slow 12.5 fps). The dependent variable was the percentage of video clips correctly identified as belonging to a DI or LD.

6.2.2.2 Participants

Sixty seven participants volunteered for this experiment. The majority of the participants were undergraduates at University of Nottingham. They were divided into two groups according to their driving experience. The experienced group consisted of

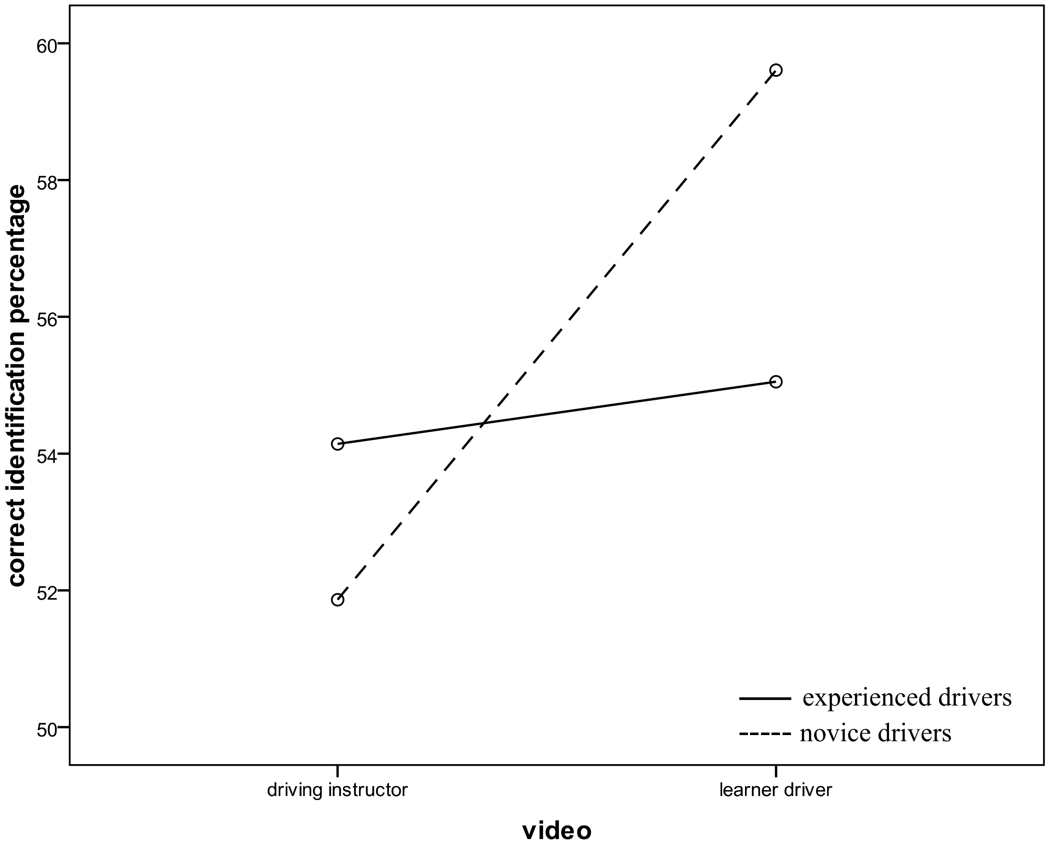

Figure 6.1. Demonstration of the correct video identification per video type.

33 participants with mean age of 22 years (SD 4, 20 females). Their mean driving experience was 53 months of driving (SD 45). The novice group had 34 participants, with 23 females. The mean age was 19 (SD 1). The driving experience for novice group was 5 months (SD 5).

6.2.2.3 Procedure – Apparatus

Following a brief questionnaire participants were sat in front of a standard 17 inch monitor and on-screen instructions were given to them in regards of the video presentation and the scoring procedure. After the presentation of each video a scoring screen appeared asking if the driver of the previous video was either a DI or a LD. Each participant saw a total of 60 videos (30 DI – 30 LD, 30 normal – 30 slow, 20 "Parked Cars" – 20 "Stop Sign" – 20 "Traffic Lights") and the presentation was randomised and counterbalanced.

6.2.3 Results

Due to the complexity of the design only the significant effects will be reported. For every significant factor an extra analysis was performed in order to identify whether the correct percentages were significantly different from chance. For that purpose multiple one-sample t-tests, with the test value of 50 % (Bonferroni corrected), were performed.

A significant effect of video type was found, $F(1, 65) = 7.5$, $MSE = 500$, $p < 0.05$ (see Figure 6.1), with the DI clips identified less correctly (mean = 53%) than LD clips' identification (mean = 57%) For the video type factor only the LDs' percentage was significantly higher than chance ($p < 0.025$). Also an interaction was found between the video type and driving experience of the viewers, $F(1, 65) = 4.7$, $MSE = 500$, $p < 0.05$, with novice drivers identifying DIs' videos (mean = 52%) less often than LDs' videos (mean = 60%), while experienced drivers identified both video categories similarly (mean DI = 54%, mean LD = 55%). For this interaction only the percentage of novices correctly identifying LDs' clips was significantly higher than chance ($p < 0.013$).

Finally a significant interaction between video type and scenario was found, $F(2, 130) = 7$, $MSE = 688$, $p = 0.001$ (see Figure 6.2), with the DI clips for the "Parked Cars" scenario had the lowest correct percentage (mean = 50) while LD clips for the same scenario having the highest percentage (mean = 63). The scores of the LD clips in "Parked Cars" and "Traffic Lights" were above chance ($p < 0.008$) while for the DI clips the only percentage that was above chance was at the "Stop Sign" scenario.

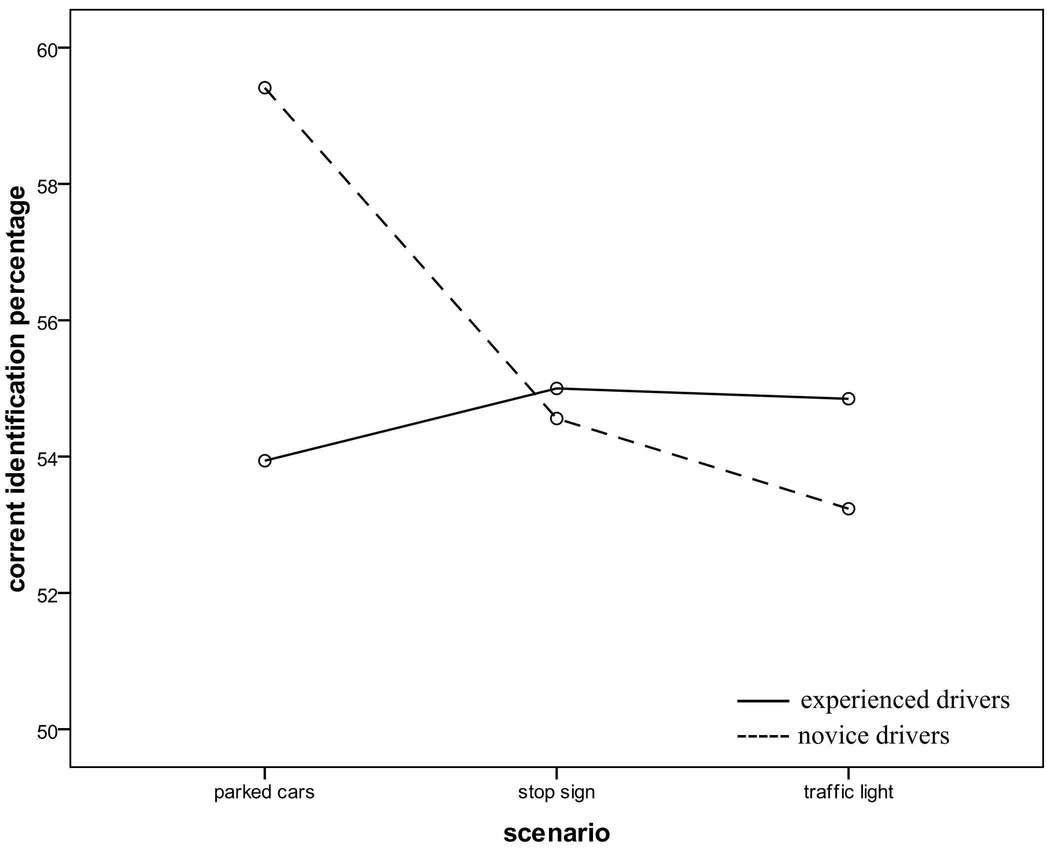

Figure 6.2. Demonstration of the correct video identification per driving scenario.

6.2.4 Discussion

Results of Experiment 6 showed that in general LD clips were correctly identified significantly more frequently than DI clips. Also novice drivers identified significantly more LD clips than DI clips. These two findings might suggest that novices were able to identify their in-group's eye movements (assuming that novice drivers are closer to learners than instructors) while their judgement for DI clips was not significantly different from chance. Experienced drivers identified both video types similarly; however LD videos had a higher correct percentage than DI videos. Finally a significant interaction was found between video type and scenario with LD clips identified significantly more often than DI clips in the "Parked Cars" scenario while in the remaining scenarios correct percentage score was similar. There is the possibility that the correct identification score was affected by the nature of the scenario which have might made any differences easier to detect. Also it is possible that the magnitude of actual eye movement differences was greater for this scenario. These two possible explanations for this interaction will be further examined in Experiment 7. Interestingly no effect of video speed was found which indicates that any recognition of eye movements' patterns is not necessary better at slow speed presentation.

The findings of Experiment 6 have generated some questions that need further investigation. First, it needs to be explored whether the correct identification of LD clips mainly from novices is a matter of introspection or just a tendency to identify all videos towards the in-group. Secondly, any effects of different scenarios would be further explored.

6.3. Experiment 7

6.3.1 Introduction

Experiment 7 was conducted in order to refine the methodology of Experiment 6 and further explore some of the questions raised. First in order to investigate whether there is any form of introspection in the identification of eye movements we decided to use the same groups as the ones that the videos represent. By using LDs and DIs as participants we will have at least two methodological advantages. We can ensure that any group differences will be detected since these groups lie at the extremes of the driving experience scale. Also, we will be able to detect if there is any introspection of eye movements in general or any in-group bias by examining the reliability of the results. In regards to the effects of the different scenario that the videos represent it was decided to add two more scenarios in order to see whether this will affect the level of correct identification.

6.3.2 “Night” and “Rain” scenarios

6.3.2.1 Introduction

Since the addition of two extra scenarios it was considered appropriate in order to explore further the effect of scenario on correct video identification it is necessary to analyse these videos frame by frame. The methodology here will be identical to the frame by frame analysis that it was used in Experiment 4 (see section 5.2.2.5).

Based on the findings of the similar analyses in Experiment 4 the hypothesis regarding the scenario analysis is that the general eye movements within the scenarios will not be different between groups. In regards to the micro-level of eye movements the hypothesis is that there would be scenario specific group differences at the areas that would be allocated.

Figure 6.3A

Figure 6.3B

Figure 6.3. Example screenshots to demonstrate the additional driving scenarios that used in Experiment 7. 2A illustrates "Night" and 2B "Rain" scenarios.

20 "Night" videos and 20 "Night" videos were chosen for the analysis. Half of the videos showed DIs while the other half showed LDs. The "Night" scenario represented a very similar situation to the "Parked Cars" scenarios with the difference that it was under night conditions (see Figure 6.3A). The "Rain" scenario represented

a two lane road with moderate traffic and the drivers on the videos were negotiating a right curve while it was raining (see Figure 6.3B).

6.3.2.2 Video analysis of "Night" and "Rain" scenarios

In order to investigate whether the scenarios had any quantifiable differences in general eye movements a 2x2 ANOVA (video type and scenario) was conducted for the total number of fixations. The dependent variable was the sum of all fixations at the predefined categories. A main effect was found for video type, $F(1, 18) = 14$, $MSE = 14$, $p < 0.05$, with DIs (mean = 11.3) producing more fixations than LDs (mean = 6.9). No effect of scenario, $F(1, 18) = 3.3$, $MSE = 8.7$, $p = 0.09$, or any interaction, $F(1, 18) < 0.001$, $MSE = 8.7$, $p = 1$, was detected.

Scenario:	Night		Rain	
Group:	DIs	LDs	DIs	LDs
Number of Fixations				
Rear View Mirror	**0.7 (0.5)**	**0.2 (0.4)**	0.6 (0.7)	0.3 (0.5)
Parked Car Left	**1.5 (0.5)**	**0.2 (0.6)**	0 (0)	0 (0)
Mean Fixation Duration (seconds)				
Road Fixation	**0.6 (0.3)**	**1.6 (0.8)**	**0.5 (0.2)**	**1.5 (1.3)**
Percentage of Fixations				
Rear View Mirror	**8.7 (7.1)**	**2 (4.7)**	4.1 (4.9)	1.9 (3.4)
Road Fixation	39 (25)	61 (24)	**31 (17)**	**66 (26)**
Parked Car Left	**11.3 (5.1)**	**1.9 (5.9)**	0 (0)	0 (0)

Table 6.1. Means and standard deviations of fixations, mean fixation durations and percentage of fixations in gaze-regions. Each value represents the group average for each region at every scenario. Values in bold denote a significant comparison, of p < 0.05.

In regards to the mean fixation duration a similar type of analysis was performed, with dependent variable the average mean fixation durations. A main effect was found for video type, $F(1, 18) = 7.0$, $MSE = 0.4$, $p < 0.05$, with DIs (mean = 0.5) having shorter mean fixation duration than LDs (mean = 1). No scenario, F (1,

18) = 1.2, MSE = 0.6, $p = 0.3$, or interaction, F (1, 18) = 1, MSE = 0.6, $p = 0.3$, was found.

For the remaining analysis it was necessary to analyse scenarios separately since many of the regions are scenario dependent, mean and standard deviations can be seen at Table 6.1 In regards to the “Night” scenario the analysis of number of fixations showed that the region “Parked Cars Left” was fixated significantly more from DIs than LDs, t (18) = 4.9, $p < 0.001$. In addition DIs fixated more times in “Rear View Mirror” than LDs, t (18) = 2.5, $p < 0.05$. The mean fixation duration was shorter for DIs than LDs in “Road Ahead” region, t (17) = -3.6, $p < 0.01$. The percentage of fixation analysis showed the same pattern of results with DIs had higher percentage of fixation than LDs for “Parked Cars Left”, t (18) = 3.9, $p = 0.001$, and “Rear View Mirror”, t (18) = 2.5, $p < 0.05$.

Regarding the “Rain” scenario the mean fixation duration of DIs was shorter than LDs in the “Road Ahead” region, t (18) = - 2.5, $p < 0.05$. Finally, DIs had lower percentage of fixation than LDs for “Road Ahead”, t (18) = - 3.6, $p < 0.005$.

6.3.2.3 Video analysis summary

In regards to the general eye movement analysis as it was predicted there was not any effect of scenario. However, in contrast with the results of Experiment 4 there were group effects probably due to the fact that the scenarios employed here amplified any group differences possibly due to visibility conditions.

Regarding the specific areas that participants inspected during the scenarios, there were differences between DIs and LDs. At the “Night” scenario the most differences were detected in relation to the other scenarios. The main two findings were that DIs inspected the cars that were parked on the left and the rear view mirror more than LDs. In the “Rain” scenario it was found that LDs had higher mean fixation duration and percentage of fixations at the road ahead in comparison with DIs.

Again as in Experiment 4 there are implications of these results however, these issues were discussed in Experiment 4 (see section 5.2.4.2) and will be mentioned again at the last Chapter. The purpose of this type of analysis here was to ensure that thes scenarios were suitable for usage in Experiment 7 so any additional discussion of the implications of the results will be mentioned in another section in the last Chapter where this discussion will be more relevant. Since there are actual differences as was revealed by observational analysis the videos (together with the videos from Experiment 6) are considered appropriate to be used as stimuli to explore eye movement identification and the effect of scenarios.

6.3.3 Method

6.3.3.1 Stimuli

The 60 normal speed videos from Experiment 6 were used. In addition 40 more videos of the same speed were added to the presented stimuli. 20 of the new videos presented the “Night” scenario and the other 20 presented a “Rain” scenario. Half of the videos presented a DI driver and the other half a LD.

6.3.3.2 Design – Procedure

The experimental procedure was the same as in Experiment 6. In regards to the design a similar methodology as Experiment 6 was deployed without any manipulation of the video speed since results of Experiment 6 did not show any significant effect of this manipulation. Since the present methodology involves driving instructors and learner drivers both as participants and drivers of the videos the acronym DIP and LDP will refer to participants while DID and LDD will refer to drivers of the videos. A 2x2x5 ANOVA was conducted with the between factor of

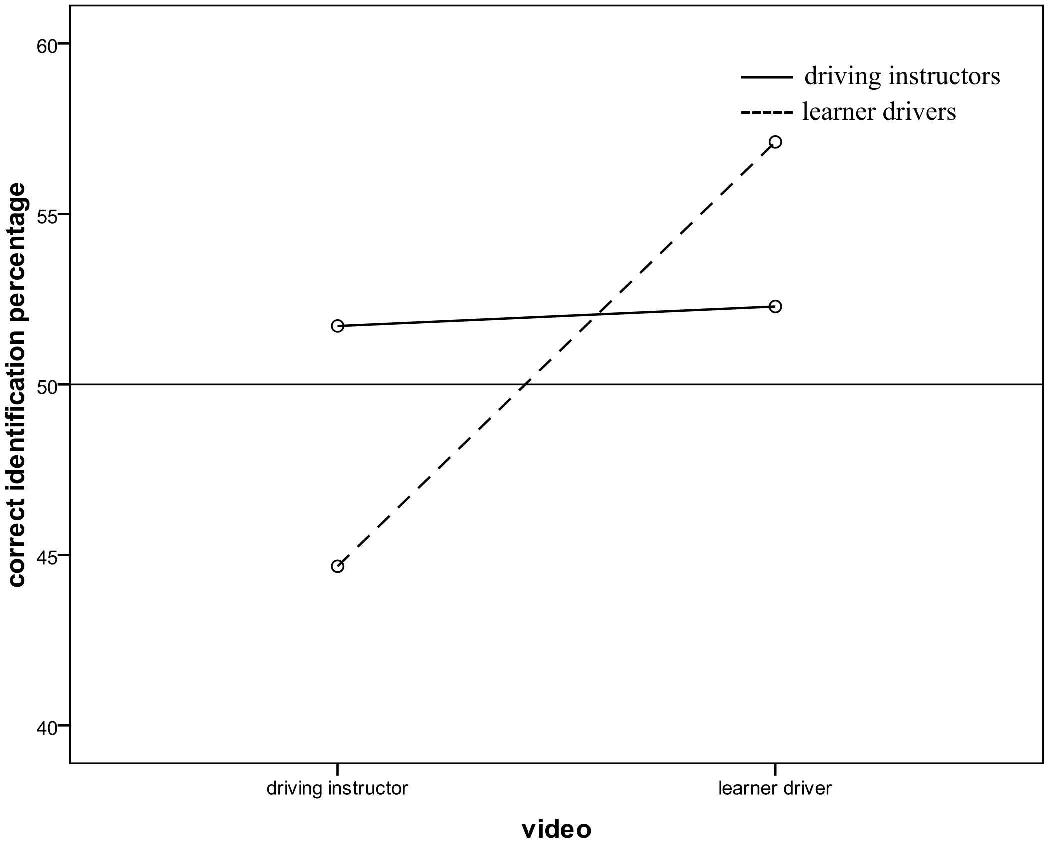

Figure 6.4. Demonstration of the correct video identification per video type.

driving experience of the viewers (DIPs and LDPs) and the within factors of the video type (DIDs and LDDs) and scenario with five levels (“Parked Cars”, “Stop Sign”, “Traffic Lights”, “Night” and “Rain”).

6.3.3.3 Participants

Fourteen driving instructors (3 females) were recruited for this Experiment. Their average age was 50 years (SD 11) and their driving experience 32 years (SD 11). Finally their experience as driving instructors was on average 8 years (SD 8). The other group was consisted of 18 learner drivers (13 females) with average age of 20 years (SD 2). Their driving experience was measured in hours of lessons with an average of 23 lessons (SD 21).

6.3.4 Results

6.3.4.1 Video Identification

As in the results session of Experiment 6 only the significant effects will be reported and the one-sample t-tests against chance. An effect of video type was found, F (1, 30) = 6.6, MSE = 504, $p < 0.05$, with DIs' videos (mean = 48%) identified correctly fewer times than LDs' videos (mean = 55%). For this factor LDPs' score on LDs' clips was significantly higher than chance ($p < 0.025$). A significant interaction was found between the driving experience of the viewers and video type, F (1, 30) = 5.5, MSE = 504, $p < 0.05$ (see Figure 6.4), where LDPs identified DID videos (mean 45%) less frequently than LDD videos (mean = 57%), while DIPs identifying DID videos (mean = 52%) and LDD videos (mean 52%) similarly. For this interaction only LDPs' score for LDD videos was significantly different from chance ($p < 0.013$).

A main effect of scenario was found (see Figure 6.5), F (4, 120) = 11.2, MSE = 159, $p < 0.001$. Post hoc pairwise comparisons corrected with the Bonferroni method showed that the correct identification score for the "Night" scenario (mean = 59%) was significantly higher than all the other scenarios with the exception of the "Stop Sign" scenario (mean = 53%). For the remaining significant comparisons see Table 6.2. Only the score for the "Night" scenario was significantly different from chance ($p < 0.01$).

	Driving Scenarios				
	Parked Cars	Stop Sign	Traffic Lights	Night	Rain
Parked Cars	x	x	x	*	x
Stop Sign	x	x	*	x	x
Traffic Lights	x	*	x	*	x
Night	*	x	*	x	*
Rain	x	x	x	*	x

Table 6.2. Pairwise comparisons, corrected with the Bonferroni method, between scenarios in experiment 7. * devotes a significant difference.

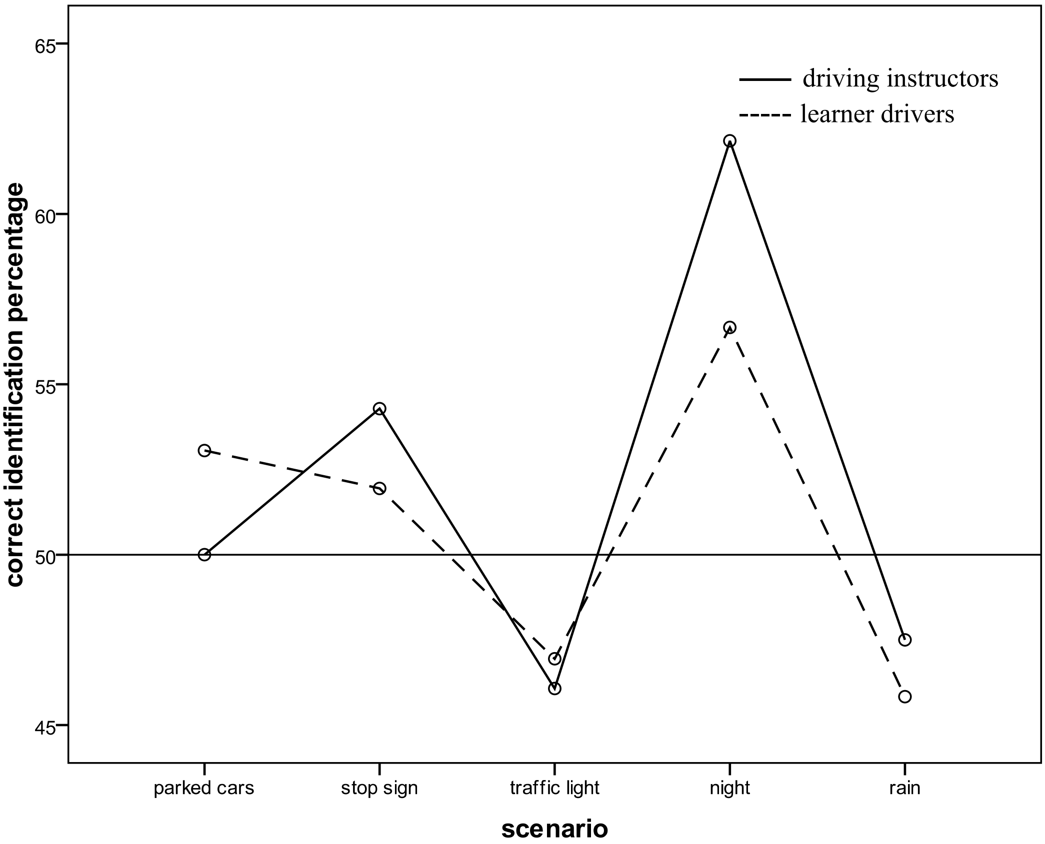

Figure 6.5. Demonstration of the correct video identification per driving scenario.

Finally a significant interaction between video type and scenario was found, F (4, 120) = 8.1, MSE = 340, $p < 0.001$ (see Figure 6.6). Pre-planned contrasts with the repeated method showed that there is significant simple effect between "Parked Cars" and "Stop Sign", F(1, 30) = 19.4, MSE = 1239, $p < 0.001$, with the correct percentage of DIs' videos increased dramatically from "Parked Cars" scenario (mean = 44%) to "Stop Sign" (mean = 60%) while the opposite pattern was observed for LDs' videos that the correct percentage was lowered significantly at the "Stop Sign" (mean = 46%) in relation to the "Parked Cars" scenario (mean = 59%). Also a simple effect was found between "Traffic Light" and "Night" scenarios, F (1, 30) = 15.1, MSE = 760, p = 0.001, with DIs' videos having similar correct identification percentages between these two scenarios (mean "Traffic Light" = 46%, mean "Night" = 50%), while LDs' videos were identified significantly more frequently in the "Night" scenario (mean =

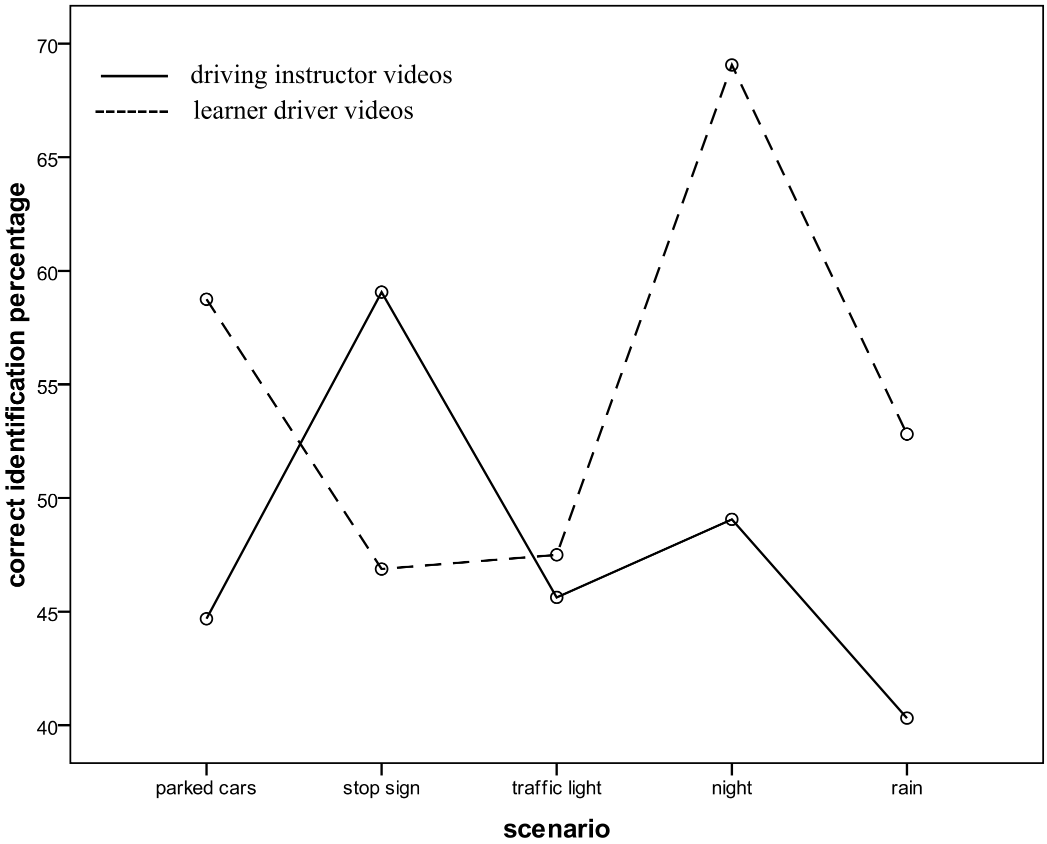

Figure 6.6. Demonstration of the correct video identification per video type.

69%) than at the "Traffic Light" scenario (47%). For this interaction only LDD videos in "Parked Cars" and "Night" were significantly different from chance ($p < 0.005$).

6.3.4 Discussion

6.3.4.1 Video Identification

In regards to the identification of video type the results of Experiment 7 were similar to experiment 6 with LD videos identified significantly more than DI videos. Again the same interaction was found with LD participants identifying LD videos significantly more times than DI videos. DI participants' correct percentage was similar for both video types. Again only LDs' correct percentage for the LD videos was significantly above chance. We can assume that the higher identification of the LDs' videos were due to the fact that LD participants identified them more times than

DI videos. It is possible that this is associated with a certain level of in-group introspection.

In regards to the effects of the specific scenario both groups of participants identified significantly more videos in the "Night" scenario. One possible explanation might be the actual observed differences at these videos. As it is illustrated at Tables 6.1 and 6.2 it can be seen that the "Night" scenario has significant group differences into more categories than the rest of the scenarios. So it is highly possible that the higher percentage of correct videos is due to the fact that there are more quantitative differences between groups (DIs and LDs) to be identified.

6.3.5 Conclusions – Future research

Novice and learner participants identified LDs' videos significantly higher and above chance than DIs' videos. This pattern of results was observed in both experiments and there are some possible explanations. First it is quite possible that novices and learners had a tendency to identify most of the videos as LDs because they belong to their group. If this is the case then someone would expect the scores for the DIs' videos to be significantly below chance. This is not the case since the one-sample t-tests with the corrected alpha value showed that novices and LDs simply guessed when they viewed DIs' videos but they were significantly above chance when they viewed LDs' videos. If it is indeed due to chance or a tendency to see everything as LDs it is very surprising that a very similar pattern was observed on both experiments.

Another possibility is that LDs and NDs showed introspection into their own group eye movements and being able to identify more times LDs' videos correctly. Of course then someone might ask why the experienced or DIs do not have the same level of introspection by being more experienced. It is quite possible to assume that since novices and LDs are still under driving training, or have only recently passed their test it is quite possible to have higher introspection due to recent retrieval cues or maybe the clips elicit their knowledge. Also, it is possible that LDs' recently received feedback about driving and scanning techniques made them more aware of their eye movements hence being able to identify similar patterns easier. In Experiment 1, it was shown that LDs and DIs have different visual search priorities which may partly explain why LDs had higher correct identification of their in-group videos.

In regards to the effects of different scenarios upon the identification the findings from Experiment 6 were somehow inconclusive possibly due to the fact that the three scenarios used had not so many differences between scenarios. In experiment two the addition of two scenarios made the pattern of the results more clear. The differences in "Rain" scenario were similar to the rest of the clips while the "Night" scenario had more differences than all the other scenarios. This might be the reason that the correct percentage at the "Night" scenario was significantly higher than the remaining scenarios and also above chance. This indicates that maybe there is a threshold of eye movement differences that can be identified. Perhaps the short video duration in combination with the few significant categories in some of the scenarios might make the identification of video type difficult.

Future training interventions should take into account that LDs and novice drivers have a tendency to understand the eye movements and visual search patterns of their in-group better than those of more experienced drivers. Since the aim is to help novices to enhance their visual search and understand better how experts scan the road it might be useful to combine the usage of eye movement video with some sort of commentary. Maybe the combination of audio and visual stimuli and if the differences were explicitly pointed out might help trainees to understand better experts' visual search strategies.

6.4 Experiment 8 – Piloting a training intervention

6.4.1 Introduction

As it was mentioned at the introduction of the Thesis (see section 1.5) the development of training interventions that can enhance the visual search strategies of novice and learner drivers is necessary. The findings from Experiments 6 and 7 indicated some important aspects that future training interventions should take into account. In this section of Chapter 6 one final experiment will be reported that investigated the effect of training on learner drivers' hazard perception skills. These data are actually part of a larger study comparing several training interventions (Crundall, Chapman, Underwood, Van Loon, & Chapman, 2006) though the other training conditions were developed outside of this Thesis and will not be discussed here.

Here we will focus only on the condition in the larger study that was developed based on the findings of Experiments 6 and 7 since the full details of this project will be reported elsewhere by the project holders. Also the statistical analysis will be reported with as much detail as possible since only some preliminary analysis is available yet. For the purpose of this Thesis Experiment 8 is considered as a pilot study that has taken into account some, but not all, of the recommendations that were derived from the findings of the previous Experiments of this Thesis.

6.4.2 The training intervention

For the purpose of this pilot study only two training modules and a control video will be described although there were other modules available.

6.4.2.1 Scenario specific training

The first training intervention consisted of a 7 minute video. At the beginning of the video a narrator explained the fact that drivers need to focus or divide their attention to objects on the road. Also it was pointed out by the narrator that since visual search while driving is situation dependent it is very difficult to teach in advance the areas that someone should attend to. However, it was also mentioned that an efficient way to improve visual search might be to watch the experts. Then participants were informed that driving instructors (DIs) had driven the same route previously, while their eye movements were recorded. They were then told that they would see some videos taken from a DI’s drive with her eye-movements overlaid on video. The scenarios that were presented in the training video with the overlaid eye movements of a DI were almost identical with the scenarios in Experiment 6 so they included a “Parked Cars”, “Stop Sign” and “Traffic Light” scenarios. Prior to the presentation of each scenario the same route but without eye movements was presented. During the video without eye movements there was commentary about where someone should look in order to anticipate any potential hazards. These verbal instructions about visual search were in agreement with what the DI would attend to in the video that would follow. During the videos with the eye movements no commentary was provided. After the presentation of all scenarios it was emphasised that in general DI’s visual search was widely spread across the scene however during specific manoeuvres DI was able to focus her attention into specific regions. Finally a summary of the key elements for an efficient visual search were presented to participants and included the following: it is necessary to divide and focus attention when driving; the driver should scan the road ahead for any potential hazards and try to anticipate the behaviour of other road users; when approaching a junction the driver should divide attention between the mirrors and the roads to the left and right.

6.4.2.2 General hazard management training

The second training video was related to general hazard management. At the beginning of the video the narrator mentioned that although driving conditions are very dynamic there are many elements that are under driver's control. It was emphasised that the driver can control the speed of the car, the effectiveness of visual search strategies and the limitation of in-car distracters. As an example of a poor vehicle control it was mentioned that the short distance from vehicle in front leaves the driver with poorer visibility condition and less reaction time hence higher possibility of an accident.

After the introductory comments, three videos, taken from an in-car camera while driving under real traffic conditions, were shown to the participants. During each video the narrator indicated the potential hazards (e.g. pedestrians) on the road together with the preventative behaviour (e.g. speed control, scanning) that the driver should have anticipated in order to minimise the occurrence of an accident. After the three videos some final comments were emphasised regarding general hazard management. It was suggested that some basic elements are necessary in order to manage traffic risks involve: scanning the road ahead and to the side for any potential hazards; checking mirrors before every manoeuvre and at every junction; driving at the appropriate speed for the road and driving conditions; maintaining a safe distance between the car under control and the vehicle in from in order to have plenty of time to react; and finally it was suggested that it is highly important for the driver to maintain awareness of the driving environment.

6.4.2.3 Control video

The control video was consisted of general comments about traffic safety. Also it was stated that the driver should be able to examine important car features. For example the significance of the correct tyre pressure was underlined and the necessary actions in order to check tyre pressure were demonstrated.

6.4.3 Method

6.4.3.1 Design

A between subjects design was employed for this study. The between factor was the training intervention with scenario specific, hazard management and control video as levels. The dependent variables were the number of fixations, as a measure of sampling rate; mean fixation durations as an indication of processing time; horizontal and vertical deviation (average standard deviations on x and y axis) as a measure of spread of search.

6.4.3.2 Participants

All participants in this experiment were learner drivers (LDs). For the scenario specific intervention 25 LDs (15 females) were recruited with the average age of 20.2 (SD 2.2) and their mean driving experience was 22.8 (SD 14.1) hours of driving lessons. For the hazard management intervention 26 LDs (15 females) were recruited with the average age of 20.1 (SD 2) and their mean driving experience was 20 (SD 18.1) hours of driving lessons. Finally for the control group 25 LDs (18 females) were recruited with the average age of 21.2 (SD 2.5) and their mean driving experience was 29.8 (SD 14.1) hours of driving lessons.

6.4.3.3 Stimuli and apparatus

The driving simulator and eye tracker that were used were the same as the ones described at Experiments 4 and 5.

6.4.3.4 Procedure

First participants completed a short questionnaire and then they sat at the driving simulator. After they wore the helmet with the eye tracker the experimenter calibrated the eye tracker. Then they had a practice drive in order to familiarise themselves with the controls of the simulator. Following the practice route participants drove the first test route which was very similar to the day route that used in Experiment 5. However, for the purposes of the project during the route there were several driving hazards, such as pedestrians walking into the road, a car pulling out of a junction etc. After the first drive either one of the training interventions or the control video was delivered to participants. When participants finished watching the video they had a second drive identical to the first test route.

6.4.4 Results

Only the eye movements of the second test route were analysed. A one-way ANOVA was used to analyse each dependent variable separately. For the total number of fixations no significant effect was found, $F(2, 73) = 1.7$, $p = 0.2$ across the three driver groups. For the mean fixation duration since Levene's test was significant the Brown-Forsythe F will be reported. No significant effect between groups was found for the mean fixation duration, $F(2, 54) = 1.7$, $p = 0.2$. In regards to the distribution of the fixations on the horizontal axis a significant effect was found, $F(2, 73) = 3.7$, $p < 0.05$. Post hoc comparisons, Bonferroni corrected, showed that participants who received the scenario specific intervention (mean = 5.7^{o}) had significantly higher horizontal spread than the participants who received the control video (mean = 4.9^{o}, $p < 0.05$). The horizontal spread of fixations of the participants that watched the hazard management training intervention (mean = 5.2^{o}) was not significantly different neither from the scenario specific sample ($p = 0.45$) or the control group (p = 0.83). Finally no effect was found for the vertical spread of fixations between groups, F (2, 73) = 1.3, p = 0.3.

6.4.5 Discussion

The results showed that only the horizontal spread of fixations was influenced by the training interventions. As expected the participants that watched the control video had the least horizontal distribution of fixations than participants in the other two conditions. More specifically, the participants that watched the scenario specific module had significantly greater spread of search on the horizontal axis than the control group while the participants at the hazard management group were in the middle of the scale but without any significant comparisons.

Based on these findings there are at least three questions that one has to tackle in order to assess the efficiency of the training modules. First why only the horizontal spread was influenced by the module? Secondly, was the initial stage of the scenario specific module successful? Finally the third question is related to possible future improvements that need to be implemented in order to create a more efficient scenario specific training intervention.

The first point of discussion that derives from the results is the fact that only the horizontal spread of fixations was influenced while the other eye movement characteristics were remained at similar levels between interventions. Although this might look a surprising finding there are some possible explanations. The most obvious explanation might be the fact that the scenario specific module explicitly encouraged wider horizontal search as can be seen by the main elements of this module (see section 6.4.2.1) and as was demonstrated by the DIs' eye movements. Indeed this was the aim of the module and one of the reasons is that it is extremely difficult to control either the number of fixations or the fixation duration in such a dynamic scene while it seems possible that horizontal scanning might be open to top-down strategies. In addition the vertical spread of search, which might be very efficient in certain driving situations, is not related to experts' visual search in general. Finally, the fact that only one eye movement characteristic of was improved, could favour the efficiency of the module. As was mentioned in Chapter 1 (see section 1.5.3) one unanswered question of previous interventions was the possibility that participants that received an intervention scanned around the scene extensively without any relation to the driving demands of the situation. Here we suggest that this was not the case since participants showed a difference only in the horizontal axis.

The second issue about the results is whether the pilot phase of the scenario specific training intervention can be considered as successful. Since it is not possible to know the visual search characteristics of an ideal and perfect driver we have to consider successful the visual search strategies of the driving groups that are represented less often in the crash statistics. It has been demonstrated many times throughout this Thesis that the more experience someone has as a driver the lesser their risk of a traffic crash. As mentioned before the horizontal distribution of fixations is indicative of spread of search and it is a very good discriminator between experienced and novice drivers. Almost every study mentioned so far in this Thesis has found experiential differences in the horizontal spread of search. So as a conclusion it could be said that an efficient horizontal spread of search is a basic element to driving safety and one of the main characteristics that experienced drivers have and novice drivers lack. So was the training module successful and thus able to improve such an important and critical skill of visual search? The findings indicate that the scenario specific module successfully increased participants horizontal visual search pattern. However, since this training module is still at the pilot stage we should be very cautious before drawing any conclusions since further methodological validation is required.

Despite the encouraging findings regarding horizontal spread of search some future improvements are necessary. First, it is necessary to determine whether the increased horizontal spread of search of participants has any time limits; has the training module permanently changed the visual search patterns of learners. A possible solution might be to retest the same participants on the virtual route to examine if the developed visual search pattern remains stable over time in relation to the control group. A second question for future research is whether this type of training has any effect on driving behaviour and whether trained drivers have fewer accidents than untrained drivers.

Due to the novelty of the training intervention it was necessary to control its development stage by stage. For this reason only the findings from Experiment 6 were taken into account. However, as was described above the additional scenarios of Experiment 7 offered higher identification percentage and possibly their addition to a future scenario-specific training intervention may enhance participants' performance in regards to visual search. Finally, due to this study being restricted by the requirements of the larger project within it was embedded it was not possible to analyse the micro-level eye movements of participants. The analysis of the attended areas while driving will answer the question of whether the increased horizontal scanning is due to random distribution of fixations or it is a result of frequent inspection of certain areas.

As a conclusion it could be said that although this training module in under development the preliminary results showed some potential but there are several issues that need further development. The scenario-specific intervention improved

LDs' scanning which is one of the essential visual skills that expert drivers possess. The scenario-specific visual skills interventions look promising and definitely need further attention.

Chapter 7: General discussion – Conclusions

7.1 Introduction

Novice drivers are at substantially higher risk of a traffic accident than experienced drivers and they are overrepresented into crash statistics. As was mentioned in Chapter 1 of the Thesis many researchers agree that one major reason for the high number of crashes of novice drivers is the lack of driving experience. This lack of experience in combination with the absence of efficient visual search strategies leaves novice drivers prone to driving errors and increases their risk of accident involvement. The parameters that influence this problematic link and possible ways to improve it were the main research questions of this Thesis. The interaction of driving experience and visual attention was investigated using four experimental methodologies that were described into Chapters 3 – 6. Initially the missing link in the teaching progress of learner drivers was explored in Chapter 3. After the theoretical examination of drivers' priorities the interaction of top-down and bottom-up influences upon drivers' visual search was examined in Chapter 4. In Chapter 5 participants were tested on a driving simulator in order to identify how visual attention is deployed between different groups of drivers and under different driving conditions. Finally, in Chapter 6 by using an identification task some aspects that can constitute an efficient training intervention were identified and showed promising results in a pilot experiment.

The aim of this Chapter is to summarise the research findings of the Thesis. The summary of the research findings of each experiment will be described together with the discussion of theoretical and practical implications that the results might have. Also in light of the whole research of this Thesis the findings of each Experiment will be discussed in relation to the other experimental findings in order to describe the research process as a whole. In addition any methodological considerations and further improvements will be mentioned. Finally some recommendations for further research will be suggested.

7.2 Experiment 1

7.2.1 Summary of findings

It has been demonstrated that novice drivers (NDs) lack effective visual skills. During the official driving training of NDs their driving instructors (DIs) are responsible for training them to control the car and to be able to avoid any hazards. It is reasonable to assume that DIs will transfer, amongst other skills, their visual skill knowledge to learner drivers. However, as has been presented many times through this Thesis, NDs do not have as efficient search strategies as that of their more experience counterparts. In Chapter 1 the link between DIs and NDs knowledge was investigated. Participants' priorities regarding visual search in nine driving scenarios were collected on Drivers Prioritisation Questionnaire (DPQ; Konstantopoulos & Crundall, 2008).

The results of Experiment 1 showed that DIs are consistent in regards to the areas that they prioritise. More over it was found that the priorities of DIs are scenario dependent and vary according to the given driving situation. This suggests that DIs have explicit shared knowledge of the optimum visual search. Surprisingly results showed that NDs were consistent amongst themselves and they also changed their priorities under different driving situations. However, the views of NDs regarding prioritisation were different to that of DIs.

7.2.2 Theoretical and practical implications

Since DIs are driving experts we can assume that their priorities should represent the optimum visual search in any given driving scenario. At the same time since NDs priorities differ from those of experts it is highly possible that they look in the wrong places in some cases. One explanation is that NDs are using a "naïve model" to guide their priorities. While this model might make NDs realise some obvious areas that the driver should look at (e.g. mirror checking when pulling away) it seems that when the complexity of the situation demands a more detailed visual search this "naive model" produces incorrect visual priorities. This can explain how in some situations the priorities between the two groups did not differ. It is possible that this agreement occurs when visual areas that the driver has to prioritise are obvious hence even the "naive model" is successful in identifying them. Nevertheless it is beyond doubt that real driving includes more complex situations that appear to be beyond the scope of the naive model.

In regards to the actual areas that were prioritised there is agreement between some areas that participants ranked as important and previous findings in the literature. For example the "Road Ahead" category was significantly amongst the highest ranked categories in most scenarios which is similar to what drivers looked at most often while they drove an instrumented vehicle and had their eye movements recorded (Underwood et al., 2003). Also in regards to the prioritisation of side and rear view mirrors the findings here showed that participants varied their preferences according to the specific scenario. Similar patterns have been identified in previous research (Pastor et al., 2006; Underwood et al., 2002a).

Another theoretical implication of the findings here is related to mental workload. Previously it has been suggested that mental workload affects driving performance and might be one of the reasons that NDs are more liable than experienced drivers to crash (Lee et al., 2007; Recarte & Nunes, 2003). However here it was demonstrated that even when there are no demands of the situation (like when completing the DPQ) DIs and NDs differ. This finding implies that although mental workload might cause further experiential differences there are differences at the more basic explicit level between NDs knowledge and that of experienced drivers.

The practical implications can extent to the teaching strategies of DIs. Perhaps it is necessary for DIs to place greater emphasis on the importance of an efficient visual skill. By acknowledging the fact the NDs possess a certain level of knowledge that might not benefit them in specific situations maybe DIs can try alternative teaching techniques in order to transfer their knowledge in a way that will enhance NDs visual skills perhaps by challenging their "naive model".

7.2.3 Future research

One issue that needs further clarification is whether the knowledge that both DIs and NDs showed in regards to visual priorities is naturally explicit or whether the DPQ acted as knowledge elicitation material. Previous research has shown that rating tasks elicit knowledge from experts that was previously implicit and moreover they showed differences between experts and novices(Hoffman et al., 1995). So it is possible that the DPQ acted as a medium that extracted the knowledge that each group has but might not otherwise be aware of while under real time dynamic driving conditions. This is something that needs to be investigated by future methodologies. Nonetheless, the DPQ provided an opportunity for drivers to think about their visual priorities when driving.

Despite the fact the number of participants was sufficient for such as exploratory study future replications of DPQ findings should consider using a larger sample of participants. Also it would be an additional point of interest to add other groups of participants such as non-drivers in order to examine how similar are the priorities between groups and investigate further the existence of the “naive model”.

The findings of Experiment 1 showed that DIs have in some cases different visual search priorities than NDs. Although it was proposed that this could indicate some sort of problematic transfer knowledge from DIs to NDs, it is probable that these differences could be attributed to DIs’ higher range and side road vigilance than NDs’. It is quite possible that these sorts of strategies have to be acquired through actual driving and they are not open to explicit instruction. Finally, it should be noted that in many cases participants’ priorities are the same, possibly indicating some shared knowledge between groups. These issues are not so clear from the results and need further investigation.

Another way of investigating further the findings of DPQ would be the measurement of eye movements of DIs and NDs like the methodologies that used in Experiments 2-5 for the specific DPQ scenarios. It seems reasonable to suggest that more dynamic driving conditions, like the route in the driving simulator that use in Experiments 4 and 5, will provide additional insights about drivers’ visual search strategies. Finally, under the light of findings in Experiments 5 and 7 it would be interesting to add driving scenarios that represent night and rain driving to the DPQ.

7.2.4 Experiment 1 conclusions

The fact the experts and novice drivers differ in their visual allocation is well demonstrated throughout the related literature. However, here it was specified that the knowledge about visual priorities when driving of these two groups differ. In addition it was demonstrated that there is high consistency amongst groups which implies that there is a shared knowledge scheme within each group. However, this knowledge differs between groups and it is scenario specific.

Some of the findings of this experiment had methodological extensions to the rest of the Thesis. The finding that visual priorities differ across driving scenarios initiated further research on this matter and in Experiments 4 – 7 the effects of different driving scenarios were examined. Also in the pilot Experiment 8 the training intervention that was developed was based on scenario specific situations. Furthermore the outcome of Experiment 1 affected the sample selection in the subsequent experiments. For example if there is not a unified view amongst different groups of drivers then a different classification of subgroups needs to be defined in order to explore visual priorities while driving. So the methodological importance of these findings is that it allows further usage of different groups of drivers with variable levels of experience. Although during the initial stages of the subsequent methodologies the same driving groups were not always used, the methodology of Experiment 1 showed that DIs and NDs are two distinct driving groups that possess different visual search knowledge. This distinction was used further in order to explore experiential differences on visual attention.

As a conclusion it could be said that the finding of Experiment 1 provided additional explanations to the findings of all the following Experiments of this Thesis. The fact that additional experimental findings from the different methodologies that were used in this Thesis can be somehow be explained by the findings of Experiment 1 shows that the DPQ provided some insights about drivers visual search strategies that have enough power to explain additional results and reflect some actual driving behaviour.

7.3 Experiments 2 & 3

7.3.1 Summary of findings

In Experiment 1 it was shown that drivers' visual priorities are guided by their knowledge. In more dynamic situations visual attention and eye movements are guided by two mechanisms; bottom-up and top-down. It has been proposed (Itti and Koch, 2000) that the properties of the stimuli influence the allocation of visual attention (bottom-up) while in contrast other researchers (Henderson, Weeks, & Hollingworth, 1999) suggested that cognitive factors (top-down), such as task related knowledge, guide visual search. Experiments 2 and 3 were conducted in Chapter 4 in order to investigate the interaction between bottom-up and top-down factors upon drivers' visual attention. One of the main differences between the two experiments was the sample that was used; in Experiment 2 novice drivers (NDs) and experienced drivers (EDs) were recruited, while in Experiment 3 driving instructors (DIs) and learner drivers (LDs) were used. Both Experiment s had two tasks. In the first experimental task participants were shown some driving pictures while their eye movements were recorded. In the second task, participants indicated (by clicking with the mouse) some areas that they considered important for visual prioritisation. Also the saliency peaks of each picture were calculated by using a bottom-up based algorithm. Three sequences (scanpaths) were measured in both experiments; first the fixation scanpath as an indicator of the behavioural aspect of visual attention, secondly the clicking scanpath as an indicator of the top-down influences and finally the saliency scanpath as an indicator of bottom-up influences. Three types of analyses explored the horizontal and vertical spread of fixations and clicks, the similarity between the scanpaths and finally the similarity of each scanpath point with the corresponding points of the other scanpaths.

The pattern of results was very similar in both Experiments. In general all four groups of drivers had a wider spread of clicks than their fixations both in the horizontal and vertical axes. Also all participants showed high similarity between looking and clicking which suggests that their looking was influenced more by the top down element or was at least open to a certain level of introspection. In regards to the point by point analysis it was found that the influence of saliency upon fixations decreased with fixation order. For the point by point analyses between clicking and saliency it was revealed that bottom-up factors influenced the second point more than the rest of the points. Finally the similarity between fixations and clicks decreases across the sequential order indicating that introspection is greatest at the initial stages. Unexpectedly, no other group differences were found on both Experiments, with the exception of a marginally significant difference that was found between DIs and LDs in the comparison of fixation and clicking.

7.3.2 Theoretical and practical implications

The findings from both Experiments provide additional support to the view that cognitive top-down factors affect visual search more than bottom-up attributes. Similar findings have been detected in previous studies on which they found that top-down factors affected visual search (Chen & Zelinsky, 2006; Henderson et al., 2007). However, there are other experimental findings that indicate the importance of bottom-up influence on visual search (Underwood & Foulsham, 2006). One of the reasons that in some previous experiments saliency influenced visual search while in Experiments 2 and 3 had a secondary role might be the fact that we used driving pictures which in themselves involve semantic structure likely to invoke additional top-down elements.

Additional support for the current methodology comes from the fact that similar similarity values have been found elsewhere. In regards to the scanpath similarity between saliency and fixations similar values have been reported previously (Henderson et al., 2007). In addition the point by point analysis showed that saliency influences early fixations more and this is again consistent with previous research (Foulsham & Underwood, 2008; Parkhurst et al., 2002).

Another interesting point that derives from the results is the fact that in general there were no group differences on both experiments, apart from spread of search. It is quite possible that the nature of the task did not allow the experiential differences to be revealed. It can be also assumed that under basic and static visual search the attentional mechanism that control gaze allocation operates similarly even to different driving groups. Perhaps the task -related cognitive factor that can influence visual search in such methodology is possessed even by the least trained LDs.

On the practical level some possible implications might be that future training interventions should take into account that under certain conditions drivers with different driving experience are influenced more by top-down factors. So for example a training intervention that needs to discriminate between driving groups might have to use more dynamic environments than static visual search.

Finally there are some methodological implications of these two Experiments. As it was mentioned in Chapter 4 (see section 4.2.3) there is not a single method to assess top-down factors. Here we used a novel way in order to explore participants' top-down elements on visual search. By clicking the areas they considered important in the present methodology we let participants themselves to define was is considered an important area of the driving scene. Under the light of the results we can be fairly confident that this new paradigm successfully controlled and measured participants' top-down influences.

7.3.3 Future research

All four groups of participants showed similar pattern of results however, it is very important to notice that it is not clear if the different groups of participants look at similar locations or they just differ systematically. It is quite possible for all participants to be influenced by their knowledge (top-down), but as we have seen in Experiment1 this knowledge is different between groups. Hence there is the possibility that participants look at different areas on the visual scene despite the fact that all were influenced by top-down factors. This is something that the current analyses could not reveal, so future improvements on this issue might involve the identification of fixation areas. Also, based on the micro-level findings of Experiment 4, and 7, we can suggest that it is very probable that different groups of drivers will attend different areas of the driving scene.

Another element that can be added to the methodology might be the manipulation of the pictures in order to have set of pictures that represent different scenarios. By using different scenarios it might reveal different pattern of results per scenario. Finally, it seems plausible that more dynamic environments such as driving simulators will provide a better understanding of the ways that visual search operates under more realistic conditions. Hence the methodological approach that was adopted in the two Experiments.

7.3.4 Experiments 2 & 3 conclusions

The novel paradigm that used in both Experiments revealed that drivers' fixations are influenced more by top-down factors than bottom-up. Results on both

Experiments were similar and showed comparable pattern of results with previous studies, indicating methodological consistency. The results from these Experiments showed that in order to investigate further the experiential differences on visual attention a more dynamic experimental condition is required. In that sense the findings of Experiment 2 and 3 affected both the knowledge pool of this Thesis while at the same time pointed out the necessary steps for the following methodologies.

7.4 Experiments 4 & 5

7.4.1 Summary of findings

The purpose of Experiments 4 and 5 was to identify how drivers' visual attention is affected by driving experience during simulated driving. In Experiment 4 the micro-level eye movements in scenario specific situations were also explored while in Experiment 5 the effects of different visibility conditions and the inspection of mirrors and speedometer were investigated in addition. In both Experiments the recruited participants were driving instructors (DIs) and learner drivers (LDs), although different participants were used for each experiment. On both Experiments participants drove a virtual route on a driving simulator while their eye movements were recorded. The virtual routes incorporated a 4-lane (2-lanes per direction) urban road with moderate traffic that included traffic lights, right and left turns, intersections, etc. In Experiment 4 the virtual route represented day conditions and clear weather while in Experiment 5 participants drove a similar route under simulated day, night and rain conditions. In both Experiments four variables were recorded; the number of fixations, as a measure of sampling rate; the mean fixation durations as an indication of processing time; and finally the horizontal and vertical deviation (average standard deviations of fixation locations on x and y axes) as a measure of spread of search. Additional frame by frame analysis was performed in order to examine scenario specific behaviour and areas of inspection for the purposes of Experiment 4 and 5 correspondingly.

In regards to global eye movement analysis the measures were similar for both Experiments. With the exception of the vertical standard deviation, all the eye movement measures were significantly different between DIs and LDs. In terms of visual search efficiency it appeared that DIs had a higher sampling rate of the driving virtual environment than LDs as reflected by a greater number of shorter fixations spread over a wider distance.

For the purposes of Experiment 4 an additional analysis was performed both on general and micro-level eye movements (for more details see section 5.2.2.5) for scenario specific situations. No scenario effect was found for the general eye movement measures but there were variations in how the drivers allocated attention to specific parts of the scene during very short scenarios.

In Experiment 5 the additional findings were that visibility conditions influence drivers' eye movements. More specifically rain driving was found to significantly affect the sample rate and processing time of both DIs and LDs. In regards to the inspected regions the general outcome is that DIs allocated more attentional resources to the side mirrors while LDs spent more time at the rear view mirror. Both results can be attributed to wider horizontal scanning of the DIs in comparison to LDs.

Finally the results of both Experiments showed that the driving simulator that was used has some relative validity in regards to experiential differences in visual search.

7.4.2 Theoretical and practical implications

One theoretical explanation for the experiential differences that were found in both experiments might be the effectiveness of peripheral vision (see also section 1.4.3). Indeed previous research has shown that the functional field of view is dependent on experience (Crundall et al., 1999, 2002). Therefore we can assume that DIs have larger functional fields of view than LDs. Within a larger field of view more information can enter the perceptual system from the inspected scene and this could possibly result in larger saccades and higher sampling rate. Although there might be alternative explanations for the results on Experiments 4 and 5 the link between driving experience and the effectiveness of peripheral vision is a very strong candidate.

In regards to the video analysis of specific scenarios in Experiment 4 there are also some theoretical explanations. The results showed that DIs were able to change their visual search to suit different scenarios. This is in agreement with previous finding that have found experienced drivers to be highly adaptable to different driving situations like different road types (Crundall & Underwood, 1998) or hazardous situations (Chapman and Underwood, 1998).

In Experiment 5 it was found that different visibility conditions and in particular driving under rain influences the effectiveness of visual search. One possible explanation for these findings might come from the field of change blindness (see also section 1.3.4). Previous research (Rensink et al., 2000) has shown that achromatic “patches” that were presented on-screen affected participants’ reaction times to identify changes. So there is high possibility that DIs and LDs in Experiment 5 had less efficient visual search under simulated rain driving because they were disturbed by the “patches” of the virtual rain. Also it is possible that the new raindrops affected the visual search pattern of the drivers. This sound possible because it has been found that new objects attract attention even if there is not luminance change (Yantis, 1993).

One methodological issue that both Experiments were concerned with was the validation of the driving simulator. This is an important methodological implication since the validation of a driving simulator is a necessary step to ensure that the experimental methodology allows generalisation of the results (see also section 2.4.3). The relative validity of the simulator can be examined by comparing the eye movement results of the present studies with similar results from other environments. It seems that the direction of results can support the hypothesis that the driving simulator used here is a valid driving research tool. The pattern of results (greater experience produces shorter and more frequent fixations and a greater spread of search of horizontal search) has been reported in other studies (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Underwood et al., 2002b). Hence it can be concluded that at least for the day driving the simulator has good relative validity. Regarding the validity of night driving we have indirect evidence that the night conditions were achieved by the pupil diameter of the participants that was significantly larger in night condition than the other two. Finally for the rain driving validation due to the novelty of the results it is very difficult to examine the relative validity because there are no similar studies available to compare the results to.

Again as in previous Experiments the practical implications of the results are towards a novel training intervention that will develop a more efficient visual search strategy. One of the possible reasons that previous attempts at training in the literature were short lived was the fact that it was very general, hence future training should consider that drivers' visual search is scenario specific and that there is different visual allocation under different conditions. A training intervention should include scenario specific training like the one that was used in Experiment 8.

7.4.3 Future research

Current studies at the simulator are now linking eye movements to actual driving behaviour though the analysis software were not available at the time the Experiments of this Thesis were conducted and it was not possible to link the visual skills of the drivers with some aspects of their driving behaviour. Future improvements of the current methodology might be to record the frequency of traffic violations while driving. Also future research questions might be the identification of speed, braking or steering differences between groups of drivers and across different driving situations.

Also despite the good relative validity of the simulator under day driving further validation is necessary for night and rain driving. Ideally replication of the results should be considered in a driving simulator with larger field of view since it has been suggested that that in order to have good speed perception a horizontal field of view of about 120^{o} is needed (Kemeny & Panerai, 2003) while the field of view of the simulator that used in Experiment 4 and 5 varied between $80^{o} – 90^{o}$.

In addition since this specific simulator does not have neither vertical nor horizontal movement it is quite difficult for drivers to “feel” like they are driving. Also, since the brain works with representations there is an issue when the sensory input (visual scene) does not correspond with proprioception information (muscle feedback). Possible improvements could include the usage of more advanced simulator or an instrumented vehicle.

Finally the findings of Experiment 5 showed that low visibility conditions (night & rain) decreased the effectiveness of drivers’ visual scanning of the road.

Although the results indicate that there are cognitive elements that affected the results it is reasonable to say that some physical properties of the stimuli like the reduced contrast (e.g. rain) or the luminance change (e.g. night) played some role. These variables should be taken into account in future research.

7.4.4 Experiments 4 & 5 conclusions

Findings from both Experiments replicate the fact that driving experience influences visual search. Furthermore it was demonstrated that drivers alter their visual allocation on scenario specific situations. In addition it was showed that visibility conditions affect the eye movements of drivers. Finally it was suggested that the driving simulator is an adequate research tool but further validation is necessary.

Experiments 4 and 5 were central to this Thesis. The majority of the theoretical findings from Experiments 1 – 3 were incorporated on these two Experiments while at the same time a more realistic driving environment allowed the extraction of additional and novel findings regarding the link between driving experience and visual allocation. The theoretical and methodological extensions of these findings added to ideas for the development of a new training intervention. Most of the findings of Experiments 4 & 5 had practical implications and they were applied to Experiments 6 – 8 with relative success. Based on the finding of these two Experiments, the scenario specific implications became robust and affected subsequent methodology. Also there were strong links between the findings and the related theories. As a conclusion it could be said that methodologies that involve driving simulators can offer both theoretical and practical insight about drivers' visual attention.

7.5 Experiments 6, 7 & 8

7.5.1 Summary of findings

Experiments 6 – 8 were the final stage of the Thesis on which some parameters that can enhance training modules were identified and were put into practice. In Experiments 6 & 7 participants saw some scenario specific videos, with the eye movements of drivers overlaid, and they had to identify whether the video belonged to a driving instructor (DI) or learner driver (LD). In regards to the identification of video type the results of both Experiments showed that LD videos were identified significantly more than DI videos. Also on both Experiments an interaction was found, with participants that had less driving experience (either novice or learner drivers) identifying LD videos significantly more times than DI videos, while the more experienced participants identified both videos types similarly. Also in Experiment 7 a scenario specific effect was found, with participants having higher identification percentage for the scenarios that had more behavioural differences as it was revealed by frame by frame analysis.

In Experiment 8 three groups of LDs drove twice on a simulated route while between the routes they watched either a control video or one of the two training interventions. One training intervention was scenario specific and it was based on the findings of previous Experiments of this Thesis. Results showed that only the horizontal spread of fixations was influenced by the training interventions. The participants that watched the scenario specific module had significantly greater spread of search on the horizontal axis than the control group while the participants at the other training module group were in the middle of the scale but without any significant differences from the other groups.

7.5.2 Theoretical and practical implications

Although the work of these three experiments is primarily focused on practical extensions there are some findings that can have some theoretical implications also. The finding that participants were able to correctly identify those videos with more observed differences (according to frame by frame analysis) could indicate that there is a threshold to the identification of eye movements in particular and pattern recognition in general.

The practical implications of these Experiments are clear and they underline the fact that scenario specific training intervention can be successful and change some visual skills of LDs in a way that they will mimic that of more experienced drivers.

7.5.3 Future research

Some additional steps that are necessary for the training intervention methodology might include examination of the effects over time. A longitudinal study is necessary in order to test the duration of these effects. Another future improvement would be the addition of extra scenarios like the ones that used in Experiment 7 (night and rain). The results of experiment 7 indicate that scenarios with more observed eye movement difference might be able to improve LDs' visual search skills further. Finally, another critical point will be the examination of micro-level eye movements of participants in scenario specific conditions since this will reveal any qualitative differences that were achieved by the intervention. Also it needs to be identified whether LDs increased horizontal scanning is due to inspection of specific areas of the driving scene.

7.5.4 Experiments 6, 7 & 8 conclusions

The majority of theoretical and practical implications of Experiments 1 – 5 were put into practice in Experiments 6 – 8. It was necessary to finish the experimental procedure of the Thesis by the development (although still at pilot phase) of an intervention that could possibly improve LDs' visual search skills. As it was mentioned at the introduction one of the directions of applied cognitive psychology should be to provide solutions in addition to the description of the mechanisms and processes that are involved in traffic crashes. This view played a significant role in the Thesis and all the findings were interpreted towards this direction. Hence Experiments 6 – 8 were vital since they added a very practical value with potential implications for traffic safety.

7.6 General conclusions

The Thesis evolved from the theoretical concepts towards a more practical approach. From this experimental process several theoretical novel findings were collected while at the same time the practical aspects of the Thesis were developed in order to construct a training module that will not lack theoretical background but it will also have practical value.

The main findings of the Thesis included the following: novice drivers have some knowledge about visual prioritisation however in some cases this knowledge points into the wrong direction since it differs from that of experienced drivers; drivers' visual search under static conditions is influenced primarily from top-down factors; driving experience results more efficient visual scanning as it is revealed by eye movements analysis; there is scenario specific scanning behaviour that is detectable even at micro-level eye movements; visibility conditions, such as rain, decrease the effectiveness of drivers' visual scanning; driving simulators provide an experimental environment capable to explore various driving behaviours but require validation before one can generalise the findings; and finally it was found that participants are able to improve some elements of their scanning behaviour with the assistance of scenario specific training modules. On general it could be said that drivers change their scanning of the road according to their experience, the situation they drive and the level of available visibility (e.g. day or night). One of the questions that derive from the findings of the Thesis is how can we improve learner drivers' visual skills? One fruitful proposal is by exposing drivers to examples of good and bad scanning behaviour. This may prove to be a useful tool in training visual search and could have direct effects to traffic safety and drivers' training.

There are three main research directions that derive from the findings of this Thesis and can generate further research. First on the practical level the preliminary findings of the scenario specific training intervention encourage further study. Secondly, on the more theoretical level it would be interesting to examine further how drivers' visual attention is influenced by top-down and bottom-up factors under more dynamic conditions. Finally, by combining both the theoretical and practical level the usage of a validated driving simulator should be strongly recommended since there are many methodological advantages that make the simulated environments the best alternative to real driving.

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APPENDIX A: The Driver Prioritisation Questionnaire

DRIVING INSTRUCTOR QUESTIONNAIRE

1) INTRODUCTION

The Accident Research Unit (ARU) at the University of Nottingham is dedicated to reducing the accident liability of all drivers through the provision of high quality research into driving skills. Our current research is focused upon the eye movement skills and strategies that learner drivers develop or are explicitly taught. Currently ARU and BSM are taking part in a national study and they are aiming to develop more efficient training methods for learner drivers. Since your profession is so closely related to the initial driving learning stages, we would be very grateful if you could find the time to fill out this questionnaire which will aid us in our research.
This questionnaire is designed to collate the opinions of driving instructors regarding learner drivers' eye movements.
The questionnaire is anonymous and all data is considered confidential. We adhere to the ethical guidelines of
the British Psychological Society .

2) PERSONAL INFORMATION[1]

2a) Sex: (please choose)	Male / Female
2b) Age: (please write)	
2c) Years Driving Licence: (please write)	
2d) Years Instructor: (please write)	
2e) City: (please write)	
2f) Affiliation: (please write)	

[1] For novice drivers questions 2c was: Years since passing test, and 2d: Number of lessons

3) QUESTIONNAIRE DESIGN - INSTRUCTIONS

The questionnaire is divided into different driving scenarios. Each scenario begins with a picture that reflects a particular, and is followed by a brief description of the task. After the description of the scenario there are some questions you should answer.

First there is a set of eight areas that represent the driver's visual scenes from inside the car. You will be asked to rank those areas from one to eight. This ranking will reflect your opinion regarding the importance of each visual area. Specific instructions of how to use the rankings are given before every ranking set.

At the end of each driving scenario there is a text box that we ask you to write any specific instructions you give to learner drivers for the corresponding task. Also you can write any information you think is relevant. We would appreciate your additional effort to add this information since it will provide very valuable insights into the strategies that are taught to learners.

If you have any questions about the questionnaire please contact us at:

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4) PULLING AWAY - URBAN ROAD

Scenario Description: The driver is inside the parked car (circled) and has to pull away and continue on the road ahead.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
4a) Road Ahead	
4b) Side Roads	
4c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
4d) Side Mirrors	
4e) Rear View Mirror	
4f) Blind Spot	
4g) Contraflow Lane / On Coming Traffic	
4h) In Car Controls (e.g. speedometer)	

5) PULLING AWAY - SUBURBAN ROAD

Scenario Description: The driver is inside the parked car (circled) and has to pull away and continue on the road ahead.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
5a) Road Ahead	
5b) Side Roads	
5c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
5d) Side Mirrors	
5e) Rear View Mirror	
5f) Blind Spot	
5g) Contraflow Lane / On Coming Traffic	
5h) In Car Controls (e.g. speedometer)	

6) DEALING WITH JUNCTIONS - GIVE WAY

Scenario Description: This is a windscreen view. The driver has to continue over the crossroads following the road as indicated by the arrow. Moderate traffic is assumed.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
6a) Road Ahead	
6b) Side Roads	
6c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
6d) Side Mirrors	
6e) Rear View Mirror	
6f) Blind Spot	
6g) Contraflow Lane / On Coming Traffic	
6h) In Car Controls (e.g. speedometer)	

7) DEALING WITH JUNCTIONS - RIGHT OF WAY

Scenario Description: This is a windscreen view. The driver has to continue on the road ahead as indicated by the arrow.
Moderate traffic is assumed.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
7a) Road Ahead	
7b) Side Roads	
7c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
7d) Side Mirrors	
7e) Rear View Mirror	
7f) Blind Spot	
7g) Contraflow Lane / On Coming Traffic	
7h) In Car Controls (e.g. speedometer)	

8) CHANGING LANES - URBAN MULTIPLE CARRIAGEWAY

Scenario Description: The driver is inside the circled car and has to move into the middle lane.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
8a) Road Ahead	
8b) Side Roads	
8c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
8d) Side Mirrors	
8e) Rear View Mirror	
8f) Blind Spot	
8g) Contraflow Lane / On Coming Traffic	
8h) In Car Controls (e.g. speedometer)	

9) CHANGING LANES - DUAL CARRIAGEWAY

Scenario Description: The driver is inside the circled car and has to move into the right lane to overtake the truck.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
9a) Road Ahead	
9b) Side Roads	
9c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
9d) Side Mirrors	
9e) Rear View Mirror	
9f) Blind Spot	
9g) Contraflow Lane / On Coming Traffic	
9h) In Car Controls (e.g. speedometer)	

10) GENERAL DRIVING - URBAN ROADS

Scenario Description: The driver is inside the circled car and has to drive on an urban road. During the route the driver has to encounter traffic lights, roundabouts, etc. Moderate traffic is assumed.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
10a) Road Ahead	
10b) Side Roads	
10c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
10d) Side Mirrors	
10e) Rear View Mirror	
10f) Blind Spot	
10g) Contraflow Lane / On Coming Traffic	
10h) In Car Controls (e.g. speedometer)	

11) GENERAL DRIVING - DUAL CARRIAGEWAY

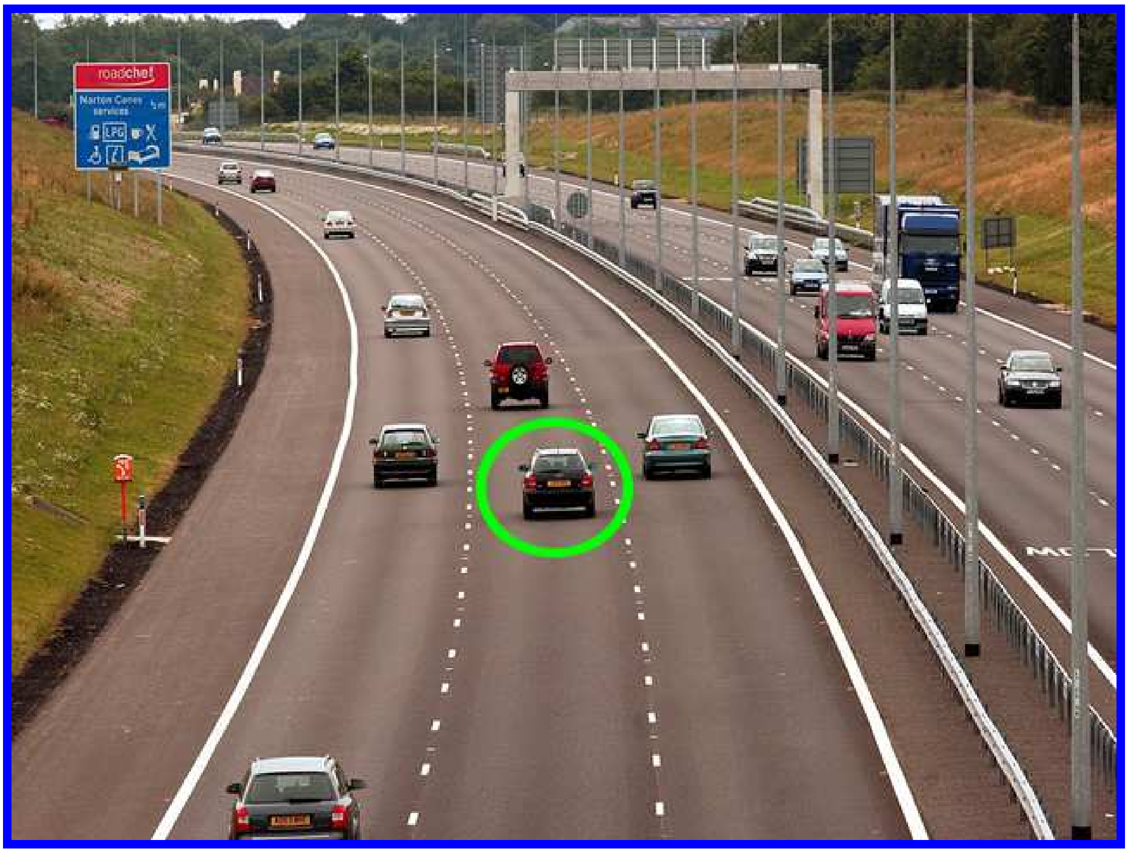
Scenario Description: The driver is inside the circled car and must continue along the road, overtaking other vehicles where necessary.

Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
11a) Road Ahead	
11b) Side Roads	
11c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
11d) Side Mirrors	
11e) Rear View Mirror	
11f) Blind Spot	
11g) Contraflow Lane / On Coming Traffic	
11h) In Car Controls (e.g. speedometer)	

12) GENERAL DRIVING - MOTORWAY

Scenario Description: The driver is inside the circled car and must continue along the road, overtaking other vehicles where necessary.



Below there are eight areas of the driver's visual scene. You should rank them between 1 and 8. Number 1 represents the area that you think should be looked at least in comparison to the rest of the categories. In contrast, 8 represents the area that the driver should look most in order to complete this task with safety and efficiency. Please rank all eight areas. You should **not give** the same ranking number twice.

Visual Scene Description	Ranking
12a) Road Ahead	
12b) Side Roads	
12c) "Off - Road Task - Relevant Information" (e.g. pedestrians)	
12d) Side Mirrors	
12e) Rear View Mirror	
12f) Blind Spot	
12g) Contraflow Lane / On Coming Traffic	
12h) In Car Controls (e.g. speedometer)	

13) FURTHER COMMENTS / SUGGESSTIONS

13a) Feel free to add any comments or suggestions you might have.

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