Eye Movements and Driving: Insights into Methodology, Individual Differences and Training

Andrew K. Mackenzie

This thesis is submitted in partial fulfilment for the degree of PhD at the

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Abstract

Driving is a complex visuomotor task, and the study of eye movements can provide interesting and detailed insights into driving behaviour. The aim of this thesis was to understand (a) what methods are useful to assess driving behaviour, (b) the reasons we observe differences in eye movements when driving, and (c) offer a possible visual training method. The first experiment compared drivers' eye movements and hazard perception performance in an active simulated driving task and a passive video driving task. A number of differences were found, including an extended horizontal and vertical visual search and faster response to the hazards in the video task. It was concluded that when measuring driving behaviour in an active task, vision, attention and action interact in a complex manner that is reflected in a specific pattern of eye movements that is different to when driving behaviour is measured using typical video paradigms. The second experiment investigated how cognitive functioning may influence eye movement behaviour when driving. It was found that those with better cognitive functioning exhibited more efficient eye movement behaviour than those with poorer cognitive functioning. The third experiment compared the eye movement and driving behaviour of an older adult population and a younger adult population. There were no differences in the eye movement behaviour. However, the older adults drove significantly slower, suggesting attentional compensation. The final experiment investigated the efficacy of using eye movement videos as a visual training tool for novice drivers. It was found that novice drivers improved their visual search strategy when driving after viewing videos of an expert driver's eye movements. The results of this thesis helps to provide insights into how the visual system is used for a complex behaviour such as driving. It also furthers the understanding of what may contribute to, and what may prevent, road accidents.

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Preface

Human factors research is concerned with the understanding of human behaviour when interacting with the environment, human-made systems or services. One of the most important aspects of human factors research is that of human safety, and this holds especially true for driving research. In his 50 years of driving research, Lee (2008) ultimately concludes that road accidents occur because drivers “fail to look at the right thing at the right time” (pp 525). In other words, a failure to scan the roadway will result in a collision. Having identified deficits in the visual attention system as a leading cause into driver error, this thesis aims to provide insights into three key questions in vision and driving research, namely 1) what are the most appropriate methods in which to investigate visual attention and driving behaviour together? 2) What are the factors which influence visual attention when driving? 3) Can training tools be developed in order to accelerate the acquisition of appropriate visual behaviour?

For the first goal, an experiment is described that explores the differences in eye movement behaviour when driving occurs in a simulated environment compared to when watching driving videos. This experiment highlights some of the advantages (and disadvantages) of studying visual attention and driving behaviour in a more realistic setting. For the second goal, two key factors are explored in two different experiments. The first is the idea that an individual’s cognitive ability may influence the distribution of eye movements when driving and the second is the idea that age, and in particular, old age, may also influence visual behaviour. Together these studies provide further insights into the individual differences in visual attention we observe in drivers. For the final goal, an experiment is described which aims to investigate a novel method to train more appropriate eye movement behaviour in novice drivers.

This thesis will begin with a general introduction which covers the background theory for the key themes identified above. A general methods section will describe the basic experimental set up that was common for all experiments, before each of the key themes are explored in four separate experimental chapters.

Chapter 1

General Introduction

This section will provide an overview of the areas of research concerned in this thesis. It will begin by discussing the field of eye movements, with particular focus on how studying eye movements in the context of ‘action’ may provide more useful insights into how and why people move their eyes when performing natural tasks. The development and importance of driving and hazard perception research will then be outlined. The overview will then explore both the fields of eye movements and driving together, with emphasis given to the development of eye movement behaviour between novice and experienced drivers, and the reasons why these differences occur. Some of the other individual differences that may contribute to differences in eye movement behaviour in driving will then be explored; focussing on differences in ‘attentional function’ and age. Finally, an overview of some of the literature that has addressed training driving and visual behaviour will be explored.

1.1 Eye movements and a case for active vision

In human vision, the fovea, which is the region of the visual field with the highest acuity, is surprisingly small. Its angular diameter is between 0.3^o and 2^o depending on how it is defined (Ransom-Hogg & Spillmann, 1980). The resolution of the visual field drops very rapidly away from the fovea. We must therefore move our eyes in order to see the environment in detail and maintain a homogenous percept of the world in which we live. There are a number of classes of eye movements, namely: saccadic and fixational movements, pursuit movements, vergence movements and stabilized fixations (Land, 2009). Of most interest to those researching cognition, and for this thesis, are saccadic and fixational eye movements. These eye movements allow us to measure and understand when someone has launched an eye movement, where the eye movement has landed and how long someone inspects the newly foveated area. In understanding these aspects of eye movements, we gain insights into visual attention – that is, the processing of information entering through the eyes (Carrasco, 2011; Chun & Wolfe, 2001). For example, fixation locations may provide details on what part of a scene a person is processing (Land, 2009; Land & Tatler, 2009) or measuring fixation durations as an indication of the processing effort where more complex scenes or tasks often illicit longer fixation durations (Rayner, 2009). Thus, in observing eye movements during tasks, one can begin to index the mental processes involved.

1.1.1 The cortical control of eye movements: A brief summary

Any action, such as simply picking up a pen, or a more complicated task such as driving a car, requires the coordination of several systems in the brain. Specifically, a system to identify the task requirements, a system to orient gaze, a system for visual perception and a motor system to engage in the task.

Initially, the visual attention and motor systems must be primed with information regarding the requirements of the task. It is likely that the pre-frontal cortex is involved in this planning control (Goel & Grafman, 1995; Goel et al., 2013; Mottaghy, 2006; Ruh, Rahm, Unterrainer, Weiller, & Kaller, 2012). A cognitive description of the processes involved is described by Baddeley within the 'Central Executive' aspect of his working memory model. It is a system that processes and organises the information required for the completion of the current goal. (see Baddeley, 2007, 2012).

This information is used by the gaze system in order to orient eye movements to the appropriate location. The frontal eye field (FEF), within the frontal cortex, is involved in the preparation and timing of the initiation of saccades (Pierrot-Deseilligny, Milea, & Müri, 2004; Pierrot-Deseilligny, Müri, Ploner, Gaymard, & Rivaud-Pechoux, 2003). One of the major outputs of the FEF is to the superior colliculus which is involved in the execution of saccades, including controlling the amplitude and speed (Everling, Dorris, Klein, & Munoz, 1999; Munoz, Pelisson, & Guitton, 1991).

After eye movements have been directed to the appropriate location or object, the motor system is then tasked with acting accordingly, whether it is to control grasping, or indeed, coordinating the turning of a steering wheel. In order for this to occur however, the visual system must provide the necessary perceptual information. For example, vision can confirm that the location/object is the correct one or provide the depth or distance information with which to control the hands. Visual input pass through the primary visual cortex (V1), or striate cortex, within the occipital lobe, before different aspects of this input are processed separately by other areas of the visual cortex e.g. V4 for colour perception (Heywood, Gadotti, & Cowey, 1992; Motter, 1994) or area MT for motion perception (Born & Bradley, 2005; Rokers, Cormack, & Huk, 2009). This information is thought to be then processed by two broadly separated pathways (Baizer, Ungerleider, & Desimone, 1991; Milner & Goodale, 1995). The ventral pathway, which projects to temporal areas of the brain, is involved in perceptual processes such as object recognition, colour and the perception of fine detail. The dorsal pathway is directed towards the parietal regions and is involved in the control of motor functions such as reaching and grasping (Glover, 2004).

1.1.2 Vision for Action

1.1.2.1 What drives eye movements?

One of the most prominent questions in eye movement research is: why do we look where we look? This question was raised in the widely cited and now classic studies by Buswell (1935) and Yarbus (1967). Yet even now researchers are still asking (e.g. Schütz, Braun, & Gegenfurtner, 2011; Tatler, 2009; Tatler, Hayhoe, Land, & Ballard, 2011), suggesting the answer is not so straightforward.

There are two different schools of thought in answering this question. The first is the idea that eye movements are driven from the bottom-up. That is, we move our eyes due to exogenous cues (cues originating from the external environment). The second is the idea that we move our eyes due to top-down processes i.e. due to influences from cognition. Although originally intended to describe attentional capture, one example in explaining bottom-up eye movement behaviour is the saliency map model (e.g. Itti & Koch, 2000, 2001; Zhao & Koch, 2011). This model is based on findings from the visual search literature suggesting that basic visual features can capture and guide attention (e.g. Treisman, 1982; Wolfe, 1998). The model attempts to predict eye fixation location based on the visual conspicuity of features in a scene. In essence, features which 'stand out', or are salient, relative to their background, are more likely to attract fixations than areas of less visual salience. This includes features defined by colour, luminance intensity or orientation. Research has shown that the saliency map hypothesis is capable of predicting eye movements, particularly initial fixations, better than chance when free viewing scenes (Henderson, Weeks, & Hollingworth, 1999; Parkhurst, Law, & Niebur, 2002).

However, this model does not account for the influence that higher level processing has on eye movement behaviour. One major criticism is the argument that eye movements change as a result of the requirements of the task. Highlighting this, in Yarbus' (1967) study, his participant had to inspect a picture, but each time a different question was asked. The eye movement patterns changed depending on what question was asked. For example, if the question related to the age of the people in the picture, faces were examined more often. If the question was related to objects in the room, a much broader search pattern was exhibited where fixations were distributed around the scene evenly. A number of studies have since shown that the requirements of the task strongly influences where and how we inspect a scene (e.g. Einhäuser, Rutishauser, & Koch, 2008; Foulsham & Underwood, 2007; Humphrey & Underwood, 2008; Underwood, Foulsham, van Loon, & Underwood, 2005).

1.1.2.2. The link between vision and action

Although top down processing is now largely favoured in explaining where we look, much of the research investigating where we look during 'natural' scene viewing, is derived from simple 'passive' tasks using static stimuli, such as picture viewing paradigms or visual search tasks. Many argue that the primary the role of vision is to guide action i.e. coordinating limb movements or steering an individual through the environment (e.g. Hayhoe & Ballard, 2005; Land, 2009; Land & Tatler, 2009; Tatler et al., 2011). As such, it has been argued that it is important to study eye movements in more naturalistic settings than those that comprise of passive viewing of static scenes. Such settings should typically involve active visuomotor behaviour.

When investigating eye movements during natural behaviour, many studies show there is an intrinsic link between where and when we look and the information required for the current motor act. One of the first studies to examine the relationship between eye movements and action was Ballard et al. (1992) with their block copying task. Participants had to produce a copy of a model of coloured blocks using blocks from a separate pool as fast as possible. It was a computerised task which involved a number of repeated sequences of looking at the model, selecting the correct block and moving it to the right place (on a computer screen). A typical sequence of behaviour would generally take the form: fixate a block in the model area, remember its colour, fixate a block in the source area with the same colour, pick up the current block, fixate back to the same block in the model area, remember its location, move the block to the fixated location, drop the block at the location. One of the most important results of the study was the finding that this was not purely a memory task. This was demonstrated by the finding that separate fixations are used to gather information about colour and location. The task was seemingly completed through a series of elementary tasks involving the eye and hand.

Regarding the spatial relationship between vison and action, Ballard et al found that the eyes look directly at the objects currently being interacted with, and as a result, a large number of eye movements are required to complete the task. Ballard, Hayhoe, and Pelz (1995) termed this eye movement behaviour the 'do it where I'm looking' strategy. This is an important finding as given the relatively small angular size of the screen, one would not expect the need to move the eyes as much as what was observed when interacting with the objects. Ballard et al. (1995) found that this task could indeed be completed with fewer eye-movements (when gaze was held on a central fixation spot), however the task was completed around three times slower than when normal eye-movements were allowed. Thus, the 'do it where I'm looking' strategy appears to be necessary for fast and efficient execution of a task.

Temporally, the fixation that provides the information for an action immediately precedes the action, typically by up to a second. In this current task, when moving the block, the location of gaze preceded where the block was going to be dropped by around one second. Ballard et al. (1995) termed these 'just-in-time' strategies. These two fixation patterns emphasize the important link between moving the eyes to optimise vision, and then engaging in action.

An argument can be made, and was indeed made by Ballard et al. (1992), that the block copying style of task does not accurately represent a wide variety of hand-eye tasks. Aspects such as gripping, body or vehicular navigation or even fine motor control do not occur during the block copying task. The tea making (Land, Mennie, & Rusted, 1999) and sandwich making (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003) studies helps to provide more valid insights into the link between vision and action in natural tasks. The close spatial coupling is again observed where eye movements are directed towards task relevant objects only e.g. fixations on the kettle and tap in the case of tea making. Highlighting this further is the finding that before the sandwich making task had commenced, fixations were distributed equally among task relevant and irrelevant objects. When the task started however, only objects which were to be interacted with were fixated. This emphasises how goal directed behaviour influences target selection. The temporal link between vision and action is also observed where fixations towards objects typically lead the action by up to a second. This behaviour is consistently observed in a number of other tasks too, such as music reading (Furneaux & Land, 1999), walking (Patla & Vickers, 2003), and indeed driving (Land & Lee, 1994; Land & Tatler, 2001).

1.1.2.3 Comparing active vision and passive viewing

The importance of investigating eye movements in the context of ‘action’ is highlighted in a series of studies (namely: Epelboim, 1998; Epelboim et al., 1995; Epelboim et al., 1997) which are reviewed in Steinman (2003). They investigated the oculomotor strategies used to complete a tapping vs looking visual search and memory task. Participants had to either search for and look at a number of targets in a specified order (look-only condition), or search for and actively tap the targets in a similar sequence (tapping condition). Despite these tasks being similar, the oculomotor strategies employed by individuals were strikingly different. One of the main differences was the finding that the seemingly more complex tapping task, which involved action, was easier and took less time to complete than the seemingly simpler task of just looking at the targets. Gaze-shift patterns (how individuals moved their eyes) were also different across these tasks, with individuals exhibiting increased gaze-shift velocity and shorter gaze-shift durations when actively tapping. Also, fewer head movements were observed when only eye movements were to be used, compared to when being actively engaged. When tapping, head movements made strong contributions in allocating gaze but not when simply looking at the targets.

Thus, the way in which the eye movement system is employed in response to a task which involves natural action is rather different to when simply moving the eyes around to complete a task. Steinman (2003) argues that we simply could not have predicted these differences in visual behaviour on the basis of prior experiments done under much less natural conditions – conditions where natural action is largely restricted. He asserts that measurements made from such impoverished conditions cannot apply to the way in which humans control vision and action under more ecologically relevant conditions. Steinman suggests that the action incorporated in the task discussed here resembles the active and purposeful tasks performed in every-day life. Of course, it is rare to encounter a situation where one has to search and tap items continuously, however differences in eye movements strategies have been found between other everyday activities and their passive viewing, laboratory based, analogies: e.g. visual search (Foulsham, Chapman, Nasiopoulos, & Kingstone, 2014) and social attention (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012). Foulsham, Walker, and Kingstone (2011), for example, showed that when actively engaged in a walking task, eye movements were closely focussed centrally above the horizon compared to passively viewing movies of someone else walking the same routes, where eye movements were distributed around the entire scene. Ultimately there is a strong case to suggest that tasks which involve passive viewing paradigms may not capture subtleties in eye movement behaviour when someone is actively engaged.

In Chapter 3, I explore how the idea of active and passive vision relates to the context of driving. Specifically, the chapter will discuss an experiment designed to investigate the eye movement differences between active simulated driving and passively watching videos of others' driving.

1.1.2.4 Cognitive Ethology and final thoughts on active vision

The ideas described above can be encapsulated by the 'Cognitive Ethology' approach put forward by Kingstone, Smilek, and Eastwood (2008). With this approach, it is suggested that only by studying behaviour in the most naturalistic settings can we begin to put forward valid theories of human cognition. By 'natural', they are referring to an environment that exists in the real world, out-with the laboratory setting. They propose that lab based experiments do not always provide a valid proxy for studying everyday behaviour. Many of the studies described above, such as the tea making and sandwich making studies, provide very good examples of this, where one could not have predicted the intrinsic link between vision and action with less naturalistic conditions. It is also suggested that by maximising experimental control and reducing environmental complexity (as is typical in lab based studies), this can often lead to results that are true only if particular laboratory settings were met.

While it is difficult to argue with the cognitive ethology ethos, particularly when investigating driving behaviour, this is arguably an extreme approach and the usefulness of lab based studies should not be ignored. It is extreme in the sense that without any experimental control, it is often difficult to make any strong conclusions regarding causal relationships between one factor and another. Thus, In a more balanced approach, Crundall and Underwood (2008) suggest that, although there should be an effort towards more naturalistic settings, including more natural stimuli (stimuli that occur in the real world), it is not always feasible to move away from the lab. They provide a good example of when studying driving behaviour in the lab is arguably just as useful as when studying real life driving. This will be discussed in a later section in more detail, but to summarise, they highlight how there are similar differences in the patterns of eye movement behaviour made between novice and experienced drivers across both video based hazard perception tasks and real life driving. This is important, particularly in such an applied field as driving research, because if one can identify ‘at risk’ drivers in the laboratory then this limits the need for expensive and potentially riskier experiments being conducted on real roads.

This balanced approach is favoured within this thesis, where the experiments described aim to investigate eye movement behaviour in the context of action, where participants are actively engaged in controlling a vehicle but still allowing for experimental control - with the use of laboratory based driving simulations.

1.2 The Importance of driving research and hazard perception

With an estimated 38 million drivers in the United Kingdom alone (Royal Automobile Club, 2015), driving is one of, if not, the most popular method of transportation. Yet, it is a complex visuomotor task, requiring not only on-line control of the vehicle being driven, but also attention to the environment itself, and changes within it; particularly given the possibility of encountering hazards. Driving is therefore not without its risks. There were 1,775 reported road deaths and 22,807 serious injuries in 2014 in the UK (Department for Transport, 2015). Somewhat encouragingly, this number represents a 45 per cent decrease in road fatalities since 2005. It is important to understand the factors which contribute to road accidents - in order to develop suitable assessment and training tools, and to help develop government policies to help promote safe driving and prevent accidents. This thesis is concerned more about the different influential factors which affect eye movement behaviour during typical driving situations i.e. driving without encountering hazards. However, this section will explore the importance of ‘hazard perception’ and situation awareness in driving, and detail the differences observed across experience groups in order to provide the reader with the potential links between hazard perception and vehicle accidents.

1.2.1 Hazard perception and the benefits of assessment

In many countries (but not all, e.g. Mexico), before an individual is legally allowed to drive, they must demonstrate they can drive safely. In the United Kingdom for example, one must be assessed in vehicle control and the practical application of driving in an on-road test. In addition, it is also a requirement to assess the ability of an individual to detect dangerous situations (Driver and Vehicle Standards Agency, 2014). This is known as *hazard perception* skill. A hazardous event is usually one which would cause a driver to either slow down, stop or change their path unexpectedly (Underwood, Crundall, & Chapman, 2011). For example, if driving in a typical urban environment and a bus has stopped ahead, there is a chance that the bus may pull out or pedestrians may step out in front of it, and therefore there is a risk of collision. A driver may therefore need to adjust their speed to suit the situation or may need to stop. Hazard perception is a very important aspect of driving safely. If someone is able to detect or indeed, predict, a dangerous situation, then it allows them to act accordingly to prevent a collision. Performance on hazard perception has been found to correlate (inversely) with crash risk (Horswill, Anstey, Hatherly, & Wood, 2010; Horswill, Hill, & Wetton, 2015; McKenna & Horswill, 1999; Pelz & Krupat, 1974; Wells, Tong, Sexton, Grayson, & Jones, 2008), where better hazard perception skill is associated with lower crash risks.

This skill can be assessed using a number of different methods. For example, measuring subjective ratings for the level of danger during video clips (e.g. Wallis & Horswill, 2007) or the more typically used method (favoured by the UK government) of assessing performance by having drivers anticipate hazards during video clips by pressing a button (e.g. Chapman & Underwood, 1998; Horswill & McKenna, 2004; Wallis & Horswill, 2007). Even during these types of un-naturalistic driving tasks (in the sense that individuals are not driving), hazard perception is a complex skill. It requires drivers to identify potentially dangerous situations, assess whether the danger will affect them and decide what behavioural response would be required to avoid a collision (Wetton et al., 2010). Importantly, any one of these processes may influence response time.

Hazard perception skill is best explained and understood by the concept of 'Situation Awareness' (Endsley, 1995a, 1995b, 2004; Wickens, 2008b). Formally, situation awareness can be described as the ability to perceive the elements in the environment, understand their meaning and predict their influence. Essentially, it can be described informally as '*knowing what is going on*'. There are three levels of awareness in Endsley (1995b) model of situation awareness. At the lowest level, one must be able to notice the unexpected event in the environment. So, to re-use the bus stopping example, the lowest level of situation awareness would equate to a driver seeing that a bus has stopped ahead. Next, one must be able to comprehend the meaning of the event. For example, the driver must comprehend that this bus has stopped to let people off. Finally, the highest level of situation awareness constitutes the ability to predict the outcome of the situation. In this example, it may be that the bus may pull out, or pedestrians may step in front of the bus. It is this higher level of situation awareness that hazard perception tests attempt to assess. Intuitively then, it is unsurprising that drivers who have this level of awareness have a lower crash risk as it allows them to alter their behaviour before a collision occurs.

1.2.2 The effects of driver experience on hazard perception performance

Younger drivers, between the ages of 17 and 24 are statistically over-represented in reported road accidents compared to drivers older than 25. A total of 1,713 people were killed or seriously injured on Britain's roads in 2013. Of this, 1,290 were younger drivers (Department for Transport, 2015). There are likely age related factors, such as driver attitudes, that contribute to this increased accident involvement (Rundmo & Iversen, 2004; Shinar, 2007; Ulleberg & Rundmo, 2003). Although arguably one of the biggest contributing factors, and most studied, is experience related hazard perception skill.

Both video based hazard perception tasks and simulated driving tasks have helped to provide insights into the difference in hazard perception skills between novice and experienced drivers. Research suggests that novice drivers have poorer hazard perception ability both in terms of detection accuracy (how many events they spot) and how fast they spot them (Castro et al., 2014; Crundall et al., 2012; Horswill & McKenna, 2004; Lee et al., 2008; Scialfa et al., 2012; Scialfa et al., 2011). Interestingly, in video tasks, this increased latency has been found to be due to increased processing time of the hazard and not necessarily in seeing (first fixating) the hazard (Huestegge, Skottke, Anders, Müsseler, & Debus, 2010). This may suggest that novices have a lower level of situation awareness, where they can see the hazard but they don't have the experience to be able to verify the hazard as one as fast. Through experience, one can built up a repertoire of possible road situations that could occur which allows them to respond more effectively. Supporting this are the findings related to differences in understanding hazardous situations. For example, when asked to predict the outcome of potentially hazardous events, Jackson, Chapman, and Crundall (2009) found that experienced drivers anticipated more correct hazardous outcomes than novices drivers. Similarly, Vlakveld (2014) found that, even when a potential hazardous event did not develop, experienced drivers were better at explaining what could happen. Importantly, the poorer hazard perception ability in novices has been linked to accident involvement. Learner drivers who fail a hazard perception task the first time, when acquiring a driver's license, are more likely to be involved in an accident when they pass (Boufous, Ivers, Senserrick, & Stevenson, 2011; Horswill, Hill, et al., 2015).

It should be highlighted however, that although research has largely supported the fact that novices have poorer hazard perception skill, this has not always been found (e.g. Sagberg & Bjørnskau, 2006; Underwood, Ngai, & Underwood, 2013). One reason for this may be due to the varying types of hazards that can be encountered on the road and therefore used in hazard perception tasks. If hazards are largely attention capturing, i.e. a pedestrian immediately stepping out on the road, then this may not be sensitive enough to discriminate between levels of experience (Underwood, Crundall, et al., 2011).

This section has provided the reader with a brief and general introduction into the importance of driving research and the assessment of hazard perception. Although hazard perception is important, and ultimately contributes to safer driving, the focus of this thesis is to primarily explore the factors that influence eye movement behaviour when driving normally, i.e. when no hazards are present. A review of this literature is the focus of the next sections.

1.3 Eye movements and driving

Newly qualified drivers are at a considerably higher risk to be involved in a road accident relative to more experienced drivers (Department for Transport, 2015) and one likely contributing factor is linked to hazard perception skill. Driving is a highly visual task (Owsley & McGwin, 2010), requiring visual attention to be directed to the road in order to control the vehicle, attention to other road users and attention to other relevant sources of information e.g. road signs. Thus, arguably the way in which visual attention is deployed also contributes to accident involvement rather than hazard perception alone. Understanding how, where and when novices move their eyes is likely to provide insights into the increased accident liability cases we see. This section aims to begin bridging the previous two topics on eye movements and on driving and explores the importance of investigating the interaction between eye movements and driving performance. This is a larger introductory section, providing detail on some of the more key themes of the thesis. It will review what typical differences occur in visual attention across experience groups, in the form of eye movement differences. The purpose is to highlight to the reader what one would consider a more efficient or indeed effective eye movement strategy when driving. This section will then explore the likely reasons why there are differences in the visuospatial deployment of attention.

1.3.1 Visual control of steering

Although this thesis is largely concerned with what factors influence the differences in observed eye movement behaviour when driving, it is important to first discuss what visual information is important to help guide a driver through the environment. Gibson (1958) originally proposed that we utilise optic flow information in order to control locomotion. That is, the pattern of apparent motion caused by an observer moving through the environment. The origin from which these motion vectors flow is known as the focus of expansion, and it is this point that individuals align their direction of travel with in order to navigate successfully. While there is some evidence to support the importance of using optic flow (e.g. Britten & van Wezel, 1998; Herlihey & Rushton, 2012; Smith, Wall, Williams, & Singh, 2006), it is not the only contributor in controlling locomotion (Harris & Bonas, 2002; Rushton, Harris, Lloyd, & Wann, 1998). Two major criticisms of optic flow in guiding locomotion is that, 1) using optic flow to control locomotion is not particularly useful when we cannot move directly to the goal (e.g. when going around a bend) and 2) optic flow is disrupted when eye movements are made (Wilkie & Wann, 2003), and since we make many eye movements, it seems unlikely we would use optic flow in many circumstances e.g. driving.

One example of how we may use eye movements to control locomotion comes from Land and Lee (1994). They showed that when driving on a bend, drivers fixate on the ‘tangent point’ of the curve. This point can be described as the apex of the bend, at the point in which the curve’s direction appears to reverse. They suggest that individuals use this point as a reference point, or visual anchor, to control the steer. However, more recently, research has suggested that the tangent point is not as important as once thought. Mars and Navarro (2012) found that individuals did not need to fixate exactly on the tangent point in order to control steering in a driving simulator. Kountouriotis, Floyd, Gardner, Merat, and Wilkie (2012) found that when the visual information of the inside road edge was degraded (the area in which the visual information of the tangent point is extracted), there was no impairment to steering. It was only when information to the outside edge of the lane was degraded that steering impairment was observed – information that is not required if drivers are using tangent point information. This suggests that the tangent point is not crucial in controlling steering when driving.

What is typically favoured now is the idea that in order to control steering, gaze is directed to points in the world we wish to pass, typically between 1-2 seconds before that point is reached (Robertshaw & Wilkie, 2008). Demonstrating this, Wilkie, Kountouriotis, Merat, and Wann (2010) instructed participants to steer in a virtual environment whilst driving either in the centre of the road, towards the outside of the road or towards the inside of the road. They found that gaze shifted depending on these instructions given, with gaze being directed towards the position participants were aiming for. Only when participants were told to take the fastest path around the bend, i.e. to cut the corner by following the 'racing line', the tangent point was used. But even so, this could be because it was a point in space they wished to pass and was not necessarily used as a visual anchoring point originally proposed by Land and Lee (1994). As described by Kountouriotis et al. (2013), the 'future path' strategy leads to a particular pattern of eye movements where an individual exhibits a series of initial saccades towards a point in space 1-2s ahead, followed by a smooth pursuit tracking movement to this point.

One argument against the future path hypothesis is that many of these studies were conducted in a simulated environment and thus the visual strategies employed may not represent driving in the real world (see Kandil, Rotter, & Lappe, 2009, 2010). However, visual strategies akin to the future path hypothesis have since been found on real roads (Lappi, Lehtonen, Pekkanen, & Itkonen, 2013; Lappi, Pekkanen, & Itkonen, 2013). In a review, Lappi (2014) suggests that fixations towards the tangent point on real roads can largely be explained by its relative salience or ease at which it can be identified, but do not help to explain in detail how steering is controlled. Although, Lappi (2014) makes clear that it is possible that these two strategies may not be incompatible with each other. Particularly when considering the role of peripheral vision in steering, where, for example, one may fixate on the tangent point but still use peripheral vision to covertly use the visual information from the future path.

Importantly though, driving is of course more about just steering a vehicle. Fixating on one particularly point in space is likely not the best visual strategy when driving – particularly when considering the number of hazards that may appear on the road. Thus we must continually move our eyes when driving. This is the focus of the next sections.

1.3.2. The transition from novice to experienced

When not solely focussing on steering, drivers typically fixate somewhere ahead of the car (Liu, 1998). Drivers will tend to look between the points in space where the car will be in the next few seconds and closer to the focus of expansion (Land & Horwood, 1995; Liu, 1998; Underwood, 2007; Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003; Wong & Huang, 2013). These fixations are thought to be advantageous in that they provide the driver with the information to maintain lane position and to maximise the time to anticipate possible hazards. Although focal points are important, safe driving requires visual attention to be distributed to other parts of the roadway, particularly on more demanding road types. As described by Underwood (2007), when individuals are not fixating on the central focal points, fixations lie to the left and right to, for example, inspect pedestrians or prepare for lane changing manoeuvres. This creates a horizontal scanning window of fixations with fewer distributions of fixations vertically (Chapman & Underwood, 1998). However, the differences in the extent of this horizontal scanning can be different across experience groups, as discussed below.

In an early, widely cited, exploratory study, Mourant and Rockwell (1972) investigated the changes in eye movement behaviour that occurs as drivers gain experience. Eye movements were recorded as novice drivers drove neighbourhood and freeway type routes. Eye movements were compared to an experienced group of drivers, on the same routes, who had driven over 8000 miles each year for five years. There were a number of findings, but only the general differences in eye movement behaviour between the novice drivers and experienced drivers will be discussed here.

As measured by the variance in horizontal axis fixations, where a higher variance suggests increased scanning, it was found that the range of horizontal scanning was more limited in the novice drivers compared to the experts, particularly during the neighbourhood drive. Intuitively, it was thought that this increased scanning behaviour in experienced drivers is representative of someone acquiring more visual information to make informed decisions to avoid accidents, e.g. looking out for pedestrians. It was suggested therefore that novices were unable to appropriately sample the scene. Another important finding was that there were fewer mirror checks in the novice groups. Indeed some mirrors were never inspected at all. This is important because using the vehicle mirrors is also indicative of someone who is acquiring more information about the current surroundings in order to driver safer. One final important finding was that there were differences in average fixation location positions (in this case, median location positions). This fixation point is important because it likely indicates the most favourable point in space to obtain the visual information for which to control the vehicle. The average central direction of gaze for the novice drivers was closer to the front of the vehicle and slightly to the right. This was a result of more frequent glances to the roadside curb, where it was suggested by Mourant and Rockwell (1972) that this information was required in order to maintain lane positioning. The results of this study provided early insights into the differences in visual attention across driver experience groups, which in turn may have provided insights into possible contributions to the increased accident liability cases for novice drivers.

Crundall and Underwood (1998) investigated the similarities and differences of novice drivers' (mean experience 0.2 years) and experienced drivers' (mean experience: 9.0 years) eye movements across different road types, namely rural, suburban and dual-carriageways. The main aim of the study was to investigate how the processing demands of the road (as reflected in the types of road) affects eye movement behaviour across the two experience groups. The influence of processing demands will be addressed in more detail in a later section, but what is important for now is the differences in the horizontal search eye movement behaviour that were found (again measured by the variance in horizontal fixation locations). Interestingly, the extent to which novices and experienced drivers scanned the roadway was similar during the rural and suburban sections of the drive. Importantly however, only the experienced drivers exhibited increased horizontal scanning behaviour (similar to Mourant and Rockwell (1972)) when driving on the dual-carriageway section. The novice drivers did not change the size of their visual search according to the road type. This is important given that a dual carriage way constitutes a number of extra hazardous areas that should ideally be attended to, such as an extra traffic lane and slip roads. It suggests that novice drivers are less able to adapt their visual strategies. Crundall and Underwood (1998) suggest this flexibility in visual search develops with experience, where initially the strategy is akin to viewing in less dynamic settings (i.e. as a pedestrian or even static picture viewing) before a visual search strategy more adapted to a dynamic real world settings is learnt. The more flexible visual strategy of the experience driver may offer insights into the lower accident liability cases we see in more experienced drivers.

This widened search strategy by experienced drivers has been observed in a number of studies since (e.g. Alberti, Shahar, & Crundall, 2014; Borowsky, Shinar, & Oron-Gilad, 2010; Falkmer & Gregersen, 2001; Falkmer & Gregersen, 2005; Konstantopoulos, Chapman, & Crundall, 2010). For instance, Alberti, Shahar, et al. (2014) explored how extending the field of view in a driving simulator influenced hazard perception, and importantly for this section, visual search. It was found that when more information is made available, by presenting a larger field of view with additional side screens, only the experienced drivers exhibited an increase in their horizontal scanning behaviour during normal driving conditions (i.e. no presence of hazards) and made better use of this wider field of view. Novice drivers still maintained fixations more centrally. Together, these findings suggests that drivers learn this horizontal scanning strategy through experience.

Perhaps the strongest evidence to highlight how this scanning behaviour improves with experience comes from studies which investigate not only experienced drivers but more specifically, expert drivers. That is to say, individuals who have more specific or advanced training in driving. Crundall, Chapman, Phelps, and Underwood (2003) present research comparing eye movements and hazard perception performance across 1) novice drivers, 2) expert police drivers who are trained in pursuit driving and 3) typical aged and experienced matched experienced drivers. One of the main purposes of this study was to determine how police drivers process different driving situations, namely, normal driving, emergency response driving and pursuit driving. After watching several video clips of these types of driving situations, they found that, overall, the trained expert drivers exhibited a further increase in their horizontal scanning behaviour relative to the novice drivers and to the matched controls. This finding would suggest that, visually, expert drivers were sampling even more of the scene than experienced drivers which provides further support to the idea that as experience increases, so does the horizontal search. This finding is important because police pursuit driving is of course very hazardous (high speeds, quicker response times required) and it shows how expert drivers better equip themselves for dealing with potential hazards by sampling even more of the scene.

This increase in scanning behaviour in experienced drivers is observed not only during ‘straight road’ driving, but also when intersections are encountered. Borowsky et al. (2010)

demonstrated that when approaching an intersection, experienced drivers fixated on the adjoining roads more often to inspect potentially oncoming vehicles. The novice drivers tended to fixate straight ahead when approaching. Scott, Hall, Litchfield, and Westwood (2013) found that experienced drivers distribute their gaze evenly across the junction compared to novice drivers who exhibit less efficient ‘sweeping’ fixations at a junction, suggesting not all areas are inspected equally.

In addition to roadway scanning, mirror viewing behaviour is also different between novices and experienced drivers. Vehicle mirrors provide the driver with added information about the surroundings and the necessary safety information with which to make informed decisions about making manoeuvres. In the early study by Mourant and Rockwell (1972), novice drivers did not look in the rear-view mirror as much as experienced drivers and almost never inspected the side-mirror; particularly in neighbourhood areas. Similarly Underwood, Crundall, and Chapman (2002) found that experienced drivers used their exterior mirrors more than novices. Importantly, in that study, during portions of the drive that involved lane changing with fast-moving traffic, the increase use of exterior mirrors was observed more in the experienced drivers. Konstantopoulos et al. (2010) also found a similar effect of experience when comparing driving instructor and novices' eye movements, where the highly experienced driving instructors fixated more often on the exterior mirrors than the learner drivers. Much like roadway scanning, these findings suggest that experienced drivers appear more equipped to identify potentially hazardous parts of the driving scene and appropriately allocate visual attention e.g. being able to identify overtaking vehicles at an early stage.

It is clear that the more skilled a driver is, the more widely they scan the scene. As mentioned, this scanning is typically measured by the variance, or ideally, standard deviation, of horizontal or x-axis fixation locations. However, as Underwood (2007) notes, this can be considered a rather crude measure, as it only indicates a very general pattern of eye movement behaviour. It certainly indicates that visual attention is directed to more of the area, however it can be argued that it is unclear exactly what is being inspected. In other words, previous studies don't necessarily capture all subtleties in eye movement behaviour. Underwood et al. (2003) attempted to overcome this limitation by using scanpath analyses to understand the content of the fixations observed across novices and experienced drivers.

Experienced and novice drivers drove on the same roads as was used in Crundall and Underwood (1998) (rural, suburban and dual-carriageway), and their eye movements were tracked. Importantly, two-fixation and three-fixation scanpaths analyses revealed certain eye movement differences across the groups. In general, analyses supported the idea that novices have a more restricted field of interest. It was found that novices favoured the road far ahead compared to the experienced drivers. Specifically, when fixations were directed towards other objects, such as other cars or mirrors, these patterns usually terminated with a fixation to the road far ahead. However novices had more of these types of transitions that resulted in far ahead fixations. One argument made for this is the idea that experienced drivers could make better use of peripheral vision to monitor events and therefore did not need to make these eye movement patterns as much. Novices showed this type of pattern for all three types of roads. The experienced drivers did not show this dominance in far ahead fixations, and were more likely to fixate to other parts of the road before fixating far ahead. What was also important from this study, was that it was actually rather difficult to characterise typical scan paths for experienced drivers compared to novice drivers, particularly for the dual carriageway routes. What this suggests is that the experienced drivers are more able to change their visual strategies to suit the current on-road situation.

So far, what has been discussed is largely about how extensively individuals scan the environment during driving, and this is seen as one of the most important differences in eye movement patterns across experience groups. However there a number of other important visual behaviours that should be considered that may give insights into the differences in processing and ultimately differences in driving performance. One of these is the idea that before the horizontal scanning bias is learnt, novices in fact favour more of a vertical distribution of eye movements compared to experienced drivers where studies typically find a larger variance in vertical fixations locations (Chapman & Underwood, 1998; Renge, 1980; Underwood et al., 2003). It appears that the horizontal bias is learnt with experience, after learning the parts of the driving scene which are more likely to give rise to potential hazards (Underwood, 2007).

In addition, research has shown that there are typical fixation duration differences across experience groups. It is likely that these fixation duration differences indicate differences in the ability to efficiently process the driving scene, where longer fixations suggest longer processing times (Rayner, 2009). Crundall and Underwood (1998) found that for novice drivers, as the complexity of the road increases, novice drivers exhibited longer fixation durations compared to less demanding roads, suggesting novice drivers require longer to process the increased complexity of the scene. This is in concordance with current literature suggesting fixation durations increase with the perceptual and cognitive demands of a task. Interestingly, it was found that experienced drivers exhibited shorter fixation durations during the more complex routes compared to rural routes. Even though the scene is more demanding to process, it appears that experienced drivers compensate by reducing the time spent fixating in order to look around the scene more. Novices are unable to appropriately disengage visual attention due to the higher processing demands. We see this increase in processing time in Crundall et al. (2003) study using a video based task, where the police drivers spend less time fixating at specific locations compared to the novice and experienced matched controls. This again suggests increased efficiency in visual sampling for more experience drivers.

In summary, this section has provided the reader with insights into the typical differences in the patterns of eye movements we observe across novice and experienced drivers. It is clear that a more effective way to sample the driving scene is to exhibit a wider spread of visual search and spend less time fixating at certain locations. It is likely that these visual behaviour differences contribute to the decreased accident liability cases we observe in more experienced drivers (Lee, 2008; Underwood, 2007). Although it is clear there are these eye movement differences, it is important to understand *why* there are these differences. This will be the focus of the next sections. In this thesis, two main contributing factors are explored, and below I devote a section to each.

1.3.3. Explaining eye movement differences: A role for situation awareness

Previously, situation awareness has been discussed as one of the main factors influencing hazard perception skill. However, the level of situation awareness also has a likely role in influencing eye movements. To recap, in driving, situation awareness (Endsley, 1995a, 1995b; Endsley & Garland, 2000) describes the ability to perceive, comprehend and predict potential hazardous situations on the road. It may be that individuals lack a developed mental model of the possible situations which can be encountered on the road (Underwood, 2007; Underwood, Crundall, et al., 2002) thus, they fail to inspect the roadway and mirrors appropriately. Only through experience of driving on the road with exposure to a number of different situations and road users, are drivers able to build up a better understanding of the types of hazards that may arise on a given road type. With this increased situation awareness, they are able to allocate eye movements, and thus visual attention accordingly.

Borowsky et al. (2010) demonstrated that when approaching an intersection, experienced drivers fixated on the adjoining roads more often to inspect potentially oncoming vehicles. The novice drivers tended to fixate straight ahead when approaching. Pollatsek, Narayanaan, Pradhan, and Fisher (2006) found that when a hazard is obscured by another object, experienced drivers inspected the area around the object more often than novice drivers. Together these results suggest that novices have not built up the knowledge of where to look, i.e. they are unaware of the likely locations that hazard may appear and thus do not allocate eye movements accordingly.

Highlighting this more clearly is research from Underwood, Chapman, Bowden, and Crundall (2002). They proposed that if the differences in the patterns of eye movements observed in Crundall and Underwood (1998) were simply due to the relatively higher cognitive demands of driving for novices, then we should not see the differences in visual scanning in a comparable video-based task. A task which removes the need to control a vehicle. If there are still eye movement behaviour differences between novice and expert drivers, then it would suggest differences in the cognitive processes involved in knowing where to look. Participants completed a hazard perception type task where they watched videos of a recorded drive (and included the roads used by Crundall and Underwood (1998)) and had to press a button when they thought they saw a hazardous occurrence. They found there was still an increase in horizontal scanning of the roadway for the experienced drivers compared to the novice drivers, particularly for the dual carriageways. These findings suggest that even in a video-based task, experienced and novice drivers think about driving scenes differently; a product of their differing situation awareness. This ultimately suggests that novices lack the knowledge of where and when to look.

This idea of limited scanning due to an impoverished mental model is important to researchers. It is a potential area which can be targeted by those wishing to explore driver training. For example, one may be able to train drivers, particularly novice drivers, to either a) fixate certain locations to increase their knowledge of the potential threats that may occur when driving or b) the converse, train drivers situation awareness to influence scanning behaviour. Doing so may result in fewer accidents. Section 1.5 of this Introduction explores this idea in more detail and the experiment described in Chapter 6 tests a possible visual training paradigm that may be useful in training drivers to look more appropriately when driving.

1.3.4 Explaining eye movement differences: A role for attentional load

A second plausible reason for differences in eye movement behaviour is the idea that the attentional demands of driving limits the efficient distribution of eye movements. Before this idea is explained in detail, it is necessary at this point to explain several concepts related to ‘attention’. Given its nature, the term attention is often difficult to fully explain. Yet, broadly speaking, attention can be defined as the selective processing of information (Pashler, 1998; Pashler & Sutherland, 1998; Posner, 1994). Whereas visual attention has been described in the context of this thesis as the processing of information entering the eyes, attention does not have to be this specific and can refer to information processing from any source. What is important in this section is specifically the idea that this attentional processing has limits and this in turn may influence eye movements.

Cognitive load is the term often used to infer the attentional demands of a task (Wickens, 2002, 2008a), i.e. the mental difficulty of a task. It has been suggested that attentional processing during a task is largely affected by the level of cognitive load (Tomasi, Chang, Caparelli, & Ernst, 2007; Wickens & Hollands, 2000) where a higher cognitive load may limit the speed at which items are processed or limit the amount of information able to be processed. This idea is explained in a ‘multiple attentional resources’ type concept (e.g. Lavie, 2010; Wickens, 2002). In any given task, there is a finite capacity of attentional resources that can be allocated. Thus, if a task is cognitively demanding (high cognitive load), more attentional resources are required, which in-turn may limit the amount of resources that can be given to a secondary task (Lavie, 2010; Lavie, Hirst, De Fockert, & Viding, 2004).

These concepts relate back to the observed differences in eye movements in novice and experienced drivers. A novice driver may experience driving as more cognitively demanding as more attention may be required for vehicle control (e.g. dual task demands of steering and changing gears). Fewer resources are then available to move the eyes around and the scene and actively searching the road more for potential hazards or other features.

Furthermore, we know that through practice and experience, task performance improves when actions become more automated. (Ackerman, 1988; Moors & De Houwer, 2006). By automatic, what is meant is idea that a process may be unconscious, fast, and importantly, requires few attentional resources (Moors & De Houwer, 2006). With driving, it may be the case that through experience, controlling the vehicle also becomes more automatic and this frees up resources to search to other parts of the scene. These ideas may help to explain some of the differences we see across novice and experienced drivers.

Regarding this idea of cognitive load influencing eye movements, research has consistently shown how increased cognitive load influences visual scanning. Recarte and Nunes (2000) and Recarte and Nunes (2003) demonstrated that when drivers had to perform several mental tasks while driving (e.g. simultaneous auditory, verbal or object detection type tasks), horizontal scanning behaviour was reduced compared to when driving as a standalone task. Similarly, Engström, Johansson, and Östlund (2005) also found increased gaze concentration towards the centre of the scene when a higher cognitive load was induced, both during real and simulated driving. In addition, Savage, Potter, and Tatler (2013) found increasing cognitive load (using a simultaneous riddle solving task) reduced horizontal scanning on video-based hazard perception tasks. Some research has suggested that increasing cognitive load reduces mirror inspection also. Harbluk, Noy, Trbovich, and Eizenman (2007) found that when performing complex mathematical problems whilst driving, the time spent inspecting the vehicle mirrors was less compared to when completing simple mathematical problems and driving. These results suggest that cognitive load may be a source for individual differences in drivers' eye movements, and possibly the differences between novices and experienced drivers’ eye movements. Importantly, this reduction in the distribution of eye movements due to cognitive load has been found to correlate with poorer hazard detection (e.g. Lee, Lee, & Boyle, 2007; Metz, Schömig, & Krüger, 2011; Reyes & Lee, 2008).

These findings prompt an interesting question. If high cognitive load limits effective eye movement behaviour when driving, does this mean that those who have better attentional function exhibit more efficient eye movement behaviour? In other words, do those who can better handle the cognitive demands of the driving task, also look around the scene more? It is an interesting question that has not been tackled as of yet. The experiment described in Chapter 4 investigates this possibility.

Before continuing, it is important to briefly define the term 'attentional function' (Mackie, Van Dam, & Fan, 2013). It is used typically to broadly describe an individual's cognitive control ability i.e. an ability to perform a number of attention tasks. It incorporates not only executive function abilities (e.g. the ability to resolve cognitive conflict (Bush, Luu, & Posner, 2000)) but also aspects of attention alerting and attention orienting. Respectively, these describe one's level of attentional vigilance to impending stimuli and ability to select necessary information from various sensory inputs (Fan et al., 2009; Mackie et al., 2013; Posner & Fan, 2008). Perhaps the best source of research to help answer the question of how attentional function ability relates to eye movement behaviour comes from the findings that better attentional function is related to better driver performance.

One related example of this is the Useful Field of View (UFOV) test (Ball, Roenker, & Bruni, 1990). This test measures one's ability to attend and process rapidly presented information. In general, it measures how much relevant information one can attend to without moving the eyes whilst ignoring distractor stimuli. It thus targets aspects of object identification, divided attention and selective attention (attending to briefly presented targets) (Clay et al., 2005). Ball, Owsley, and Beard (1990) found that those with poorer attentional ability, as measured by the UFOV, also report more problems with driving. Ball, Owsley, Sloane, Roenker, and Bruni (1993) found that poorer performance in the UFOV task correlates with more reported road accidents. A meta-analysis by Clay et al. (2005) supported the claim that poorer performance in the UFOV task is associated with poorer driving performance – suggesting a direct link between attentional function and driving ability.

Since the UFOV was developed, there have been other successful attempts to demonstrate the relationship between attentional function and driving performance, many of which use variations of the visual attention tasks used in the original UFOV assessment (e.g. Aksan, Anderson, Dawson, Uc, & Rizzo, 2015; Anstey, Horswill, Wood, & Hatherly, 2012; Casutt, Martin, Keller, & Jäncke, 2014; Keay et al., 2009; Schuhfried, 2005). One recent assessment test used is the Attention Network Test (ANT) (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT assessment tool is closely based on a known neurocognitive model of human attention which separately assesses the three components of attentional functioning mentioned above: executive control, attentional orienting and alerting networks. The executive control networks involve mechanisms to deal with cognitive conflict and ignoring irrelevant stimuli. The attentional orienting mechanisms are involved in selecting and guiding attention to potentially relevant areas of the scene. And the alerting networks are sensitive to changes in incoming stimuli, over both short and long periods of time (see Fan et al., 2002; Petersen & Posner, 2012; Posner, 2008). This is important as these attentional components are likely involved in successful driving. For example, one must be able to successfully attend to relevant hazardous areas whilst ignoring other stimuli (executive control), orient attention to potential hazardous cues (attentional orienting) and increase readiness to respond and sustain attention to the driving environment (alerting network). Importantly it has been found that better attentional function, as measured by the ANT test predicts better driving performance (Roca, Crundall, Moreno-Rios, Castro, & Lupianez, 2013; Weaver, Bédard, McAuliffe, & Parkkari, 2009).

Therefore, since we know that better attentional function relates to better driving behaviour, the next step is to determine if this holds true for eye movement behaviour when driving. Does better attentional function predict more efficient visual behaviour? Using this section as background, an experiment designed to answer this question is described in Chapter 4 of this thesis.

1.4 The effects of age on driving performance and visual behaviour

Much like novice drivers, drivers who are aged 65 or above are at a higher risk of being injured or killed on the road (Evans, 2000). In the United States for example, in 2012, 5,560 people who were over 65 were killed and another 214,000 were injured (U.S Department of Transportation, 2014). Age related-decline in perceptual, visuomotor and cognitive abilities have been well documented (Birren & Schaie, 2001; Salthouse, 2009; Shanmugaratnam, Kass, & Arruda, 2010), and it is likely that these impairments contribute to the increased number of accidents we observe in an older adult population (Anstey et al., 2012; Anstey, Wood, Lord, & Walker, 2005; McGwin & Brown, 1999). This section will provide a brief overview of the eye movements differences that are known to exist between older adult populations and younger adult populations of drivers, which will hopefully provide insights into what makes older drivers an ‘at-risk’ population. It will explore the hazard perception skill of older adults before exploring older adults’ attentional functioning and how this contributes to their driving performance. It will then discuss the research pertaining to older adults’ eye movements and driving.

1.4.1 Older adults’ driving performance, hazard perception skill and cognitive ability

Throughout the literature, there are two key differences in driving behaviour that are consistently identified that are in-line with typical age-related deficits. The first is that older adults typically exhibit less safe driving. This includes driving slower, poorer lane positioning and making more driver errors (Aksan et al., 2012; Bunce, Young, Blane, & Khugputh, 2012; Dawson, Uc, Anderson, Johnson, & Rizzo, 2010; Raw, Kountouriotis, Mon-Williams, &

Wilkie, 2012). The second is that, although they are just as likely to inspect hazardous areas and hazards, older adults are typically slower to respond to them (Borowsky et al., 2010; Horswill et al., 2008; Horswill et al., 2009). It therefore makes sense that this population is at an increased risk for accident involvement.

What is it that contributes to the typical poorer patterns of behaviour identified? One of the main suggestions that has been explored relates, again, to cognitive and attentional function. Several studies have demonstrated how the cognitive demands of driving influence older adults' driving performance. Chaparro, Wood, and Carberry (2004), found that inducing a higher cognitive load using verbal or visual tasks while driving negatively influenced older adults' driving performance. Compared to young adults, they were less able to detect road signs and took longer to complete the drives. Schwarze, Ehrenpfordt, and Eggert (2014) found that the mental workload experienced, as measured by cardiac output, was higher for older drivers during difficult driving situations compared to younger adults (e.g. complex, multi-lane turns). Moreover, the UFOV task has been widely used to assess attentional performance in older adults. Performance in the UFOV is often poorer in older adults (Clay et al., 2005; Rogé, Ndiaye, & Vienne, 2014) and thus they have deficits in attentional function. Poorer performance on this task seems correlated with increased crash risk (Bruni & Roenker, 1993; Owsley, Ball, Sloane, Roenker, & Bruni, 1991) and general driving performance in older adults (Cushman, 1996; Roenker, Cissell, Ball, Wadley, & Edwards, 2003; Wood & Troutbeck, 1995). It is likely that the impairment in attentional function is a direct factor leading to poorer driving ability, where, for example, older adults may not have the attentional capacity to attend to multiple objects at once or process hazard information as fast (Horswill et al., 2008). The opposite is also true. For example, older adults with better attentional function are better at anticipating hazardous events than older drivers with poorer functioning (Andrews & Westerman, 2012). But how does their cognitive and attentional capabilities relate to eye movement behaviour?

1.4.2 Older adults' eye movements and driving

Given the limitations to older adults' attentional functioning, are there eye movement differences in an older population compared to younger adults when driving? Surprisingly, there are few studies which address this in either a) a naturalistic driving setting which incorporates active control of a vehicle or b) under non-hazardous driving conditions.

An early study investigating eye movement differences in older adults comes from Maltz and Shinar (1999). In their second experiment, older adults and younger participants had to inspect static images of driving scenes as if they were the driver. They found evidence to suggest that older adults had a more impoverished visual search, including smaller saccades and increased number of fixations. They also found that the younger participants were better able to distribute eye movements more evenly across the scene and made less re-fixations to certain locations. However, since general visual search is typically impaired in older adults (Ball, Beard, Roenker, Miller, & Griggs, 1988), it can be argued that these findings are simply a product of a poorer general visual search capacity and may have little relevance to eye movements and driving in real life situations.

Older adults' eye movements have since been tracked while they watch videos of driving scenes, but it is difficult to consistently identify general patterns of fixations made. Underwood, Phelps, Wright, Van Loon, and Galpin (2005) found that there was very little difference in scan patterns between younger and older drivers when watching video clips – both during non-hazardous events and hazardous events. This included no differences in scanning of the roadway and inspection times. Thus, there were no observed effects of age-related decline in viewing driving clips. However, Yeung and Wong (2015) found the opposite during a similar video task, where older adults typically scanned the roadway less than younger adults. It would appear that more research is required to identify if there are age-related eye movement differences across populations.

More promising evidence for highlighting the differences in eye movement behaviour comes from research investigating older adults' eye movements during specific real or simulated driving events, namely; tackling intersections. Romoser and Fisher (2009) and Romoser, Pollatsek, Fisher, and Williams (2013) identified that during simulated driving, older drivers were less likely to scan the roadway (at least any more than once) and adjacent lanes when tackling intersections. Romoser et al. (2013) proposed that this inability to search appropriately is because older adults prioritise the need to monitor vehicle control. Supporting this, Min, Min, and Kim (2013) found that older drivers tended to fixate more on the direction of the turn rather than anywhere else compared to younger drivers. Dukic and Broberg (2012) found evidence that older drivers tended to fixate on road markings to help with positioning and manoeuvring when approaching intersections, whereas younger drivers were more likely to fixate on potential hazardous objects such as moving cars. In addition, they also found that older drivers took longer to make an initial fixation to the intersection and had longer average fixation durations during inspection. This also suggests an impairment in planning and processing the information at an intersection. Together, these findings highlight that impairment in attentional processing may in fact limit effective eye movement behaviour in older adult drivers – at least when navigating intersections.

However, it still remains to be seen if there are differences in eye movements during normal driving situations. Thus, an experiment is described in Chapter 5 which explores the possible differences in eye movement behaviour and driving performance between older adult drivers and young adult drivers.

1.5 Driving and Visual Training

In keeping in line with the last goal of this thesis, this final introductory section will discuss research that provides insights into driver training. A number of effective techniques have been identified in training driving performance, and in particular, hazard perception performance. The ‘commentary drive’ technique has been used, which involves individuals to give verbal descriptions of the current events of the drive. The idea is that this gets them to think about the driving environment and help them to predict possible hazardous events that may occur. This has been effective somewhat in training individuals to respond to hazardous situations more effectively (see Crundall, Andrews, Van Loon, & Chapman, 2010; Isler, Starkey, & Williamson, 2009). Although, see also Young, Chapman, and Crundall (2014) who found that commentary driving actually slowed the responses to hazards. One other typical and successful paradigm to train hazard perception involves getting people to predict what events may occur. A standard experiment may involve individuals watching a series of video clips and suddenly the video would either stop or turn black, and it is the participant’s task to predict what event may occur on the road (e.g. Horswill, Falconer, Pachana, Wetton, & Hill, 2015; Horswill, Taylor, Newnam, Wetton, & Hill, 2013; Meir, Borowsky, & Oron-Gilad, 2014). However, while there has been considerable research investigating how hazard perception performance can be trained, less is known about how visual behaviour can be trained. This is discussed below.

1.5.1 Visual Training

As discussed in section 1.3, one of the reasons that individuals, particularly novice drivers, may not exhibit effective eye movement behaviour when driving is that they lack situation awareness, and therefore, the knowledge of where to look. Therefore, when investigating ways in which driving behaviour, and in particular, visual behaviour, can be trained, it makes sense to try and develop tools which aim to address this lack of knowledge in directing visual behaviour.

There have been a number of attempts to influence scanning behaviour when driving. Many of which utilise augmented reality or visual cues to direct visual attention (e.g. Eyraud, Zibetti, & Baccino, 2015; Pomarjanschi, Dorr, Bex, & Barth, 2013; Rusch et al., 2013). These have proven successful in directing eye movements to particular areas of the scene e.g. slip roads on the side of the road, or points in space that help with making manoeuvres. However, it seems intuitive that unnatural stimuli appearing on screen while driving would direct visual attention, given their relative salience. It doesn't necessarily answer the question of *why* individuals should look at these areas. In other words, the cueing of visual behaviour may be too explicit using these types of techniques to influence cognition.

In an early attempt to tackle this, Chapman, Underwood, and Roberts (2002) developed a training programme which targeted three main aspects of safe driving: knowledge of the road, scanning of the road and the ability to anticipate. Their programme utilised the commentary driving techniques to encourage individuals to think about where they are looking and the anticipatory 'what will happen next' type training. For the visual training aspect, drivers watched videos of potentially dangerous situations and a widened visual search was encouraged by having critical areas of the road circled. The videos were viewed at half speed in order to give participants time to process why the areas were highlighted. In addition, feedback was given as to why the areas were highlighted after viewing the clips. Participants were tested on real roads and a number of measures of driving performance and eye movements were recorded. Testing took place three times. The first was soon after novices had passed their driving test. The training was then administered and testing occurred again after three months and six months after passing their test. They found that those who received the in-depth training programme had a wider horizontal visual search both to non-hazardous and hazardous areas. This was found both after the training (at three months) and, encouragingly, after the 6 month follow up. What was important, was that the training lasted less than an hour. This suggests that the successful training of visual behaviour need not necessarily be elaborate. However, an issue with this programme was that the effects of training did not appear to extend beyond visual behaviour. Participants still drove at the same speed and exhibited similar braking patterns.

In another similar attempt to train visual behaviour, a series of studies (Fisher, Pollatsek, & Pradhan, 2006; Pollatsek et al., 2006; Pradhan, Pollatsek, Knodler, & Fisher, 2009) was conducted in order to develop and validate a PC based hazard perception and awareness programme. Participants were presented with top down views of driving situations where a hazard could potentially develop. Feedback was given on where individuals should scan and the consequences for not doing so. The training proved effective in positively influencing scanning behaviour in both simulated and real road driving. Unfortunately, testing usually occurred soon after training. Therefore it is unclear if the effects were a product of this recency or if the training instilled a long lasting effect on visual behaviour. Further, these more developed training tools may also suffer from the same problem as the basic visual cueing methods, namely that cueing is still rather explicit, and may not be influencing cognition at a deeper level.

Therefore, there is still a requirement for research to provide the necessary understanding of why an individual should be directing eye movements to a particular part of the scene. Konstantopoulos, Chapman, and Crundall (2012) conducted a study which attempted to investigate whether showing the eye movements of drivers can provide the information on why it is important to look at certain areas of the scene. They showed slowed-down traces of drivers' eye movements to novice and experienced drivers (driver instructors). They proposed that if one can discriminate between “good” and “bad” eye movement patterns, then individuals should therefore have an understanding of why one visual strategy is better than another. Surprisingly however, the discrimination task proved to be somewhat difficult. For example, the instructors were unable to correctly identify the differences between expert and novice patterns better than chance. However, novice and learner drivers were able to correctly identify novice patterns of eye movements beyond chance level. Though it would appear that the use of eye movements may be limited in training more appropriate visual behaviour when driving. This idea is explored further in Chapter 7. In an attempt to provide a more implicit learning tool, it was tested whether showing eye movements, and then observing people drive, can be an effective tool for visual training in driving.

1.6 Thesis Overview

This introduction has provided the background research for the following experimental chapters. Based on the theoretical ideas put forward in section 1.1, where eye movements are arguably best investigated under the context of action, the first experimental chapter (Chapter 3) was conducted. It investigated if there were differences in the spatial deployment of eye movements when individuals watched video clips of hazard perception driving and when they performed a similar hazard perception task when actively driving in a simulated environment. The results provide insights into how the strategies adopted by the visual and attentional systems may change depending on the demands of the driving task.

Using the literature described in section 1.3, Chapter 4 aims to investigate the relationship between an individuals' attentional function and their capacity for exhibiting efficient eye movement behaviour when driving. Individuals performed a series of visual attention tasks and performance was compared to their visual behaviour during simulated driving. The results provide insights into the individual differences that may influence eye movements when driving and offer implications for driver assessment and training. In another attempt to highlight some of the individual differences that may influence visual behaviour when driving, Chapter 5 explored the idea that older adults may adopt different visual strategies when driving compared to their younger counterparts. The results help to further the understanding of how the visual system changes with age and copes with the attentional demand of driving.

In the final experimental chapter (Chapter 6), the aim was to investigate if using the information gained from experienced driver's eye movement patterns can implicitly train novice drivers to scan the road more. The results offer insights into a possible driver training intervention.

These experiments are described in full after a General Methods section. A final General Discussion section summarises, discusses and offers implications and limitations of the experiments to ultimately provide the reader with a thorough, yet broad, account of eye movements and driving, with insights into methodology, individual differences and training.

Chapter 2

General Methods

The exact methodologies that were used were different across each experiment. Thus, each data chapter will describe the methods used in more detail than what will be described here. In this chapter, the apparatus that was common across experiments will be described, along with the general aspects of the driving simulation apparatus used and the methods for collecting and analysing eye movement data.

2.1 Apparatus

2.1.1 Experimental Computer

In order to run all software used in the investigations, a Hewlett Packard z210 desktop computer with a 3.3GHz processor and NVIDIA Quadro 600 graphics card was used.

2.1.2 Steering wheels and pedals

For the first experiment (Chapter 3) a Thrustmaster 5 Axes RGT Force Feedback steering wheel, with left and right indicators, and pedal combination was used. For subsequent experiments, a Logitech Driving Force GT steering wheel and pedals combination was used to control the vehicle.

2.1.3 Driving Simulations

In order to simulate a driving environment, two low-level widely available pieces of driving simulator software were purchased. Each are explained in detail separately below. In general, for each simulation, the environments were typical of everyday driving situations and contained a number of familiar stimuli such as pedestrians, multi-lane traffic, stop signs and speed limit signs. Participants were always instructed to drive as they normally would and to obey regular traffic rules and regulations.

Each course was chosen on a trial-and-error basis. The experimenter performed a number a test drives in order to select appropriate courses. In line with the simulated driving literature, a number of stimuli criteria were identified. The main criteria was that the courses had to represent the different types of driving environments encountered in the real world given the differences in eye movements that are typically exhibited across driving environments (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Land & Tatler, 2009). Thus, country, urban and suburban routes were selected. In addition, the number of complex events were kept to a minimum in each course. Specifically, complex intersections and junctions and roundabouts containing more than 3 exits were not included. This was to remove the possibility that any differences in eye movements could be due to differences in participants' ability in tackling these types of events. It was also important to maintain uniformity within each course, in that the environment and the types of stimuli present should not change throughout the length of the course. In this way, eye movement measures could be averaged across the course. However, it is acknowledged that this judgement of uniformity is subjective. As such, although not investigated here, there may be eye movement differences across specific sections within the same course. See below for specific details about the driving simulator software used.

2.1.3.1 Driving Simulator 2011

The driving simulator software Driving Simulator (2011) (Excalibur Publishing Limited, 2011) was used for the first experiment investigating eye movement differences across video and active driving methods (Chapter 3). With this software, the physical properties of the vehicle could be programmed to mimic the feel of driving a car through a naturalistic environment. The properties were programmed using the software's configuration files. The car driven was a typical 'Sedan' style car. It was set to a mass of 1450kg and the engine had a maximum motor torque (Newton Metres) of 240. A list of all vehicle parameters used, e.g. drag coefficient data, braking data, steering data, etc. can be viewed in Appendix 1.1.

Regarding the driving environments, this software simulated driving on the right, resembling, for example, driving in most North American or mainland European countries. Each route resembled typical road types that would be encountered in the real world. In total, four different virtual areas were used in the experiment. The first, named by the software as "Hohenkirchen: Bus Terminal" was a typical modern suburban environment, characterised by longer and straighter sections of road. The second, named "Mittstedt: Marketplace" was an urban style environment with a more dense traffic network than the suburban route. The third area was named “Mittstedt: Residential Area” and, as the name implies, was an urban residential area. The final area was named “Mittstedt: Mount” and was characterized by a road in the country containing a number of curved bends. See Figure 2.1 for example static representations of each area. For each area, the level of traffic could be moderated, from no traffic to very dense traffic levels. Arial representations of the courses can be viewed in Figure 2.2

Figure 2.1 Example scenes within each of the four different general areas used when using Driving Simulator 2011. (a): suburban area, (b): urban area, (c): residential area, (d): country road.

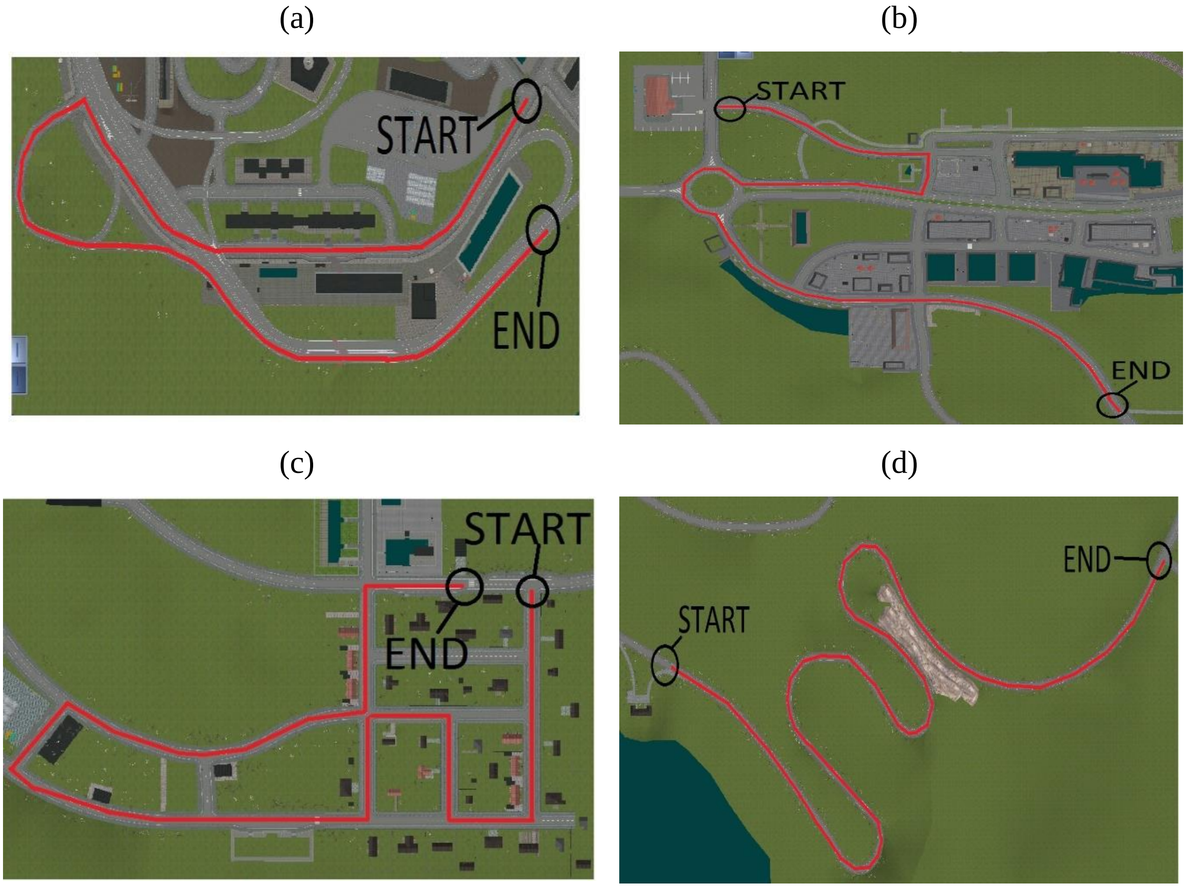


Figure 2.2. Arial representations of the routes used in Driving Simulator (2011). (a) suburban area, (b): urban area, (c): residential area, (d): country road.

2.1.3.2 City Car Drive

The driving simulator software City Car Drive (Forward Development, 2014) was used for the experiments described in Chapters 4, 5 and 6. Like the previous software, the physical properties of the vehicle could be programmed to mimic the feel of driving a car through a naturalistic environment. The properties were again programmed using the software's configuration files. The vehicle driven was a similar but larger sedan type car. It had a simulated mass of 1727kg. The full list of vehicle properties can be inspected in Appendix 1.2.

With this software, both a right hand and left hand driving environment could be simulated, allowing for the inclusion of drivers with experience of driving in the United Kingdom. For the driving environment, three different general areas were used in the experiments. The first was a country highway. This was the least complex area that consisted of one large road with few intersections, containing single and dual lane carriageways (Figure 2.3a). The second area was a motorway type area. This contained multiple lanes of traffic and there was the presence of slip roads (Figure 2.3b). The third area was a typical urban area with a number of intersections and pedestrian crossings (Figure 2.3c). Each course contained a moderate amount of traffic. Arial representations of the courses can be viewed in Figure 2.4.

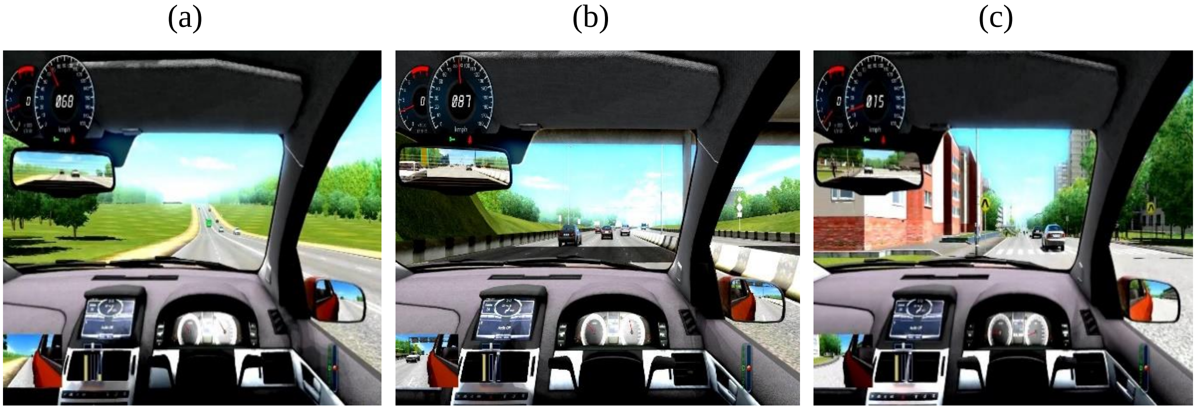


Figure 2.3 Example scenes within each of the three different general areas used when using City Car Drive. (a): country highway, (b): motorway, (c): urban area.

The urban route used within Chapter 6 was deemed inappropriate for consistent testing across participants because of the addition of traffic lights (see Chapter 6 for details). Therefore, this was changed for the experiments described in Chapters 4 and 5 (which were conducted after the experiment described within Chapter 6). The alternate route used in chapter 6 can be viewed in Figure 2.5)

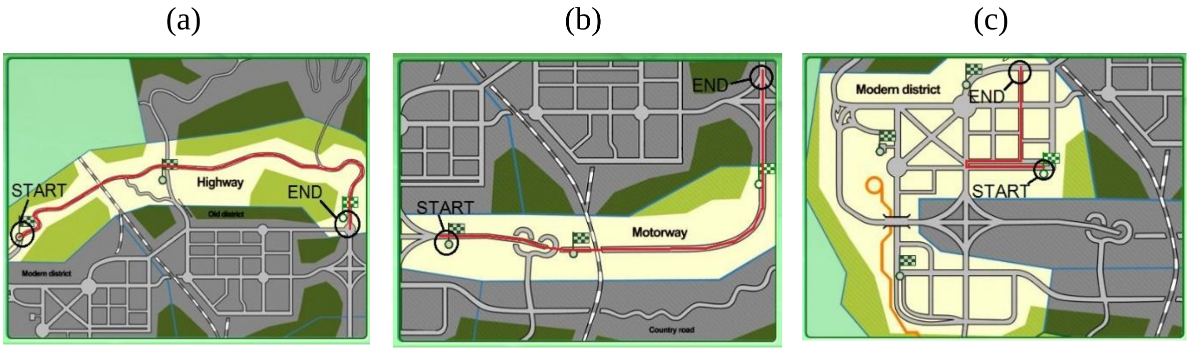


Figure 2.4. Arial representations of the routes used in City Car Drive. (a): country highway, (b): motorway, (c): urban area.

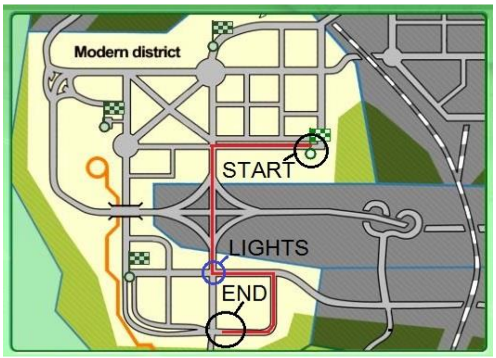


Figure 2.5. Arial representation of the urban area route used for Chapter 6.

2.2 Eye Movement Recording

2.2.1 Eye movement data collection

For the first experiment (Chapter 3), an SR Eyelink 1000 eye tracker, with tower mount and chin rest apparatus was used to record eye movements, sampling at 1000 Hz. Fixations and saccades were determined using software provided with the eye tracker, which gave a displacement threshold of 0.1deg, a velocity threshold of 30^{o}/s and an acceleration threshold of $8000^{o}/s^{2}$ (SR Research Ltd, 2013). A 12 point calibration ensured that recordings had a mean spatial error of less than 0.8 deg. Calibration was performed using a standard procedure where participants were asked to fixate on the dots that would appear one at a time around the display screen. For subsequent experiments, an SR Research Eyelink II eye tracking system was used to record eye movements, sampling binocularly at 250Hz. Fixations and saccades were determined using a displacement threshold of 0.1 deg, a velocity threshold of 30°/s and an acceleration threshold of 8000°/s^2 (SR Research Ltd ,2013). Head movements were not restricted in these experiments. For the experiments described in Chapters 4 and 5, the Eyelink II Scene Camera hardware was used to capture eye movements and stimulus display. Refer to each individual data chapter for more detailed descriptions of how the eye tracking was implemented in the experiments.

2.2.2 Eye movement data preparation and analysis

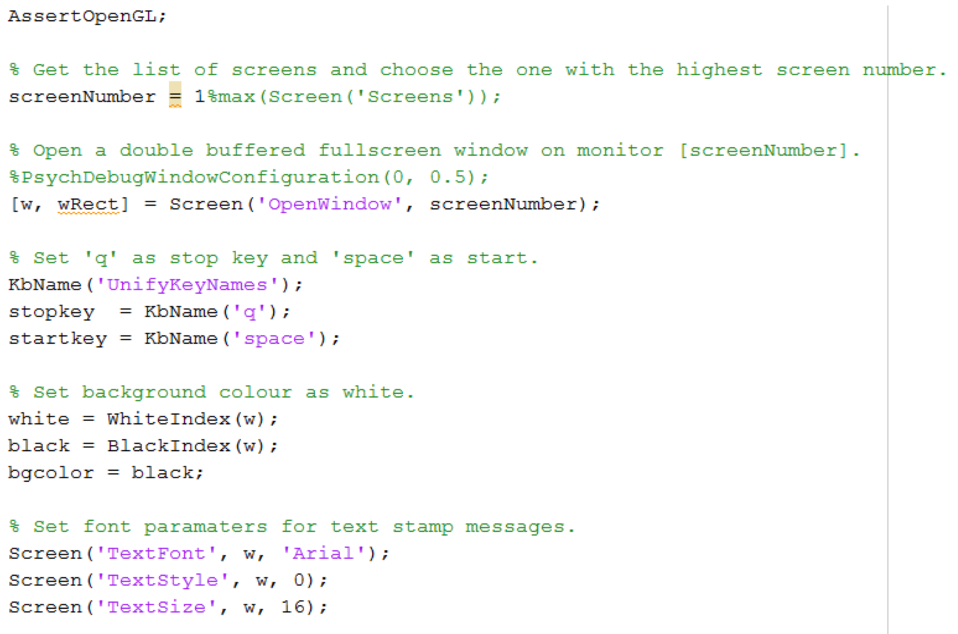
All eye movement data was processed by the Eyelink host computers and was prepared for analysis using SR Research Data Viewer. With this software, areas of interest (AOI) could be defined and created. Since the stimulus display was always from the viewpoint of a first person drive, static AOIs could be defined. These were created by using a screenshot of the environment (for each experiment) as a template to 'draw' AOIs around important regions of the scene, e.g. the roadway or vehicle mirrors. Each experiment had different AOIs (see individual chapters for details). All fixation and saccade information relating to these AOIs, for example, fixation location, fixation duration, average saccade velocities, were computed by the Data Viewer software and these values were reported in a spreadsheet style format. The values in these spreadsheets were used to statistically analyse differences in eye movements.

2.2.3 Creating dynamic stimulus recordings and eye movement overlays

In addition to the static representation of eye movements, it was also important to capture a dynamic representation of when and where participants looked, in the form of video recordings. For the experiments described in Chapters 4 and 5, the Eyelink II scene camera was capable of producing this without the requirement for an additional computer programme. This was because the stimulus was projected onto a much larger field of view. However, for the experiments described in Chapters 3 and 6, a computer monitor was used to display the stimulus, and the eye tracker was unable to produce a high resolution video recording of both the dynamic real time stimulus and corresponding eye movements. This limitation was overcome by creating a MatLab ® (MathWorks ®, 2015) script with the Psychtoolbox application (Kleiner et al., 2007). This, along with video capture software, allowed the eye movement data to be recorded synchronously along with a real time display capture. It was then possible to overlay the eye movements into the captured video using two methods. The first involved using a MatLab script and the second involved video editing software. The main procedures are summarised below. The full MatLab scripts used can be viewed in Appendix 2.

2.2.3.1 Recording eye movements and screen capture simultaneously

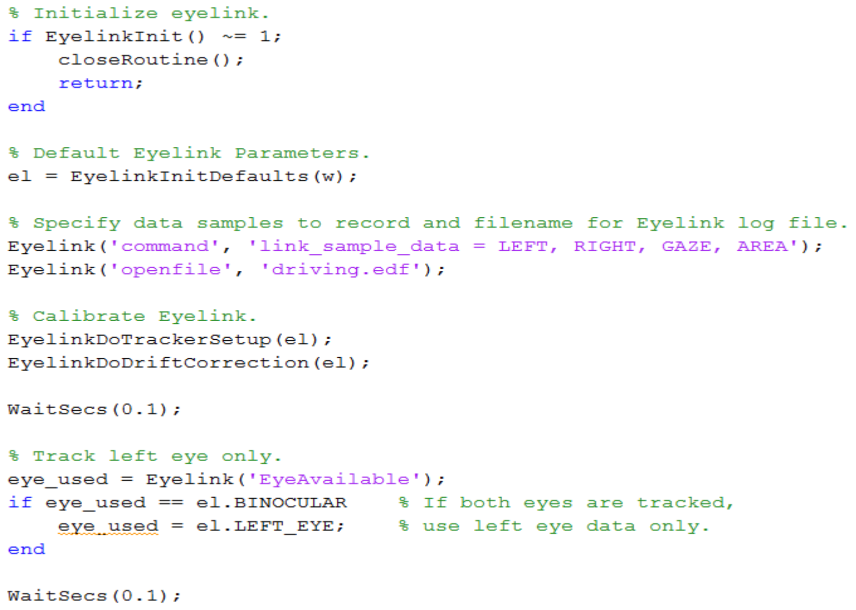
Before eye movements were overlain onto the corresponding video file using either the MatLab or video editing software method, the initial stage of the procedure was to record a video of the experimental trial and the eye movements of the observer simultaneously using an intial MatLab script. The function initially opened a pre-experimental window which allowed for eye tracking calibration and defined a start and stop key (see Figure 2.6. Comments are in green).



```
AssertOpenGL;

% Get the list of screens and choose the one with the highest screen number.
screenNumber = 1%max(Screen('Screens'));

% Open a double buffered fullscreen window on monitor [screenNumber].
%PsychDebugWindowConfiguration(0, 0.5);
[w, wRect] = Screen('OpenWindow', screenNumber);

% Set 'q' as stop key and 'space' as start.
KbName('UnifyKeyNames');
stopkey  = KbName('q');
startkey = KbName('space');

% Set background colour as white.
white = WhiteIndex(w);
black = BlackIndex(w);
bgcolor = black;

% Set font paramaters for text stamp messages.
Screen('TextFont', w, 'Arial');
Screen('TextStyle', w, 0);
Screen('TextSize', w, 16);
```

Figure 2.6. Script used to create the pre-experimental window and to define start and stop keys

The function wRect created a rectangular window on the desired display screen which was defined by screenNumber; where screenNumber was usually 0,1 or 2 depending on the physical set up of the displays (i.e. single monitor or dual monitors set up). The script then called for the initialisation of the Eyelink using the inbuilt Eyelink Toolbox functions within Psychtoolbox (Figure 2.7)



```
% Initialize eyelink.
if EyelinkInit() ~= 1;
    closeRoutine();
    return;
end

% Default Eyelink Parameters.
el = EyelinkInitDefaults(w);

% Specify data samples to record and filename for Eyelink log file.
Eyelink('command', 'link_sample_data = LEFT, RIGHT, GAZE, AREA');
Eyelink('openfile', 'driving.edf');

% Calibrate Eyelink.
EyelinkDoTrackerSetup(el);
EyelinkDoDriftCorrection(el);

WaitSecs(0.1);

% Track left eye only.
eye_used = Eyelink('EyeAvailable');
if eye_used == el.BINOCULAR     % If both eyes are tracked,
    eye_used = el.LEFT_EYE;     % use left eye data only.
end

WaitSecs(0.1);
```

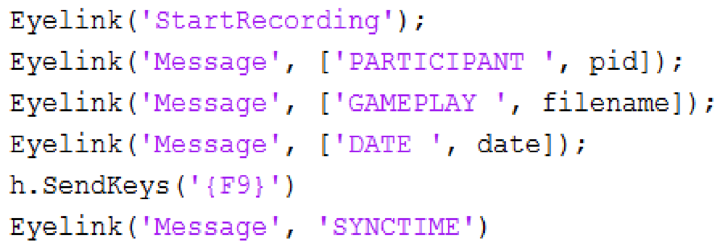
Figure 2.7. Script outlining the initialisation of the Eyelink Tracker to allow for calibration

This script allowed MATLAB to open up the default calibration screen in the window as defined and controlled within the Eyelink Toolbox directory of Psychtoolbox (el = EyelinkInitDefualts (w)). EyelinkDoTrackerSetup(el) allowed for calibration and EyelinkDoDriftCorrection(el) allowed for a drift correction which again was controlled by the default scripts through the Eyelink Toolbox directory (Figure 2.7).

```
h = actxserver('WScript.Shell')
h.Run('C:\Fraps\fraps.exe')
WaitSecs(5);
h.Run('"C:\Users\ Program Files\Lightrock Entertainment\Driving Simulator 2011\Driving Simulator 2011.exe
WaitSecs(60);
```

Figure 2.8 The function which executes the opening of FRAPS video capture software and the stimulus software executable file.

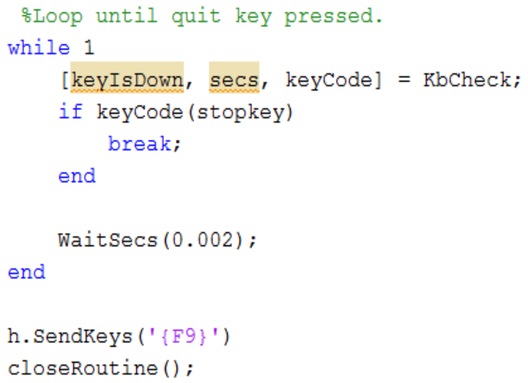
The next stage of the procedure was the simultaneous recording of the stimuli and eye movements. This was accomplished through video screen capture executed by the MATLAB script, which also executed the function to allow the eye tracking software to record the eye movements. The screen capture was controlled by FRAPS video capture software. The function commanded FRAPS software to open along with the stimulus programme to be presented (e.g. Driving Simulator 2011). This was accomplished using the script outlined in Figure 2.8. The actxserver function allowed MatLab to call the video recording software FRAPS and then after a user defined waiting period, it called the desired experimental stimulus programme.



```
Eyelink('StartRecording');
Eyelink('Message', ['PARTICIPANT ', pid]);
Eyelink('Message', ['GAMEPLAY ', filename]);
Eyelink('Message', ['DATE ', date]);
h.SendKeys('{F9}')
Eyelink('Message', 'SYNCTIME')
```

Figure 2.9. Script to execute the recording of the eye movements and the screen capture simultaneously

After the waiting period, MatLab executed a script to allow the eye tracker to begin tracking the eye movements and allowed FRAPS to record to the display screen. Importantly, there is a line placed here which told MatLab that the F9 key has been pressed [h.SendKeys ('(F9)')] which was the key used by FRAPS to begin recording the screen capture. This step allowed both the eye movements and the screen to be recorded simultaneously.



```
 %Loop until quit key pressed.
while 1
    [keyIsDown, secs, keyCode] = KbCheck;
    if keyCode(stopkey)
        break;
    end

    WaitSecs(0.002);
end

h.SendKeys('{F9}')
closeRoutine();
```

Figure 2.10. The termination code to close the experiment whilst terminating the screen capture recording and eye movement recording

Finally, the complete function terminated the experiment, which in turn synchronised the termination of both the eye movement recording and video capture recording. This was accomplished with a simple check loop until the previously defined stop key was pressed. Upon manually pressing the stop key, this terminated the experiment and within a user defined time frame, terminated the video recording. This was accomplished using the example code presented in Figure 2.10.

2.2.3.2 Overlaying the recorded eye movement and video file using a Matlab script

This method was used in Chapter 3. However, this method was not developed by me, but another researcher (Paul Cox, acknowledged). Thus, it is difficult to describe the process in detail. The whole script can be viewed in Appendix 2.2. To summarise, the script took the raw eye movement data created from the Eyelink software and recorded the x and y coordinates of each fixation. It then used this information to draw a red coloured circle on the recorded video file at the corresponding time frame. It went through the video on a frame-by-frame basis continually drawing a red circle given the x and y coordinates of each fixation. It then pieced each of these frames together to produce a new video file of the recorded drive and the eye movements overlain.

2.2.3.3 Overlaying the recorded eye movement and video file using video editing software

This method was used for each of the subsequent Chapters (Chapters 4, 5 & 6). The eye movement video trace was exported to an avi file directly from the Eyelink Data Viewer Software. This video file simply consisted of the eye movement pattern over time, presented as a coloured circle, on a black background. This video file was imported to Adobe Premiere Pro (Adobe Systems Software, 2014), along with the recorded video of the stimulus display. Using this video editing software programme, the eye movement file was overlain on top of the stimulus video. The black background of the eye movement video was filtered out by applying a chroma key compositing technique. A blend was applied until the black background could not be seen but the contrasting hue of the eye movement gaze cursor could. This left the underlain stimulus recording with the overlain eye movement trace.

All other pieces of software or apparatus that was used in the experiments are described in more detail in each of the experimental chapters.

Chapter 3

Eye Movements and Hazard Perception in Active and Passive Driving: Insights into Driving and Eye movement Methodology

This experimental chapter aims to explore the eye movement differences in driving between a passive video hazard perception task and an active simulated driving task. The aim was to provide insights into how the visual system adopts different strategies depending on the demands of the driving task. The results help to provide further understanding of how vision and action interact during natural activity and have implications for driver assessment and training tools.

3.1 Introduction

During natural activity, foveal attention must be directed towards informative areas, in both time and space, which aid task completion. As discussed quite extensively in section 1.1, current models of visual guidance in complex scenes are often based on data derived from simple tasks using static stimuli, such as picture viewing or visual search. Although recent progress has been made in this area (Borji, Sihite, & Itti, 2011; Borji, Sihite, & Itti, 2014; Johnson, Sullivan, Hayhoe, & Ballard, 2014), there exist few frameworks, computational or otherwise, that can successfully predict eye movements in complex, dynamic and naturalistic environments, such as driving.

A now more favoured method to model eye movement behaviour is by using movie based paradigms which, by definition, allows dynamic information to be presented. However, it is often difficult to generalise the findings to real world contexts. Hirose, Kennedy, and Tatler (2010) found that cuts in a movie resulted in disruptions to both memory and eye movement behaviour compared to normal scene perception. Dorr, Martinetz, Gegenfurtner, and Barth (2010) showed that the eye movement behaviour exhibited by individuals when viewing different movie types (stop motion, Holly-wood movies and natural movies) was rather variable and not representative of natural viewing behaviour. These studies suggest that using movies may have limited utility when investigating eye movement behaviour during everyday tasks.

Given the intrinsic link between vision and action (Ballard et al., 1992; Land, 2009; Tatler et al., 2011), Land and Tatler (2009) have argued that passive movie viewing paradigms do not capture the same visual behaviour that one would observe under more ecologically valid circumstances, i.e. tasks which incorporate visuomotor control. As mentioned in section 1.1, the neural substrates involved in vision for action and vision for perception are often considered separate (Baizer et al., 1991; Glover, 2004; Milner & Goodale, 1995) and eye movement behaviour differences consistent with this separation have been found across passive viewing paradigms and their real life analogies. For example differences have been found in visual search (Foulsham et al., 2014) scene viewing (Foulsham et al., 2011) and social attention (Risko et al., 2012). Thus, there is a wide literature, drawing from a number of areas, suggesting that movie based paradigms may not accurately represent the specific goal directed visual behaviour we would observe in more active environments.

This therefore has relevance for driving research. As discussed throughout the General Introduction, there has been considerable research into driving and driving skill, particularly of hazard perception, with many studies involving participants either viewing pictures of driving scenarios (Underwood, Humphrey, & Van Loon, 2011) or using movie viewing based paradigms (Borowsky, Oron-Gilad, Meir, & Parmet, 2012; Chapman & Underwood, 1998; Savage et al., 2013; Underwood, Phelps, et al., 2005). These studies have allowed us to identify possible oculomotor strategies employed by drivers of differing experience. For instance, more exaggerated horizontal eye scanning patterns have been found in experts than in novice drivers (Crundall et al., 2003; Crundall & Underwood, 1998). But these studies did not incorporate visuomotor control of a vehicle, and thus, may measure something different from when participants actively control a car.

The interactivity of driving (be it real or in a simulated environment) is likely to place more of a demand upon the visual system than when observers are faced with a passive movie-viewing environment. Certain locations which need to be fixated by the driver in order to control the car successfully may be more important in an active driving task. For example, tangent points (Land & Lee, 1994) or direction of heading points (Wilkie et al., 2010). These fixation patterns are less important in a movie based task. As a consequence, this may limit the visual search for hazards that could otherwise be accomplished when simply viewing videos; and as such, may be reflected in differences in eye movements. In addition, there will likely be increased attentional demands in an active driving task compared to passively viewing and we know that increasing cognitive load when driving (by introducing a secondary task) limits visual scanning when driving (Engström et al., 2005; Recarte & Nunes, 2003; Savage et al., 2013).

3.1.1 Current Study

The primary purpose of this chapter therefore, was to identify and quantify differences in oculomotor behaviour and hazard perception performance across a passive, movie based hazard perception driving task, compared with an active, simulated hazard perception task. This was achieved by studying and comparing eye movement fixation patterns and hazard detection performance when driving in a simulated setting that incorporated active control of a vehicle, compared with passive movie viewing.

In the active driving condition, participants drove around a number of set routes using a driving simulator programme and responded (using a button press) to hazards. In the non-driving condition, participants watched a series of video clips from the same driving software and responded to the hazards using a button press. Eye movements were recorded throughout, using foveal fixation location as a measure of attentional deployment. The main eye movement measure was the extent to which each individual scanned the roadway. Reaction times to detect hazards were recorded using a button press. Since distinctions have been drawn between processes of perceptual guidance and perceptual identification (see Godwin, Menneer, Riggs, Cave, & Donnelly, 2015; Huestegge et al., 2010), this overall reaction time was broken down into (1) latencies for individuals to fixate the hazards (measured as the time of first fixation) and (2) the latencies to verify the hazards as such (measured as the time between first fixation and the button press).

Although this experiment was largely exploratory, some predictions were made regarding the differences in visual behaviour and hazard perception. Specifically, the lower levels of attentional demands in the video task may (1) allow individuals to search more extensively for hazards, resulting in a wider visual search pattern, and (2) result in faster processing of hazards which would result in faster overall reaction times. This experiment was, to the best of my knowledge, the first study to measure absolute behavioural comparisons across video based driving tasks and simulated driving tasks. This experiment has been published as a short article (Mackenzie & Harris, 2014) and as a larger extended article (Mackenzie & Harris, 2015).

3.2 Methods

3.2.1 Participants

Thirty-four participants took part in the study (five males) with an age range of 19–31 years (mean age 22.3 years). All participants had normal or corrected-to-normal vision and were recruited through the University of St. Andrews SONA experiment participation scheme. They were paid £5 for participation. All participants had held a drivers' licence for at least one year and were from countries where driving on the right side of the road is standard. Driving experience did not significantly differ across conditions (mean years since licence received, Driving task, 3.1 years [3.4 SD]; Non-driving task experience 2.6 years [1.5 SD]). The study was approved by the University of St. Andrews University Teaching and Research Ethics Committee (UTREC).

3.2.2 Stimuli and Apparatus

3.2.2.1 Driving Simulation and hazards

The driving simulation used is described in the General Methods section 2.1, including the environment and the types of routes driven. The driving environment could be controlled and the locations of the hazards determined. The hazards used here were fully developed obstructions on the roadway, involving other vehicles that, under normal circumstances, would cause an approaching car to slow down, stop or change direction. Specifically, drivers/viewers would encounter a vehicle collision that had already occurred. The term fully developed is used here to highlight that these hazards have occurred prior to encountering them (see Figure 3.1).

The hazards were created by re-programming the artificial intelligence of other (virtual) road users so that they would frequently collide with another road user and create an obstruction. When encountered, individuals would need to slow down to manoeuvre around the hazard. The onset of a hazard was defined as being when it first became visible on-screen. Information about distance to the hazard was not available from the software. On average, the time each hazard was available to respond to did not differ across driving and non-driving conditions.

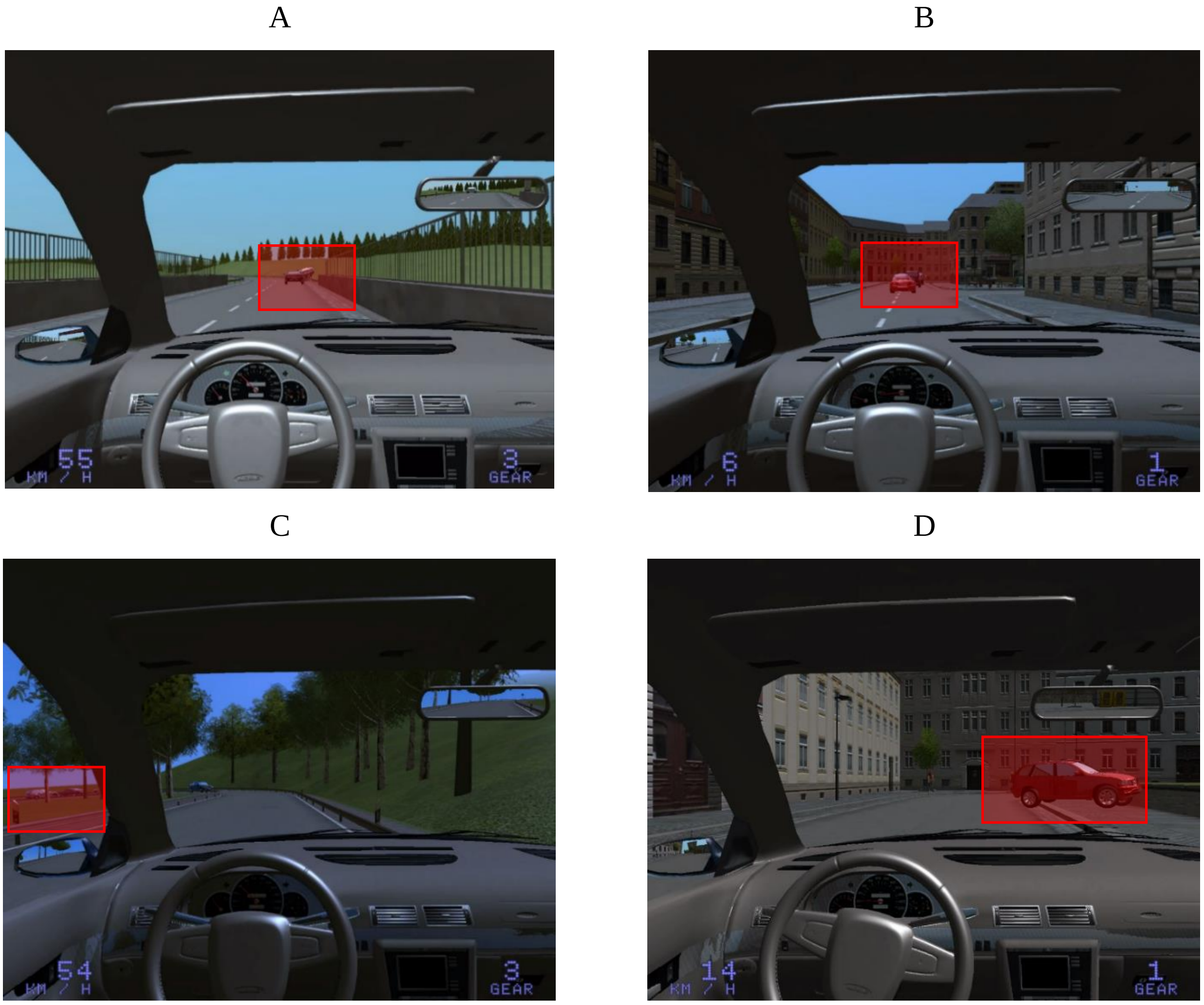


Figure 3.1. Examples of fully developed hazards used throughout both conditions. Note that in all, the collision has occurred prior to the driver encountering the hazard and would require the driver to slow down, stop or change position.

A pilot study was conducted to confirm that these hazards could be detected easily. Participants viewed four movies showing hazardous situations (six total hazards) and four movies showing non-hazardous situations. When asked to detect the hazardous events by pressing a button, participants correctly identified the hazardous situations significantly more than non-hazardous driving situations ($\chi^2(2, 36) = 41.17$, $p < .001$, using chi squared). There was only one participant who did not respond to one of the hazards and only two false detection responses. These results are unsurprising given the nature of the hazards, nevertheless this pilot study provided evidence that the types of fully developed hazards used in the main experiment are easy to detect and are suitable to measure individuals' hazard perception performance.

3.2.2.2 Video and driving stimuli

Eight video clips were shown in the non-driving condition. They were pre-recorded driving scenes from the driving simulator software. The scenes were captured using FRAPS® video capturing software at a frame rate of 30 frames per second and a resolution of 1280 × 1024 (with a 5:4 monitor aspect ratio). These videos took the form of a first person perspective driver view of a vehicle (Figure 3.2) driving around suburban and urban areas with varying amounts of traffic whilst adhering to the normal rules of the road i.e. by staying within the speed limit, stopping at stop signs, etc. Four of the course clips contained either one or two hazards (six in total). The other four course clips contained no hazardous events.

For the driving condition, participants drove a total of eight courses, which consisted of the same suburban and urban routes as the video condition with either no traffic, light traffic or dense traffic. Four of the courses contained either one or two hazards in the form of a collision (up to six to detect across the four courses). The other four courses contained no hazards. The courses used across the conditions were the same. Only the four courses without hazards were used in the eye movement analyses to minimize eye movement measurements associated with hazard specific events. In an attempt to eliminate differences in eye movements being due to differences in visual motion or duration across conditions, the number of turns and distances driven were set to be, on average, equivalent across driving and non-driving conditions. The consistency between driving and non-driving tasks limited differences in steering performance. The average time for viewing the video clips in the non-driving condition was 143.5 s (minimum, 103 s; maximum 183 s). The average time for driving the courses was 151.8 s (minimum, 61 s; maximum 240 s).

3.2.2.3 Eye movement recording

An SR Eyelink 1000 eye tracker, with tower mount apparatus was used to record eye movements, as described in the General Methods 2.2. A chin rest was used in this experiment which restricts naturalistic head movements, however given the relatively small visual field, head movements were not required in order to view the display screen. See figure 3.2 for the experimental set up and a representation of a participant's viewpoint.

During the driving task, each participant's drive was recorded using the FRAPS video recording software. The temporal and spatial attributes of the eye movement coordinates were overlain onto these video recordings using the method previously outlined in section 2.2.3.2 and Appendix 2.2. The produced video consisted of the recorded drive and fixation locations in the form of a red dot. The programme was coded so that this dot turned green when the participant had pressed the button indicating they had detected the hazard. Similarly for the non-driving task, each participant's eye movement data was overlain onto the pre-recorded videos. The eye movements were also represented as a red dot which turned green when the participant had detected the hazard by pressing the button.

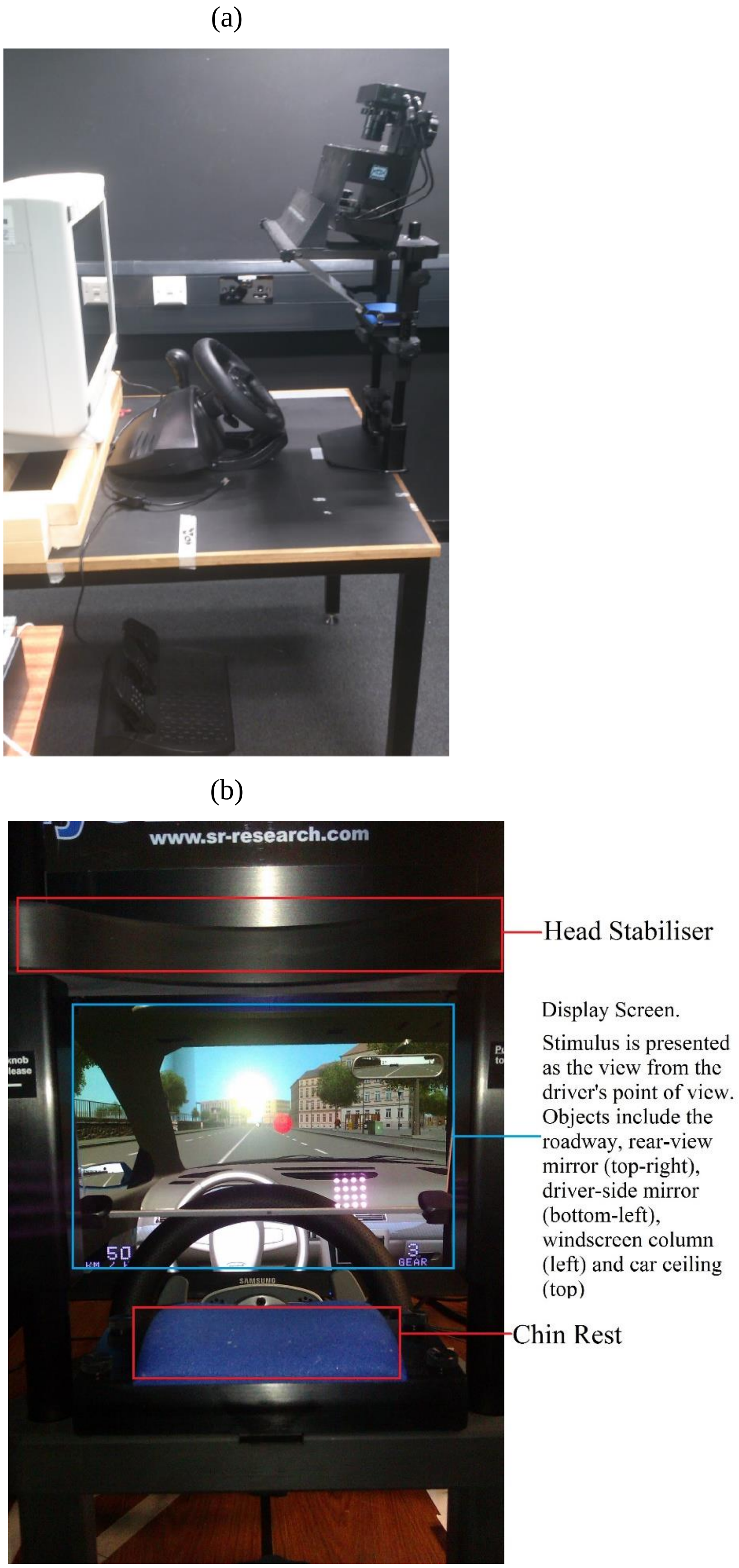


Figure 3.2. Pictures showing the eye tracking and driving set-up (a) and (b) a representation of the typical participant view point

3.2.3 Measures

3.2.3.1 Eye movement measures

Eye movement information (i.e. fixation coordinates) was recorded and collated using SR Research Data Viewer software.

Fixation locations/Spread of attention. The standard deviations of eye fixations across the horizontal and vertical axis (using x-axis and y-axis pixel coordinates) were measured to provide an indicator of the spread of eye movements. A larger standard deviation would suggest a wider distribution, and thus wider spread of visual attention.

Average y-axis fixation location. The mean y-axis fixation was measured using the mean y-axis coordinate as an indicator of how far, on average, along the road participants fixated. Since this measure is converted from screen pixels, a smaller y-axis fixation value would suggest that individuals looked higher up in the image and thus further ahead along the road.

3.2.3.2 Hazard detection

Response accuracy to the hazards was recorded. The overall probability of detecting the hazards was calculated by the percentage number of correct button presses when hazards were present. The probability for fixating the hazards was also recorded which was calculated by the percentage number of those hazards that were directly fixated (recorded by looking through each video). The probability to fixate the hazard without detecting was also recorded which was calculated as the percentage number of times individuals fixated the hazards but did not push the button to verify the hazard as one.

Using the button press, reaction times were also measured. The time between when the hazard first appeared on the screen and when the participant pressed the button was calculated as overall reaction time. This total reaction time measure was also split into two constituent time periods: the time it took to see the hazard and the time it took to verify the hazard as a hazard. The “Time to See” the hazard was measured from the time the hazard appeared on the screen (the first frame the hazard was visible) to when a participant fixated on the hazardous area. The “Time to Verify” was measured from the time that the initial fixation occurred to when the button press was made—where the eye movement dot would turn green on the video file. Reaction time analyses and the judgements of the initial saccades were performed manually, offline by viewing the video files on a frame-by-frame basis and recording the timestamps at which these events occur. All timings were calculated using Apple Quick Time^{TM} video player.

3.2.4 Procedures

3.2.4.1 Driving task

Participants were instructed they would be performing a hazard perception task whilst driving around a number of courses in a virtual environment. It was explained that they would be detecting hazards that were fully developed, and that such a hazard was one that would cause (the driver) to slow down or change direction in some way to avoid the hazard. The experimenter gave a full explanation accompanied by a demonstration in how to use the apparatus to control the vehicle in the virtual environment. Participants were shown how to use the gas, brake, how to steer and how to use the button press when they detected the hazard. They were also shown how to navigate through the virtual environment whilst obeying all traffic laws as they normally would if driving in the real world: such as stopping at red lights, approaching slowly at closed junctions and use of indicator signals etc. Each participant was given time for a test drive in order to use the set-up comfortably. Participants’ eye movements were calibrated before each course.

Participants then began to drive whilst their eye movements were recorded. The order of the eight courses driven was randomized. Throughout each course, the experimenter gave simple navigation instructions such as “turn first right” or “follow the road”. These instructions were given at least five seconds in advance of any visible hazardous situation in order for the instruction to be fully processed before encountering the hazard. Participants pressed the button as soon as they saw a hazard. For the four courses containing hazards, the experimenter stopped recording the eye movements after the first or second hazardous event had occurred and the participant was asked to stop the vehicle. There were six hazards across the four courses. For the four courses that did not contain hazardous events, after a certain location (known to the experiment only) was reached in the drive, the experimenter stopped recording eye movements and asked the participant to stop the vehicle. The experiment lasted one hour.

3.2.4.2 Non-driving task

Participants were instructed that they would be performing a hazard perception task where they would be watching a series of video clips of driving situations and would press the button on the steering wheel when they detected a hazardous event. The same definition of a fully developed hazard was given as that used for the active task. Eye movements were calibrated before each video. Participants were instructed to watch the video as if they were the driver. Although participants were instructed to view the clips as if they were a driver, it was not possible to measure if this was what they did, since they were not requested to commentate or report on the clips. Participants viewed the eight video clips, presented in a randomized order, whilst their eye movements were tracked. They were asked to press the button as soon as they saw a hazard. Four of the courses contained six hazards, each ending a short time after the first or second hazardous event occurred. The four non-hazardous courses were terminated at the same section of course as in the active driving condition. The experiment lasted one hour.

3.2.5 Design

For the eye movement and hazard perception performance analyses, the independent variable being manipulated was condition (Driving and Non-driving conditions). This is a between subjects variable where participants took part in either the Driving (n = 17) or Non-driving (n = 17) condition. Between subjects *t*-tests were used to determine significant differences in eye movement and reaction time measures.

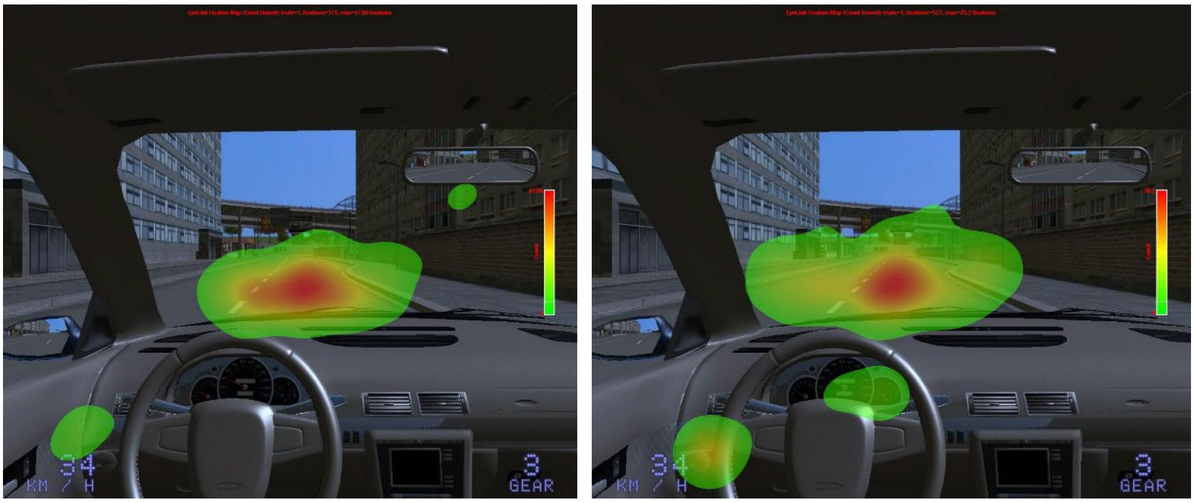
3.3 Results

For eye-movement analyses, only the four courses that did not contain hazards were considered, to avoid hazard specific artefacts. Hazard detection times are also reported, including response accuracy, the time to see the hazard and time to verify the hazards. All reaction time data was manually coded by viewing the recorded video files on a frame-by-frame basis and recording the event related timestamps.

3.3.1 Eye movement analyses

Eye movement data were averaged and collapsed across the four courses. The specific area of interest is that of the roadway (Figure 3.3) which excludes vehicle specific areas such as rear-view mirrors, wing mirrors and speedometer. Each measure was compared across the driving and non-driving conditions.

Figure 3.3. Illustration of the visual area of interest (roadway) highlighted in yellow. Screen dimensions: 1280 × 1024 pixels (41.9 × 33.4 cm; 38.5 × 31.1 deg). Interest area dimensions: 1280 × 266 pixels (41.9 × 8.7 cm; 38.5 × 8.3 deg).



(a) (b)

Figure 3.4 Examples of individual participant density heatmaps showing the distribution of fixations for (a) the driving and (b) non-driving conditions.

First, to investigate road scanning behaviour, the standard deviations of the x-axis and y-axis fixation locations were measured within the roadway field of interest illustrated by Figure 3.3. A larger standard deviation of the distribution of fixation locations would equate to a larger spread in eye movements; suggesting increased scanning of the road. Figure 3.4 provides a representation of the distribution of fixation locations for both driving and non-driving conditions in the form of density heat maps.

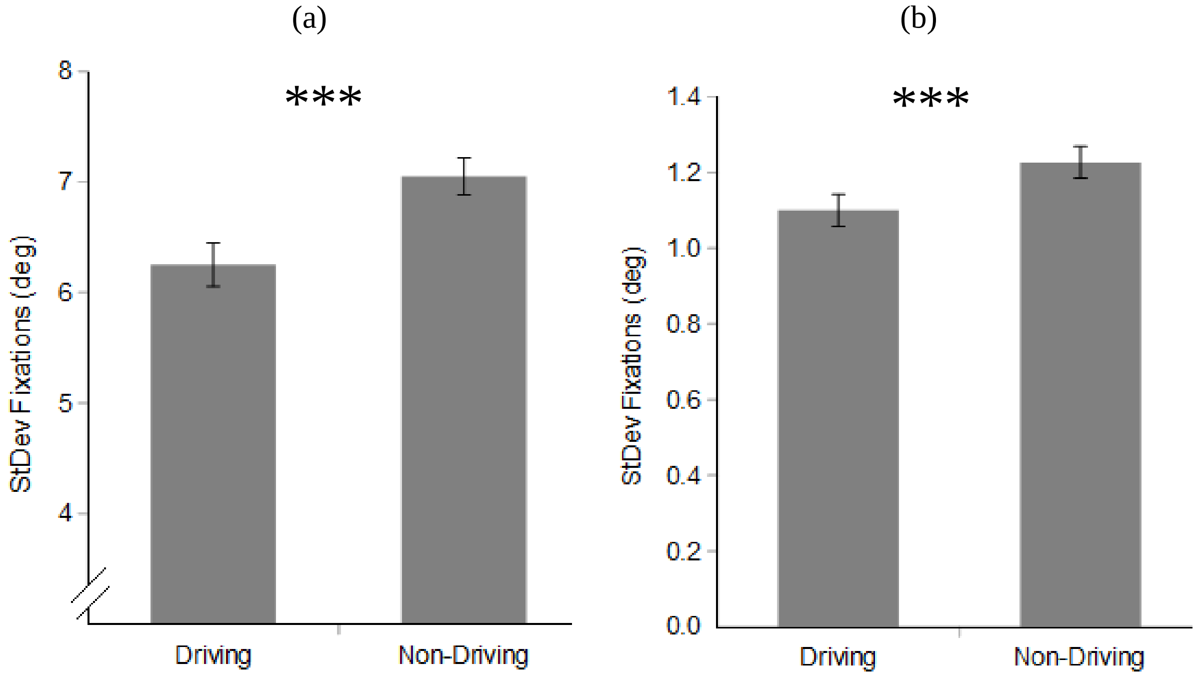


Figure 3.5. Mean standard deviations of (a) horizontal fixations, (b) vertical fixations across driving and non-driving conditions. Error bars show standard error of the mean. *, ** and *** denotes significance at the 0.05, 0.01 and <0.001 levels respectively.

Figure 3.5 shows the horizontal (a) and vertical (b) distribution of eye movements along the roadway for each condition. The distribution of fixations was larger for both the horizontal and vertical directions for the non-driving condition. Between-subjects *t*-tests revealed the difference to be significant (horizontal: $t(32) = 4.29$, $p < .001$, $d = 1.52$; vertical: $t(32) = 3.19$, $p = .001$, $d = 1.13$).

To investigate how far, on average, along the road participants fixated, the mean y-axis fixation was measured. This was measured as an angle (degrees), from the top of the screen (0 deg) to the bottom (31.1deg). A larger value thus equates to individuals looking lower down in the display and thus closer to the front of the vehicle.

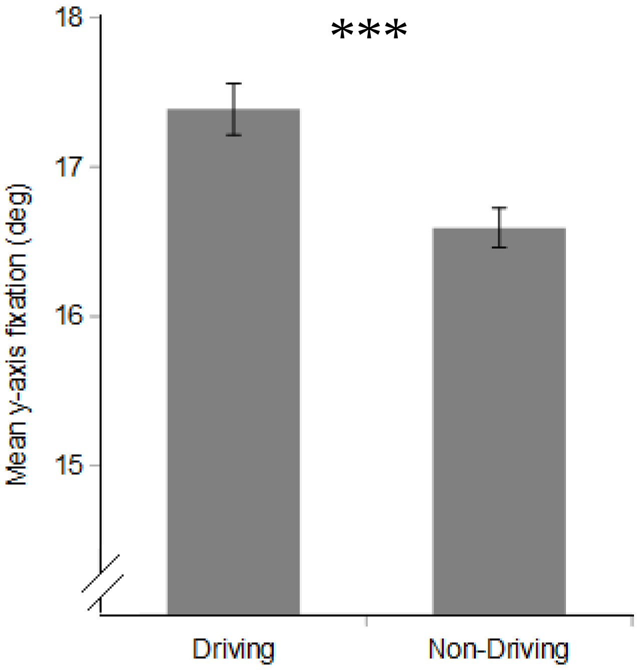


Figure 3.6. Mean y-axis fixation for driving and non-driving conditions. Error bars show standard error of the mean.

Figure 3.6 shows the differences in mean y-axis fixations for each of the driving condition. It was found that those in the driving condition fixated lower down in the scene than the non-driving condition. This difference was statistically significant ($t(32) = 7.48$, $p < .001$, $d = 2.54$).

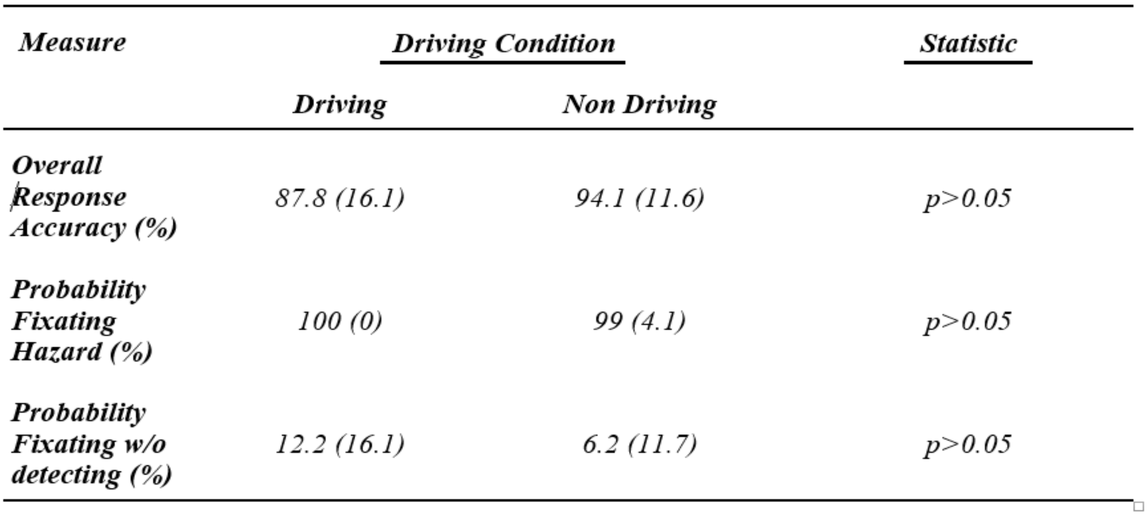
Although absolute differences may be modest, in terms of distance on the road, it is important to note that several metres of the simulated roadway will correspond to a relatively small visual angle. It was not possible to accurately calculate the absolute distances along the road because “ground truth” information concerning the simulated depth distances and dimensions of the road was not available. It is also important to note that although data were collapsed across courses, Multivariate analyses (MANOVA) revealed similar significant overall effects which suggest the effects are consistent across courses (horizontal scanning: $V = 0.53$, $F(4,29) = 4.91$, $p < 0.001$; vertical scanning: $V = 0.57$, $F(4,29) = 9.46$, $p < 0.001$; mean y-axis fixation: $V = 0.7$, $F(4,29) = 16.83$, $p < 0.001$).

One other important point to note is that these eye movement measures were averaged across the whole course, and thus it is unclear whether the differences in eye movements were consistent across time. However, there was an attempt to control for this by using courses which remain uniform across time (see section 2.1.3). That is, the environment, road events and stimuli did not change throughout the course. As such, it was predicted that these differences would remain consistent across time, across different sections of the road.

3.3.2 Hazard detection performance

Response accuracy to the hazards was recorded as the mean probabilities for detecting the hazards, the mean probabilities for fixating the hazards and the mean probabilities for fixating the hazard but not detecting it. This was recorded for the driving and non-driving conditions. The mean values can be viewed in Table 3.1. Response accuracy was high in both conditions (Table 3.1). This was likely due to the highly attention capturing hazards used.

Table 1. Mean probabilities for hazard detection and standard deviations.



Measure	*Driving Condition*		*Statistic*
	Driving	*Non Driving*	
Overall Response Accuracy (%)	*87.8 (16.1)*	*94.1 (11.6)*	*p>0.05*
Probability Fixating Hazard (%)	*100 (0)*	*99 (4.1)*	*p>0.05*
Probability Fixating w/o detecting (%)	*12.2 (16.1)*	*6.2 (11.7)*	*p>0.05*

Overall reaction times were measured using the button press. This reaction time was taken as the latency from the first frame of the video when the hazard appeared to when individuals pressed the button.

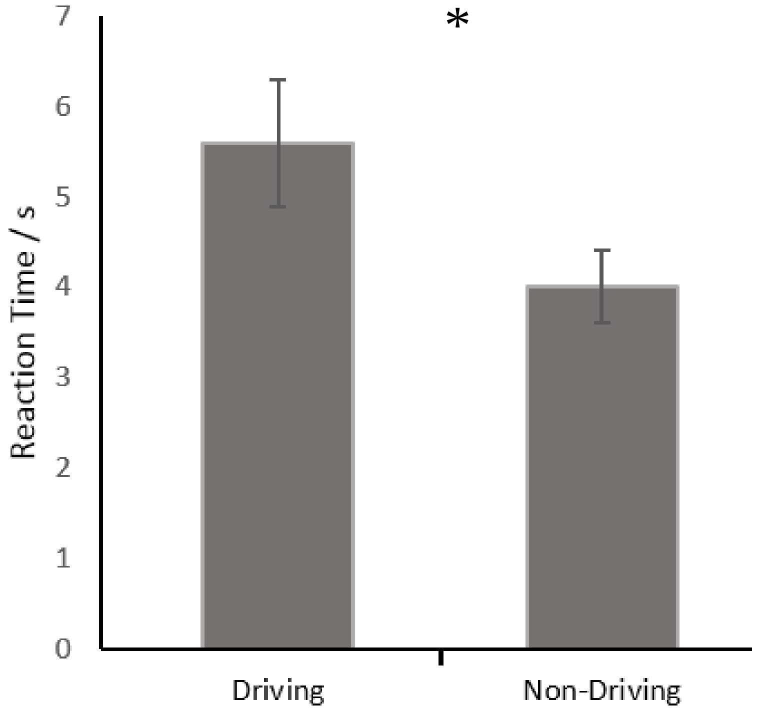


Figure 3.7. Overall reaction time to the hazards for driving and non-driving conditions. Error bars show standard error of the mean

Figure 3.7 shows the differences in reaction time between driving and non-driving conditions. Hazards in the driving condition were responded to slower than those in the non-driving condition. This difference was significant ($t(32) = 2.0$, $p = 0.042$, $d = 0.7$).

Two hypotheses were proposed in explaining this increased latency for participants in the driving condition. The first is the idea that there is a longer latency in seeing the hazard. That is, participants do not fixate as quickly when driving. Alternatively, the latency may be the result of a processing, or verification issue, in that participants successfully fixate the hazard but it takes longer to acknowledge the hazard. Indeed, it may be possible that both of these factors result in the longer latencies observed.

As described in the Methods 3.2.3, the average time it takes to see the hazards (Time to See) was calculated as the time between when the hazard first appears to when participants first fixate on or near the hazard. Processing time (Time to Verify) was calculated as the time from the initial fixation to when participants responded using the button press. Figure 3.8 shows these measures plotted for the two conditions. If either the Time to See or Time to Verify accounts for the reaction time latency across the tasks, a statistical interaction between these two timing measures and the two driving conditions should be observed.

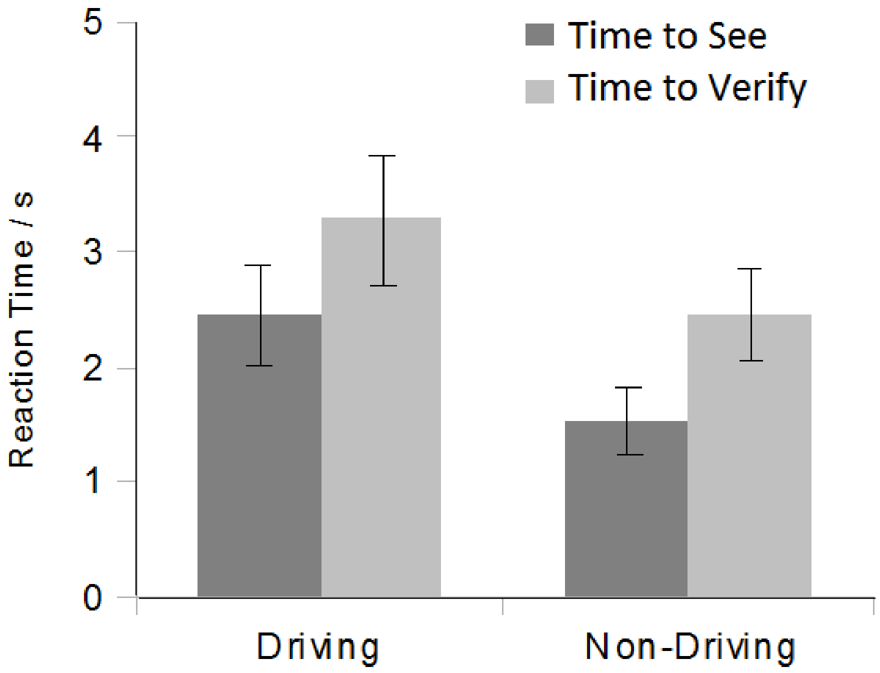


Figure 3.8. The interaction of the average time taken to see and verify the hazard. Error bars show standard error of the means.

A 2x2 mixed measures ANOVA was conducted using driving condition (driving and non-driving) and timing measure (Time to See and Time to Verify) as independent variables. There was a main effect of driving condition on the overall timings (*F*(1,32)=8.69, *p*=0.007), where those in the non-driving condition responded to the hazards faster overll. This is simply repeating the overall reaction time measure above. There was also a main effect of the timing measure (*F*(1,32)=8.6, *p*=0.008), where, independent of task, the time to verify took longer than the time to see the hazards. This may be attributed to the largely contextually salient nature of the hazards which could be attracting eye movements more exogenously – which would require less processing time.

Importantly however, the ANOVA showed that there was no significant interaction between these variables (*F*(1,32)= 0.14, p=0.77) . It is inferred therefore, that both the Time to See the hazard and the Time to Verify the hazard contribute to the increased latency to respond to the hazard in the driving task.

3.4 Discussion

Current models of visual guidance in complex scenes are often derived from relatively simple tasks using stimuli that do not represent a naturalistic setting. The primary aim here was to therefore measure and quantify, under controlled conditions, any differences in eye movement behaviour and hazard detection times between active driving and non-driving conditions. A number of differences were found. Namely that individuals scan the roadway more and are faster to respond to hazards during passive video driving tasks compared to simulated driving.

Before the results are discussed in more detail, it is important to briefly highlight the research by Underwood, Crundall, et al. (2011). They reviewed a number of studies to compare the visual behaviour between different experience groups across different methods of analyses, namely: video tasks, simulated tasks and real driving. They showed that there are clear similarities across these tasks. For example, inexperienced drivers may scan the roadway less than experienced drivers across both video and active driving task (e.g. Crundall & Underwood, 1998; Underwood, Chapman, et al., 2002). These similarities provide relative validity across tasks; where *similar patterns* of behaviour are observed across different testing conditions (Godley, Triggs, & Fildes, 2002). Relative validity is important, particularly if we are able to differentiate between safe and non-safe drivers using simpler methods in the laboratory. Therefore the importance and usefulness of video based tasks should not be disputed. However, absolute measures, for example, exactly how much less inexperienced drivers scan than experienced drivers, may differ across video and active tasks. Such absolute comparisons of behaviour can only be made across driving methods if stimuli and environments are as similar as possible.

In this current experiment, video recordings of the driving simulator environment were used for the non-driving condition, making the stimuli the same across conditions allowing for absolute behavioural comparisons. In line with the predictions made, there were some differences found in the tasks measured, each of which are discussed below. The main eye movement and reaction time findings are discussed separately with possible explanations for the results before describing how these results contribute to our current understanding of driving and more generally, to models of eye movement behaviour during everyday tasks.

3.4.1 Eye Movement Behaviour

There were a number of visual behaviour differences across driving and non-driving tasks. Overall, individuals searched less of the scene with their eyes when performing the driving task than the non-driving task; as indicated by the smaller distribution of fixations across both the horizontal and vertical planes (Figure 3.5). The main reason proposed here is that there is increased demand placed upon the visual and attentional systems by the interactive nature of the active task.

Perceptually, certain areas of the environment are likely more informative to an active driver than a passive viewer in order to successfully navigate the environment, and thus drivers may dedicate fewer resources to generally scanning the roadway in an active task. Specific locations within the scene may be important when driving. The focus of expansion (FoE) is the apparent point from which motion vectors flow, and normally corresponds to the direction of heading

(Gibson, 2014; Warren, Kay, Zosh, Duchon, & Sahuc, 2001). Some research suggests that the area on or near the FoE is typically favoured by drivers (Mourant & Rockwell, 1972; Underwood et al., 2003) because it provides information to the drivers about vehicle direction. However, this source of visual information is likely less favoured in complex driving where for example, the FoE may exist only beyond a bend, it may be too degraded to be of any use (as will likely be the case in low resolution simulated driving experiments), or it may not exist at all (such as approaching an intersection). More recently then, gaze has been found to be directed towards points in space one wishes to pass (Robertshaw & Wilkie, 2008; Wilkie et al., 2010; Wong & Huang, 2013) typically around several seconds before the vehicle reaches the gaze point (Land, 2006; Underwood, 2007). For locomotor steering, a number of different sources of information, as described by Kountouriotis et al. (2013) are thought to influence control. These include visual direction (Rushton et al., 1998), the lane splay angle (Li & Chen, 2010) and the visual appearance of lane markers (Wallis, Chatziastros, & Bülthoff, 2002). What is important here is the idea that these sources of information allow successful control and guidance through the driving environment and are therefore useful only for an active driving task. If one is not actively controlling the vehicle, there is little need to fixate on or near these sources of information, because direction information is less critical when not actively controlling the vehicle through an environment. It is possible that observers can dedicate eye movements to searching the environment more exhaustively for hazards when not driving. Such a hypothesis could explain the difference between conditions for the distribution of fixation locations presented here (Figure 3.5).

Cognitive attentional factors could have also influenced the pattern of results here. There is likely to be a cognitive load imbalance across the driving and non-driving tasks. Specifically, the driving task required allocation of attentional resources to drive, including steering, braking and lane positioning. As mentioned, increasing cognitive load during driving tasks results in a decrease in scanning behaviour (Engström et al., 2005; Recarte & Nunes, 2003; Savage et al., 2013). Thus it is likely that the increase in cognitive load when performing the active driving task here could reduce the range of scanning behaviour.

There is also a possibility that the observed scanning differences in eye movements was simply due to less visual motion in one condition relative to the other. This is unlikely because of the design. For the eye movement analyses, each of the four courses driven and viewed were identical across conditions and contained the same number of turns with no differences in the number of lane changes across conditions. On average, the active driving condition was completed slower than the non-driving task, where analyses found a mean difference of 8.3 s (refer to Methods 3.2.2). One could argue that driving slower in the active condition than the driving speed in the video condition could deliver different visual motion across the conditions. However, on average, the 8.3 s difference was around 5% of the total drive—a proportion which is likely not large enough to induce large differences in visual motion processing.

It was also found that individuals tended to fixate closer to the front of the vehicle, and thus less far ahead along the road, in the active driving condition than the non-driving condition. This could be due to different use of information (e.g. to maintain lane position in the driving condition) or it could reflect biases in the non-driving condition. For example, it is well known that static scenes framed in a display monitor typically elicit a bias to fixate the centre of the image, regardless of content (Tatler, 2007; Vincent, Baddeley, Correani, Troscianko, & Leonards, 2009). The same eye movement behaviour is also seen in movie viewing paradigms (Cristino & Baddeley, 2009). If our data for the non-driving condition reflects this bias, it could be argued that the interactivity of the visuomotor task allows the visual system to override this phenomenon and allows visual attention to be allocated towards more task relevant information.

These differences in fixation patterns provide evidence to suggest that less naturalistic settings do not fully capture important subtleties about where gaze is deployed during natural tasks. This could be because non-active tasks do not elicit the same specific goal directed visual behaviour seen during more natural tasks where visuomotor control is incorporated. We propose that the different fixation patterns described here provide support for the claim that studying vision under the most naturalistic conditions delivers a different pattern of visual behaviour than for less naturalistic conditions.

3.4.2 Hazard detection

From the results obtained in this experiment, it is clear that individuals are faster at detecting hazardous situations when taking part in a non-driving hazard perception task than when driving. Participants were around 1–1.5 seconds slower to respond to the hazards in the driving task than the non-driving task. One could argue that differences in reaction times between conditions are due to a delayed motor response in the active task since the button must be pushed whilst also driving. The set-up was designed to reduce this possibility, with the response button located where the right thumb would naturally be when holding the wheel.

Two explanations are proposed here to explain the increased latency. First, it was identified that individuals scanned the roadway less in an active driving task and look closer to the vehicle (Figure 3.5 and 3.6). Drivers may be slower to identify the hazards because of this more impoverished search. The second idea relates to the problem of cognitive load. The multiple procedures in driving are comparable to dual tasking; that is, performing two or more activities concurrently. When dual-tasking, attentional limitations occur where cognitive load is high and, as a result, task performance is poorer, particularly on a secondary task (e.g. Pashler, 1998; Moors & De Houwer, 2006; Sala, Baddeley, Papagno, & Spinnler, 1995). Therefore, one may expect to observe longer processing times in the driving task. Statistically, both the time to first fixate the hazards and the time to verify the hazards appeared to influence hazard perception times together (Figure 3.8).

These reaction time findings again provide support for the idea that video-based methods of investigating driving behaviour are of limited utility, because they do not predict the slower reaction times that we find when participants are engaged in an active driving task.

3.4.4 Conclusions

The aim of this chapter was to provide insights into driving and eye movement behaviour methodology. Based on the idea that investigating eye movement behaviour may be more useful when investigated under the context of action, this chapter sought to compare driving and non-driving conditions while performing a hazard perception task to make an absolute comparison between the two kinds of task. A number of visual and behavioural differences across these two typical driving experimental methods were identified and it can be concluded that the interactivity of simulated driving places more of a demand upon the visual and attentional systems than simply viewing first-person-view driving movies. Therefore, video based methods do not always provide a valid proxy for active driving. In addition, more evidence is provided that the generation of models of eye guidance should ideally originate from more naturalistic methods (Borji et al., 2014; Johnson et al., 2014). There may also be implications for providing more ecologically valid driver training and assessment tools – these are discussed in the General Discussion (Chapter 7).

Chapter 4

Insights into individual differences in eye movements: A case for attentional function

This study explored how individual differences in visual cognition may correlate with ‘good’ visual scanning behaviour typically associated with ‘safer’ drivers. The competition for processing resources could limit efficient driving behaviour, both in terms of driving performance and eye movement behaviour. Therefore, those better able to deploy attention might show good visual scanning behaviour. An approach similar to that of ‘cognitive ethology’ (Kingstone et al., 2008) was taken, where the aim was to observe differences in eye movement behaviour occurring naturally, due to an individual's own underlying cognitive processes. This study also explored a range of visual cognition tasks to test the hypothesis that active visual attention tasks, requiring sustained attention and visuomotor control, will be the best predictor of visual scanning behaviour and driving performance. Before the study is described, some of the literature regarding eye movements and driving is recapped before exploring more specifically how an individual's visual attentional function might relate to visual behaviour and driving performance.

4.1 Introduction

As discussed in detail in section 1.3, an efficient visual strategy, as observed in experienced drivers, is to exhibit a wide horizontal visual search and to make use of the vehicle mirrors (Alberti, Shahar, et al., 2014; Crundall et al., 2003; Crundall & Underwood, 1998; Falkmer & Gregersen, 2005; Underwood, Chapman, et al., 2002). This type of visual behaviour is important because it is likely representative of someone who is scanning the road for potential hazards, e.g. looking to the side pavements for possible pedestrians stepping out, inspecting slip roads often for joining traffic, or looking around for possible undertaking or overtaking vehicles in demanding situations. It is important to understand why some individuals may exhibit less effective visual strategies when driving, particularly between experienced and novice drivers. If we can identify the reasons for the different visual strategies, this knowledge could lead to development of visual training and assessment tools for driving.

It was suggested in Section 1.3.3 that an individual's ability to handle the cognitive demands of the driving task may be a likely source of the individual differences in eye movements that are observed. Studies show that by increasing the cognitive load when driving, by introducing a secondary mental task, overall scanning behaviour decreases (Engström et al., 2005; Recarte & Nunes, 2003; Savage et al., 2013). In Chapter 3, individuals' eye movement behaviour during a passive video-based was compared to eye movement behaviour in an analogous active simulated driving task. It was found that those who performed the active driving task scanned the roadway less than those who performed the video watching task. Because the apparatus, visual stimuli and environment were identical across the two tasks, it was possible to infer that differences in eye movement behaviour were in part due to the additional attentional demands involved with actively controlling the vehicle. Thus it is plausible to suggest that the improvement in visual behaviour we see in experienced drivers is because the process of controlling the vehicle has become more of an automated process, freeing up resources to visually attend to other areas of the driving environment. Therefore, the question is proposed, do those with better ‘attentional function’ distribute their eye movements more appropriately when driving? (see Section 1.3.3)

Although little is known about the link between attentional function and eye movement behaviour, tasks such as the Useful Field of View (UFOV), demonstrate the links between attentional function and driving performance. To recap, this task aims to assess aspects of attention such as perceptual span, visual processing speed and working memory function. Better performance on this task, thereby demonstrating higher level of attentional function, has been linked to better, and indeed, safer driving behaviour (Ball, Owsley, et al., 1990; Ball et al., 1993; Clay et al., 2005) (Section 1.3.3).

The limits of the UFOV should be highlighted here however. Bowers et al. (2011) noted that the UFOV task only measures selective and divided attention, it does not require sustained attention (attention over longer durations) to complete. In addition, the stimuli used are static. Compare this to real life driving, where sustained attention (attention over longer durations of time) to dynamic stimuli is crucial to driving safely. Bowers et al. (2011) explored how performance on a multiple object tracking (MOT) task, where attention must be directed to multiple moving objects whilst ignoring distractors, relates to driving performance. Those who performed worse on the MOT task also had higher error scores on a road test (Bowers et al., 2011). In addition, MOT was also a stronger predictor than UFOV in predicting the ability to detect hazardous pedestrians during simulated driving in those with central visual field loss (Alberti, Horowitz, Bronstad, & Bowers, 2014). These results highlight not only the link between attentional function and driving but also suggest the importance of incorporating a dynamic assessment of sustained visual attention when studying driving performance – which is therefore included in this experiment.

4.1.1 Aims and hypotheses

There are two main aims in this study. The first is to identify if individuals who exhibit better attentional function also show better eye movements behaviour when driving. In other words, are differences in eye movement behaviour partly due to one's ability to successfully manage the attentional demands of driving? Participants were given three visual attention tasks to measure attentional function and then asked to drive a number of routes in a driving simulator programme, whilst eye movements were tracked. The attention tasks attempted to target a number of visual and attentional components used in driving, including divided and sustained attention, attention alertness, spatial awareness and visuomotor control. Performance on the attention tasks was compared with visual behaviour on the simulated driving task. It was hypothesised that those who performed better in the attention tasks, thereby demonstrating better general attentional function, would exhibit more effective or efficient visual behaviour while driving.

The second aim was to further the understanding of the tasks that may be useful to assess driving performance. Whilst maintaining the previously mentioned dynamic and sustained attentional properties of a task, it was investigated whether tasks incorporating active visuomotor control predict both driving performance and eye movement behaviour. Performance across a passive multiple object tracking task and two ‘object avoidance’ tasks, both of which incorporated a visuomotor control component, was compared. It was hypothesised that better performance on each of the two object avoidance tasks would more strongly predict more efficient visual behaviour and driving performance than the multiple object tracking task. This is because driving also involves active visuomotor control. Details of these tasks are explained in section 4.2 below.

4.2 Methods

4.2.1 Participants

Twenty-seven participants took part in the study (12 males). Two participants were excluded due to poor eye movement calibration (>2 deg). This left a sample of twenty-five (11 males) with an age range of 18-51 years (mean age = 22.5 years; St. Dev = 6.6). All participants had normal or corrected-to-normal vision and were recruited through the University of St Andrews SONA experiment participation scheme. They were paid £10 for participation. All participants had held a drivers' licence for at least one year (mean = 4.3; St. Dev = 5.7) and were from countries where driving on the left (e.g. UK) is standard. Participants reported having no previous experience with a driving simulator. Given the possible similarities between the driving simulation and attentional tasks to a video game environment, participants were recruited with little or no video game experience. This experience did not differ significantly across the high and low performance groups. The study was approved by the University of St Andrews University Teaching and Research Ethics Committee (UTREC).

4.2.2 Stimuli and Apparatus

All testing was conducted at the University of St. Andrews' Social Immersion suite. Participants performed both the driving simulation and attentional tasks on the same viewing screen. Images were projected using an NEC MT1065 video projector. Participants sat 338cm from the projection screen which had dimensions of 377cm (58.3 deg) x 212cm (34 deg). See Figure 4.1 for the basic apparatus set-up.

Figure 4.1. Photograph showing the basic experimental set-up. Participants sat 338cm from the projection screen. Screen dimensions: 377cm (58.3 deg) x 212cm (34.8 deg).

4.2.2.1 Driving Simulation

The driving simulator software used was City Car Drive (Forward Development, 2014) (see General Methods). Side mirrors, a rear-view mirror and speedometer were available to the participants on-screen (see Figure 4.2 for instrument layout). The simulated field of view was programmed to be 85 degrees, similar to that in a real car. A Logitech Driving Force GT steering wheel and pedals combination was used to control the vehicle. The virtual driving environments consisted of three courses; 1) a country highway 2) an urban driving scene and 3) a motorway environment (Figure 4.2). Courses are ordered here by increasing road complexity. For example, the country highway consisted of only single and dual lane carriageways with no chance of encountering pedestrians. The urban environment contained a number of extra visual stimuli such as pedestrian crossings and contained sections with multiple lanes (up to three at times). Finally, the motorway consisted of fast moving traffic with multiple driving lanes and slip roads. Each course contained a medium-level amount of traffic. The driving simulator software also tracked driving performance using a points system (see Measures section for more details).

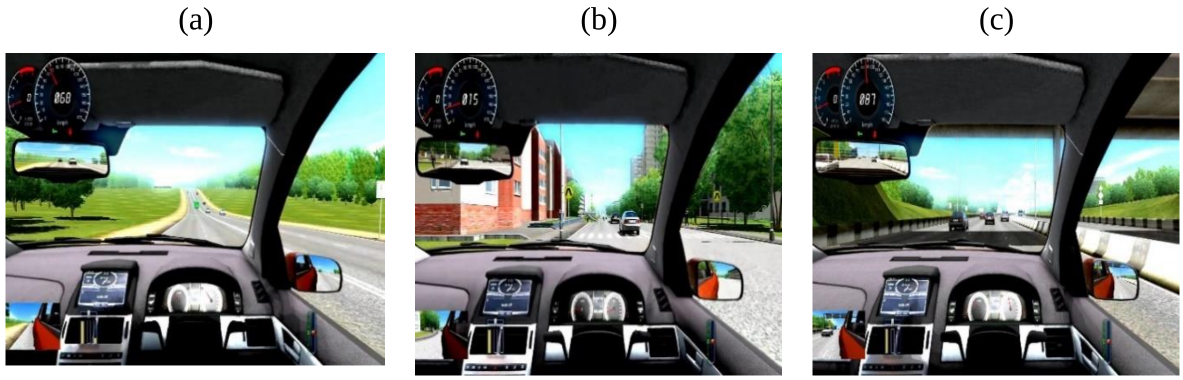


Figure 4.2. Screenshot images of the typically environments encountered in the (a) country highway, (b) urban area and (c) motorway. Note the speedometer is located in the top-left of the scene, with centre rear-view mirror below it, and passenger side mirror to the lower left

4.2.2.2 Visual Attention Tasks

Multiple Object Tracking. The MOT task was programmed using EventIDE software (OkazoLab Ltd). Ten stationary white circles (diameter = 2.2 deg, luminance = 21.93 cd/m2) appeared on a black background on the screen (58.3 deg x 34.8 deg). After 50ms, 5 flashed orange for 2 seconds. They returned to white and all ten circles then moved around the display at random for 7 seconds. Motion speeds ranged from 4 deg/s to 9 deg/s and directions followed a random walk. Circles did not overlap each other while moving. When the motion stopped, all ten circles remained stationary until the participant indicated which five had originally flashed, by clicking on each with a mouse (Figure 4.3). Immediate feedback was given to the participant indicating how many (out of 5) had been correctly selected. The percentage correct for each trial was taken as the performance measure, averaged across all 30 trials.

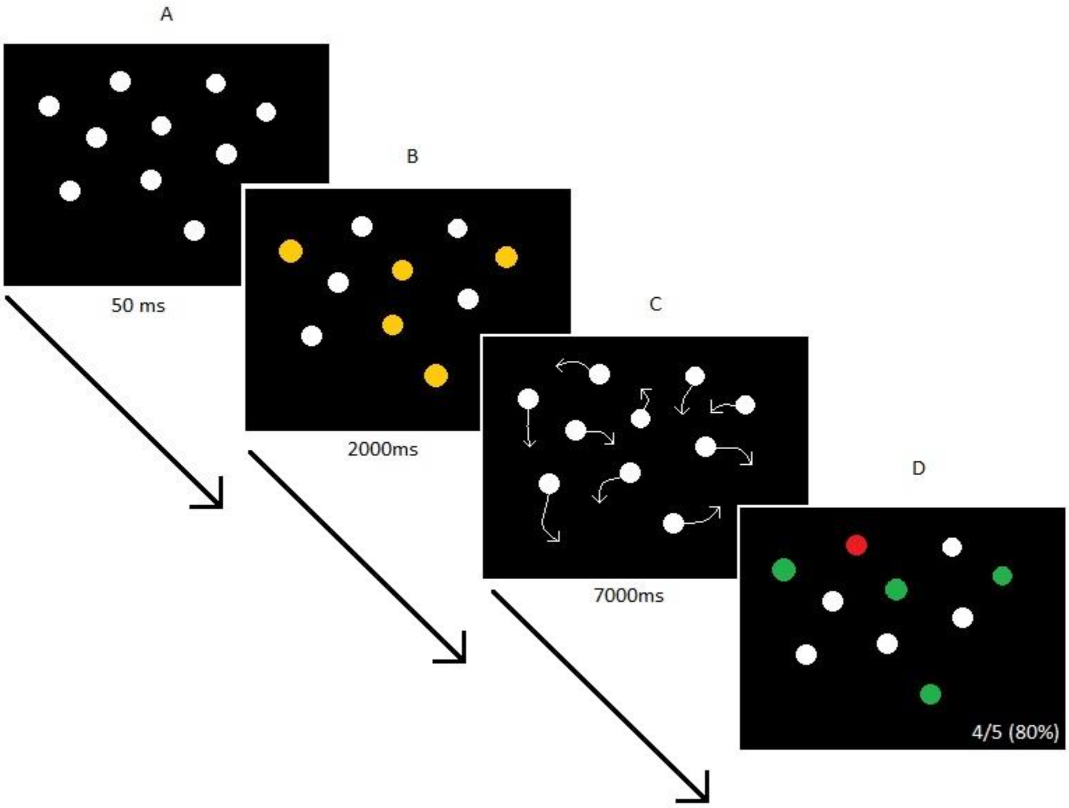


Figure 4.3. Multiple Object Tracking Task. Participants are presented with the stimuli (A) briefly before five dots begin to flash orange (B). All dots turn back to white and then move randomly around the scene for seven seconds (C). Motion stops and the participant must select the five dots which had flashed orange (D). In this example, the participant has correctly identified four out of a possible 5 targets. (Note, the final positions of the dots is not the same as the original location as pictured here– this is for illustrative purposes only).

2-Dimensional Object Avoidance. Participants controlled a blue circle (diameter = 2.0 deg, luminance = 2.86 cd/m2) on the screen using the mouse. The task was to move the circle left-right or up-down the screen (size 34.5 x 32.2 deg) to avoid it touching a number of moving red circles (diameter = 2.0 deg, luminance = 2.86 cd/m2). Initially, three red circles were present. After 14 seconds a new red circle appeared, and so on until the controlled blue circle collided with one of the red circles (Figure 4.4). The total time of each trial was taken as a measure of performance where a longer time indicates better performance. Times were averaged across three trials. (Note, software for this task used was freely available online and was accessed by *www.funnygames.co.uk/avoid-the-balls.htm*. It was not programmed by the experimenters and therefore, specific parameters of the task e.g. circle movement speed, could not be altered or recorded.)

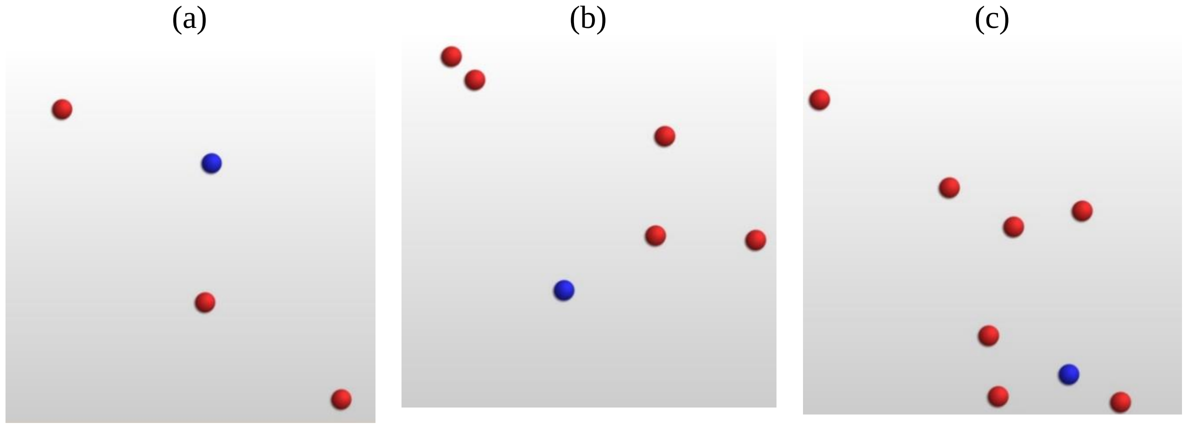


Figure 4.4. A static representation of the 2D object avoidance task. The task starts with three red balls moving (a), then gets increasingly more difficult such as in (b) with five balls and in (c) with seven balls.

3-Dimensional Object Avoidance. Using the right and left arrows on a keyboard, participants controlled the left-right motion of a small grey triangular object (size = 4.1 deg at base) through a virtual 'field' presented on screen that simulated self-motion in depth towards a clearly defined horizon (58.3 x 33 deg). The task was to avoid the red and yellow cubes that blocked the target's path (maximum size = 5.1 x 5.1 deg, luminance = 7.6 cd/m2) (Figure 4.5). Participants could not control the speed of the object, only move the target triangle left or right to avoid the oncoming cubes. The software tracked the performance using a score system where the longer the participant was able to avoid the cubes, the higher the score. Scores were averaged across four trials. (Note: The task used was freely available online and was accessed by *www.cubefield.org.uk*. It was not programmed by the experimenters and thus, the specific parameters of the task, e.g. speed of forward motion could not be altered or recorded.)

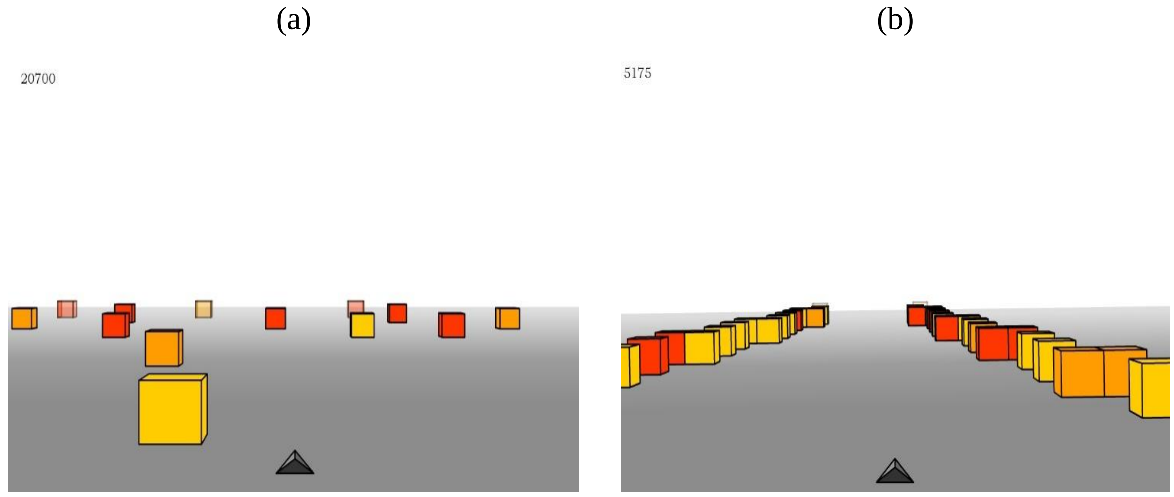


Figure 4.5. Static representations of the 3D object avoidance task. In (a) the participant is navigating an area where the cubes are randomly located. In (b), the participant has reached an area where the cubes form a more unified tunnel through which to navigate.

4.2.2.3 Eye movement recording

An SR Eyelink II eye tracking system was used to record eye movements as described in the General Methods. An initial 12 point screen calibration at a distance of 98cm (using a secondary screen) was done to ensure that recordings had a mean spatial error of less than 0.5 deg. This screen was lowered away from the field of view during recording. A 9 point depth calibration was conducted on the stimulus display screen at a distance of 338cm to correct for depth parallax. Participants were free to move their head.

4.2.3 Measures

4.2.3.1 Task Performance Ranking

As an overall measure of attentional function, participants' performance on each of the three visual attentional tasks was recorded. An averaged rank system was used to split participants into low task performance and high task performance groups. Specifically, participants' task performance was ranked (out of 25 participants) for each of the individual tasks. The rank position was then averaged across all three tasks before a median split of the total average ranks was used to separate high performers and low performers. For example, if an individual ranked 2/25 in the MOT, 3/25 in the 2DOA task and 4/25 in the 3DOA task, then the averaged rank score would be 3; which would place this individual in the high task performance group. And conversely, for example, an individual who ranked 20/25 in the MOT, 21/25 in the 2DOA task and 22/25 in the 3DOA task, would deliver an averaged rank score of 21; which would place this individual in the low performance group. Eye movement behaviour and driving performance was compared across these two groups (see below). The median rank was calculated to be 14.

4.2.3.2 Eye Movement Measures

All eye movement information was recorded and collated via SR Research Data Viewer software. Using this software, the driving scene was divided into four different interest areas (Figure 4.6): the rear-view mirror, driver-side mirror, passenger-side mirror and the roadway. Note, the passenger-side mirror was superimposed to the left of the screen as shown in Figure 4.6. Speedometer fixations were not included in the analyses.

Figure 4.6. Static illustrations of each interest area. 1) Rear-view mirror (16 deg x 5 deg); 2) Passenger-side mirror (12 deg x 5 deg); 3) Driver-side mirror (19 deg x 7 deg); 4) Roadway (58 deg x 27 deg at maximum length and height).

Fixation locations. The standard deviations of eye fixation locations along the vertical and horizontal axes (using x and y-axis pixel coordinates) were measured to provide an indicator of the spread of visual attention. These were converted from screen units into degrees. A larger standard deviation would suggest a larger distribution of fixations and thus a larger spread of visual attention. Only fixations located within the roadway were included in this analyses; mirror or speedometer fixations were excluded.

Mirror Interest Area analyses. To measure how much individuals inspected the vehicle mirrors, the total average fixation count (as a percentage of the total fixations) and total average fixation dwell time (as a percentage of the total drive time) was calculated for the interior mirror, driver-side mirror and passenger-side mirror.

Visual processing. Average saccade velocities were recorded to infer the efficiency at which the scene was sampled, where faster average saccades may suggest increased information processing. Average saccade sizes were also measured. Saccade analyses were performed for the overall scene (i.e. all interest areas) and for the roadway interest area separately. Fixation durations and the number of fixations were also recorded for the roadway and the overall scene as a measure of cognitive processing. Longer fixation durations and more fixations made would suggest longer processing times.

4.2.3.3 Driving Performance

Driving performance was measured on a point system tracked by the simulator software. 500 points were allocated to each 'minor' infringements such as driving 10kmph over the speed limit, not maintaining lane positioning, obstructing another vehicle causing it to break unexpectedly and not observing priority at junctions. More 'major' infringements were scored 1000 points and were characterised as accidents or dangerous driving, for example, crashing into another vehicle or pedestrian or driving 20kmph over the speed limit. The total points awarded provided a measure of driving performance where a larger number of points suggests poorer driving performance. A single total measure of driving score was recorded.

4.2.4 Procedures

Participants were instructed they would be completing a two-part study on driving and visual attention, one part being the driving simulation and the other being completion of the visual attentional tasks. All participants first completed a questionnaire examining their level of vision and driving experience. Potential participants completed a Landolt C visual acuity test and were included if acuity was measured as <2.0 Minimal Angle Resolution. Thirteen participants performed the driving task first and twelve participants performed the attention tasks first. Breaks were given between tasks and at any point required by the participant.

For the driving task, participants were presented with the first person viewpoint of a car in a large car park on screen. They were instructed in how to use the car: including how to steer, use the pedals, turn signals and mirrors. They were then given five minutes to practice the simulated driving in the car park and informed they would be completing a number of set routes. Eye movements were calibrated using the Eyelink II at both the calibration distance and at the video screen distance. Calibration was done before each course and recording began at the start of each course just as participants began to drive. Each of the three courses was driven in a randomized order. For the country highway, participants were simply instructed to follow the road at the beginning of the drive. For the motorway course, participants were again instructed to follow the motorway until a certain exit was to be taken. For the urban district, participants were instructed to take three turns (a left turn, a right turn and another left turn) at certain point on the course. These instructions were given at least 10 seconds in advance of the turn to avoid awkward or dangerous manoeuvring of the vehicle by the participant. After a certain location was reached (known to the experimenter) in each of the courses, recording of the eye movements stopped and the participant was instructed to stop the vehicle.

Either after the driving task or before, participants completed the three attention tasks. The order of the attention tasks was completed based on a Latin square design to guard against practice effects. Although not relevant for the purposes of this current study, eye movements were calibrated and tracked for each of the tasks. For the MOT task, participants were instructed they had to track, with their eyes, five circles on screen amongst a total of ten. They were told that they should pay attention to the five circles that flashed orange at the beginning of each trial and try to maintain attention on these circles as they moved around the screen. Five practice trials were given before they completed all thirty experimental trials. For the 2DOA task, participants were instructed they were to control the blue ball on screen with the mouse and had to actively avoid the moving red balls. They were informed that more red balls would continue to appear as the trial went on. One practice trial was given before three experimental trials were completed. Each trial ended when the blue ball touched one of the red balls. For the 3DOA task, participants were instructed they would have to control the small grey triangle at the bottom of the display and navigate the 3D environment using the left and right arrow keys on a keyboard. They were instructed to try and avoid the red and yellow cubes which appeared. Each trial ended when one of these cubes was hit. The complete experiment lasted a maximum of two hours. Two practice trials were complete for four experimental trials.

4.2.5 Design

For eye movement and driving performance analyses, the independent variable was the task performance group (high task performance and low task performance). This is a between subjects variable where, based on their averaged rank performance during the visual attention tasks, participants were either classed as low task performers or high task performers. Between measures t-test were used to test for significant differences in eye movement behaviour and driving performance across these two groups. Pearson correlations were also performed to identify if performance in each of the individual visual attention tasks correlated with the main eye movement measures of horizontal visual scanning and driving score.

4.3 Results

4.3.1 Task performance analyses for eye movement measures and driving performance

Participants were split into either high or low task performance groups based on their average rank scores for the attentional tasks (section 4.2.3). Figure 4.7 shows the raw scores in each of the attention tasks for each participant. Dark bars indicate participants who were assigned to the high performance group, and light bars to those in the low performance group.

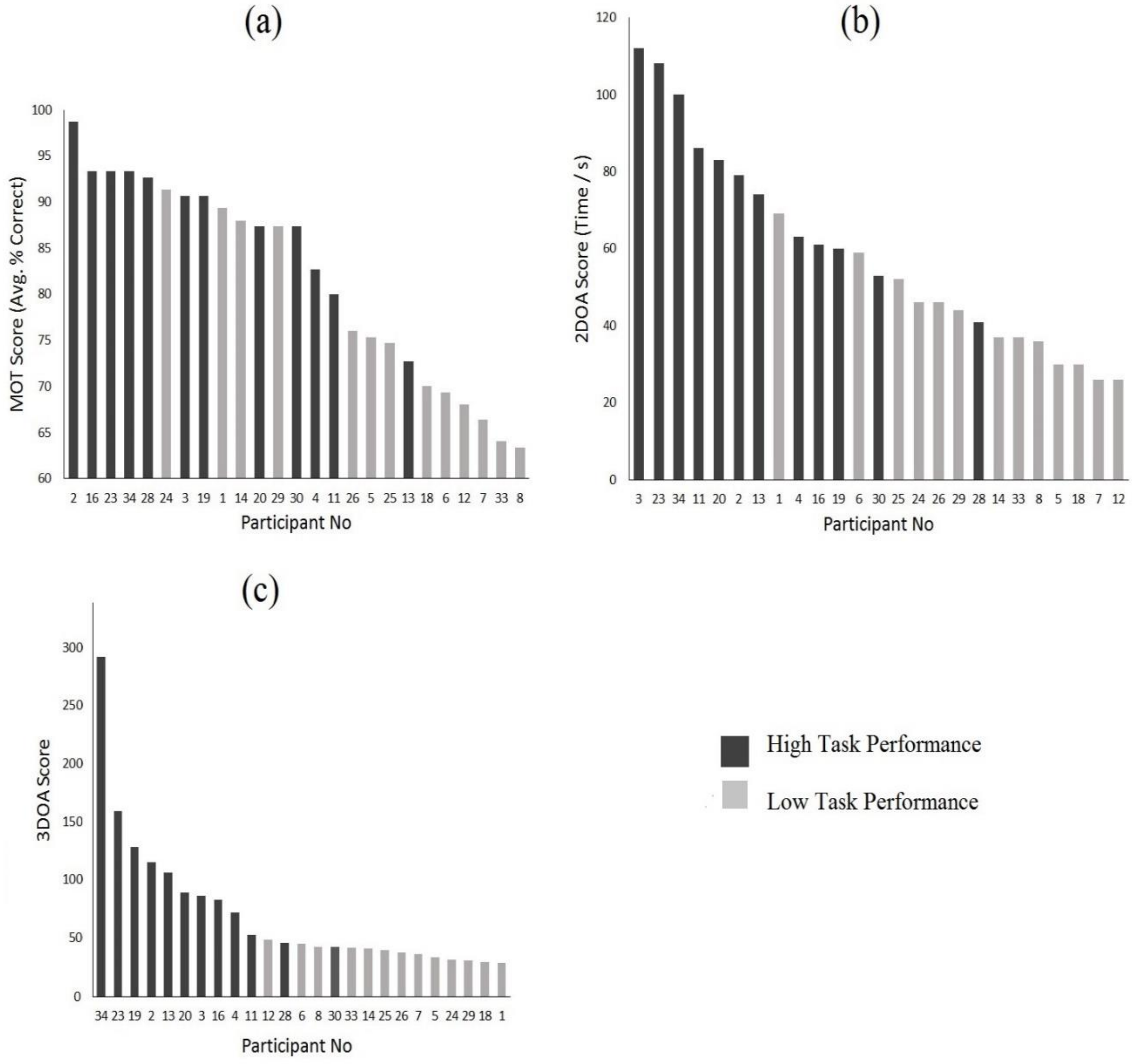


Figure 4.7. Raw scores for each task and for each participant. (a) MOT task, (b) 2DOA task, (c) 3DOA task.

A number of eye movement measures and driving performance were compared across these two group using between subjects *t*-tests. For most of the measures, the data across the three different courses were collapsed by averaging the data.

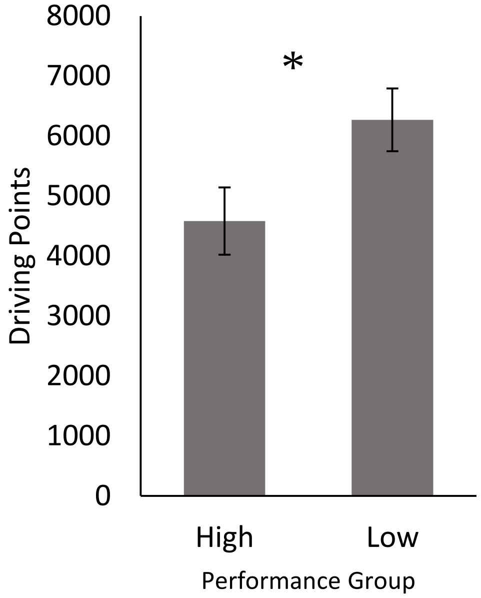


Figure 4.8. Differences across high and low task performance groups for overall driving performance. Error bars show standard error of the mean.

Figure 4.8 shows how those who performed better in the attention tasks also exhibited better overall driving performance as indicated by the lower number of penalty points received ($t(23) = 2.21$, $p = 0.038$, $d = 0.92$).

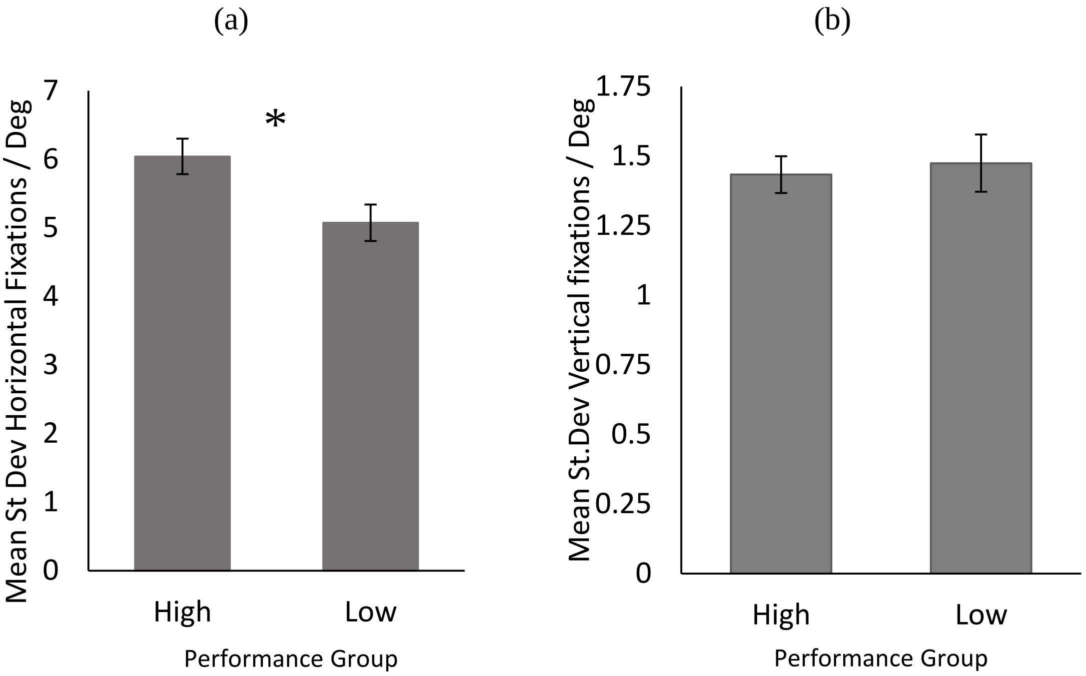


Figure 4.9 Showing the difference in (a) horizontal and (b) vertical visual scanning of the roadway. Error bars show standard error of the mean

Figure 4.9 shows the distribution of eye movements along the vertical and horizontal axes. There was a significant difference in horizontal scanning behaviour across task performance groups (Figure 4.9a). Those who performed better in the attention tasks exhibited an increase in their horizontal visual scanning of the roadway ($t(23) = 2.60$, $p = 0.016$, $d = 1.08$). There was no difference in vertical scanning (Figure 4.9b) ($t(23) = 0.38$, $p = 0.7$, $d = 0.16$).

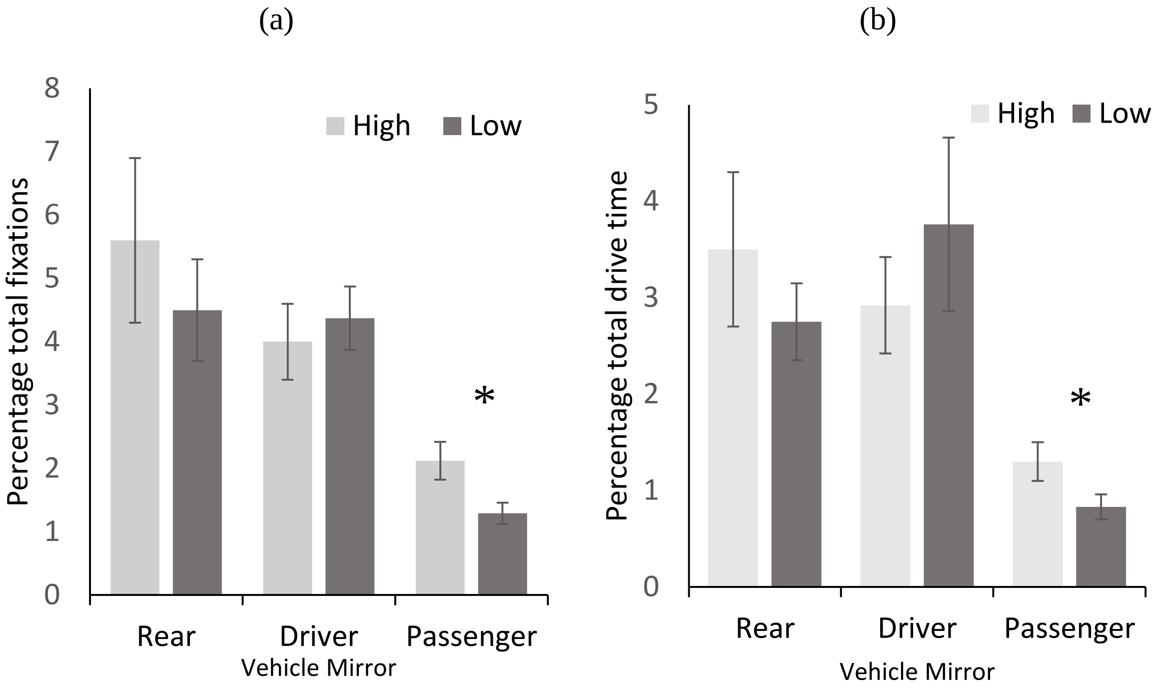


Figure 4.10. Differences between task performance groups for (a) use of the mirrors as measured by total percentage of fixations (b) use of the mirrors as measured by the total percentage dwell time. Error bars show standard error of the mean.

Figure 4.10a shows the total number of fixations on the different mirrors and 4.10b the total dwell time. There were no significant differences found between the performance groups for the total number of fixation and dwell times for inspection of the rear-view and driver-side mirrors. There was however a significant difference between the performance groups when inspecting the passenger-side mirror where those in the high performance group inspected this mirror more than those in the low performance group, as measured by the percentage of fixations ($t(23) = 2.20$, $p = 0.038$, $d = 0.92$) and percentage dwell time ($t(23) = 2.34$, $p = 0.028$, $d = 0.98$).

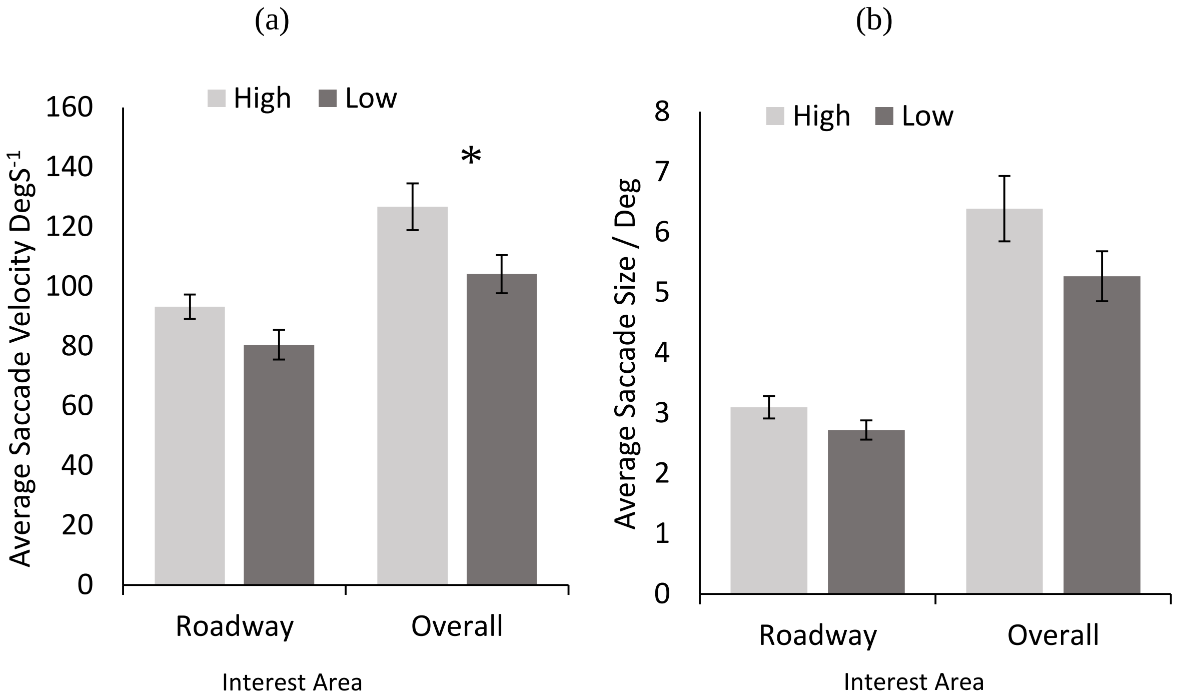


Figure 4.11. Showing the differences between task performance groups for (a) average saccade velocity and (b) average saccade size for the roadway and overall scene. Error bars show standard error of the mean.

Figures 4.11a and 4.11b show the differences in average saccade velocities and average saccade sizes. Although not significant, there was a clear trend (< 0.015 above significance level; effect size > 0.8) in the differences in saccade velocities across task groups when inspecting the roadway ($t(23) = 1.94$, $p = 0.064$, $d = 0.81$). Where those in the high performance groups exhibited faster saccades. They also exhibited significantly faster saccades when sampling the overall scene ($t(23) = 2.25$, $p = 0.034$, $d = 0.98$). These effects are independent of saccadic amplitude, where there was no difference in average saccade sizes across the groups for inspection of the roadway ($t(23)=1.54$, $p=0.14$, $d = 0.64$) and the overall scene ($t(23)=1.64$, $p=0.12$, $d = 0.68$). This suggests that those with better attentional function were faster at distributing eye movements around the scene.

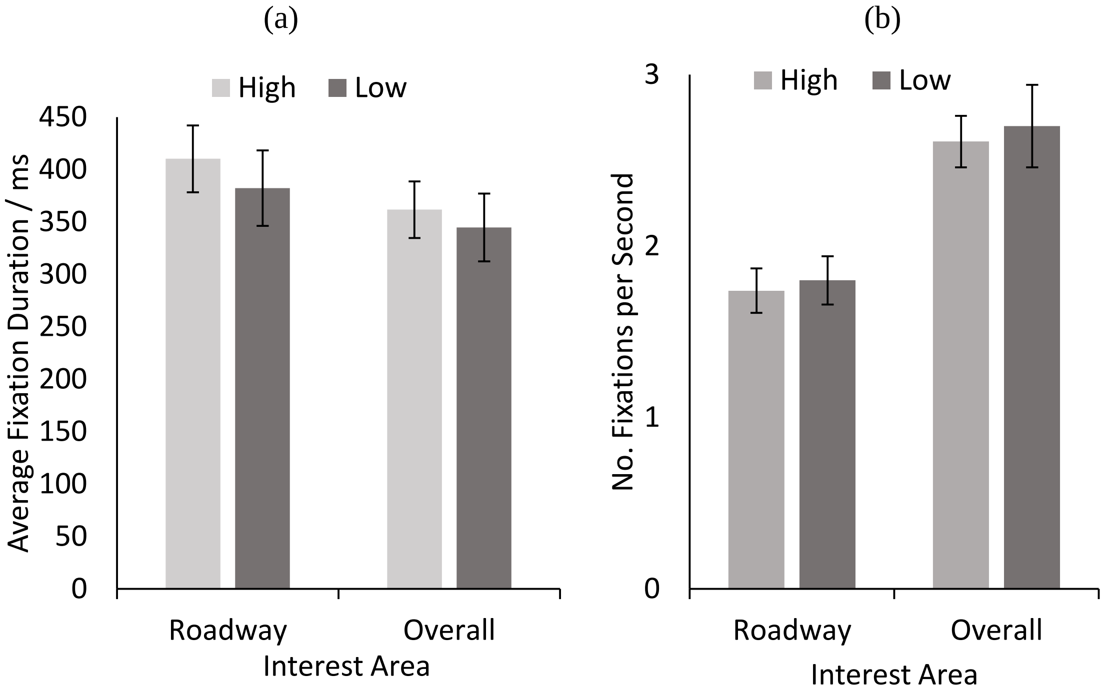


Figure 4.12. Fixation duration (a) and average number of fixations (b) for high and low attentional function groups for both the roadway and overall areas of the scene.

Figure 4.12a shows the differences in the average fixation durations for each group for both the roadway interest area and all interest areas combined. There was no significant difference between the attention groups when fixating the roadway ($t(23) = 0.58$, $p = 0.57$, $d = 0.24$) and the overall scene ($t(23) = 0.40$, $p = 0.69$, $d = 0.24$). Figure 4.12b shows the average number of fixations made by each group for the roadway and overall scene. There was no significant difference when fixating the roadway ($t(23) = 0.49$, $p = 0.62$, $d = 0.2$) and the overall scene ($t(23) = 0.32$, $p = 0.75$, $d = 0.33$). Together these results suggest that the efficiency of visual processing was similar between the groups when fixating.

4.3.2 Scanning behaviour as a function of road complexity

It was found that those with higher attentional function scan the roadway more. Given Crundall & Underwood's (1998) result that horizontal scanning differences occurred only for a more cognitively demanding dual carriageway route (compared to suburban and rural routes), it was investigated whether the differences in scanning behaviour between attentional function groups occurred for all road types, or whether this effect was stronger for when the road complexity was higher. Figure 4.13 shows the differences in horizontal scanning behaviour across attentional function groups for each of the routes driven.

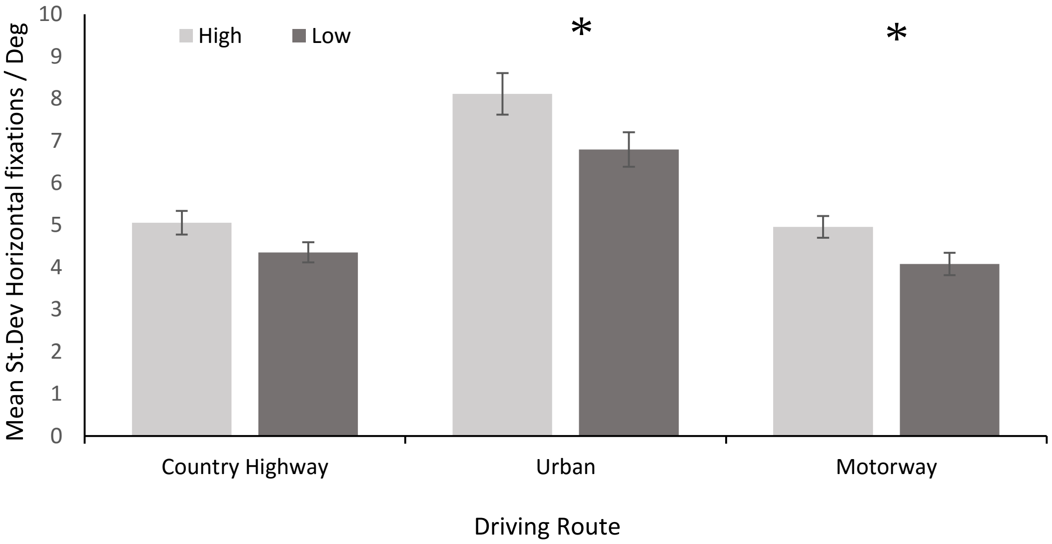


Figure 4.13. Differences in horizontal scanning behaviour across each of the driving routes. Error bars show standard error of the mean.

Between subjects t-tests revealed significant differences in horizontal scanning behaviour between attentional function groups for the more complex urban ($t(23) = 2.07$, $p = 0.05$, $d = 0.86$) and motorway environments ($t(23) = 2.36$, $p = 0.027$, $d = 0.98$) but not the less visually demanding country highway ($t(23) = 1.91$, $p = 0.068$, $d = 0.80$) (after Bonferonni corrections).

4.3.3 Individual task predictions of scanning behaviour and driving performance

In line with the second aim of the study, in order to identify which tasks better predict certain behaviours, Pearson correlations between performance on the individual tasks and the main measures of horizontal scanning and driving performance were conducted. These can be viewed in Figure 4.14. Performance in all three tasks significantly positively correlated with each other (data not shown in figure). This is unsurprising given they each attempt to tap into related attentional mechanisms

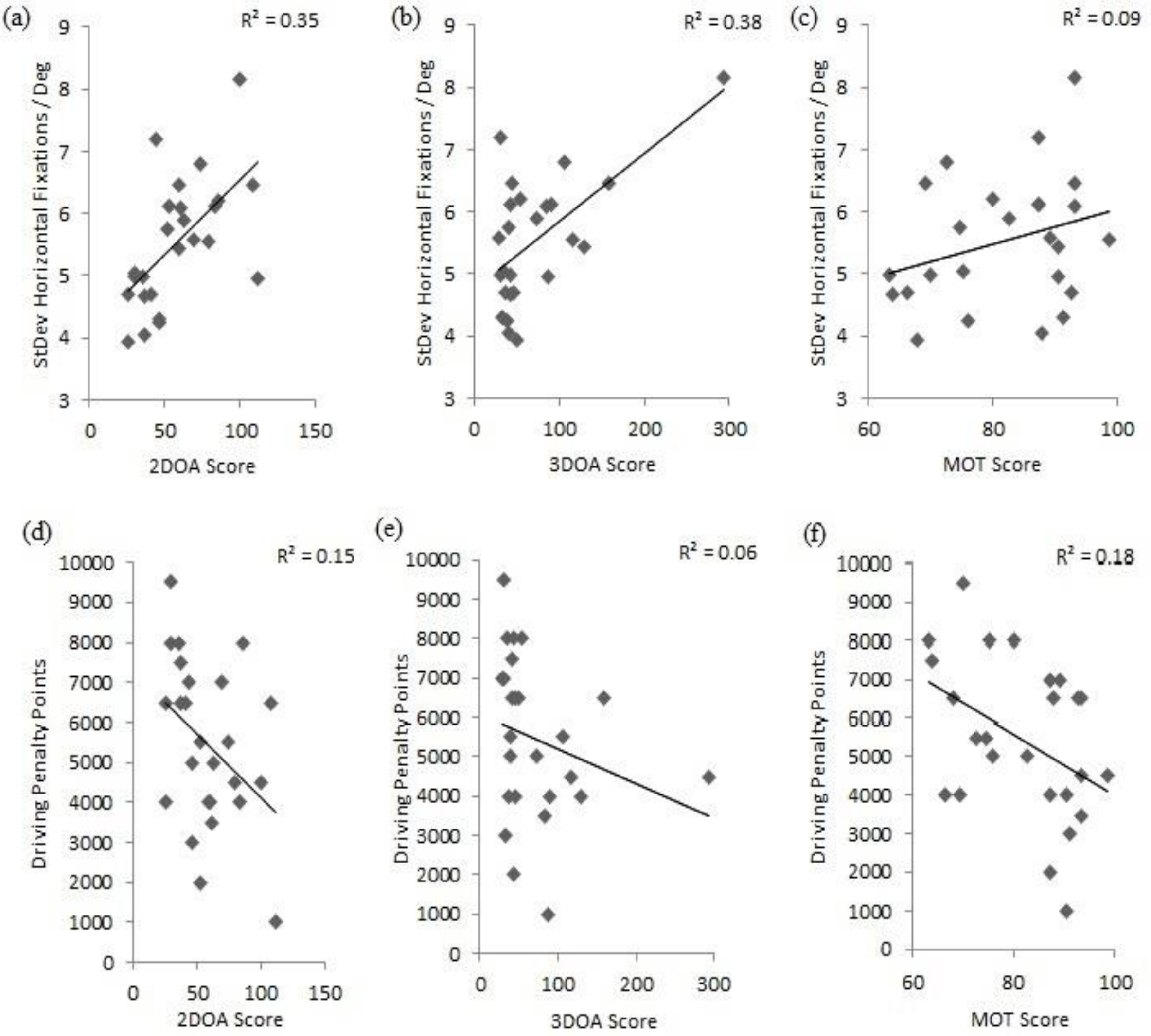


Figure 4.14. Correlations between task performance and horizontal scanning (a, b and c) and driving performance (d, e and f).

. Performance on the 2DOA and 3DOA tasks significantly positively correlated with a larger average horizontal spread of fixations (*r*(25) = 0.59, *p* = 0.001; *r*(25) = 0.613, *p* = 0.001) (Figures 4.14a; 4.14b), whereas performance on the MOT task did not (*r*(25) = 0.3, *p* = 0.08) (Figure 4.14c). However, in the case for the 3DOA task, it is likely that the outlying participant is driving the significance. This is discussed below in the discussion below (section 4.4.4) For driving performance, performance on the 2DOA task significantly negatively correlated with driving penalty points (and therefore positively with driver performance [$r(25) = -0.39$, $p = 0.026$]) (Figure 4.14d). The MOT also significantly negatively correlated with the number of driving penalty points ($r(25) = -0.424$, $p = 0.017$) (Figure 4.14e), but interestingly, the 3DOA task did not ($r(25) = -0.25$, $p = 0.115$) (Figure. 4.14f). Collectively, these results suggest that the 2DOA task is the better predictor for both visual and driving behaviour.

4.4 Discussion

The main aim of this study was to use a specific set of cognitive tasks to test whether individual differences in eye movement behaviour when driving is partly due to one's ability to manage attentional demands. The specific hypothesis was that those individuals who performed better on the attention tasks, and thus have better attentional function, would exhibit more effective, and safer, visual and driving behaviour. A number of results were found that support this.

4.4.1 Comparing eye movement behaviour

Those who performed better on the attention tasks also exhibited more efficient visual behaviour (Figures 4.9; 4.10; 4.11), behaviour we would typically associate with more experienced or safer drivers. Competition for attentional resources during driving may limit scanning behaviour. Recarte and Nunes (2003) showed that when performing mental tasks while driving (thereby increasing the cognitive load), overall horizontal scanning of the scene decreased. Engström et al. (2005) also found increased gaze concentration towards the centre of the scene when a higher cognitive load was induced, both during real and simulated driving. In addition, Savage et al. (2013) found that increasing cognitive load (using a simultaneous riddle solving task) reduced horizontal scanning on video-based hazard perception tasks. These results suggest that cognitive load may be a likely source for individual differences in drivers' eye movements. In this study, the levels of cognitive load when driving were not manipulated. Instead, attentional function was measured in a separate series of tasks. The evidence here suggests that those who have better control over attention resources in general are better able to distribute their eye movements to more relevant areas of the driving scene, as shown by increased horizontal scanning (Figure 4.9a).

This is evidenced further by the finding that this scanning effect appears to become more pronounced when road complexity increases. Previous research has found differences in eye movement strategies due to the different processing demands of the road type (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Underwood, Chapman, et al., 2002). For example, Crundall and Underwood (1998) showed that the size of horizontal visual scanning on the roadway was similar for novices and experienced drivers on rural and suburban routes. However, on dual carriageways, where the layout is much more complex (e.g. presence of slip roads), only experienced drivers exhibited a wider horizontal visual scanning strategy. In this study, for the less demanding country highway, there was no difference in horizontal scanning behaviour between high and low attentional performance groups (Figure 4.13). Thus, even with poorer attentional function, the lower demands of the task allowed individuals to successfully distribute eye movements across the scene. Importantly however, when the scene became increasingly complex i.e. urban or motorway environments, there was evidence of increasing scanning behaviour in those with better attentional function. These more complex driving environments likely place a higher cognitive load on the visual and attentional systems and will limit scanning behaviour more in those with poorer attentional function.

These findings suggest that those with better attentional function are better equipped to search the road more for hazards. Inattention and failures to scan the roadway are often contributing factors to road accidents (Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Lee, 2008; Lestina & Miller, 1994), and thus the findings may suggest that the reasons for these contributing factors is due to poor attentional function.

The finding that there was no difference in vertical scanning between groups (Figure 4.9b) is not surprising given that the vertical bias in allocating visual attention is lost, typically after three months of driving (Chapman & Underwood, 1998; Underwood, 2007; Underwood, Crundall, et al., 2011).

Some research has suggested that increasing cognitive load reduces mirror use (e.g. Harbluk et al., 2007; Recarte & Nunes, 2003). Harbluk et al. (2007) found that when performing complex mathematical problems whilst driving, the time spent inspecting the vehicle mirrors was shorter compared to when completing simple mathematical problems while driving. Related to this, it was found here that those with better attentional function used the passenger-side mirror more (Figure 4.10). In this experiment, the passenger-side mirror appeared approximately 22 x 9 deg from the screen centre. The position of the rear-view and driver-side mirror were closer by comparison (17 x 3 deg; 15 x 4 deg respectively). It is speculated that those with better attentional function may be better able to allocate eye movements to this part of the driving scene more often – as it requires the most effort to deploy attention to (given its distance from the average fixation point on the road). The unnatural location of this mirror (see Figure 4.6) may have influenced inspection times, however each participant in both performance groups was made aware of its location before the drive. The lack of differences in rear view and driver side mirror glances between attentional function groups is not too surprising (Figure 4.10). Even if an individual has poorer attentional function, the rear view mirror and driver side mirror are still hugely important when driving since they provide the driver with added roadway information. As such, they should be inspected often. They also require the least amount of effort to inspect; where usually small head or eye movements are sufficient.

The finding here may be linked to what we know about the importance of situation awareness in driving. Through experience, mental models are built in order to allow drivers to predict, perceive and respond to certain situations more appropriately (Endsley, 1995a, 1995b, 2004; Underwood, 2007; Underwood, Crundall, et al., 2011; Wickens, 2008b). Inspection of the passenger-side mirror will likely increase one's situation awareness of the current environment, particularly on the multi-lane roads used in the current experiment as found in Shahar, Alberti, Clarke, and Crundall (2010).

In addition, there was some evidence to suggest individuals with better attentional function are more efficient at visually sampling the scene, as evidenced by the average faster saccade velocities (Figures 4.11). Average saccade velocity was independent of saccade size where we found no differences across the groups. This suggests that the increase in saccade speeds were not simply a product of a wider search. Mean saccade velocity has previously been used to infer information processing, where faster saccades have been associated with increased information processing (Galley & Andres, 1996) and the converse, where smaller velocities are associated with lower levels of vigilance (Galley, 1989; 1993). This finding may thus be an indicator of increased processing performance for those with better attentional function. However there were no differences found regarding fixation durations and the number of fixations made (Figure 12). Typically, longer fixation durations and more fixations are indicators that an individual is experiencing greater cognitive load (Land, 2009; Land & Tatler, 2009; Rayner, 2009). Therefore, although those with better attentional function were more efficient at moving their eyes, the time and efficiency of processing the information when fixating were equivalent. This suggests that the lack of cognitive resources available when driving does not necessarily affect processing visual information when fixating, only when moving to the next fixation location.

4.4.2 Comparison with studies comparing expert and novice driving

The current study investigated individual differences in eye movements in a population with similar driving experience. However there are parallel conclusions that can be drawn with the literature concerning the differences in eye movement behaviour between novice and experienced drivers. The results are consistent with published data showing that there are differences in eye movement behaviour between novices and experts (e.g. increased horizontal scanning in experts). This provides implicit support for the idea that these differences may be due to competing attentional resources of controlling the vehicle and observing the roadway. As a novice, more attention may be required for aspects of the driving task itself; both cognitively (e.g. dual task demands of steering and changing gears). Fewer resources are then available to allocate visual attention to searching the road more for potential hazards or other features. We know that through practice and experience, task performance improves when actions become more automated and there is less of a requirement for conscious intervention (Ackerman, 1988; Moors & De Houwer, 2006). With driving, it may be the case that through experience, controlling the vehicle also becomes more automatic and this frees up resources to allocate visual attention to other parts of the scene. This may also explain the individual differences observed here: controlling the vehicle may require more attentional resources in some individuals, resulting in less attentional resources to give to scanning the road. These results suggest that some individuals may be better equipped for predicting, detecting and responding to hazards. Even if an individual has the knowledge of where to look, if total attentional resources limits their ability to scan certain areas of the roadway and mirrors, then this in turn may limit their hazard perception ability.

4.4.3 Attentional function and driving ability

The Useful Field of View task (UFOV) (Ball, Roenker, et al., 1990) aims to assess visual processing speed and attentional function through responses to briefly presented targets in the periphery. Ball, Owsley, et al. (1990) found that those with poorer attentional function, as measured by the UFOV also report more problems with driving. Ball et al. (1993) found that poorer performance in the UFOV task correlates with more reported road accidents. A meta-analysis by Clay et al. (2005) supports the claim that poorer attentional function is associated with poorer driving performance – particularly in older drivers.

Since the UFOV was developed, there have been other successful attempts to demonstrate the relationship between attentional function and driving performance, many of which use variations of the visual attention tasks used in the original UFOV assessment (e.g. Aksan et al., 2015; Anstey et al., 2012; Casutt, Martin, et al., 2014; Keay et al., 2009; Schuhfried, 2005). One assessment test used is the Attention Network Test (ANT) (Fan et al., 2002). The ANT assessment tool is more closely based on a known neurocognitive model of human attention which separately assesses the three components of attentional functioning mentioned earlier: executive control, attentional orienting and alerting networks. The executive control networks involve mechanisms to deal with cognitive conflict and ignore irrelevant stimuli. The attentional orienting mechanisms are involved in selecting and guiding attention to potentially relevant areas of the scene. And the alerting networks are sensitive to changes in incoming stimuli, over both short and long periods of time (see Fan et al., 2002; Petersen & Posner, 2012; Posner, 2008). This is important as these attentional components are likely involved in successful driving. It has been found that better attentional function, as measured by the ANT test predicts better driving performance (Roca et al., 2013; Weaver et al., 2009).

A similar result is found in this study where those who performed better in the visual attention tasks also demonstrated better driving ability (Figure 4.8). Here, the three attentional components (above) would have been engaged during the visual attention tasks. Within the MOT task, the goal is to attend to a certain number of moving objects amongst distractors; a task which likely targets executive control functions. The two object avoidance tasks, whilst they also require executive control to attend to multiple stimuli, may also use attentional orienting mechanisms where one must allocate attention to parts of the scene in order to guide the object and predict the movement/positions of the obstacles. One must also be alert to the oncoming stimuli that appears during these two tasks, i.e. more balls appearing or cubes appearing, which likely tap into the alerting networks. These aspects are all likely involved in driving where drivers must 1) successfully attend to relevant hazardous areas whilst ignoring other stimuli (executive control), 2) orient their attention to potential hazardous cues (attention orienting) and 3) increase readiness to respond and sustain attention to the driving environment (alerting network). This may explain why better attentional function relates to better driving performance found here.

4.4.4 A place for visuomotor assessment tools?

Bowers et al. (2011) discuss how the UFOV, and similar tasks, only measures selective and divided attention. It does not require sustained attention to complete. In other words, stimuli are only presented for up to several hundred milliseconds, and as such, only capture brief spans in attention. Driving is a more complex task and the attentional mechanisms involved in driving may not be accurately represented when performing the UFOV task. The MOT, which is a more dynamic and sustained assessment of executive control, was proposed and was found to correlate to driving performance (Alberti, Horowitz, et al., 2014; Bowers et al., 2011). In this current study, there is also evidence to support the claims that performance on the MOT predicts better driving performance (Figure 4.14f).

However, one of the aims was to provide further insights into the types of tasks which can be used to predict overall driving behaviour by investigating tasks which incorporate visuomotor control. Therefore 2D and 3D object avoidance tasks were used here to capture the active visual attention processes involved in driving. It was predicted they would better predict driving performance and scanning behaviour more than the MOT. It was found that performance on the 2DOA task supports this (Figure 4.14). An MOT type task is passive in nature, it does not require active visuomotor control. As such, the eye movement strategies involved are likely different to a more active task, one which incorporates the vision and action link we see in many everyday tasks (Hayhoe & Ballard, 2005; Land et al., 1999). For example, the 2DOA task requires vision to initially select a point in space in which to move the ball to, which precedes the action of moving the ball. A visual strategy often used in MOT is to make fewer eye movements and use covert attention to group stimuli (Fehd & Seiffert, 2008; Oksama & Hyönä, 2016; Zelinsky & Neider, 2008). Indeed, there was evidence that individuals made significantly fewer fixations in the MOT task than the 2DOA task (MOT mean fixations per second: 2.3, 2DOA mean fixations per second: 2.7; $t(20)=3.1$, $p=0.006$) [1]. This may explain why the MOT task does not significantly predict eye movement scanning behaviour in a more active task such as driving.

Contrary to the predictions, the 3DOA task does not predict both driving performance and visual scanning behaviour (Figure 4.14). This could be due to task difficulty where the speed at which the object moved through the environment was too fast to be successfully controlled. There is some evidence for this task difficulty problem in the data. In Figure 4.13b, it is clear that most performance scores are clustered towards the lower end, suggesting a floor effect in performance. Only one participant obtained a score above 200. Indeed, removing this outlier removes the significance in the correlation between performance and scanning behaviour originally found, and thus the 3DOA used here is arguably not a suitable predictor for visual behaviour and driving performance. This limitation could not be overcome in this study as it was not possible to manipulate the code to make the task easier. In summary, although there is evidence that visuomotor tasks better predict both scanning behaviour and driving performance, this may not hold true for all visuomotor tasks. Future investigations should aim to explore these issues further.

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[1] Eye movement recording was not possible for all 25 participants during the attention tasks due to calibration errors. Thus, the degrees of freedom are different from our main analyses.

4.4.6 Conclusions

It was found that there are individual differences in eye movement behaviour and driving performance even amongst those with similar driving experience. This study has provided evidence that one's attentional function is a contributing factor to these differences; where better control over attentional processes results in eye movement and driving behaviour typically associated with safer driving. This is demonstrated without explicitly inducing a high cognitive load in order to maintain a more naturalistic driving setting. There is evidence to suggest that tasks utilising a visuomotor component may provide better prediction tools for driving; where both visual scanning and driving performance are accounted for. The results ultimately provide further insights into how the visual and attentional systems interact during driving tasks. They may also have implications for future driver assessment protocols, which are discussed in the general discussion.

Chapter 5

Insights into individual differences in eye movements: A case for age

With older adults considered an ‘at risk’ driving population, in terms of the number of accidents reported, the aim of this study was to explore the eye movement behaviour in drivers over the age of 59. The first experiment describes an experiment to observe the visual scanning behaviour of older adults when driving in a simulated environment. The second experiment described within was conducted in order to assess their attentional function and driving speed. The literature regarding eye movements and attentional function in older adults is recapped before these experiments are described in detail. The results provide further insights into the individual differences that may occur in driving due to age.

5.1 Introduction

As discussed in section 1.4, older adults (which are typically defined as being older than 65 years (Aksan et al., 2015; Fisk & Rogers, 1997)) are more likely to be involved in road accidents (Evans, 2000). Much of these accidents are attributed to typical age-related decline factors which affect older adults e.g. poorer attentional processing (Anstey et al., 2005; Ball, Edwards, & Ross, 2007). For example, deficits in dividing attention to multiple stimuli or slower processing of hazardous events than younger drivers have been linked to poorer driving performance and increased crash rates (Aksan et al., 2015; Andrews & Westerman, 2012; Clay et al., 2005; Horswill et al., 2008).

Even though older adults typically exhibit poorer driving performance and increased crash risk, less is known about the eye movement behaviour that is exhibited by older adults. To recap, video studies show some conflicting results. Some have found no differences in scanning behaviour between older adults and a young adult population (Underwood, Phelps, et al., 2005). Others have found that older adults scan the roadway less than their younger counterparts (Yeung & Wong, 2015). In Chapter 4, it was found that those with poorer attentional function were less able to distribute eye movements across the roadway. Thus, one might predict that the same might be observed in older adults, a population which typically exhibits poorer attentional function. There is some evidence of this, where older adults exhibit less efficient search patterns at road junctions by typically fixating on locations that help control the vehicle and do not search for potential hazards that may occur (Dukic & Broberg, 2012; Min et al., 2013; Romoser & Fisher, 2009; Romoser et al., 2013).

Despite this, there is still much to understand about how older adults move their eyes when driving; namely, where do older adults look when driving during normal, typical, driving conditions. In this study, the main goal was to identify if there were any differences in eye movement behaviour between older adults and young adults. In Experiment 1, a group of older adults performed the same simulated drives as was described in Chapter 4 whilst their eye movements were tracked. Their visual behaviour was compared to the group of younger adults used also from Chapter 4. It was predicted that, since it is known that older adults typically exhibit poorer attentional function, the older adults would exhibit less efficient visual behaviour.

The results of Experiment 1 were somewhat inconclusive, where similar eye movement behaviour was found across populations. Thus experiment 2 aimed to provide a possible explanation for these findings by measuring older adults' attentional function (to confirm that it is poorer in older adults) and determine whether driving slower was a compensatory measure which allowed the efficient visual behaviour to be exhibited.

5.2 Methods: Experiment 1

5.2.1 Participants

5.2.1.1 Older adult participants

Fifteen participants over the age of 59 took part in the study. Six participants were excluded due to either, poor visual acuity (> 2.0 MAR), poor eye movement calibration (> 2 deg) or experiencing motion sickness. This left a sample of 9 participants (5 males) with an age range of 60-80 years (mean age = 69.78; St. Dev = 6.16). All participants had normal or corrected-to-normal vision. They were recruited through a number of methods which included, poster advertising at local health centres, libraries and the University. They were paid £10 for participation. All participants had held a drivers' license for at least one year (mean = 48.8 years, St. Dev = 6.5) and were from countries where driving on the left (e.g. U.K.) is standard. Participants reported having no previous experience with a driving simulator. The study was approved by the University of St Andrews University Teaching and Research Ethics

Committee (UTREC). This group of older adults' eye movements were compared to the same group of younger adult participants used in Chapter 4.

5.2.1.2 Younger adult participants

The twenty-five participants aged under 59 from Chapter 4 were used as the comparison group in this experiment. The age range was 18-51 years (mean age = 22.5 years; St.Dev = 6.6). The participants had held a drivers' licence for at least one year (mean = 4.3; St. Dev = 5.7) and were from countries where driving on the left (e.g. UK) is standard. The number of hours the older adults drove on average in a week was not significantly different to the younger adults after accounting for unequal variances across groups using a between measures *t*-test ($t(10.34) = 1.62$, $p = 0.14$).

5.2.2 Stimuli and Apparatus

All apparatus and driving simulation was identical to the experiment outlined in the methods section in Chapter 4.

5.2.3 Measures

All eye movement information was recorded and collated via SR Research Data Viewer software. Using this software, the driving scene was divided into four different interest areas (Figure 4.6): the rear-view mirror, driver-side mirror, passenger-side mirror and the roadway. Note, the passenger-side mirror was superimposed to the left of the screen as shown in Figure 4.6.

Fixation locations. The standard deviation of eye fixations along the horizontal axes (using x-axis pixel coordinates) was measured to provide an indicator of the spread of visual attention. This was converted from screen units into degrees. A larger standard deviation would suggest a larger distribution of fixations and thus a larger spread of visual attention. Only fixations located within the roadway were included in this analyses; mirror or speedometer fixations were excluded. The vertical spread of eye movements was not recorded in this experiment. Due to the nature of the older population, calibration often proved difficult e.g. some wore bi-focal glasses which reflected the infrared light used by the eye tracker. Therefore there was often vertical drift in the recording of eye movements, and as such, no accurate measure of vertical fixation location could be determined.

Mirror Interest Area analyses. To measure how much individuals inspected the vehicle mirrors, the total average fixation count (as a percentage of the total fixations) and total average fixation dwell time (as a percentage of the total drive time) was calculated for the rear-view mirror, driver-side mirror and passenger-side mirror.

Visual processing. Average saccade velocities were recorded to infer the efficiency at which the scene was sampled, where faster average saccades may suggest increased information processing. Average saccade sizes were also measured. Saccade analyses were performed for the overall scene (i.e. all interest areas) and for the roadway interest area separately. Fixation durations and the number of fixations were also recorded for the roadway and the overall scene as a measure of cognitive processing. Longer fixation durations and more fixations made would suggest less efficient processing.

Driving Performance. Driving performance was measured on a point system tracked by the simulator software. 500 points were allocated to each 'minor' infringements such as driving 10kmph over the speed limit, not maintaining lane positioning, obstructing another vehicle causing it to break unexpectedly and not observing priority at junctions. More 'major' infringements were scored 1000 points and were characterised as accidents or dangerous driving, for example, crashing into another vehicle or pedestrian or driving 20kmph over the speed limit. The total points awarded provided a measure of driving performance where a larger number of points suggests poorer driving performance. A single total measure of driving score was recorded.

5.2.4 Procedures

Participants completed the three simulated driving routes in the same manner as Chapter 4. All participants completed a Landolt C visual acuity test and were included if acuity was measured as < 2.0 Minimal Angle Resolution. Participants were instructed how to use the car, including how to steer, use the pedals, turn signals and mirrors and were given five minutes to practice the simulated driving in the car park. Eye movements were calibrated using the Eyelink II at both the calibration distance and at the video screen distance. Calibration was done before each course and recording began at the start of each course just as participants began to drive. Each of the three courses were driven in a randomized order. After a certain location was reached (known to the experimenter) in each of the courses, recording of the eye movements stopped and the participant was instructed to stop the vehicle.

5.2.5 Design

The eye movement data and driving performance of the older adult and younger adult populations were compared. This is therefore a between subjects design. The data for the older adults were not normally distributed for the eye movement measures and group sizes were uneven, therefore non-parametric independent samples Mann-Whitney U tests were used to identify differences between older adults and young adults.

5.3 Results: Experiment 1

In the figures below, the boxplots represent the median, interquartile ranges and range of the data. Outliers are represented by either a O or a ◊ symbol depending the degree. A significance of <0.05 is denoted by a * in the figures. Data were collapsed across the three courses as with the previous experiment.

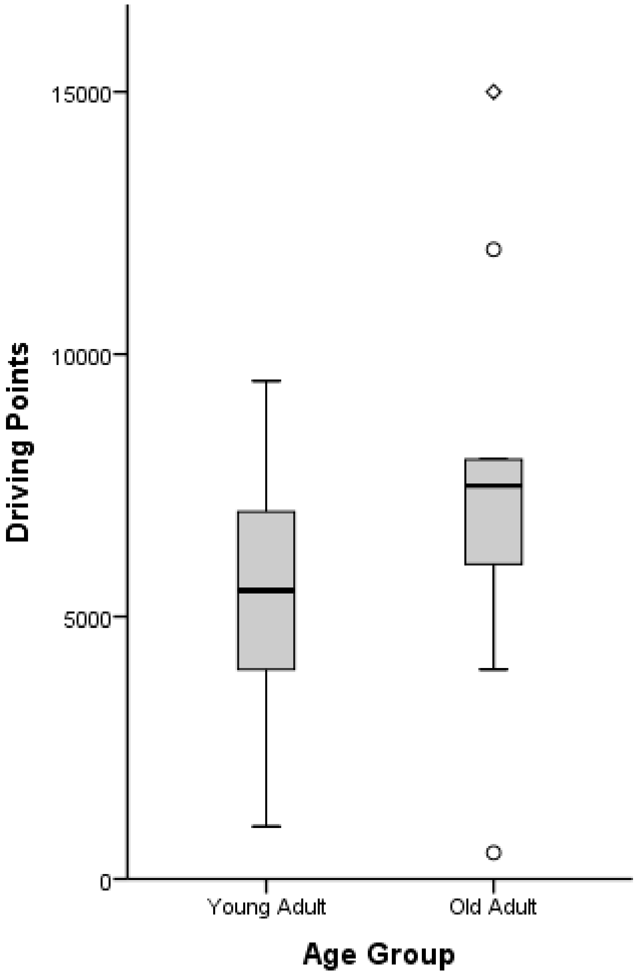

Figure 5.1 Box plot showing the median differences in driving performance between young and old adults.

Figure 5.1 shows the median values for driving performance for the young and old groups. There was no significant difference between the two groups ($U = 150$, $z = 1.45$, $p = 0.15$), suggesting that, on average, both groups made the same amount of driving errors.

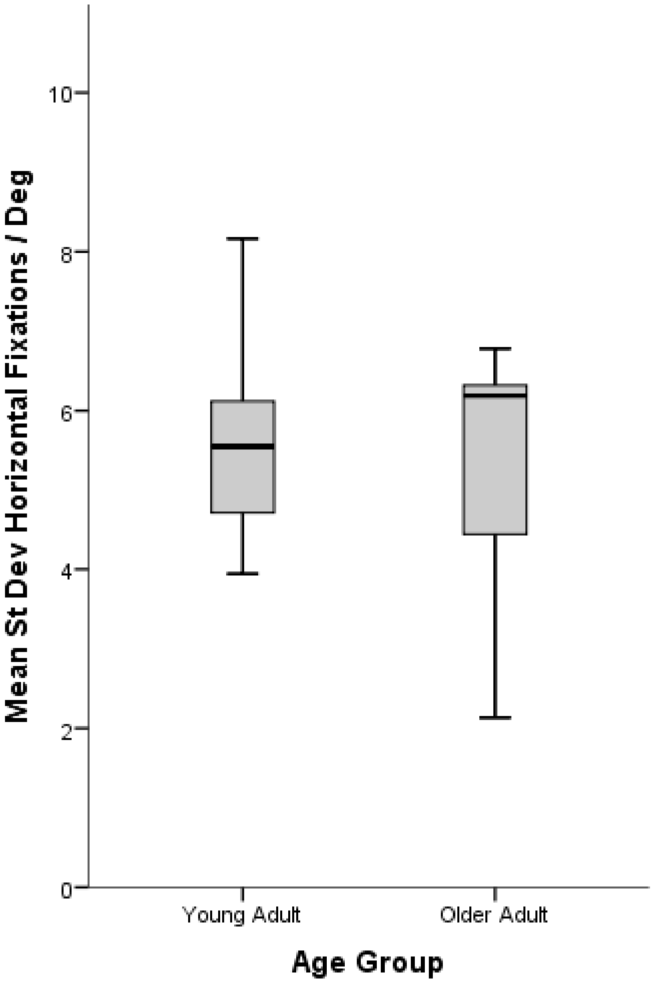

Figure 5.2 Box plot showing the median differences in horizontal visual scanning of the roadway.

Figure 5.2 shows the distribution of eye movements along the horizontal axes. There was no significant difference between the two groups (*U* = 122, *z* = 0.37, *p* = 0.73) suggesting the both age groups scanned the roadway equally.

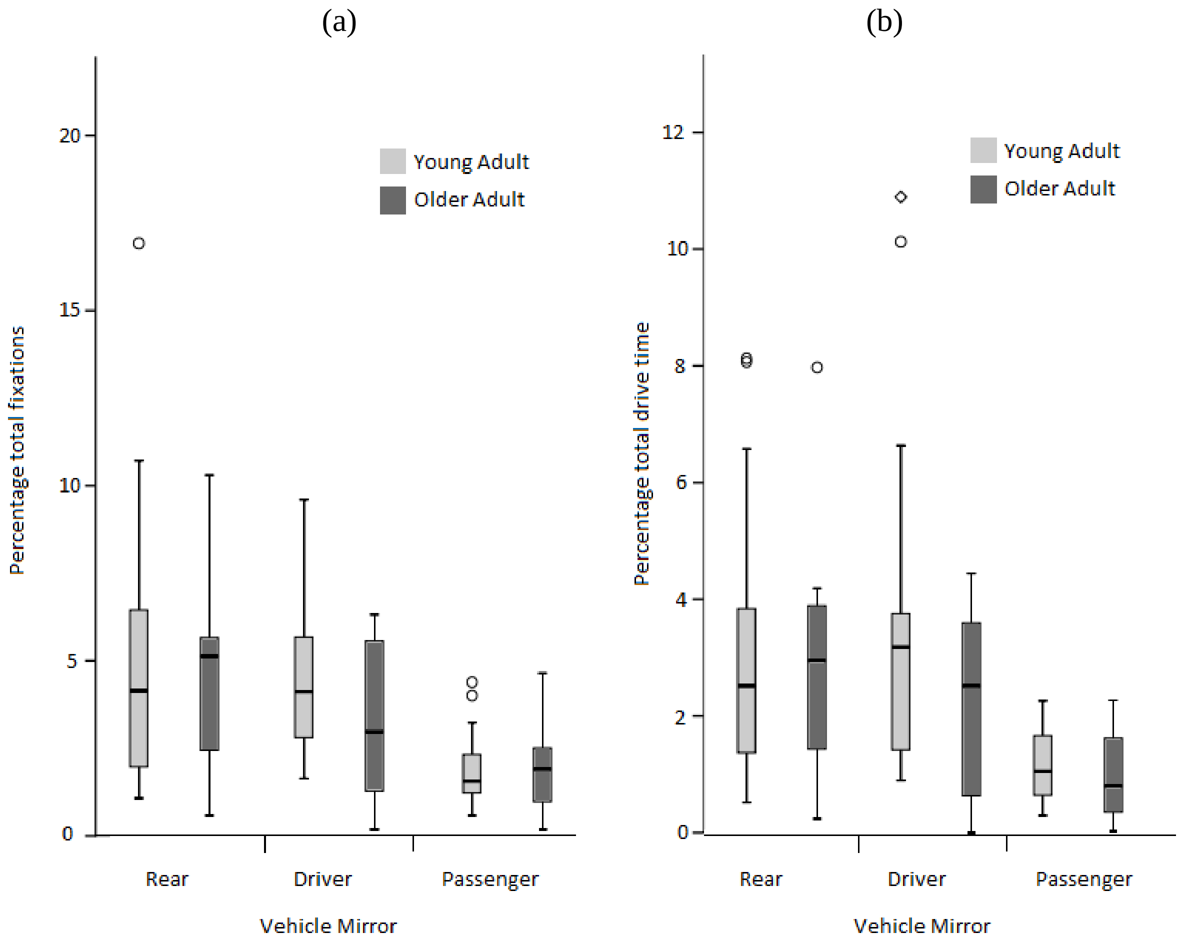

Figure 5.3. Box plots showing the median differences between older and younger drivers in the use of the vehicle mirrors as measured by (a) total percentage of fixations and (b) total percentage dwell time.

Figure 5.3 show the total number of fixations on the different mirrors and total dwell time. There was no significant differences between age groups for inspection of the rear-view mirror (Fixation count: $U = 106$, $z = 0.254$, $p = 0.82$; Dwell time: $U = 112$, $z = 0.02$, $p = 0.98$), driver-side mirror (Fixation count: $U = 86$, z= 1.03, $p = 0.32$; Dwell time: $U = 92$, z = 0.8, $p = 0.44$) and passenger-side mirror (Fixation count: $U = 118$, z = 0.22, $p = 0.85$; Dwell time: $U = 98$, z = 0.59, $p = 0.57$). This suggests each group used the mirrors equally.

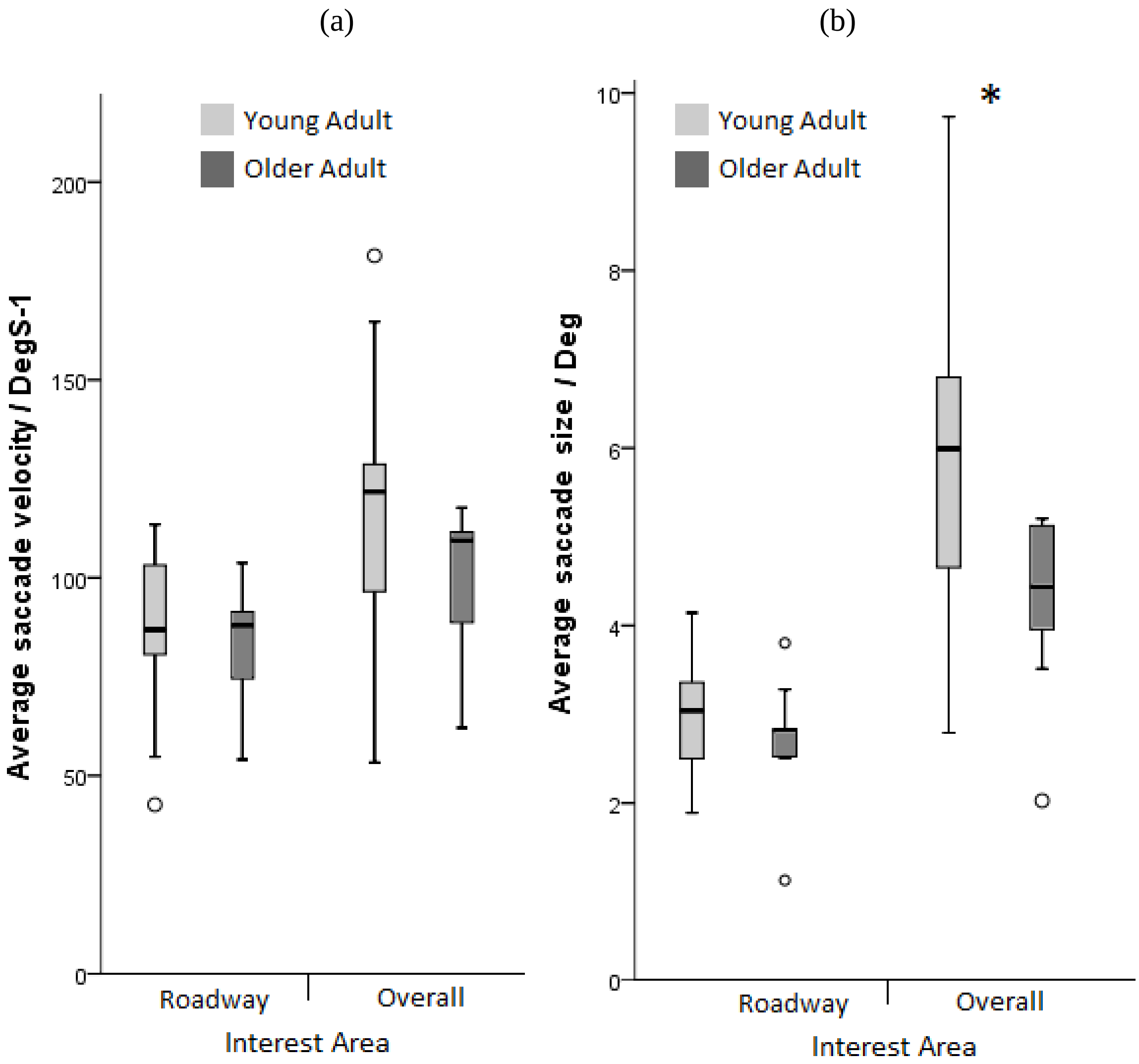

Figure 5.4. Box plots showing the median differences in (a) the velocities of the saccades made and (b) sizes of the saccades made between older and younger drivers for the roadway interest area and the overall scene.

Figure 5.4 shows the differences in the sizes and velocities of the saccades made between older and younger drivers. There was no significant differences in the velocities of saccades between groups for the roadway (*U*=102, z=0.41, *p*=0.70) and the overall scene (*U*=71, z=1.62, *p*=0.11). There was no significant difference in the sizes of saccades made on the roadway (*U*=98, z=0.57, *p*=0.59), but there was a significant difference in the sizes of saccades made for the overall scene (all interest areas included) (*U*=49, z=2.48, *p*=0.01). The younger adults made, on average, larger saccade than the older adults when inspecting the overall scene.

This overall difference in the sizes of saccades when inspecting the overall scene is interesting because inspection of the mirrors and roadway were equal across age groups. Although not considered in the original analyses, it therefore might be attributed to fixations directed towards the speedometer. Speedometer fixation counts and dwell times are plotted in Figure 5.5 below. There was a significant difference between older and younger drivers for inspection of the speedometer (Fixation count: $U = 41$, $z = 2.79$, $p = 0.004$; Dwell time: $U = 48$, $z = 2.52$, $p = 0.011$). Younger adults inspected the speedometer more often and for longer than older adults (Figure 5.5).

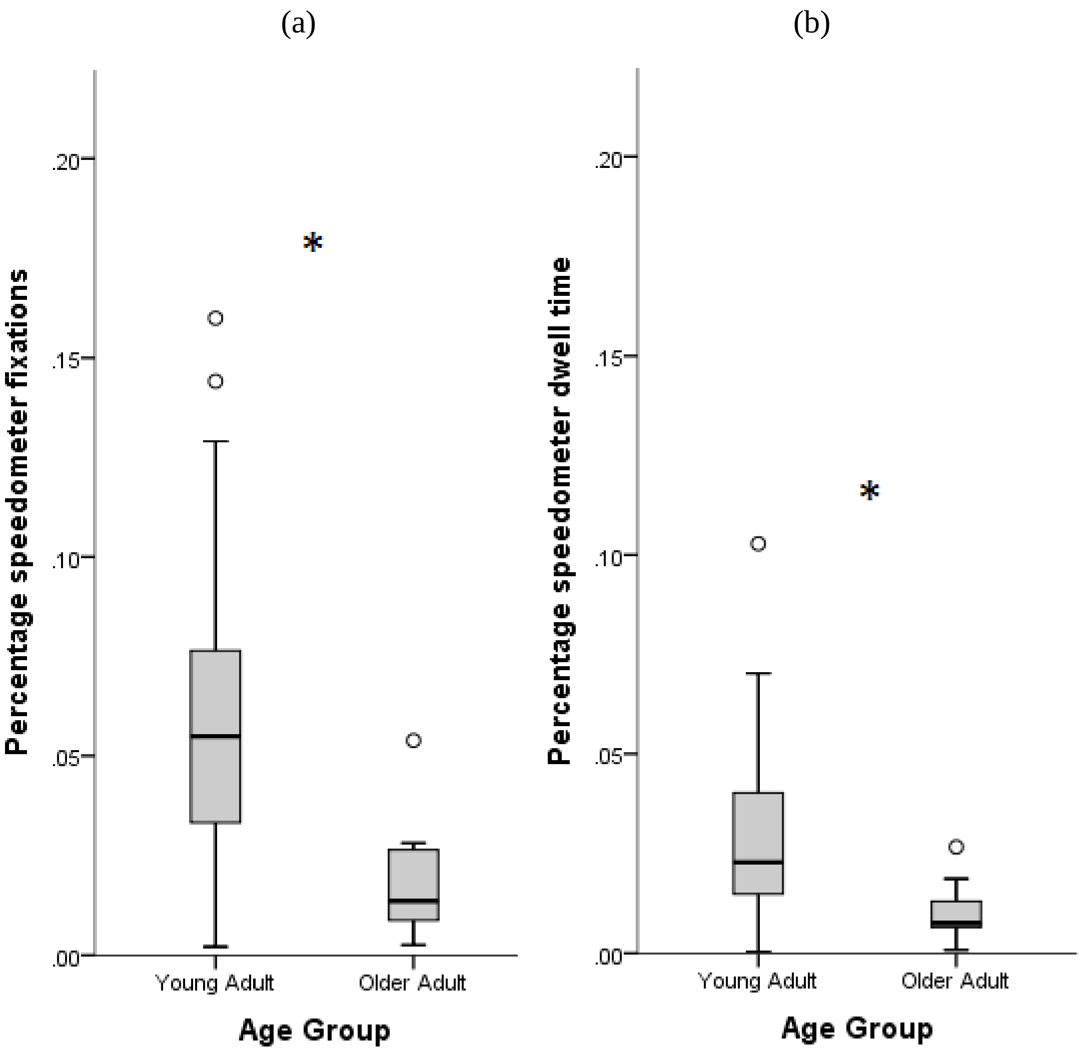
(a) (b)

Figure 5.5. Boxplot showing the median differences in inspection of the speedometer between younger and older adults, as measured by (a) fixation counts and (b) dwell times.

Figure 5.6 shows the differences in average fixation durations and the number of fixations made by older and younger adults for the roadway and the overall scene. There was no significant differences for average fixation durations (Roadway: *U*=99, z=0.53, *p*=0.62; Overall: *U*=119, z=0.25, *p*=0.82) and the number of fixations made (Roadway: *U*=157, z=1.737, *p*=0.09; Overall: *U*=106, z=0.25, *p*=0.82). This suggests that the ability to process visual information when fixating was equivalent across older and younger adults (Figure 5.6)

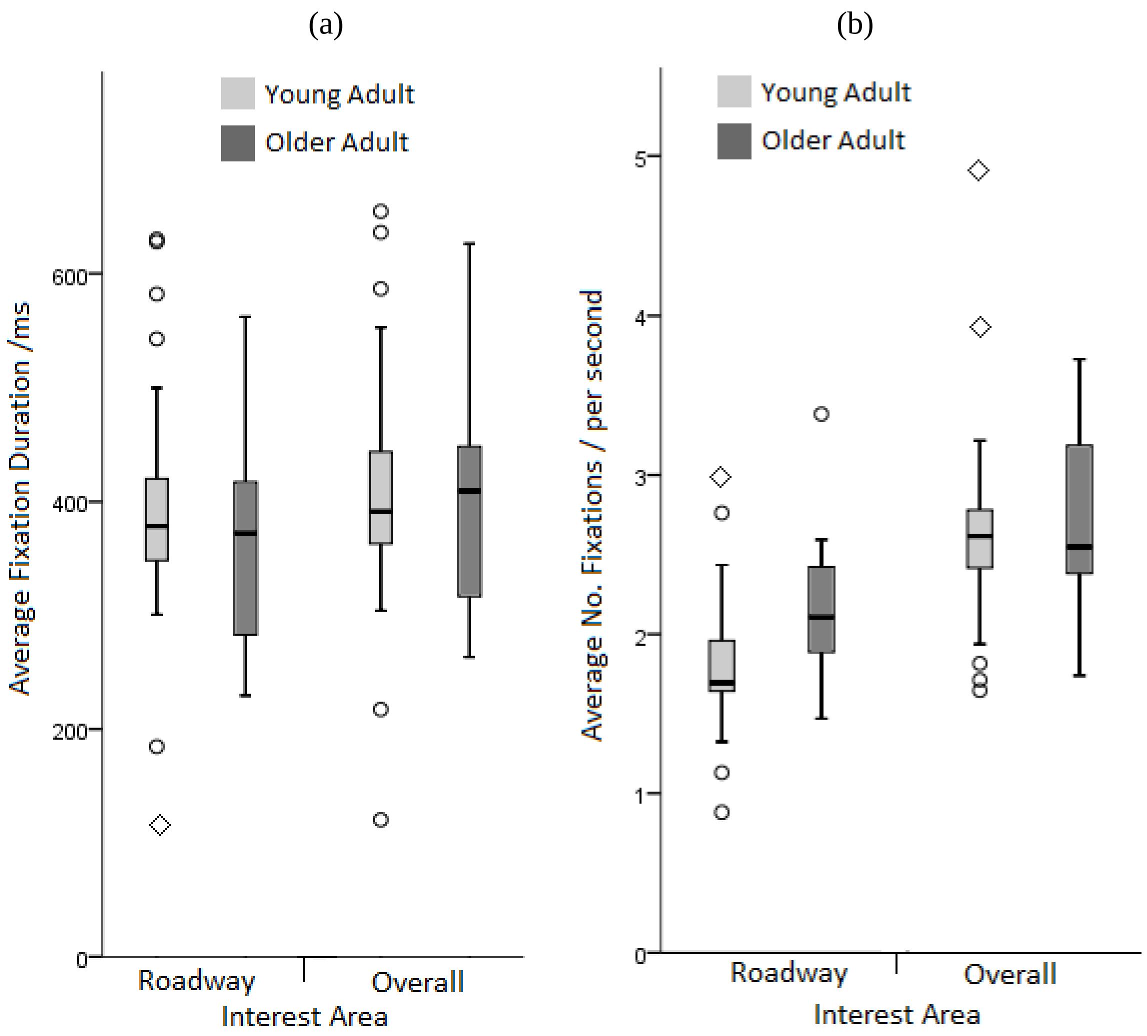

Figure 5.6 Boxplot showing the median differences in (a) the average fixation durations and (b) the average number of fixations made by older and younger adults.

5.4 Discussion: Experiment 1

When driving, there was little difference in how an older adult moves their eyes around the scene compared to a younger adult. This supports the findings by Underwood, Phelps, et al. (2005), who found that scanning behaviour was equivalent for older and young adults when viewing hazard perception videos. Given what we know about the limitations of attentional function in older adults, it is possible no differences were found in that study due to the lack of vehicle control required; which thus reduced the cognitive load of the task. However, the lack of differences is surprising here, where vehicle control was required.

However, from observing each drive, it was clear that the older adults drove much slower than the young adults. Thus, although eye movement behaviour would appear as efficient as younger adults, it is possible that this was achieved only by compensating for the attentional demands of driving by driving slower. Therefore, Experiment 2 aims to 1) test the attentional function of the older adults to confirm that attentional functioning was poorer in the older adult population used in this study and then 2) statistically quantify the differences in the times it took to complete the courses between older and younger adults.

5.5 Experiment 2

Given the research which shows that older adults typically have poorer attentional function than young adults (Ball et al., 1993; Owsley et al., 1991; Owsley & McGwin, 2010), this experiment aimed to determine if this was true for the population used here. The older adults completed the visual attention tasks used in Chapter 4 to measure attentional function. The next step was to determine if there was a significant difference in the time taken to complete the drives between older and younger adults. If attentional functioning is impaired in this sample and if the older adults drove slower, then this may indicate that driving slower is a compensatory process to allow older adults to handle the attentional demands involved in driving. This may explain why the eye movement behaviour was as efficient as the younger adults.

5.6 Methods: Experiment 2

The older adults completed the three attentional tasks as described in Chapter 4. This includes the Multiple Object Tracking test, the 2-Dimensional Object Avoidance task and the 3-Dimensional Object Avoidance task (see section 4.2). However, it was observed that older adults were having particular difficulty with the Multiple Object Tracking task. Therefore the range of speed that the circles moved was changed to 2-6 deg/s (compared to the 4-9 deg/s speed used with the younger adults).

5.7 Results: Experiment 2

The older adults' performance on each of the three visual attention tasks was compared to the performance of the young adults used in Chapter 4. The medians and ranges are presented in Figure 5.7.

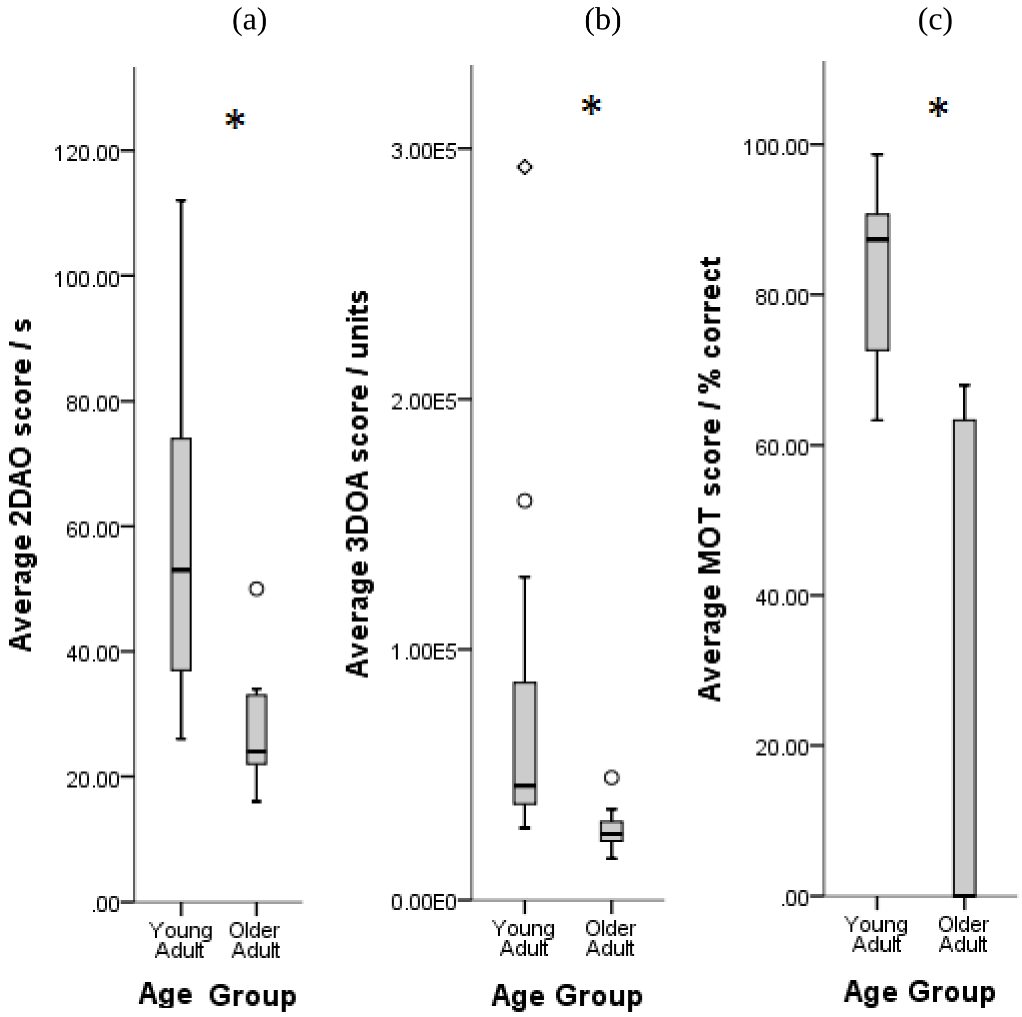

Figure 5.7. Boxplot Showing the differences in performance in the visual attention tasks between younger and older adults for (a) 2DOA task, (b) 3DOA task and (c) MOT task.

Independent Mann-Whitney U tests revealed that there was a significant difference between age groups for each of the visual attention tasks (2DOA: $U = 22$, $z = 3.54$, $p < 0.001$; 3DOA: $U = 22$, $z = 3.53$, $p<0.001$; MOT: $U = 7$, $z = 4.13$, $p < 0.001$). For each of the tasks, older adults' performance was poorer. This suggests that their overall attentional function was poorer than the young adults.

Next, the time taken to complete each course was recorded for both the older and younger adults and was averaged across all three courses. These medians can be viewed in Figure 5.8.

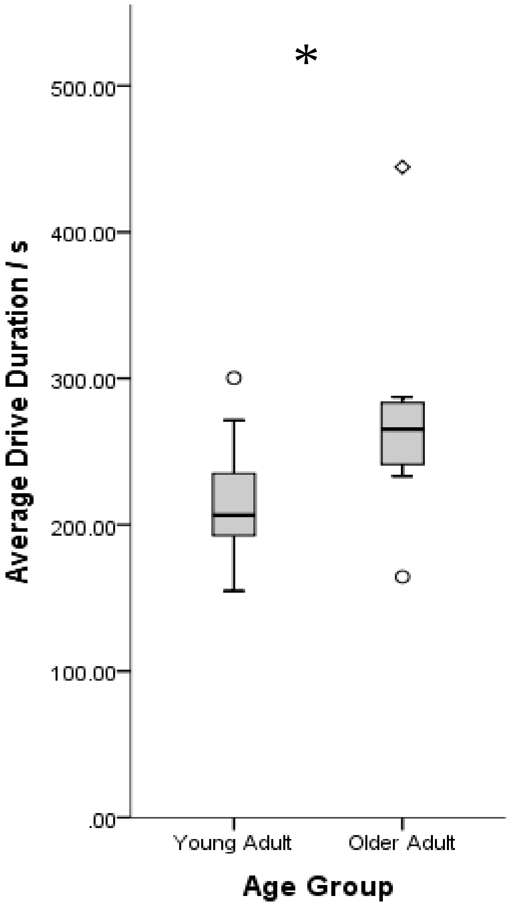

Figure 5.8. Box plot showing the median differences in the overall time it took to complete the drivers for older and younger adults.

There was a significant difference in the time it took to complete the drives on average (U = 158, z = 2.44, p = 0.013). Younger adults completed the drives faster than the older adults, who were around 60 seconds slower (Figure 5.8).

5.8 Experiment 2 Discussion

The aim of this experiment was to determine if the similar eye movement behaviour displayed by the older and younger adults was possibly due to the older adults' compensating for their poorer attentional function by driving slower. It was confirmed that their visual attentional function was indeed poorer and that they drove significantly slower than the younger adults on average. Together this suggests that the eye movement behaviour that was exhibited, which was similar to younger adults, may have been achieved by compensating for the attentional demand of the task by driving slower. The overall findings are discussed below.

5.9 Experiment 1 & 2 General Discussion

The overall aim of this experiment was to measure the eye movement behaviour of older adults while they drove in a simulated environment. Specifically, to investigate if there were any differences compared to a younger adult population. From the finding in the previous experiment, where poor attentional control was linked with a poor visual search strategy, it was predicted that the older adults would exhibit a limited visual search strategy. The results however did not support this. The extent to which the older adult scanned the roadway, used their mirrors and sampled the scene was similar to the young adult population.

Perhaps this is unsurprising to a certain extent. Both groups were considered experienced drivers, but the older adults were in fact more highly experienced. The average time that they had held a driver’s license was 45 years more than their younger counterparts (~ 48 years compared to ~ 4 years for the younger adults). It is the likely case that these drivers have become so experienced that they are experts. Experts have been found to fixate to locations on the road that even experienced counterparts do not, as they have developed extensive knowledge of where hazardous situations are likely to develop (Crundall et al., 2003; Falkmer & Gregersen, 2005). Thus with this expertise they are better able to distribute eye movements more widely. This may explain why older adults scanned the roadway at least as equivalent to the younger adult population.

Given that the older group are experienced drivers, the idea that they know where to look was not in doubt. However, given the well documented cognitive and attentional decline that is associated with old age, there may have been difficulty in being able to allocate eye movements. In other words, even though they know where to look or know how to scan the roadway, the cognitive load of the driving task may have limited their ability in allocating visual attention. This was not found. This however may have been because of attentional compensation. The older adults were found to have poorer attentional function supporting the literature (Clay et al., 2005; Dawson et al., 2010; Mathias & Lucas, 2009; Wagner, Muri, Nef, & Mosimann, 2011), but they drove significantly slower. This may have freed the attentional resources required to distribute their eye movements around the scene. By driving slower, this may give the driver more time to focus the eyes and indeed, the mind, to react to driving situations (Posner, 1995). This suggests that the visual strategies adopted by older adults are similar to younger drivers, but that there is a cost.

The finding that older drivers drive slower is interesting. In this experiment, it lead to what would seem effective visual behaviour and indeed relatively safe driving performance, at least as equivalent to the younger controls (Figure 5.1). It is likely that driving slower gave the participants more time to plan and react to the events that would occur during the drives. This is consistent with reports of older adults typically exhibiting more risk adverse behaviour when driving (Anstey et al., 2005; McGwin & Brown, 1999). However, driving slow may not always be an appropriate substitute for poor skill or attentional limitations. Reaction times are still often slower when driving (Andrews & Westerman, 2012), vehicle control can still be poorer (Bunce et al., 2012) and importantly, crash rates are still high in older adult populations (Evans, 2000). On real roads, it is not necessarily high speed that is a risk factor in accidents, but rather the differences in vehicle speeds on a road (Dellinger, Sehgal, Sleet, & Barrett-Connor, 2001; Lowenstein, 1997; Sullman, Gras, Cunill, Planes, & Font-Mayolas, 2007), particularly if a driver is driving ‘too slow’. For instance, driving too slow may force a driver from behind to overtake on a section of road that they otherwise would not attempt had the driver in front been driving faster. This is often why minimum speed limits are introduced in areas (Department for US Transport, 2014), although this has not been enforced in the UK. The implications of these findings are discussed more broadly in the final chapter (Chapter 7).

5.10 Conclusions

This study aimed to observe if there were any differences in the spatiotemporal deployment of eye movements between older adult drivers and young adult drivers during a typical, non-hazardous simulated drive. The results show that the eye movement strategies were similar across the two populations. It is likely that their driving experience provided them with the knowledge of where they should be looking. However, to account for the cognitive limitations measured, it was likely that the effective visual strategy was achieved by adopting a slower driving strategy. The results help to provide insights into the individual differences that may, or in this case, may not arise in different age populations when driving. The results may have implications for visual and attentional training, and indeed potential law enforcement policies. These are discussed in the General Discussion (Chapter 7).

Chapter 6

Insights into eye movement training and driving

In this final experimental chapter, the aim was to develop and investigate the efficacy of a new method to train eye movement behaviour when driving. Showing eye movements to trainees has been found to be an effective implicit training technique in other tasks, particularly tasks of a more passive nature. Therefore, the aim was to investigate whether this technique is useful for a more active and dynamic task such as driving. The literature relating to driver training is recapped before focussing on, more broadly, eye movement training in other tasks, and how this may relate to visual training in driving.

6.1 Introduction

Within section 1.5 of the Introduction, it was discussed how there are a number of studies which attempt to train driving performance and hazard perception (e.g. Crundall et al., 2010; Horswill et al., 2013; Isler et al., 2009). However, little research has specifically investigated training visual behaviour. A common technique is to use visual cueing, where areas on the road are explicitly highlighted to the driver in attempts to cue eye movements to important areas of the driving scene (e.g. Eyraud et al., 2015; Pomarjanschi et al., 2013; Rusch et al., 2013). More thorough and effective training programmes have been developed (Chapman et al., 2002; Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009) which aim to improve the understanding of why an individual should look around more. As useful as these types of programmes have been, a number of limitations can be identified. Namely, testing often takes place immediately after training and therefore the longitudinal effects of training cannot be established. Also, training can often appear superficial, in that it can influence visual behaviour but does not often influence driving behaviour i.e. individuals do not drive more safe.

Perhaps another method which may prove useful in training visual behaviour could involve some form of implicit learning. Implicit learning, in its purest form, can be described as learning without conscious awareness (Seger, 1994; Stadler & Frensch, 1998). Although it is now largely accepted that attention is required in some capacity during implicit learning (Frensch & Rünger, 2003; Jiang & Chun, 2001). The acquisition of language can be viewed as an example of implicit learning (Dienes & Berry, 1997; Ellis, 1994). Importantly for this experiment, some research has proposed the benefits of implicit visual learning in guiding visual attention (Chun, 2000; Chun & Jiang, 1998, 1999). An example of this in driving comes from Thompson and Crundall (2011). They found that when participants were made to view and scan a horizontal array of letters in one task, this lead to increased scanning of the road when viewing videos of driving scenes. The scanning behaviour learnt in the word task was implicitly carried over to the unrelated driving task. It should be highlighted however that, given the results from Chapter 3, the effects of scanning were possibly exaggerated due to the participants not needing to control a vehicle.

Another implicit visual learning method may be to use the information gathered from viewing eye movement scanning patterns (eye movement traces). Konstantopoulos et al. (2012) asked people to view the eye movement patterns of novice and expert (driving instructor) drivers, but demonstrated that both novices and expert drivers found discriminating between novice and experienced eye movement patterns rather difficult. If one is unable to distinguish between 'good' and 'bad' patterns of eye movements, this would appear to limit the possible effectiveness of using eye movements as a visual training tool.

A slightly different approach is taken within this experiment in an attempt to show the usefulness of using eye movements in training paradigms. When looking at someone's eyes, their gaze can influence and direct the observer's eye movements to certain parts of a scene or stimuli (Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002; Tatler et al., 2007). With this information, studies have shown that, for certain tasks, eye movements can be directed by artificially following where somebody is looking, through viewing eye movement recordings. And this often improves task performance, such as the ability to detect lung nodules in x-ray viewing or solving complex physics problems (Litchfield & Ball, 2011; Litchfield, Ball, Donovan, Manning, & Crawford, 2008; Nodine & Kundel, 1987). Sadasivan, Greenstein, Gramopadhye, and Duchowski (2005), conducted an experiment whereby videos of an expert aircraft-inspector's eye movements, performing an aircraft inspection, were shown to novices. Performance accuracy on the inspection task improved as a result, (albeit, seemingly at a speed cost). Some research has went further and suggested that showing expert eye movement traces may influence how people think, (Grant & Spivey, 2003; Thomas & Lleras, 2007). For example, Litchfield and Ball (2011), argue that when individuals view the eye movement patterns of those who successfully solve Duncker and Lees (1945) classic radiation problem, they are not only cued to a certain location of the problem, but are cued a particular thought process. They suggest that, after viewing the expert eye movement gaze patterns, the change in individuals' eye movement behaviour that results when viewing the problem a second time, suggests a change in the way the individual is thinking (see Litchfield & Ball, 2011).

6.1.1 Current Study

The research discussed in the previous paragraph investigated eye movement cueing paradigms in passive based tasks, where individuals are usually simply viewing scenes or inspecting static images. In this study therefore, the aim was to investigate if using eye movements as a training tool can be effective in guiding eye movements in a complex and dynamic task such as driving. The goal was to accelerate a novice driver's adoption of an experienced eye movement patterns. Without being explicitly told to follow eye movements, if a novice driver sees an expert scan the roadway more or fixate on certain parts of the scene, then they may learn to also.

For this experiment, pre-license drivers performed a simple simulated drive much like that in earlier chapters. After one week, one group was shown recorded video clips of an expert drive with the corresponding eye movements overlain. The other group were not shown the videos, and both groups were asked to drive again. Eye movements of the drivers were compared before and after the video training. After six months, those who received the training were asked to drive once more and their eye movements were compared to their pre and post training sessions. For the purposes of this study, the primary interest was in fixation behaviour, specifically fixation location. Interactions between the training group and training sessions were predicted, where it was hypothesised that those who were given the eye movement training would exhibit increased horizontal scanning of the road and increased use of the mirrors compared to those who were not shown the video.

6.2 Methods

6.2.1 Participants

23 participants took part in the study (9 males). 3 participants were excluded due to poor eye movement calibration. This left a sample of twenty (8 males) with an age range of 17-34 years (mean age = 22.2, St. Dev = 3.9). All participants had normal or corrected-to-normal vision. Each was paid for participation at a rate of £5 per hour. All participants did not have a driver's license and had either never driven or were taking driving lessons at the time of testing. Of those who were taking lessons, they reported having no more than 10 hours of teaching. The simulation could be calibrated for both left and right-hand drivers so both types of road users were accepted into the study. Participants had no prior experience of simulated driving. Ten participants were given the eye movement training videos and the other ten were not. Only six participants from the eye movement training group were successfully recalled for the 6-month follow-up. It was not possible to recall enough participants in the control group to use in the follow-up. The study was approved by the University of St Andrews University Teaching and Research Ethics Committee (UTREC).

6.2.2 Stimuli and Apparatus

6.2.2.1 Driving Simulation

This study utilized the City Car Drive simulator software and the Logitech Driving Force GT steering wheel as described in the General Methods. The simulation was presented on a 22 inch LED monitor set at a resolution of 1920x1080. The virtual environment was viewed at a distance of 70cm (horizontal viewing angle of 40.03^o). See Figure 6.1 for experimental set-up

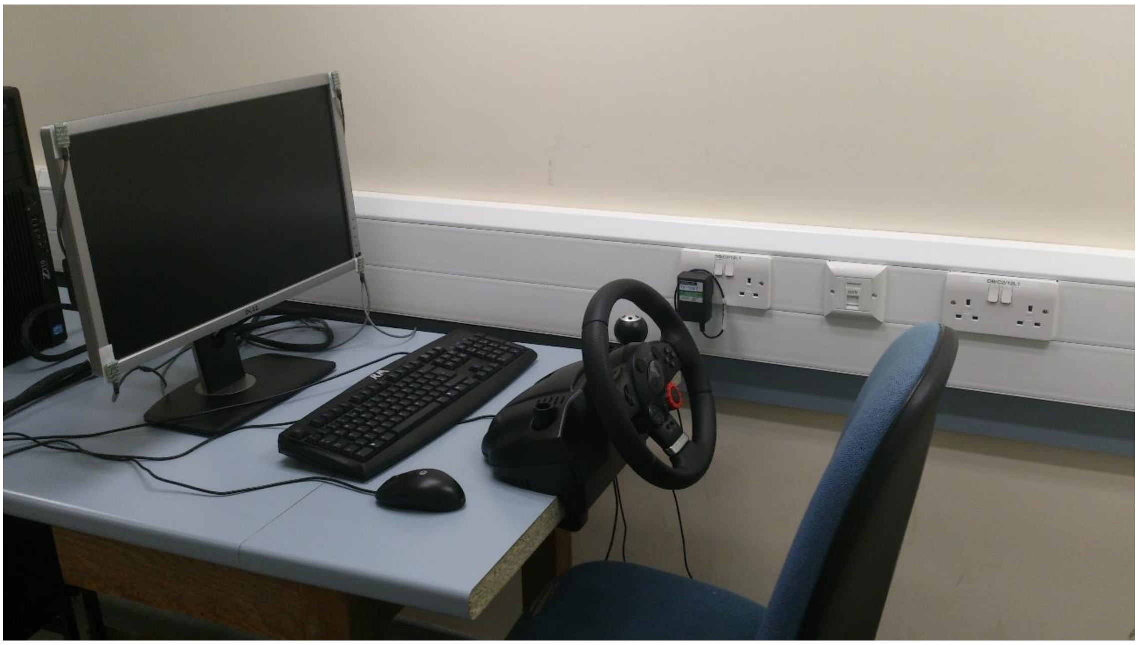

Figure 6.1. Apparatus set-up. Participants sat on the seat on the right and viewed the driving simulation on the monitor and controlled the vehicle using the steering wheel. Note, the keyboard and mouse were used by the experimenter, these were not used during the driving task.

6.2.2.2 Eye movement recording and measures

As described in the General Methods, an Eyelink II system was used to record eye movements. Head movements were allowed and tracked using the Eyelink screen markers on the monitor. For this study, the eye movement measure of most significance is fixation location. Similar to Chapter 4, there were four areas of interest: the rear-view mirror, the driver-side mirror, the passenger-side mirror and the roadway (Figure 4.6). Speedometer fixations, and saccades to and from, were not included in the analyses. The measures recorded were the horizontal and vertical spread of eye movements on the roadway and mirror fixation counts and dwell times.

6.2.2.3 Experienced eye movement training videos

The eye movement training videos were created by recording the eye movements of the experimenter (myself) whilst driving in the simulated environment. The experimenter is an experienced driver, holding a licence for 4 years, and driving most days, and was familiarised with the simulated environment before recording. The eye movements, in the form of a red dot (diameter 1.2cm), were synchronously overlain onto video recordings of the drivers via the video editing software method previously described (Chapter 2). Two videos were used in the experiment. The first video was that of a generic motorway drive that consisted of a long stretch of road with multiple lanes with traffic joining and exiting the motorway via side slip roads. The second video showed a drive on a winding country road with single and dual lanes. These videos were slowed to 60% of the original speed to allow participants to view and process the movement of the experienced driver’s eyes more effectively. Each video lasted 5 minutes. The routes driven were similar but not identical to those routes driven by the participants.

6.2.3 Procedures

6.2.3.1 Pre-training session

All participants were instructed they would be driving a number of routes in a driving simulator programme whilst their eye movements were being tracked. They were shown how to use the driving simulator software and set up. It was explained to them how to use the gas pedal to accelerate and the brake pedal to slow the car and they were instructed on how the wheel turned the vehicle. The turn signals were highlighted to the participants. It was also shown to participants where the mirrors and speedometer were depicted on the monitor. Each participant was given a short five minute test period where they drove around a large car park, with no other road users present, whilst avoiding a pre-programmed placement of traffic cones. This was to allow participants to acclimatise to the feel of the car and the environment they would be driving in. Participants were then asked to drive three routes. The three routes were driven in a random order. Participants were asked to adhere to simple traffic laws, such as staying within the speed limit, maintain proper lane position and stopping at red lights. For each drive, their eye movements were recorded along with a video of the drive. Given that each individual drive was unique, the duration of the drives differed across participants. Across all participants, on average, each drive lasted 3 minutes 48 seconds minutes. The eye movement training group and the control group drove the same courses.

6.2.3.2 Training session

The post-training session occurred one week after the first session. For the eye movement training group, participants were instructed that they were to watch two short video clips depicting an expert driver driving. They were told that there would be a red dot visible throughout the video and that this corresponded to the driver's eye movements – in other words, the red dot is where the driver is looking. They were not explicitly told to follow the dot. Eye movements were not tracked for these videos, however the experimenter closely monitored the physical movement of the eye on the eye tracker host computer to detect if any participants were not allocating attention toward the screen. The control group were not shown the video recordings. Participants, both the eye movement and control groups, were then instructed to drive three courses whilst their eye movements were tracked. The courses were the same as the first session but this was not mentioned to the participant.

6.2.3.3 Six month follow-up

Only six participants from the eye movement training group were successfully recalled. After six months from the initial training, these participants were once again asked to drive in the simulated routes whilst their eye movements were tracked. Participants were fully debriefed afterwards.

6.2.4 Design

Regarding the initial pre and post training sessions, the independent variables being manipulated were the experimental group (eye movement group and control group) and the experimental session (pre-training and post-training). This study used a mixed design where all participants participated in the pre and post experimental sessions and half the participants were randomly selected for either the eye movement group or control group. A 2x2 mixed factorial ANOVA was conducted for each of the eye movement dependent measures described. Interactions were predicted, where an improvement for the trained group but not the control group is expected. For the follow-up analyses, the six participants' eye movement data were compared to their pre and post eye movement data using one way ANOVA with three levels (pre training session, post training and follow-up).

6.3 Results

6.3.1 Pre-training and immediate post-training sessions

Data were collapsed and averaged across the three courses. Eye movements were compared across the two groups: those who received the eye movement training (eye movement training) and the group who did not (control), and across the pre training and post training session. 2x2 mixed measures ANOVAs (session and training group) were used to analyse differences across these conditions. It is the possible interaction effects which are of most interest, where, ideally, improvement would be observed between pre and post sessions for the eye movement training group but not the control group. Bonferroni corrections were used when pairwise comparisons were conducted.

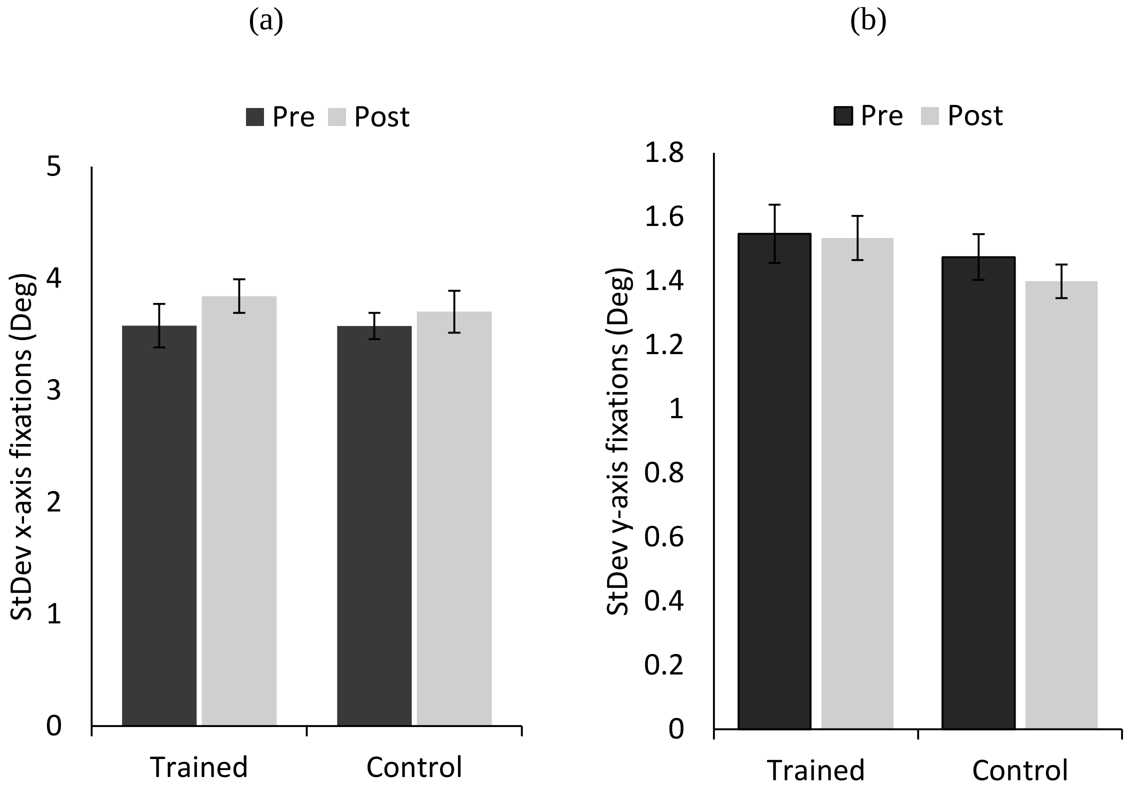

Figure 6.2. Standard deviation of fixations for (a) horizontal axis and (b) vertical axis. Error bars show standard error of the mean.

Figure 6.2 shows the differences in the spread of eye movements as measured by the standard deviation of x-axis and y-axis fixations for the trained and untrained groups during the pre-training and post-training sessions. There were no significant main effects of session on the distribution of horizontal eye movements ($F(1,18) = 3.63$, $p = 0.073$, $\eta_p^2 = 0.17$) and vertical eye movements ($F(1,18) = 0.51$, $p = 0.48$, $\eta_p^2 = 0.03$). There were no significant main effects of group for both the horizontal ($F(1,18) = 0.12$, $p = 0.74$, $\eta_p^2 = 0.01$) and vertical ($F(1,18) = 1.64$, $p = 0.22$, $\eta_p^2 = 0.8$) eye movement distributions. There was no interaction between session and group for horizontal eye movements ($F(1,18) = 0.44$, $p = 0.52$, $\eta_p^2 = 0.02$) and vertical eye movements ($F(1,18) = 0.26$, $p = 0.62$, $\eta_p^2 = 0.01$). This suggests there was no effect of training the scanning the roadway.

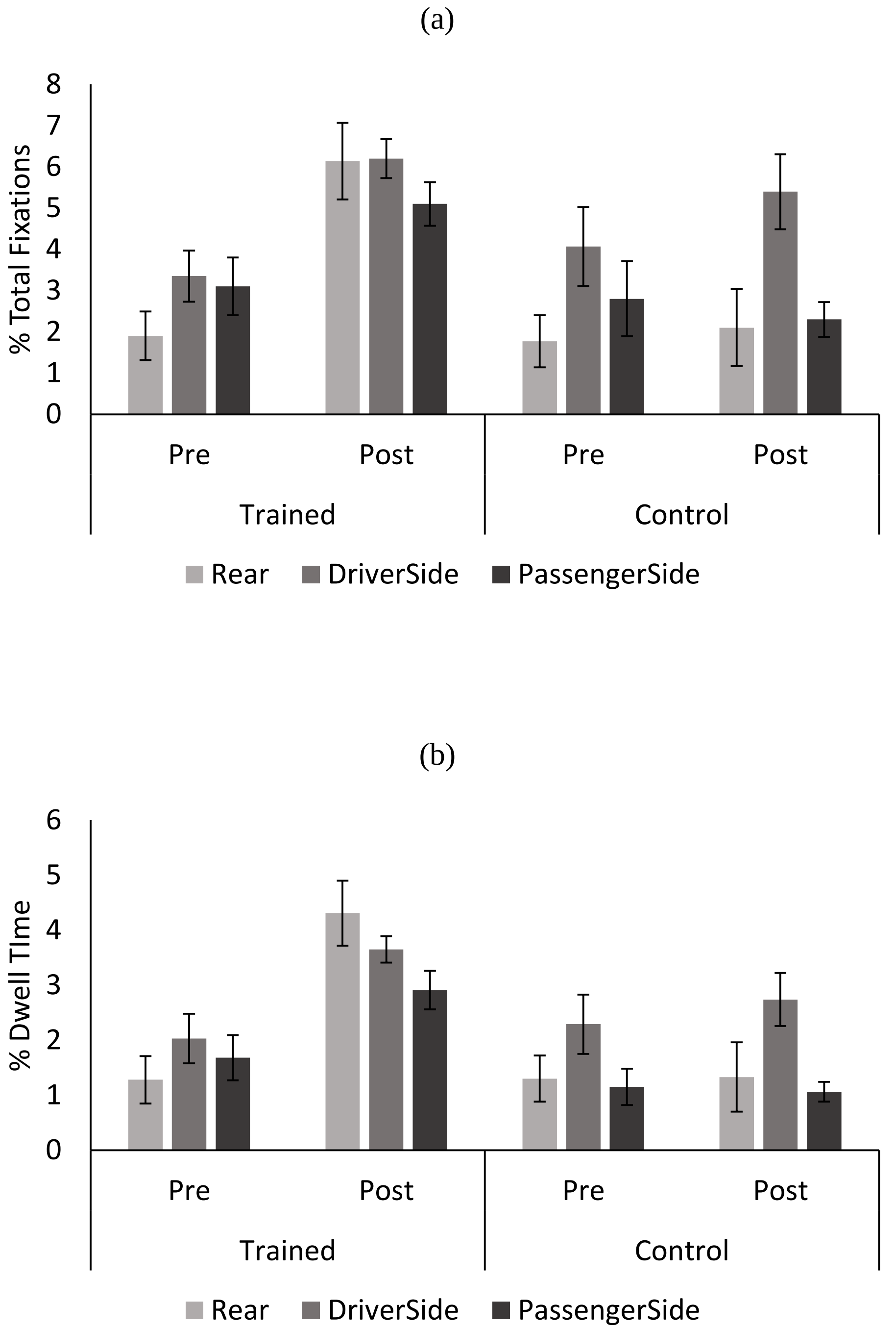

Figure 6.3. Inspection of the mirrors as measured by (a) fixation counts and (b) fixation dwell times.

Figure 6.3 shows the differences in mirror inspection for the trained and untrained groups during the pre-training and post-training sessions. There was a significant main effect of session on inspection of the rear-view mirror as measured by fixation counts ($F(1,18) = 16.91$, $p = 0.001$, $\eta_p^2 = 0.48$) and fixation dwell times ($F(1,18) = 17.38$, $p = 0.001$, $\eta_p^2 = 0.49$). There were also significant main effects of group on rear-view mirror inspections for fixation counts ($F(1,18) = 1,18$, $p = 0.04$, $\eta_p^2 = 0.21$) and fixation dwell times: ($F(1,18) = 5.19$, $p = 0.035$, $\eta_p^2 = 0.22$). Importantly, there was a significant interaction between session and group for fixation counts ($F(1,18) = 12.36$, $p = 0.002$, $\eta_p^2 = 0.41$) and fixation dwell times ($F(1,18)=16, 70$, $p = 0.001$, $\eta_p^2 = 0.48$). Bonferonni adjusted comparisons revealed a significant increase in the use of the rear-view mirror for the trained group as measured by fixation counts ($p < 0.001$) and fixation dwell times ($p < 0.001$). There was no increase in the use of the rear-view mirror for the untrained group. This suggests that training improved use of the rear-view mirror.

There were significant main effects for session regarding the use of the driver-side mirror as measured by fixation counts ($F(1,18) = 16.344$, $p = 0.001$, $\eta_p^2 = 0.48$) and dwell times ($F(1,18) = 11.83$, $p = 0.003$, $\eta_p^2 = 0.40$). This suggests that both trained and untrained groups improved in their use of the driver-side mirror between sessions. There were no main effects of group for either the number of fixations ($F(1,18) = 0.001$, $p = 0.97$, $\eta_p^2 = 0$) or dwell times ($F(1,18) = 0.35$, $p = 0.56$, $\eta_p^2 = 0.02$). There was also no significant interaction between session and group for fixation counts ($F(1,18) = 2.16$, $p = 0.16$, $\eta_p^2 = 0.11$) and dwell times ($F(1,18)=3.81$, $p = 0.067$, $\eta_p^2 = 0.17$).

There was no significant main effects for session regarding the use of the passenger-side mirror as measured by fixation counts ($F(1,18) = 1.36$, $p = 0.26$, $\eta_p^2 = 0.07$) and dwell times ($F(1,18) = 3.27$, $p = 0.087$, $\eta_p^2 = 0.20$). There was a significant main effect of group for fixation counts ($F(1,18) = 5.00$, $p = 0.038$, $\eta_p^2 = 0.22$) and dwell times ($F(1,18) = 11.85$, $p = 0.003$, $\eta_p^2 = 0.40$). From figure 6.3 there was a trend that those in the trained group used their driver-side mirror more than those in the untrained group and improved most after the training session, although this interaction was not significant for fixation counts ($F(1,18) = 3.82$, $p = 0.066$, $\eta_p^2 = 0.18$) and dwell times ($F(1,18) = 4.38$, $p = 0.051$, $\eta_p^2 = 0.2$).

From these results, it appears that, overall, the eye movement training intervention was not successful in inducing more effective eye movement scanning patterns. However, it was observed that there were large inconsistencies in the driving events that occurred in the urban route across participants in this experiment. Due to some random events that could not be controlled within the simulation software, each drive was not comparable. For example, some drivers had to stop at a red light, whereas others would not have had to stop as the traffic light was green. Those who had to stop would likely have had different eye movement patterns compared to those who did not. For this reason, the analyses were conducted again with the urban route omitted.

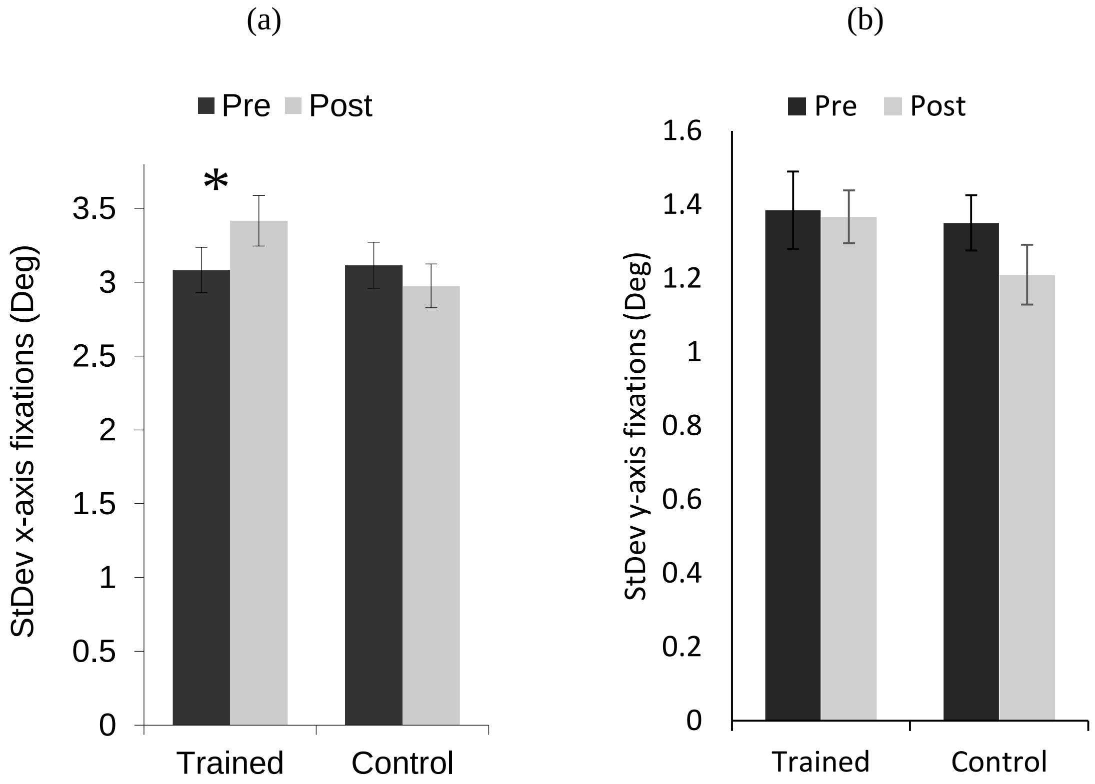

Figure 6.4. Standard deviation of fixations along the (a) horizontal and (b) vertical axes with the urban environment omitted. Error bars show standard error of the mean.

For horizontal scanning behaviour (Figure 6.4), there was no main effect of session ($F(1,18) = 1.0$, $p = 0.329$, $\eta_p^2 = 0.05$) or group ($F(1,18) = 0.74$, $p = 0.4$, $\eta_p^2 = 0.04$). There was an interaction between session and group ($F(1,18) = 6.08$, $p = 0.024$, $\eta_p^2 = 0.25$). Pairwise comparisons were conducted and it was found that there was a very small, but significant increase in the standard deviation of x-axis fixations for the eye movement trained group (p = 0.025) but not for the control (p = 0.32). This means that those in the trained group searched the road slightly more than the control group after training. There was no main effect of session ($F(1,18) = 1.18$, $p = 0.29$, $\eta_p^2 = 0.06$), group ($F(1,18) = 1.04$, $p = 0.32$, $\eta_p^2 = 0.06$) or interaction ($F(1,18) = 0.70$, $p = 0.41$, $\eta_p^2 = 0.04$) for vertical distributions of eye movements.

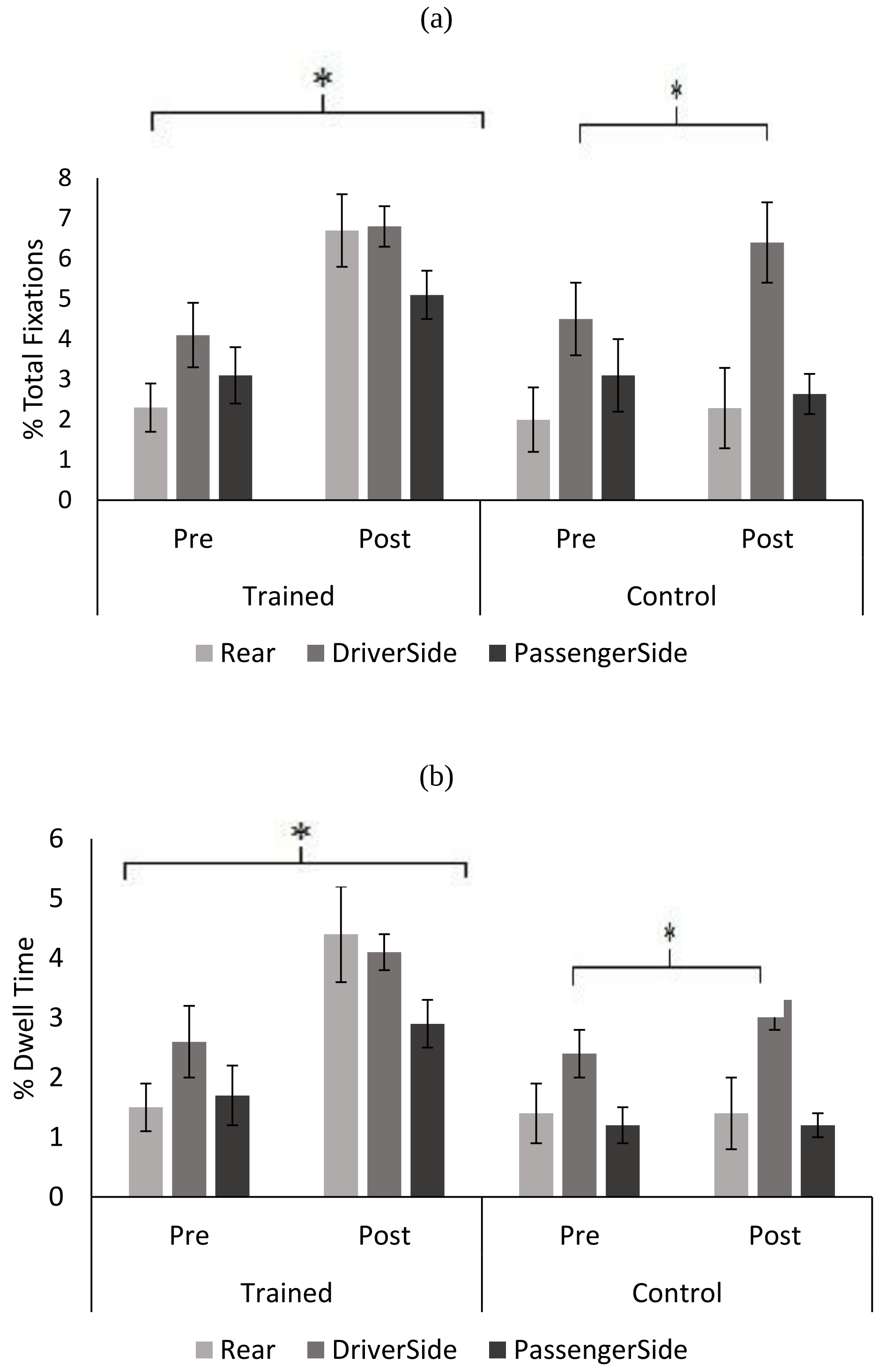

Figure 6.5. Inspection of the mirrors as measured by (a) fixation counts and (b) fixation dwell times with the urban environment omitted. Error bars show standard of the mean.

For mirror analyses (Figure 6.5), there were significant main effects of session for the total percentage of fixations and the total percentage dwell time for fixating the rear-view mirror ($F(1,18) = 14.8$, $p = 0.001$, $\eta_p^2 = 0.45$; $F(1,18) = 11.11$, $p = 0.004$, $\eta_p^2 = 0.38$, respectively).

There were also main effects of group ($F(1,18) = 4.92$, $p = 0.042$, $\eta_p^2 = 0.21$; $F(1,18) = 4.55$, $p = 0.047$, $\eta_p^2 = 0.2$). Importantly there were significant interactions between group and session for fixation counts and dwell times for rear-view mirror fixations ($F(1,18) = 11.0$, $p = 0.004$, $\eta_p^2 = 0.38$; $F(1,18) = 12.0$, $p = 0.003$, $\eta_p^2 = 0.4$). Bonferonni adjusted comparisons revealed a significant increase in mirror fixation counts and fixation dwell times for the trained group ($p = 0.009$; $p < 0.001$) but not the control group ($p = 0.71$; $p = 0.93$). This suggests that training improves the use of the rear-view mirror. (Figure 6.5).

There were also similar effects for use of the passenger-side mirror. For fixation counts, there was no main effect of session ($F(1,18) = 1.32$, $p = 0.27$, $\eta_p^2 = 0.07$) or group ($F(1,18) = 2,86$, $p = 0.12$, $\eta_p^2 = 0.14$). There was also no significant interaction between session and group ($F(1,18) = 3.23$, $p = 0.089$, $\eta^2 = 0.15$), however there was a clear trend (Figure 6.5) and thus pairwise comparisons were conducted. There was an increase in the number of fixations for the trained group ($p = 0.05$) but not the untrained group ($p = 0.65$). Similarly for fixation dwell times, there was a trending interaction ($F(1,18) = 3.45$, $p = 0.078$, $\eta_p^2 = 0.16$) and pairwise comparisons revealed a significant increase in dwell time for the trained group ($p = 0.02$) but not the untrained group ($p = 0.936$). These results indicate training improved the use of the passenger-side mirror (Figure 6.5).

Interestingly, for the driver-side mirror, there was a significant main effect of session where there was an increase in use for both groups as measured by the fixation counts ($F(1,18) = 22.20$, $p < 0.001$, $\eta_p^2 = 0.55$) and fixation dwell times ($F(1,18) = 16.10$, $p = 0.001$, $\eta_p^2 = 0.47$). There were no main effects of group or interactions.

6.3.2 Six month follow-up

Only six participants were successfully recruited back, all from the eye movement training group. The analyses here therefore lack statistical power somewhat, and thus, any strong conclusions cannot be made. With this in mind, the aim was to determine whether the positive fixation location behaviour observed after immediate training is retained after six months for those six participants. A one-way ANOVA was conducted across pre, post and follow-up training stages with pairwise comparisons specifically comparing the eye movement behaviours between post-training and six month follow-up stages.

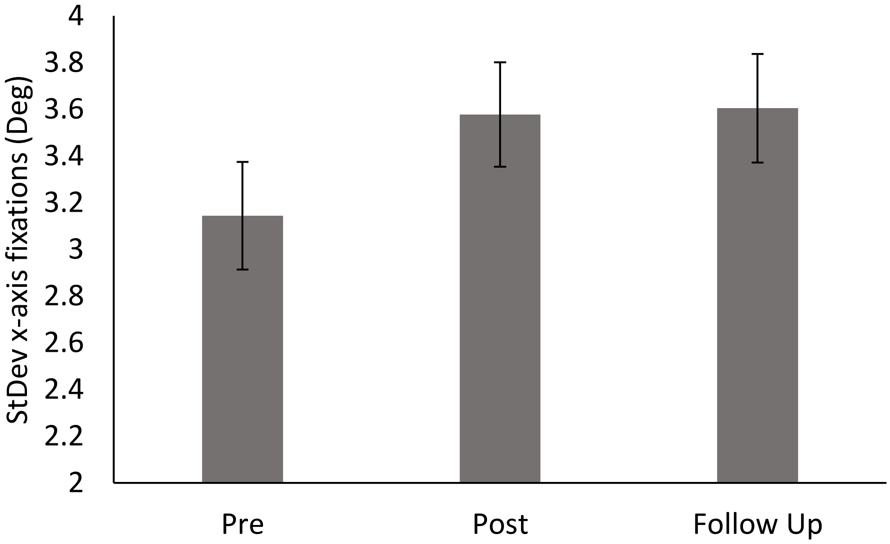

Figure 6.6. Standard deviation of x-axis fixation locations for pre-, post- and follow-up drives for the 6 participants.

Figure 6.6 shows the horizontal scanning behaviour for pre, post and follow up sessions. There was no overall effect of session. ($F(2,10) = 1.74$, $p = 0.224$, $\eta_p^2 = 0.26$). Promisingly, planned comparisons revealed no significant difference between post and follow-up sessions (p=1.00), suggesting that the improvement in visual behaviour was retained for the 6 participants. However, given the smaller sample size, there was no significant effect between pre and post sessions ($p = 0.77$) and pre and follow-up sessions ($p = 0.25$) as previously found. Although there is a clear trend (Figure 6.6)

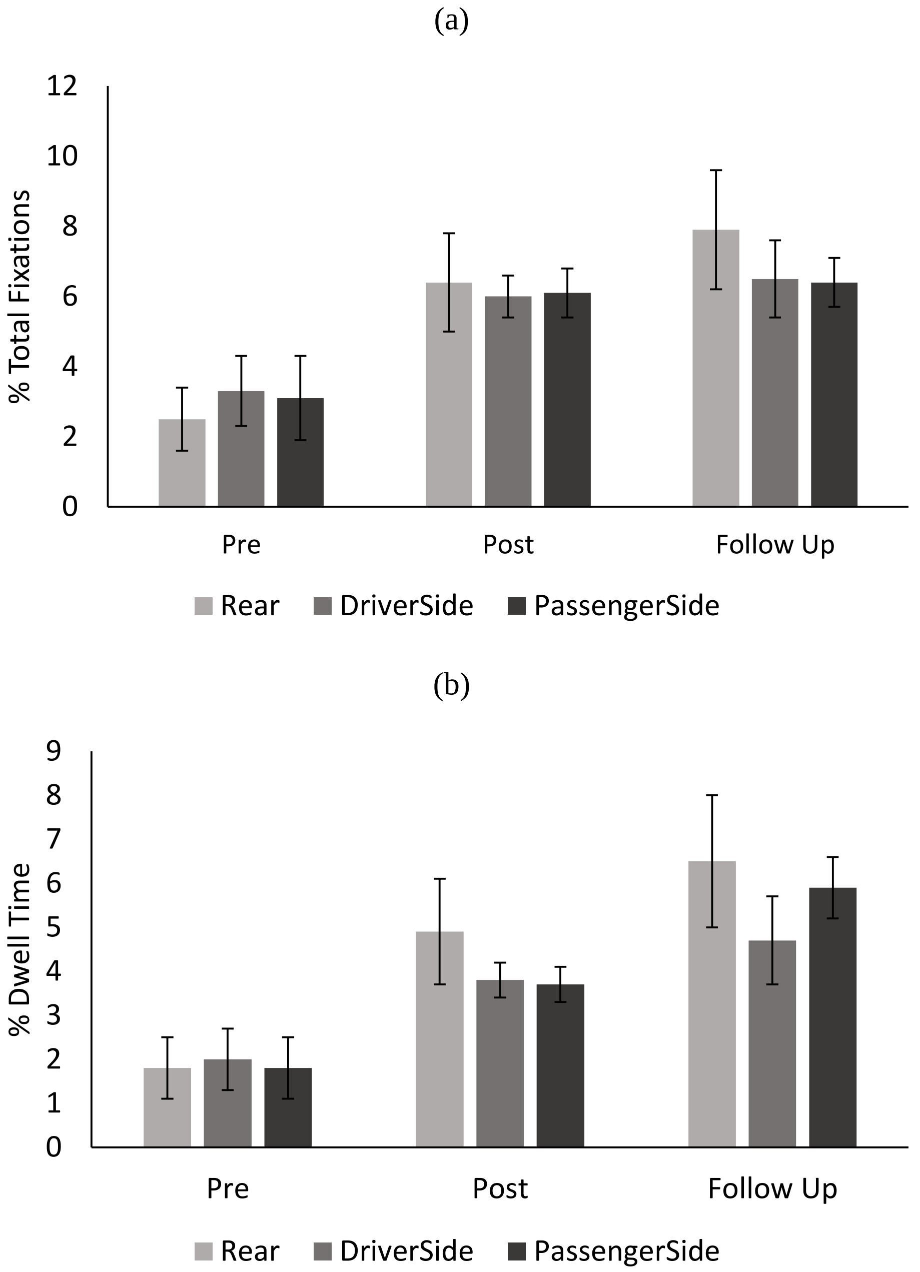

Figure 6.7. Fixation counts (a) and fixation dwell times (b) for pre- post- and follow-up drives.

Figure 6.7 shows the use of each of the three mirrors as measured by fixation counts (a) and dwell times (b). There was an overall effect of session for rear-view mirror fixation counts ($F(2,10) = 8.39$, $p = 0.007$, $\eta_p^2 = 0.63$) and rear-view mirror dwell times ($F(2,10) = 10.01$, $p = 0.004$, $\eta_p^2 = 0.67$). Planned comparisons showed there was no significant difference between post and follow up sessions for fixation counts ($p = 0.08$) and fixations dwell times ($p = 0.1$). The significant positive effects previously observed between pre and post sessions was carried-over here in the smaller sample (Pre v Post fixations counts: $p = 0.03$; Pre v Post fixation dwell times: $p = 0.02$)

For the passenger-side mirror, there was an overall effect of session on fixation counts ($F(2,10) = 6.09$, $p = 0.02$, $\eta_p^2 = 0.55$) and fixation dwell times ($F(2,10) = 15.68$, $p = 0.001$, $\eta_p^2 = 0.76$). There was no significant increase between post and follow up sessions for fixation counts ($p = 1.0$) but interestingly there was for fixation dwell times ($p = 0.03$). The improvement from pre to post, found before, was found to be trending for fixation counts ($p = 0.07$) and dwell times ($p = 0.06$)

There was an overall effect of session for driver side mirror fixation counts ($F(2,10) = 3.86$, $p = 0.05$, $\eta_p^2 = 0.44$) and for fixation dwell times ($F(2,10) = 4.76$, $p = 0.035$, $\eta_p^2 = 0.49$). Pairwise comparisons revealed no significant difference between post and follow up sessions for fixation counts ($p = 1.0$) or fixation dwell times ($p = 0.194$). The improvement from pre and post was trending for fixation counts ($p = 0.06$) and fixation dwell times ($p = 0.06$).

Collectively, these results suggest that the visual behaviour that was learnt due to training was successfully retained at follow-up. However, it was clear that some of the improvement effects that were originally observed, had been lost due to the smaller sample size.

6.4 Discussion

The aim of the present experiment was to investigate whether showing an expert driver's eye movement scan pattern can directly influence a novice driver's eye movements while driving. It was hypothesised that the eye movement training would induce an overall increase in scanning behaviour. There was some evidence for this when the differences in driving situations were controlled for. It was found that those who were given the two training videos exhibited a slight increase in scanning the roadway and use of the mirrors more than those who did not receive the training videos. These findings are consistent with eye movement training studies in other areas such as x-ray viewing (Litchfield et al., 2008) problem solving (Litchfield & Ball, 2011) and aircraft inspection (Sadasivan et al., 2005), where after viewing experienced or more appropriate eye movement scan patterns, task performance improved. Although there was no task here per se, the novice drivers exhibited more appropriate eye movement patterns similar to experienced drivers after viewing the eye movements patterns of an experience driver.

It is encouraging that there was a slight increase in how much the novice driver scanned the road after training. Typically, experienced drivers scan the roadway more, particularly on more demanding road situations (Underwood & Crundall, 1998; Crundall et al. 2003; Konstantopoulos et al. 2013), suggesting they have an increased understanding of the road and the possible situations that may occur e.g. looking for oncoming traffic, looking for overtaking/undertaking vehicles etc. One interpretation for the results in this experiment is that the novice drivers have learned that, after viewing the scan patterns of experts, sampling more of the road may prove to be a more effective visual strategy when learning to drive. Although it is difficult to say for sure given the data recorded.

Vehicle mirrors provide the driver with the necessary information concerning current traffic conditions and also provides the visual information for the driver to make decision before conducting manoeuvres, e.g. changing lanes. It is known that experts and experienced drivers utilise their mirrors more than novice drivers (Konstantopoulos et al., 2010; Underwood, Crundall, et al., 2002). In this study, there was an increase in the use of all the mirrors for the trained group. The use of these mirrors is crucial for complex and demanding roads like the ones used in this experiment; roads which incorporate a number of lanes with fast moving traffic. Interestingly, in this experiment, both the trained group and untrained group exhibited an increase in the use of the driver-side mirror. One could speculate that this may be as a result of practice effects, where individuals realised the importance of the mirror during the initial testing stage and changed their visual strategy during the second stage of driving.

Although one should be vigilant on all roads, arguably, this vigilance should be magnified on the types of roads used here - even when hazards are not present. One must continually: monitor traffic joining at junctions and slip roads or approaching from behind, over-taking vehicles and survey opportunities for lane changing. This study therefore yields promising results in offering potential driver safety training. Furthermore, the results suggest that the training may not need to be complex or lengthy, given the results were found only after two short (5 minute) video clips.

Where previous research has been successful in influencing visual behaviour (Chapman et al., 2002; Pradhan et al. 2009; Rusch et al., 2013), questions remain (but still remain in this study also) regarding the superficiality of the change in visual behaviour (see Konstantopoulos et al. 2012), where driving behaviour does not change. Explicitly highlighting areas of the driving scene may not be as effective in improving a novice driver's knowledge of the driving scene; i.e. they still may not know why they should be looking there. A more beneficial outcome of training would be to train a specific thought process, which may result not only in a change in eye movement behaviour but also driving behaviour. Although it is rather debatable, some research has suggested that different thought processes can be cued by viewing eye movement patterns (Litchfield & Ball, 2011; Frischen, Bayliss & Tipper, 2007). In this study, it is not known whether novice drivers did think about the scene different after training. However, although quite tenuous, it is plausible that the novice drivers did adopt a new thought process when driving, since there was some evidence of the positive learned visual behaviour being retained after six months.

There is a limitation in this study related to this point that should be highlighted here though. Driving performance was not recorded in this experiment due to a technical fault of the simulator software. Ideally, changes in vehicle control and safe driving behaviour would have been quantified (as in Chapter 3 and 4) and cross-referenced. This would have given an indication of whether the eye movement training influenced not only visual behaviour, but also driving performance. This, in turn, would have provided clearer indication of whether individuals changed their thought processes when driving.

On saying this, with this study, there is at least the foundational evidence that we can positively influence eye movement behaviour while driving (at least in basic simulated driving). Thus, future research using eye movement training in driving should build on these results by considering some factors not directly investigated here. The first is of course, how this can transfer to real roads, with real traffic conditions and larger fields of view. If we can find similar results in field studies, then using laboratory eye movement training may be an effective tool to train visual behaviour, or indeed simply educate drivers, in a safer environment. In addition, although eye movement training can seemingly induce a broader scanning behaviour, it is not known how this relates directly to hazard perception. A failure to search the road may result in an accident (Lee, 2008), and as such, research would benefit directly investigating how and if a trained widened search coincides with increased hazard perception ability.

6.4.1 Conclusions

This study, to my knowledge, is the first study to illustrate the potential benefits of using experts' eye movements for training in complex, dynamic environments. Although some effects are modest in size, it was found that individuals do indeed adopt a new visual strategy after viewing an experienced driver's scanning behaviour. Therefore, this preliminary work suggests the potential effectiveness of using this type of visual training for early stage drivers. Future research should ideally expand on the results by using more robust driving simulation techniques or indeed field studies whilst also looking at how eye movement training can influence hazard detection and safer driving. General implications and the limitations of this study are explored in the General Discussion of this thesis.

Chapter 7

General Discussion

This final chapter will offer further discussion of the results found in each of the experiments, with particular attention to the potential implications for the findings, possible future experimental directions and the limitations of the studies. This section, and with it, the thesis, will end with a general summary and conclusions for the thesis as a whole.

Driving is a common every-day, yet, complex task. It requires attention to the road in order to control the vehicle, attention to other road users to avoid collisions and attention to other sources of information to aid navigation and safe driving e.g. road signs or speed limit signs. It therefore requires a high level of visual function and attention. Investigating the eye movements of drivers can provide insights into how the visual system is used for such complex behaviour. Given its complexity though, driving carries a number of safety risks. Being a highly visual task, it is reasonable to propose that one of the main factors which may lead to road accidents is deficits in visual attention. This is consistently found in research where inattention and failures to scan the roadway are continuously reported as factors which lead to accident involvement (Dingus et al., 2006; Lee, 2008; Lestina & Miller, 1994; Underwood, 2007). As such, investigating eye movements may also help to provide possible insights into what may contribute to accidents, and indeed, what contributes to the prevention of accidents. These themes were broadly explored in this thesis.

Three main questions were addressed. The first, in Chapter 3, what are the most valid tools for measuring and assessing eye movements and driving? The results helped to further the understanding of how vision and action interact during natural activity and also helped to provide insights into the usefulness of active hazard perception driving tasks. The second aim was to investigate some of the individual differences associated with eye movements and driving. Two experiments were described to investigate individual differences. The experiment in Chapter 4 explored how visual attentional function may contribute to effective eye movement behaviour for driving. The results helped to further the understanding of what contributes to better driving and also provided insights into the development of more effective driver assessment tools. The experiment in Chapter 5 explored another factor that may contribute to the differences in eye movements, that of age. The results provided insights into the visual and driving strategies adopted by older adults which may in turn have consequences for the higher older adult accident liability cases observed (e.g. Evans, 2000). The final aim related to visual training, where the final experiment in Chapter 6 investigated a novel method with which to train more effective visual behaviour when driving. The results yielded promising results that could inspire a potential training tool that can be used by novice drivers when learning to drive. These experimental findings are discussed further below in turn, with particular focus on the theoretical and practical implications of the findings. In addition, many of the experimental limitations are outlined in order to provide critical evaluation for the studies conducted.

7.1 The use of active driving tools

The first aim of this thesis was to investigate if there were any differences in the spatial deployment of eye movements when driving in a simulated environment (active) and a typical video based hazard perception task (passive). The broader goal was to determine the suitability of video tasks when investigating eye movements and driving. The main results from Chapter 3 were that individuals scanned the roadway more and responded to hazards faster in a video based task compared to a task where they were asked to drive (Figure 3.5). Thus it was proposed that passive driving tools, such as video viewing paradigms, may not capture the subtleties in visual attention that on-road driving would.

Much like the results found within the active vision literature (e.g. Foulsham et al., 2014; Foulsham et al., 2011; Steinman, 2003; Tatler et al., 2011), these findings suggest that the way in which the eye movement system and attentional system are deployed in an active task is different than tasks of a passive nature e.g. visual search. The main explanations given were two-fold. Firstly, the visual search may be limited in an active driving task when one needs to fixate on certain parts of the roadway in order to control the vehicle. Secondly, there is a higher cognitive load associated with active control of the vehicle may also limit visual search. These may also explain the increased latency to respond to the hazards.

Arguably, what is identified here is not only performance differences across video and simulated tasks, but also possible performance *deficiencies* in oculomotor behaviour and hazard perception while participants undertake the active driving task (i.e. less scanning, slower reaction times). This may have implications for assessment and training methods used in driving and particularly in hazard perception. If the scanning behaviour seen in a video-based non-driving task over-estimates how much an individual would scan the road when driving, then training of scanning behaviour may be more appropriate in a setting that incorporates both the visual and driving demands of the tasks. Encouragingly, such naturalistic approaches have been used to investigate eye movement control and its relation to improved driving (Chapman et al., 2002; Pollatsek et al., 2006; Rusch et al., 2013). Although, since there is no direct evidence here to suggest this may be the case, this is merely speculative at this point.

Hazard perception video training has proven to be very useful where it has been shown to increase situation awareness in early stage drivers (e.g. Horswill et al., 2013) and this training may be a contributing factor to the lower accident liability cases we have observed each year (Horswill, Falconer, et al., 2015). As such, this thesis certainly acknowledges the usefulness of these types of tests. However, when actively engaged in the driving hazard perception task here, individuals were slower to detect hazards than if searching for them when performing a standalone task. If one assumes that this is partly due to the increase in cognitive load associated with driving the vehicle, then this may have implications for attention in real life driving. Specifically, since inattention related road accidents make up a large proportion of cases (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Lee, 2008), hazard perception video training tools are therefore removing one of the aspects of driving which relates to accident involvement – that of divided attention. Performance on complicated cognitive tasks improves with practice where actions become more automated requiring less conscious intervention (Moors & De Houwer, 2006; Underwood & Everatt, 1996). One may therefore argue that investigating hazard perception and how it can be trained, training that includes performing the tasks of driving and hazard perception together, could be more effective. One good example of this is Casutt, Theill, Martin, Keller, and Jäncke (2014) who demonstrated that active driving simulator training improved on-road driving performance better than passive attention training (training which involved selective attention). It remains to be seen how this type of training influences eye movement behaviour. However, one could predict that driving simulator training would also improve eye movement behaviour too.

7.2 Promoting visual cognitive training in driving

Chapter 4 presented the first of two investigations into the reasons we may observe individual differences in eye movement behaviour when driving. It explored how an individual's cognitive control, specifically termed attentional function here, may be linked to effective eye movement behaviour when driving. There was evidence in Chapter 4 to suggest that individuals with better attentional function may make better drivers overall, both visually and driving safely. Specifically, individuals who were found to have better attentional function scanned the roadway more, used their passenger side mirror more and drove safer. It was suggested that better attentional function may be a factor which leads to better eye movements in experienced drivers, where driving becomes more automatic which frees up attentional resources to allocate eye movements more appropriately. However there may be further implications for these results, particularly when considering potential cognitive training. It should be emphasised that these implications below go beyond the results found during this experiment and, although interesting, are largely theoretical at this point.

It is suggested here that attention tasks could be useful, not only as assessment tools, but as driver training tools. The benefits of training on performance, particularly on complex tasks, has been well documented (e.g. Anguera et al., 2013; Dux et al., 2009; Vance et al., 2007) and indeed, through training and learning, the brain can undergo a number of measureable functional and structural changes (Draganski et al., 2004; Erickson et al., 2007; Scholz, Klein, Behrens, & Johansen-Berg, 2009; Voss et al., 2012). One can propose that there may be cognitive transfer benefits between tasks which activate the neural networks used in driving, but do not include driving per se. If so, then training on some non-driving tasks could result in a measurable level of improvement in driver safety.

The idea of using attentional tasks to train more complex everyday tasks is not a new one as there is evidence of computer based training positively influencing task performance in other real-world domains (e.g. Cassavaugh & Kramer, 2014; Giannotti et al., 2013; Gopher, Well, & Bareket, 1994). In driving, there have been attempts to use cognitive training in older adult populations (e.g. Roenker et al., 2003; Rogé et al., 2014). Ball, Edwards, Ross, and McGwin (2010) found that the number of accident liability cases were less in a group of older adults who were given several training sessions aimed to train speed of processing. Other research has yet to investigate the use of active visuomotor tasks, as used here, as cognitive training tools or how cognitive training influences eye movement behaviour when driving.

One potential line of research related to these unanswered questions is that of video-game training. We know that action video game players exhibit better attentional function than non-gamers (Green & Bavelier, 2006; Boot, Kramer, Simons, Fabiani & Gratton, 2008), and this can often be trained (Green & Bavelier, 2008). We also see examples of transfer to everyday tasks, for example, Giannotti et al. (2013) showed how training using the Nintendo Wii aids laparoscopic surgery skills. Thus, future research should include studies showing how visuomotor training may provide reliable visual training and assessment tools in driving.

7.3 Old age: End of the road?

In another attempt to highlight some of the individual differences in driving behaviour, Chapter 5 investigated the influence of age on driving and eye movement deployment whilst driving. There has been widespread literature suggesting that there are perceptual, attentional and motor deficits associated with older age (Craik & Salthouse, 2011; Verhaeghen & Cerella, 2002). Given the intrinsic link between the attention and eye movements systems, it is plausible that these deficits are represented by differences in eye movement behaviour compared to younger adult drivers. This however was not found in the experiment presented in Chapter 5. Older adults exhibited a similar level of scanning behaviour, utilised the mirrors as regularly and also exhibited similar visual processing behaviour as the younger adult population. In some way, this is unsurprising given that both groups of drivers were experienced participants. However it was found that the older adult population did indeed exhibit attentional limitations, where they performed poorer than the younger adult population on the Multiple Object Tracking and Object Avoidance tasks. It was thus suggested that there was a possible reason for the similar eye movement behaviour, despite the cognitive deficit. It was found that older drivers drove considerably slower than the younger group. Driving slower could allow the visual system to adapt to the demands of the road which may allow a more effective distribution of eye movements.

These results raise some important discussion points. Even though older adults exhibit less risky driving behaviour, performance deficits are still reported in other experiments, both in vehicle control (Aksan et al., 2015; Aksan et al., 2012; Bunce et al., 2012; Raw et al., 2012) or hazard perception (Borowsky et al., 2010; Horswill et al., 2008; Horswill et al., 2009). Importantly, this is reflected in the accident statistics where older adults are typically over-represented (Adler & Rottunda, 2006; Aksan et al., 2012; Anstey et al., 2005; Bruni & Roenker, 1993). Because of this, there has been considerable research into older adult training and assessment. As mentioned in the section above, experiments have attempted, with success, to cognitively train the attentional networks typically used in driving, by using tasks outside of driving (Ball et al., 2007; Ball et al., 2010; Floyer-Lea & Matthews, 2004; Kramer, Larish, & Strayer, 1995; Roenker et al., 2003; Rogé et al., 2014). Improvements have been observed in speed of visual processing, dual tasking and visuomotor control. In addition to cognitive training, research has also seen success in older adult's hazard perception training (e.g. Horswill, Falconer, et al., 2015). Again though, there is still a requirement for research to investigate how training influences older adults' eye movements (e.g. Romoser & Fisher, 2009).

With the (increasing) numbers of older adults driving on the road, driving assessment becomes more important. Currently in the UK, there is a legal requirement that drivers should exhibit a level of visual acuity suitable to driving. They must meet the minimum eyesight for driving which is a visual acuity score of 0.5 measured on the Snellen scale (with wearing either glasses or contact lenses if required) (Driving & Vehicle Standards Agency, 2015). In addition, individuals must inform the Driver and Vehicle Agency (DSA) about any medical condition that could impede driving performance. Beyond these basic requirements however, it is largely down to the judgement of the individual themselves whether they are fit to drive. This judgement is usually based on a number of self-reported criteria, including increased response times to events, increasing feelings of anxiety when driving and family influence (Adler & Rottunda, 2006; Dellinger et al., 2001; Johnson, 1998). From the results in this study, and others, more rigorous assessment for older adults is encouraged e.g. attentional function assessment.

7.4 The advantages and disadvantages of visual training

The aim in Chapter 6 was to develop a potential visual training tool for drivers. There was an attempt to implicitly train visual behaviour when driving. Participants had to view videos of driving situations with expert eye movements overlain. The results appear promising. There was a clear improvement in overall scanning behaviour during country highway and motorway driving. Importantly, for those participants successfully recalled, this improvement was retained at a 6-month follow-up. The results may help to develop a widespread and easily accessible training tool that could be used in conjunction with other tools currently available. For example, when learning to drive, it is common for individuals to study hazard perception videos before they attempt to take both the on-road and hazard perception assessments required. In addition to this, time spent viewing eye movement videos may prove fruitful in training visual behaviour at an early stage. Not much time is required: the training in this experiment comprised of two short five minute videos. Future research would benefit from investigating how extensive viewing of eye movement videos would have to be to influence visual behaviour more effectively than what was demonstrated here.

For horizontal scanning behaviour however, it is acknowledged that these effects are rather modest at best. This may highlight an important consideration for visual training. It is possible that, although participants are aware they should ideally scan the roadway more, they were constrained by the demands of the task. The participants used in this experiment were those who had not yet received a valid driver’s licence, with many of them taking driving lessons at the time of testing. As such, they are still adapting to the driving experience where they are learning the rules of the road, building up experiences of certain driving situations, and importantly, still learning how to control a car. Thus it is important to also consider the potential negative impact of visual training in a complex task such as driving. With novices, it is possible that the driver's restricted visual search is, in part, because of a need to fixate in certain locations to control the vehicle (Mourant & Rockwell, 1972). If eye movements are directed to parts of the environment that otherwise would not be attended to, then this may be at a cost of vehicle control.

Unfortunately, driving performance was not recorded accurately during the experiment, due to a technical issue. Thus, any loss of vehicle control or increase in unsafe driving could not be quantified. However, the recorded videos were inspected by the experimenter and participants’ pre and post video recordings were subjectively compared. No obvious differences in driving performance was observed. Thus, it is still maintained that eye movement training is a promising tool for driver training.

7.5 Experimental limitations

Each of the studies described herein have their limitations. Some of these are discussed below. Note that these limitations are largely aimed at experimental design choices that are specific to the experiments discussed here and not at the general idea that simulated driving is a limitation of itself. Indeed, the benefits of this type of research are highlighted in the next section (7.6).

For the experiment described in Chapter 3, one limitation concerns the videos used. Each participant in the passive condition viewed the same hazard perception clips. However, each drive would have been different in the active driving task, and as such, each hazard would have been experienced differently. This should not have been an issue for eye movement measures, given that eye movements for the hazardous courses were not considered in the analyses. However, for reaction times measures to hazards (necessarily measured for courses containing hazards), this may have been problematic. Even though there was an attempt at controlling these factors, those in the active condition may have been slower to respond to the hazards because, for example, the speed of approach to the hazards were different, the exact locations of the hazards were different or the hazard was less obvious in some cases. One potential way to control for this would have been to use the recorded videos from the active condition for the passive condition. In this way, although a different individual would be observing the clips, they would have at least been the same hazardous situations encountered in both conditions.

Regarding the experiments investigating attentional function and visual training (Chapters 4 and 6), one obvious limitation was that hazard perception performance was not assessed. Throughout this thesis there has been the inference that scanning the road and using the mirrors more is indicative of a safer visual search; one that represents surveying the road conditions for potential hazards. However, without directly assessing hazard perception performance, the link between visual behaviour and hazard perception ability cannot be made in these experiments. As a consequence, these experiments cannot directly link attentional function to hazard perception performance or demonstrate how trained visual behaviour influences hazard detection therefore. Although, for the experiment discussing attentional function (Chapter 4), it was inferred from the driving performance scores, that those with better attentional function may have had better hazard awareness since this score was linked to safe driving.

One final limitation that should be mentioned is the older adult population sample size (Chapter 5). Only nine participants were successfully tested. Although power analyses for the dependent variables revealed moderate to high values (values ranged from 0.7 to 0.95), there were observable non-normal distributions of data within the older adults. This is likely because it is difficult to obtain a normal distribution with such a small sample size. Several more participants were recruited, but due to the nature of the population, many could not take part because of: poor visual acuity (beyond the 2.0 MAR requirement), difficulty calibrating with the eye tracker and feeling unwell (see below) during testing. Despite this limitation, the results still provide useful insights into eye movement and driving behaviour in an older adult population.

7.6 Notes on simulated driving

Within the first chapter, it was discussed how this thesis favours a more naturalistic approach to studying eye movements. This was accomplished using simulated driving environments rather than using driving videos. Indeed, the first chapter highlighted how using videos may not fully capture the visual attentional properties of a driving task. However, simulated environments fall short compared to on-road driving as the most useful method to investigate driving behaviour. The major limitation is that the eyes and the vestibular system are working somewhat in opposition during simulated driving. When turning a corner, the eyes will signal that one is turning, yet the semicircular canals signal that the person is stationary (Land & Tatler, 2009). At best, this causes a slightly unnatural feeling and makes the individual aware that they are not driving in real life. As a consequence, the behaviour measured may not fully represent on-road driving behaviour. In more extreme cases, this can lead to people experiencing motion sickness (Domeyer, Cassavaugh, & Backs, 2013); something which is more common in older adults (Brooks et al., 2010). Indeed, although none of the younger adult population described in these experiments reported experiencing motion sickness, several older adults did. Some in fact showed serious symptoms of sickness including discoloration and loss of balance. The experiments were of course immediately stopped in these cases, but this highlights a problem with simulated driving experiments.

However, the benefits of using simulated driving are numerous. Apart from the obvious benefits of cost reduction and the removal of the risk associated with crashing, one of the main benefits is that experimenters can run a driving experiment in a controlled environment. Keeping consistency across participants: traffic levels can be programmed to be constant, the weather can be controlled, hazards can be programmed etc. This of course makes for better scientific practice.

Although they are useful, how valid are driving simulators? That is, how close do they mirror the behaviour in real on-road driving? This question has been tackled within the literature by a number of researchers. Meuleners and Fraser (2015) found no difference between performance during a simulated drive and an on-road drive. This included inspection of the mirrors, the speed at which individuals drove and rule following, such as stopping at stop signs. Similarly, (Chan et al., 2010) found that the hazard perception performance of novice drivers compared to experienced drivers in a simulator was similar and therefore comparable to an on-road driving assessment. Furthermore, there are similar patterns of visual behaviour between novices and experience drivers in both simulated and on road driving. For example, experienced drivers scan the roadway more than novices during both these driving methods (Underwood, Crundall, et al., 2011). Given that driving performance, hazard perception ability and eye movements are similar across these methods, this helps to provide support for the validity of using driving simulators as an investigative tool.

Finally, the validity of the simulations used in these experiments should be discussed. Although these were not relevant to the main experimental chapters, and as such were not reported, there were two main findings that may help to provide some validation. The first is related to experience and hazard perception. It was not necessary to make the distinction between experienced and inexperienced drivers in the first experiment, only to make sure that the average experience was not different across groups. However, analyses revealed that there was a significant difference in the reaction times to hazards when participants were split into inexperienced drivers (< 3 year experience) and experienced drivers (> 3 year experience). Those with more experience responded faster than those with less experience, which has been found in other studies (Castro et al., 2014; Crundall et al., 2012; Horswill & McKenna, 2004; Lee et al., 2008; Scialfa et al., 2012; Scialfa et al., 2011). The second is the finding that eye movements changed as a function of road type. During on-road driving, compared to undemanding rural drives, individuals have been found to scan the road more during dual carriageways (Underwood, Chapman, et al., 2002) and even more in complex urban environments (Land, 2009; Land & Tatler, 2009). There is a similar pattern of results in this study which suggests that participants are treating the simulated drive much like they would a real drive. Together, these findings help to provide some validity for the simulated experiments used in these experiments.

7.7 Overall conclusions and summary

Driving is a highly complex visuomotor task, and the study of eye movements can provide interesting and detailed insights into driving behaviour. The overall aim of this thesis was to understand (a) what methods are useful assess driving behaviour, (b) the reasons we observe differences in eye movements when driving, and (c) offer a possible visual training method. Several general conclusions can be drawn.

The first is that when measuring driving behaviour in an active task, vision, attention and action interact in a complex manner that is reflected in a specific pattern of eye movements that is different to when driving behaviour is measured using typical video paradigms.

It is also concluded that one of the reasons that there are differences in eye movement behaviour across individuals is due to levels of individual cognitive function. Also in relation to individual differences, it can be concluded here that eye movements are similar across younger and older adult age groups. Yet there are differences in driving behaviour, where older adults drive slower in order to compensate for the attentional demands.

Finally, although the results were somewhat modest, it is concluded that eye movement training is a promising technique with which to train more effective visual behaviour in novice driver populations.

Collectively the experiments have provided further understanding into the fields of eye movements and driving. With driving still a source for so many injuries and death throughout the world, hopefully the results will aid other researchers, driving educators and policy makers to develop laws, road systems and assessment tools that will contribute to safe driving.

(Of course, there is the very real possibility that self-driving cars may become a widespread reality which removes the risk associated with human error…but that’s a story for another thesis.)

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Appendices

1.0 Driving simulation vehicle properties

1.1 Vehicle properties for “Driving Simulator, 2011”

```
[General]
Name                          = Bonum C4 2.0i
Group                         = Sedan
ExtModel                      = Sedan 001.e.d3d
IntModel                      = Sedan 001.i.d3d
MaterialScript                = Sedan.lua
Price                         = 34500


[Camera]
Position                      = -0.29;0.35;-0.18


[LeftSideMirror]
Position              = -0.88;1.05;0.7
Normal         = 0.0.0;0;-1


[RightSideMirror]
Position              = 0.88;1.05;0.7
Normal         = -0.33;0;-1


[RearViewMirror]
Position              = 0.0;1.28;0.55
Normal         = -0.30;-0.09;-1


[Dashboard]
MaxSpeedOnSpeedIndicator      = 220
MaxSpeedIndicatorRadian       = 3.8
MaxRPMOnRPMIndicator  = 6000
```

```
MaxRPMIndicatorRadian  = 2.07


[MassInformations]
Mass                          = 5000
CenterOfMassRelX              = 0.0
CenterOfMassRelY              = -1.25
CenterOfMassRelZ              = 0.0
CustomInertiaEnabled          = true
InertiaRadiusX         = 1.13
InertiaRadiusY         = 1.10
InertiaRadiusZ                = 0.6

[Engine]
IdleRPS                = 12.5
MinMotorTorqueRPS             = 30
MinMotorTorque         = 1150.0

MaxMotorTorqueMinRPS   = 50.0
MaxMotorTorqueMaxRPS   = 80.0
MaxMotorTorque         = 1300.0

MaxRPS                        = 1000
MotorTorqueMaxRPS             = 975.0

MaxPowerRPS                   = 500
MaxPower                              = 1000

MaxMotorBrakeTorque           = 400.0

ShiftDownRPS                  = 18.0
ShiftUpRPS                            = 33.0
```

```
[SteeringValues]

MinDynamicTransmission       = 500

MaxDynamicTransmission       = 2000.0

ActiveSteering                       = true

MinActiveSteerAngleSpeed     = 5.5

MaxActiveSteerAngleSpeed     = 22.22

MinSteerAngleTransmission    = 0.2

MaxSteerAngleTransmission    = 10.0

MaxSteeringWheelAngle  = 300

AckermannFactor              = 1.0


[Gears]

AxleDriveRatio_R                     = 4.2

GearRatio_R                          = 4.84

MouldingBodyCoefficient_R            = 1.47

AxleDriveRatio_1                     = 4.2

GearRatio_1                          = 3.43

MouldingBodyCoefficient_1            = 1.47

AxleDriveRatio_2                     = 4.2

GearRatio_2                          = 1.95

MouldingBodyCoefficient_2            = 1.16

AxleDriveRatio_3                     = 4.2

GearRatio_3                          = 1.21

MouldingBodyCoefficient_3            = 1.09

AxleDriveRatio_4                     = 4.2

GearRatio_4                          = 0.93

MouldingBodyCoefficient_4            = 1.06

AxleDriveRatio_5                     = 4.2

GearRatio_5                          = 0.73

MouldingBodyCoefficient_5            = 1.05

AxleDriveRatio_6                     = 4.2

GearRatio_6                          = 0.59

MouldingBodyCoefficient_6            = 1.04
```

```
[FrontWheels]

Mass                  = 60

SuspensionTravel      = 0.5

SpringCoefficient     = 26500.0

DamperCoefficient     = 450.0

TargetValue           = -0.1

HeightModifier = 0.0

MotorRatio            = 0.0

BrakeRatio            = 0.7

HandBrakeRatio = 0.0


[RearWheels]

Mass                  = 100

SuspensionTravel      = 0.5

SpringCoefficient     = 26500.0

DamperCoefficient     = 450.0

TargetValue           = -0.1

HeightModifier = 0.0

MotorRatio            = 1.0

BrakeRatio            = 0.3

HandBrakeRatio = 1.0


[Brakes]

BrakeTorque           = 45000.0

HandBrakeTorque       = 95000.0


[LongitudinalTireFunction]

ExtremumValue         = 1.05

AsymptoteValue        = 0.95


[LateralTireFunction]

ExtremumSlip                  = 0.17
```

```
ExtremumValue         = 0.85

AsymptoteSlip         = 0.255

AsymptoteValue        = 0.65


[Miscellaneous]

DragCoefficient       = 0.38
```

1.2 Vehicle properties for “City Car Drive”

```
[Common]

WheelRadiuses= 0.325000 ;0.325000

WheelCenterShiftFromPhysicalCar   =   (front=-0.761985;-0.475861;-1.421122,   back=-0.762013;-
0.475861;1.298885)

RotateWheelsAroundZ = (left=true, right=false)

PlayerCar = false

HWDShift = 0; -0.28; -1.444

Probability = 0.3

Width = 1.746

Heigth = 4.542

DamagedCarParts = (FrontPart=0.28, BackPart=0.25, LeftPart=0.1, RightPart=0.1)

VelocityMax = 190

VelocityPrefer = 75

VelocitySlow = 25

VelocityMin = 3

AccelerationMaxTableVel=0; 10;       20;    30;    40;    50;    60;    70;    80;    90;
       100; 110; 120; 130;   140; 150; 160; 170;   180; 190; 200; 210; 220; 230; 240; 250

AccelerationMaxTableAcc=2.1; 2.6; 2.7; 2.93; 3.2; 3.25;     2.78; 1.75;    1.79;  1.79;  1.69;
1.47; 0.88; 0.86; 0.75; 0.7; 0.52; 0.46; 0.1; 0.01; 0; 0;   0; 0;   0;      0

AccelerationMax = 0.1

AccelerationPrefer = 0.05

AccelerationMin = 0.05

BrakingMax = 9.541

BrakingPrefer = 3

BrakingMin = 1

DistanceMax = 60
```

```
DistancePrefer = 4

DistanceMin = 1.0

FrontWheelRadius = 0.292

useDevicePanelOnFlags = true

TuningConfigPath = "cars/Car28/tuning.xml"

SoundBankName = "oyota"



[Cameras]


CameraProfile="cars/Car28/cameras.xml"


LookAtLeftAngle = 55.0

LookAtRightAngle = 55.0

LookAtBackAngle = 165.0


[Mirrors]

MirrorCenterFOV = 30.0

MirrorLeftFOV = 30.0

MirrorRightFOV = 30.0


MirrorCenterPosition = 0; 0.5; 0.4

MirrorCenterLookAt = -0.3; 0.5; 2.30


MirrorLeftPosition = -0.9; 0.27; -0.7

MirrorLeftLookAt = -1.6; 0.27; 2.28


MirrorRightPosition    =      0.9; 0.27; -0.7

MirrorRightLookAt =    1.6; 0.27; 2.28


[SpeedometerAndTachometer]

SmtrDivValue = 20.0

SmtrDivCount = 12
```

```
SmtrDivAngle = 0.34

SmtrZeroOffset = 0.006


TtmrDivValue = 5.0

TtmrDivCount = 12

TmtrDivAngle = 0.25

TmtrZeroOffset = 0.008


[Headlights]

faraFrom_near_R = 0.542; 0.7; -1.8

faraXangle_near_R = -25

faraYangle_near_R = -5

faraRange_near_R = 80

faraColor_near_R = 0.6; 0.6; 0.5; 0


faraFrom_near_L = -0.542; 0.7; -1.8

faraXangle_near_L = -40

faraYangle_near_L = 5

faraRange_near_L = 20

faraColor_near_L= 0.6; 0.6; 0.5; 0


#-------------------------------------


faraFrom_far_R = 0.542; 2.0; -1.0

faraXangle_far_R = -30

faraYangle_far_R = -0

faraRange_far_R = 300

faraColor_far_R = 0.6; 0.6; 0.5; 0


faraFrom_far_L = -0.542; 2.0; -1.0

faraXangle_far_L = -30

faraYangle_far_L = -10

faraRange_far_L = 100
```

```
faraColor_far_L= 0.6; 0.6; 0.5; 0


[BodyColors]


#from toyota.com

#Barselona Red Metallic

Color = (color = 68;10;11; 255 ,      Probability=0.025)

#Color = (color = 136;19;21; 255 ,    Probability=0.025)


#Black Sand Pearl

Color = (color = 9;9;12; 255 ,        Probability=0.1)

#Color = (color = 17;18;23; 255 ,     Probability=0.0)


#Magnetic Gray Metallic

Color = (color = 42;43;43; 255 ,      Probability=0.3)

#Color = (color = 84;85;86; 255 ,     Probability=0.0)


#Classic Silver Metallic

Color = (color = 95;97;98; 255 ,      Probability=0.3)

#Color = (color = 189;193;195; 255 ,  Probability=0.0)


#Blue Streak Metallic

Color = (color = 34;62;90; 255 ,      Probability=0.3)

#Color = (color = 68;124;180; 255 ,   Probability=0.0)


#Super White

Color = (color = 119;119;119; 255 ,   Probability=0.2)

#Color = (color = 238;238;238; 255 ,  Probability=0.0)


#Desert Sand Mica

Color = (color = 119;115;109; 255 ,   Probability=0.025)

#Color = (color = 238;230;218; 255 ,  Probability=0.0)
```

```
#Capri Sea Metallic

Color = (color = 25;44;44; 255 ,     Probability=0.025)

#Color = (color = 50;88;87; 255 ,    Probability=0.0)


#ñòàðûå öâåòà

#×åðíûé àíòðàöèò

#Color = (color = 20;20;20; 255 ,    Probability=0.1)

#Color = (color = 40;40;40; 255 ,    Probability=0.0)


#Áåëûé

#Color = (color = 122;122;119; 255 , Probability=0.2)

#Color = (color = 244;245;239; 255 , Probability=0.0)


#Ñåðåáðèñòûé

#Color = (color = 96;99;106; 255 ,   Probability=0.3)

#Color = (color = 193;199;213; 255 , Probability=0.0)


#Ïåïåëüíî-ñåðûé

#Color = (color = 44;44;46; 255 ,    Probability=0.025)

#Color = (color = 89;88;93; 255 ,    Probability=0.0)


#Êðàñíûé

#Color = (color = 84;17;17; 255 ,    Probability=0.025)

#Color = (color = 168;34;35; 255 ,   Probability=0.0)


#Ñâåòëî-ãîëóáîé

#Color = (color = 109;113;115; 255 , Probability=0.3)

#Color = (color = 219;227;230; 255 , Probability=0.0)


#Òåìíî-ñèíèé

#Color = (color = 22;26;38; 255 ,    Probability=0.025)

#Color = (color = 45;53;76; 255 ,    Probability=0.0)
```

```
#Ñèíå-çåëåíûé

#Color = (color = 16;33;30; 255 ,     Probability=0.025)

#Color = (color = 33;67;60; 255 ,     Probability=0.0)





[bodyDetail]

bodyName = "body"

lodName0 = "carLod0"

lodName1 = "carLod1"

lodName2 = "carLod2"

lodName3 = "carLod3"


saloonName = "saloon"

saloonLeftName = "saloon_l"

saloonRightName = "saloon_r"


driverName = "driver"

fairingName = "tuning/obtekatel/obtekatel"

pipeName  = "tuning/glushitel/glushitel"

spoylerName = "tuning/spoyler/spoyler"


uName = "tuning/U/U"

shadowPlaneName = "shadow_plane"



[wheelDetail]

carFrontRightWheelName = "tuning/wheel_front/wheel_front"

carFrontLeftWheelName = "tuning/wheel_front/wheel_front"
```

```
carBackRightWheelName = "tuning/wheel_back/wheel_back"
carBackLeftWheelName = "tuning/wheel_back/wheel_back"

carMiddleRightWheelName = "tuning/wheel_middle/wheel_middle"
carMiddleLeftWheelName = "tuning/wheel_middle/wheel_middle"

wheelsCount = 4

[licensePlateDetail]
carLicensePlate = "license_plate"

[lightDetail]
#---Ïåðåäíèå ôàðû---
carHeadLightVisibleName = "head_light_visible"
carHeadLightVisibleColor = 255; 255; 255

carHeadLightsName = "head_light"
carHeadLightsColor = 250; 250; 250

carNearLightsName = "head_light"
carNearLightsColor = 180; 180; 180

#---Ïîâîðîòíèêè---
carLeftStrafeLightName = "left_strafe_light"
carLeftStrafeLightColor = 255; 120; 30

carLeftStrafeLightVisibleName = "left_strafe_light_visible"
carLeftStrafeLightVisibleColor = 255; 255; 255

carRightStrafeLightName = "right_strafe_light"
carRightStrafeLightColor = 255; 120; 30

carRightStrafeLightVisibleName = "right_strafe_light_visible"
```

```
carRightStrafeLightVisibleColor = 255; 255; 255

#---Ñòîïàðè è ãàáàðèòêè---
carStopLightName = "hwd_back_light"
carStopLightColor = 200; 50; 0

carStopLightVisibleName = "stop_light_visible"
carStopLightVisibleColor = 255; 255; 255

carHwdsFrontName = "head_light"
carHwdsFrontColor = 80; 90; 100

carHwdsBackName = "hwd_back_light"
carHwdsBackColor = 100; 25; 0

carHwdsBackLightVisibleName = "hwd_back_light_visible"
carHwdsBackLightVisibleColor = 255; 255; 255

#---Çàäíèé õîä è ïëþøêè íà çåìëå---
carBackLightName = "back_light"
carBackLightColor = 140; 150; 160

carBackLightVisibleName = "back_light_visible"
carBackLightVisibleColor = 255; 255; 255

carFrontFallingLightName = "head_front_light_visible"
carFrontFallingLightColor = 255; 255; 255

carBackFallingLightName = "head_back_light_visible"
carBackFallingLightColor = 255; 255; 255

#---Ñèãíàëû â ñàëîíå---
carLeftSaloonLightName = "signal_left"
```

```
carLeftSaloonLightColor = 0; 255; 0

carRightSaloonLightName = "signal_right"
carRightSaloonLightColor = 0; 255; 0

carBrakeLightName = "signal_brake"
carBrakeLightColor = 255; 0; 0

carFarLightName = "signal_farlight"
carFarLightColor = 255; 255; 255

carAccumLightName = "signal_discharge"
carAccumLightColor = 255; 0; 0

carReverseLightName = "R"
carReverseLightColor = 255; 0; 0

carNeutralLightName = "N"
carNeutralLightColor = 255; 0; 0

carParkLightName = "P"
carParkLightColor = 255; 0; 0

carDriveLightName = "D"
carDriveLightColor = 255; 0; 0

carDrive1LightName = "D1"
carDrive1LightColor = 255; 0; 0

carDrive2LightName = "D2"
carDrive2LightColor = 255; 0; 0

carDrive3LightName = "D3"
```

```
carDrive3LightColor = 255; 0; 0


carManualLightName = "mechanic"

carManualLightColor = 255; 0; 0




[mirrorDetail]

carMirrorLeftName = "mirror_left"

carMirrorCenterName = "mirror_center"

carMirrorRightName = "mirror_right"


[saloonDetail]

carSaloonName = "body"

carSpeedometerArrowName = "speedometer_arrow"

carTahometerArrowName = "tachometer_arrow"

carOilArrowName = "oil_arrow"

carFuelArrowName = "fuel_arrow"


carWindShieldName = "glass_windshield"

carWindShieldCleaner1Name = "cleaner_windshield_left"

carWindShieldCleaner2Name = "cleaner_windshield_right"

carWindShieldTopLeft = -0.7;  0.6; -0.3

carWindShieldTopRight = 0.7;  0.6; -0.3

carWindShieldBottomLeft = -0.7; 0.2; -1.2

carWindShieldBottomRight = 0.7; 0.2; -1.2


carLeftWindowName = "glass_left"

carLeftWindowTopLeft = -0.6;  0.6; 1.1

carLeftWindowTopRight = -0.6;  0.6; -0.8

carLeftWindowBottomLeft = -0.8; 0.2; 1.1

carLeftWindowBottomRight = -0.8; 0.2; -0.8


carRightWindowName = "glass_right"
```

```
carRightWindowTopLeft = 0.6;  0.6; -0.8
carRightWindowTopRight = 0.6;  0.6; 1.1
carRightWindowBottomLeft = 0.8; 0.2; -0.8
carRightWindowBottomRight = 0.8; 0.2; 1.1

carBackWindowName = "glass_back"
carBackWindowTopLeft = 0.6;  0.6; 1.1
carBackWindowTopRight = -0.6;  0.6; 1.1
carBackWindowBottomLeft = 0.6; 0.3; 1.8
carBackWindowBottomRight = -0.6; 0.3; 1.8

newbieSignName = "learner"
beginnerSignName = "beginner"

carSteeringWheelName = "driving_wheel"

carIsLeftSaloon = true
carIsRightSaloon = true
SaloonTypeOppositeSideOfMovement = true


[modelLodInfo]
modelLodDistance1 = 10
modelLodDistance2 = 120
modelLodDistance3 = 200

[Humans]
DriverAnimatedModel = (Driver="cars/Car28/driver", Wheel="cars/Car28/wheel")

AutoSeatingInRightSaloon = true
Driver = (Shift = -0.393; -0.267; -0.192, Angle=0.)
Passenger = (Shift = 0.383; -0.267; -0.192, Angle=0.)
Passenger = (Shift = -0.378; -0.267; 0.750, Angle=0.)
```

```
Passenger = (Shift = 0.349; -0.267; 0.750, Angle=0.)


Driver = (Shift = 0.393; -0.267; -0.192, Angle=0., Saloon = "right")

Passenger = (Shift = -0.383; -0.267; -0.192, Angle=0., Saloon = "right")

Passenger = (Shift = -0.378; -0.267; 0.750, Angle=0., Saloon = "right")

Passenger = (Shift = 0.349; -0.267; 0.750, Angle=0., Saloon = "right")



[Force Feedback.SteeringResistance]

ff_SteeringResistance_enabled = true

ff_SteeringResistanceAdd = 0.2

ff_SteeringResistanceMax = 8000

ff_SteeringResistancePoint=(Speed=5, Resistance=0.3)


[Force Feedback.SideForce]

ff_SideForce_enabled = true

ff_SideForce_Transformation= (DeadZone=0.01, Curvature=1, ReflectCurve=true)

ff_SideForce_AngleFactor = 0.5

ff_SideForce_SpeedFactor = 0.5

ff_SideForce_MaxSpeed = 60

ff_SideForce_SteeringFactorDeadZone = 0.0

ff_SideForce_SteeringFactorLimit = 0.1

ff_SideForce_GasFactor = 0.2


[Force Feedback.Crash]

ff_Crash_enabled = true

#type values: Square=0, Sine=1, Triangle=2, SawtoothUp=3, SawtoothDown

ff_Crash_periodic = (type=1, Magnitude=1000, Period=10000, Phase=0, Offset=0)

ff_Crash_duration = -1

ff_Crash_envelope = (AttackLevel=2000, AttackTime=10000, FadeLevel=0, FadeTime=50000)


[Force Feedback.GroundTrembling]

ff_GroundTrembling_enabled = false
```

```
ff_GroundTrembling_periodic = (Magnitude=1000, Period=1000, Phase=0, Offset=1000)

ff_GroundTrembling_duration = 10000


[Force Feedback.SuspensionTrembling]

ff_SuspensionTrembling_enabled = true

ff_SuspensionTrembling_duration = 100000

ff_SuspensionTrembling_magnitude_factor = 50000

ff_SuspensionTrembling_delta = 0.01


[Force Feedback.StartEngine]

ff_StartEngine_enabled = true

ff_StartEngine_periodic = (Magnitude=2000, Period=50000, Phase=0, Offset=0)

ff_StartEngine_duration = -1

ff_StartEngine_envelope = (AttackLevel= 0, AttackTime=200000, FadeLevel=1000, FadeTime=2000000)


[Force Feedback.LowSpeedTrembling]

ff_LowSpeedTrembling_enabled = false

ff_LowSpeedTrembling_periodic = (Magnitude=1000, Period=1000, Phase=0, Offset=0)

ff_LowSpeedTrembling_EndOfLowSpeed = 50

ff_LowSpeedTrembling_StartDelay = 5500000
```

2.0 MATLAB Scripts

2.1 MATLAB script for recording real time eye movements and display screen

```
function ActiveStudy2(pid, filename)

% Record video + record eye movemoents
%
% Paul Cox, prc23@st-andrews.ac.uk
% Andrew Mackenzie, akm9@st-andrews.ac.uk
% School of Psychology + Neuroscience, University of St Andrews
%
% Input arguments:
%   pid         - participant id (String)
%   filename    - name of driving scene to record (String)

commandwindow;

if nargin < 1 || isempty(pid)
    % No partid given: Use our test id:
    pid = 'actest';
end
if nargin < 2 || isempty(filename)
    % No moviename given: Use our default filename:
    filename = 'ActiveTest';
end

% Wait until user releases keys on keyboard:
KbReleaseWait;

try
    AssertOpenGL;

    % Get the list of screens and choose the one with the highest screen
number.
    screenNumber = 0%max(Screen('Screens'));

    % Open a double buffered fullscreen window on monitor [screenNumber].
    %PsychDebugWindowConfiguration(0, 0.5);
    [w, wRect] = Screen('OpenWindow', screenNumber);

    % Set 'q' as stop key and 'space' as start.
    KbName('UnifyKeyNames');
    stopkey  = KbName('q');
    startkey = KbName('space');

    % Set background colour as white.
    white = WhiteIndex(w);
    black = BlackIndex(w);
    gray = GrayIndex(w);
    bgcolor = black;

    % Set font paramaters for text stamp messages.
    Screen('TextFont', w, 'Arial');
    Screen('TextStyle', w, 0);
    Screen('TextSize', w, 16);
```

```
% Set output folder and create if it does not exist.
outputFolder = 'OutputStudy2';
mkdir(outputFolder);

% Timestamp string.
date = datestr(now, 30);

% Hide mouse pointer and set priority to maximum.
HideCursor;
priorityLevel = MaxPriority(w);
Priority(priorityLevel);

% Initialize eyelink.
if EyelinkInit() ~= 1;
    closeRoutine();
    return;
end

% Do eyelink stuff.
el = EyelinkInitDefaults(w);

%PsychEyelinkDispatchCallback(el);
%if Eyelink('Initialize', 'PsychEyelinkDispatchCallback') ~=0
    %error('eyelink failed init')
%end
%result = Eyelink('StartSetup',1);

% Specify data samples to record and filename for Eyelink log file.
Eyelink('command', 'link_sample_data = LEFT, RIGHT, GAZE, AREA');
Eyelink('openfile', 'driving.edf');

%setup the proper calibration foreground and background colors
%el.backgroundcolour = [50 50 50];
el.calibrationtargetcolour = [255 0 0];
EyelinkUpdateDefaults(el);

% Calibrate Eyelink.
EyelinkDoTrackerSetup(el);
EyelinkDoDriftCorrection(el);

WaitSecs(0.1);

% Track left eye only.
eye_used = Eyelink('EyeAvailable');
if eye_used == el.BINOCULAR    % If both eyes are tracked,
    eye_used = el.LEFT_EYE;    % use left eye data only.
end

WaitSecs(0.1);

% Display friendly start message.
msgStart = 'Press the ''space'' key to start the experiment when ready.';
Screen('FillRect', w, gray);
DrawFormattedText(w, msgStart, 'center', 'center', black);
Screen('Flip', w);

% Wait for keyboard input.
while 1
    [keyIsDown, secs, keyCode] = KbCheck;
    if keyCode(startkey)
```

```
            break;
        end
        if keyCode(stopkey)
            closeRoutine();
            return;
        end
        WaitSecs(0.002);
    end

    h = actxserver('WScript.Shell')
    h.Run('C:\Fraps\fraps.exe')
    WaitSecs(2);
    h.Run('"C:\Users\akm9\Desktop\City Car Driving Home Edition"')
    WaitSecs(20);

    Eyelink('StartRecording');
    Eyelink('Message', ['PARTICIPANT ', pid]);
    Eyelink('Message', ['GAMEPLAY ', filename]);
    Eyelink('Message', ['DATE ', date]);
    h.SendKeys('F9')
    Eyelink('Message', 'SYNCTIME')

    joystickId = 0;
    i = 0;

     %Loop until quit key pressed.
    while 1
        [keyIsDown, secs, keyCode] = KbCheck;
        if keyCode(stopkey)
            break;
        end
        [jx, jy, jz, jbuttons] = WinJoystickMex(joystickId);
        if jbuttons(4)
            msg = 'PRESS';
            Eyelink('Message', msg);
        end
        WaitSecs(0.002);
    end

    h.SendKeys('F9')
    closeRoutine();

    % Rename .edf file and move to Output directory.
    outputFilename = ['OutputStudy2/', pid, '-', filename, '-', date,
'.edf'];
    movefile('driving.edf', outputFilename);
    WaitSecs(2);
    Convert(outputFilename);
    return;

catch
    psychrethrow(psychlasterror);
    sca;
    ShowCursor;
    Priority(0);
end
```

2.2 MATLAB script for overlaying eye movements onto recorded video

```
function Process(videoInFile, eyeFile, videoOutFile)

% Play video + record eye movemoents
%
% Paul Cox, prc23@st-andrews.ac.uk
% School of Psychology + Neuroscience, University of St Andrews
%
% Input arguments:
%   videoInFile  - name of video used as stimulus
%   eyeFile      - converted .asc file of eyetracker data
%   videoOutFile - name of final video with eyetracker data overlay

debug = 0;
commandwindow;

if nargin < 1 || isempty(videoInFile)
    videoInFile = 'Output/actest-ActiveTest-20130117T134436.mp4';
end
if nargin < 2 || isempty(eyeFile)
    eyeFile = 'Output/actest-ActiveTest-20130117T134436.asc';
end
if nargin < 3 || isempty(videoOutFile)
    videoOutFile = 'Output/actest-ActiveTest-20130117T134436-
converted.mp4';
end

% Wait until user releases keys on keyboard:
KbReleaseWait;

global GL;

try
    AssertOpenGL;
    InitializeMatlabOpenGL;

    % Get the list of screens and choose the one with the highest screen
number.
    screenNumber = 0%max(Screen('Screens'));

    % Open a double buffered fullscreen window on monitor [screenNumber].
    [w, wRect] = Screen('OpenWindow', screenNumber);

    % Set background colour as white.
    black = BlackIndex(w);
    bgcolor = black;

    % Set font paramaters for text stamp messages.
%     Screen('TextFont', w, 'Arial');
%     Screen('TextStyle', w, 0);
%     Screen('TextSize', w, 12);

    % Open eye tracker data file.
    eyeFID  = fopen(eyeFile, 'r');
    line = fgetl(eyeFID);

    % Skip through to start of recorded samples
    while ~feof(eyeFID)
        [token, remain] = strtok(line);
        if isequal(token, 'MSG')
```

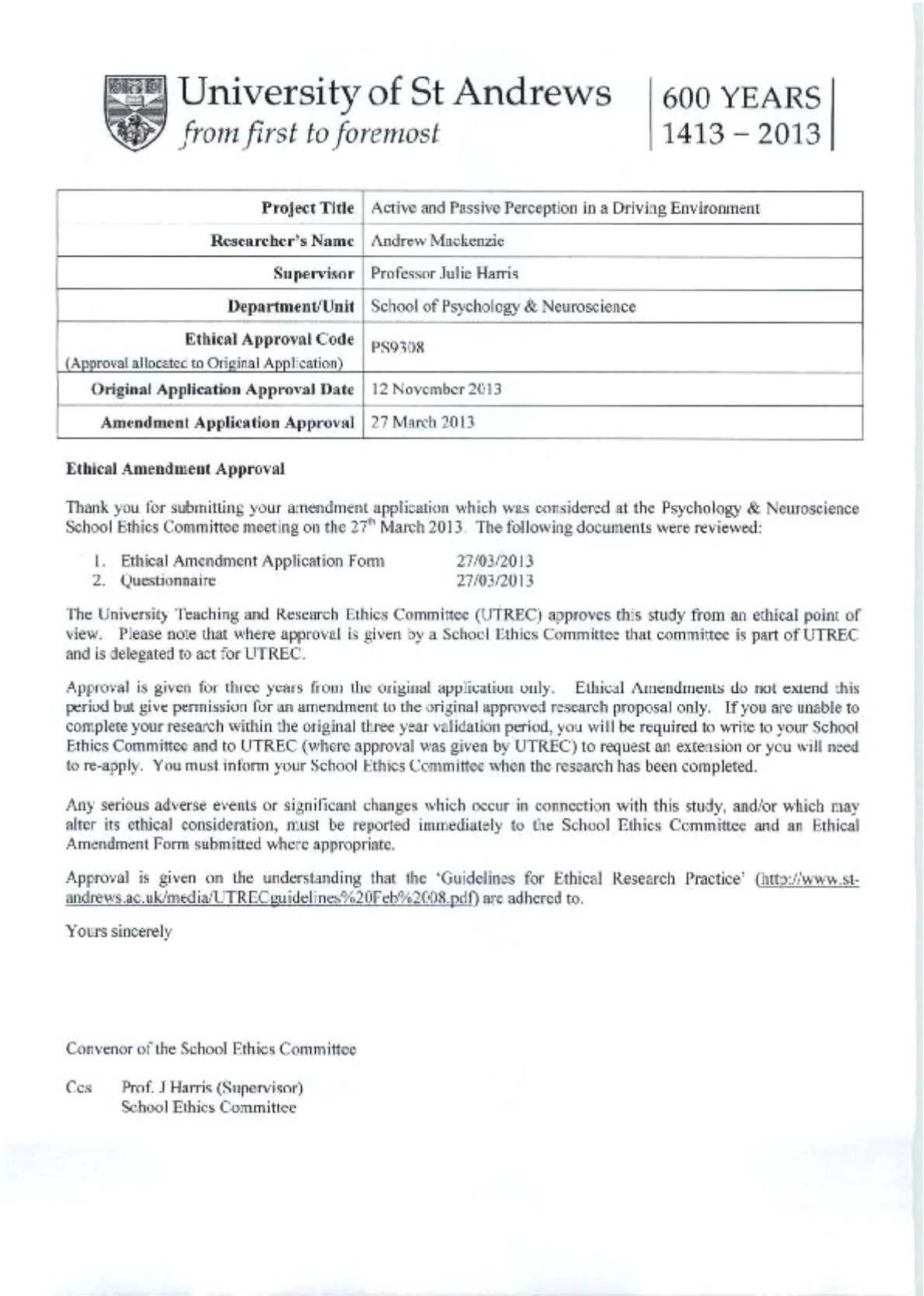
```
            [token, remain] = strtok(remain);
            synctime = str2double(token);
            [token, remain] = strtok(remain);
            if isequal(token, 'SYNCTIME')
                line = fgetl(eyeFID);
                break
            end
        end
        line = fgetl(eyeFID);
    end
    [token, remain] = strtok(line)
    while isnan(str2double(token))
        line = fgetl(eyeFID);
        [token, remain] = strtok(line);
    end

    % Open input movie file:
    movie = Screen('OpenMovie', w, videoInFile);
    readerobj = VideoReader(videoInFile);
    frametime = 1 / readerobj.FrameRate * 1000;

    % Create output movie file
    writerobj = VideoWriter(videoOutFile);%, 'MPEG-4');
    writerobj.FrameRate = readerobj.FrameRate;
    open(writerobj);

    % Wait until all keys on keyboard are released.
    KbReleaseWait;

    i = 0; j = 0;
    cx = 0; cy = 0;

    % Loop until video ends or quit key pressed.
    while i < readerobj.NumberOfFrames
        i = i + 1;
        pressed = 0;

        % Get average fixation point for frame.
        while str2double(token) < synctime + (frametime * i)
            if ~isnan(str2double(token))
                j = j + 1;
                [token, remain] = strtok(remain);
                if ~isequal(token, '.')
                    cx = cx + str2double(token);
                end
                [token, remain] = strtok(remain);
                if ~isequal(token, '.')
                    cy = cy + str2double(token);
                end
            end


            % Look for msg or end of movie in next line
            line = fgetl(eyeFID);
            [token, remain] = strtok(line);
%             [checka, remaina] = strtok(remain);
%             [checkb, remainb] = strtok(remaina);
%             [checkc, remainc] = strtok(remainb);

%             if isequal('MOVIE', checkb) && isequal('END', checkc)
%                 break
%             end
```

```
            while isnan(str2double(token))
                if isequal(token, 'MSG')
                    [token, remain] = strtok(remain);
                    [token, remain] = strtok(remain);
                    if isequal(token, 'PRESS')
                        pressed = 1;
                    end
                end
                line = fgetl(eyeFID);
                [token, remain] = strtok(line);
            end
        end

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        if ~j
            j = 1
        end

        cx = cx / j;
        cy = cy / j;
        j = 0;

        Screen('BlendFunction', w, GL_ONE, GL_ZERO);
        Screen('FillRect', w, bgcolor);

        % Wait for next movie frame, retrieve texture handle to it
        tex = Screen('GetMovieImage', w, movie);

        % Valid texture returned? A negative value means end of movie
reached:
        if tex<=0
            % We're done, break out of loop:
            break;
        end;

        % Draw the new texture immediately to screen:
        Screen('DrawTexture', w, tex);

        % Change blending mode and draw the scotoma.
        Screen('BlendFunction', w, GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);

        % Draw fixation point and centre points.
        if pressed
            Screen('FillOval', w, [0, 255, 0, 128], [cx-32, cy-32, cx+32,
cy+32]);
        else
            Screen('FillOval', w, [255, 0, 0, 128], [cx-32, cy-32, cx+32,
cy+32]);
        end

        % Screenshot
        imageArray = glReadPixels(0, 0, 1680, 1050, GL.RGB,
GL.UNSIGNED_BYTE);
        writeVideo(writerobj, imrotate(imageArray, 90));

        % Update display:
        Screen('Flip', w);

        % Release texture:
```

```
            Screen('Close', tex);
        end

        % Stop playback:
        Screen('PlayMovie', movie, 0);

        % Close movie:
        Screen('CloseMovie', movie);

        % Close Screen, we're done:
        Screen('CloseAll');

        return;

    catch
        psychrethrow(psychlasterror);
        sca;
        ShowCursor;
        Priority(0);
    end
```

3.0 Ethical Approvals

3.1 Ethical approval for Experiment 1 (Chapter 3)



University of St Andrews
from first to foremost

600 YEARS
1413 – 2013

Project Title	Active and Passive Perception in a Driving Environment
Researcher's Name	Andrew Mackenzie
Supervisor	Professor Julie Harris
Department/Unit	School of Psychology & Neuroscience
Ethical Approval Code (Approval allocated to Original Application)	PS9308
Original Application Approval Date	12 November 2013
Amendment Application Approval	27 March 2013

Ethical Amendment Approval

Thank you for submitting your amendment application which was considered at the Psychology & Neuroscience School Ethics Committee meeting on the 27th March 2013. The following documents were reviewed:

1. Ethical Amendment Application Form 27/03/2013
2. Questionnaire 27/03/2013

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years from the original application only. Ethical Amendments do not extend this period but give permission for an amendment to the original approved research proposal only. If you are unable to complete your research within the original three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply. You must inform your School Ethics Committee when the research has been completed.

Any serious adverse events or significant changes which occur in connection with this study, and/or which may alter its ethical consideration, must be reported immediately to the School Ethics Committee and an Ethical Amendment Form submitted where appropriate.

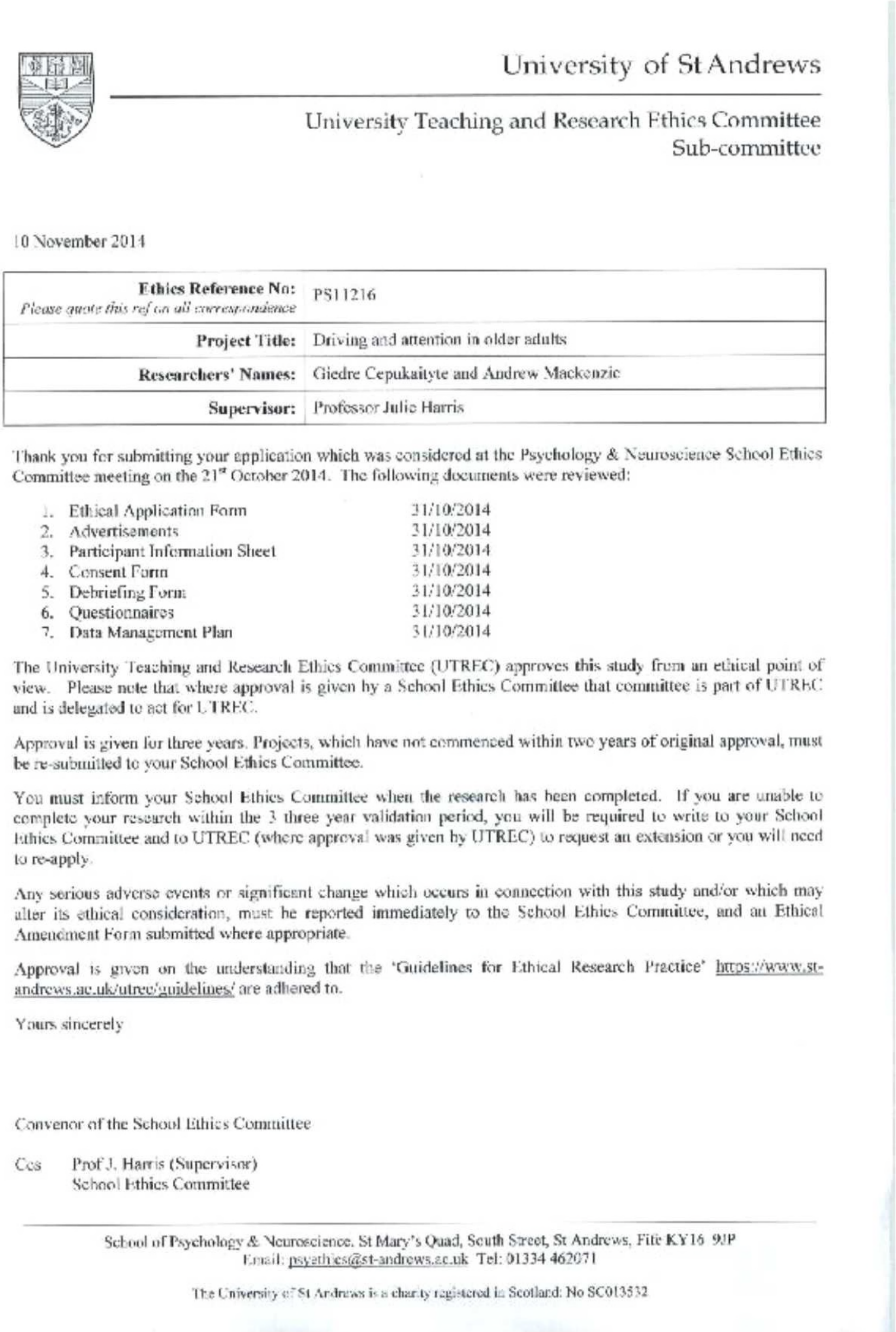
Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' (http://www.st-andrews.ac.uk/media/UTRECguidelines%20Feb%2008.pdf) are adhered to.

Yours sincerely

Convenor of the School Ethics Committee

Ccs Prof. J Harris (Supervisor)
School Ethics Committee

3.2 Ethical approval for Experiments 2 and 3 (Chapters 4 and 5)



University of St Andrews

University Teaching and Research Ethics Committee
Sub-committee

10 November 2014

Ethics Reference No: *Please quote this ref on all correspondence*	PS11216
Project Title:	Driving and attention in older adults
Researchers' Names:	Giedre Cepukaityte and Andrew Mackenzie
Supervisor:	Professor Julie Harris

Thank you for submitting your application which was considered at the Psychology & Neuroscience School Ethics Committee meeting on the 21st October 2014. The following documents were reviewed:

1. Ethical Application Form	31/10/2014
2. Advertisements	31/10/2014
3. Participant Information Sheet	31/10/2014
4. Consent Form	31/10/2014
5. Debriefing Form	31/10/2014
6. Questionnaires	31/10/2014
7. Data Management Plan	31/10/2014

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years. Projects, which have not commenced within two years of original approval, must be re-submitted to your School Ethics Committee.

You must inform your School Ethics Committee when the research has been completed. If you are unable to complete your research within the 3 three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply.

Any serious adverse events or significant change which occurs in connection with this study and/or which may alter its ethical consideration, must be reported immediately to the School Ethics Committee, and an Ethical Amendment Form submitted where appropriate.

Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' https://www.st-andrews.ac.uk/utrec/guidelines/ are adhered to.

Yours sincerely

Convenor of the School Ethics Committee

Ccs Prof J. Harris (Supervisor)
School Ethics Committee

School of Psychology & Neuroscience. St Mary's Quad, South Street, St Andrews, Fife KY16 9JP
Email: psyethics@st-andrews.ac.uk Tel: 01334 462071

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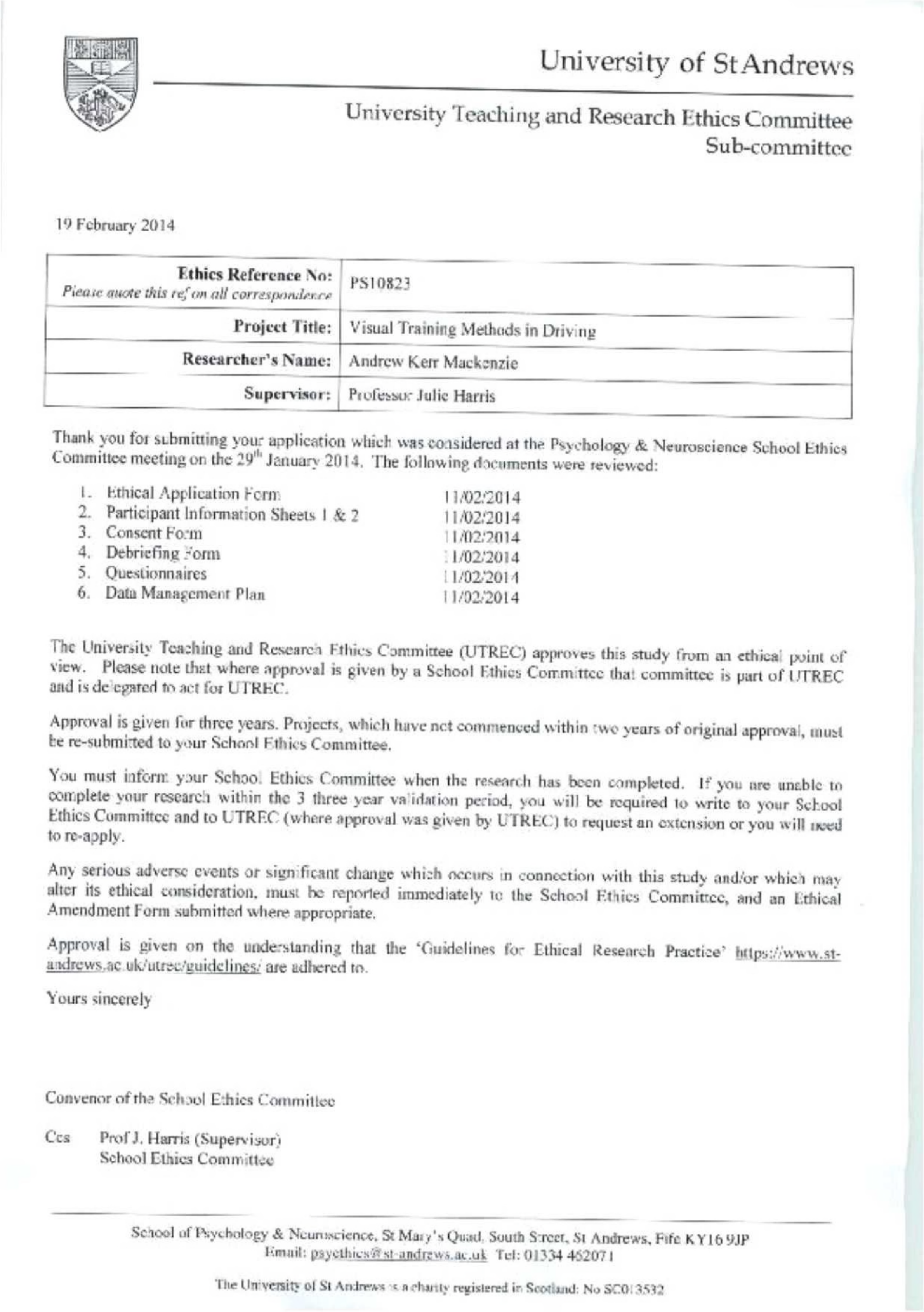
3.3 Ethical approval for Experiment 4 (Chapter 6)



University of St Andrews

University Teaching and Research Ethics Committee
Sub-committee

19 February 2014

Ethics Reference No: *Please quote this ref on all correspondence*	PS10823
Project Title:	Visual Training Methods in Driving
Researcher's Name:	Andrew Kerr Mackenzie
Supervisor:	Professor Julie Harris

Thank you for submitting your application which was considered at the Psychology & Neuroscience School Ethics Committee meeting on the 29th January 2014. The following documents were reviewed:

1. Ethical Application Form	11/02/2014
2. Participant Information Sheets 1 & 2	11/02/2014
3. Consent Form	11/02/2014
4. Debriefing Form	11/02/2014
5. Questionnaires	11/02/2014
6. Data Management Plan	11/02/2014

The University Teaching and Research Ethics Committee (UTREC) approves this study from an ethical point of view. Please note that where approval is given by a School Ethics Committee that committee is part of UTREC and is delegated to act for UTREC.

Approval is given for three years. Projects, which have not commenced within two years of original approval, must be re-submitted to your School Ethics Committee.

You must inform your School Ethics Committee when the research has been completed. If you are unable to complete your research within the 3 three year validation period, you will be required to write to your School Ethics Committee and to UTREC (where approval was given by UTREC) to request an extension or you will need to re-apply.

Any serious adverse events or significant change which occurs in connection with this study and/or which may alter its ethical consideration, must be reported immediately to the School Ethics Committee, and an Ethical Amendment Form submitted where appropriate.

Approval is given on the understanding that the 'Guidelines for Ethical Research Practice' https://www.st-andrews.ac.uk/utrec/guidelines/ are adhered to.

Yours sincerely

Convenor of the School Ethics Committee

Ccs Prof J. Harris (Supervisor)
School Ethics Committee

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Email: psyethics@st-andrews.ac.uk Tel: 01334 462071

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