# Children's gaze behaviour at real-world and simulated road crossings

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Contents

ABSTRACT

Children and older adults are overrepresented in pedestrian accidents (Department for Transport, 2010a, 2010b). Gaze behaviour is cited as a contributing factor in the majority of such accidents (Department for Transport, 2010a, 2010b); however, remarkably little is known about how children, adults and older adults control their gaze during either real or simulated road-crossing tasks. Because evidence suggests that behaviour in the laboratory may not accurately reflect that in more realistic situations (Dicks *et al*., 2010; 't Hart *et al*., 2009), this thesis used a real-world, active road-crossing task to compare, for the first time, how pedestrians across the lifespan direct their gaze during real road crossing. A total of 70 participants took part in the studies: 42 children (mean age 8.6 yrs, $SD$ = 0.4); 14 young adults (mean age 24.1 yrs, $SD$ = 4.5) and 14 older adults (mean age 70.7 yrs, $SD$ = 4.1). In the first experiment, participants were escorted on a short walk while wearing a mobile eye tracker and asked to cross the roads along the way when they felt it was safe to do so. Gaze behaviour during the last 3 seconds before crossing the road at a signalised crossing was analysed. Both children and older adults directed their gaze significantly less often to traffic-relevant features (such as the road and vehicles) than young adults. However, their gaze patterns were very different. Older adults looked more at the ground ahead of them, which most likely reflects a functional adaptation to reduce the risk of tripping and falling as falls represent a serious risk in this population (Jensen, 1999). Children fixated traffic-irrelevant features more, which may indicate poorer attentional control or insufficient practice or experience. A serendipitous finding from this study was that the presence of a distractor (ice cream) acted to further draw attention away from the direction of oncoming vehicles in the sample of children. Based on these findings, a subsequent aim of the thesis was to explore whether two road-crossing training interventions (Crossroads and Safety Watch) would improve the amount of time children fixated traffic-relevant

features of the environment: neither programme was found to have a significant impact on gaze behaviour compared to the control condition (no intervention). Another aim of the thesis that followed from the results of the first experiment was to further examine the attentional control of gaze behaviour in children. Two simulated road-crossings were purposely developed in the laboratory, allowing more controlled investigation of gaze behaviour at (simulated) signalised and unsignalised crossings, with and without a non-spatial secondary task (counting in threes). It was found that the addition of this secondary task affected children's gaze behaviour in one of the simulation types but not the other. This demonstrated that cognitive processes are context dependent and not invariant across conditions. In light of the growing concern raised with respect to the use of artificial laboratory settings and tasks, the final aim of this thesis was to compare gaze behaviour of children under three display conditions: monitor simulation, projector simulation, and real-world; the results suggested that behaviour in the laboratory did not correspond with real-world behaviour. In real road-crossing situations, children looked significantly more often at the ground ahead of them (walkway) and at lights and signs than when performing in the "monitor" or "projector" simulations. These findings further emphasise the context-dependence of cognition and behaviour. This thesis contributes to the argument that a real-world setting provides rich and meaningful data and that, although the laboratory setting has certain methodological advantages, transfer of laboratory findings to the real-world context cannot be assumed. Similarly, road-crossing skills trained in a simulated setting (on a computer) do not appear to transfer to the real-world context. This thesis therefore advocates a real-world approach to the research and training of behaviour and underlying cognitive processes.

# **CHAPTER 1**: GENERAL INTRODUCTION

Crossing the road safely is a highly complex task which relies on a number of different skills, including scanning the environment for potential dangers or threats, focusing attention on relevant parts of the world (e.g. traffic), ignoring irrelevant or distracting stimuli, integrating visual and auditory information to localise vehicles, calculating the relationship between the pedestrian's own speed and that of vehicles, correctly identifying a safe location and time to cross, and stepping out and crossing the road at an appropriate speed. Pedestrians must, therefore, be able to correctly interpret the information from their environment and make an appropriate decision about where and when to cross.

Children and older adults are overrepresented in pedestrian accidents (DfT, 2010a; DfT, 2010b). Indeed, children may be more than 30 times as likely to be injured or killed as pedestrians than as passengers in cars (e.g., Sonkin *et al.*, 2006). Why are children and older people at greater risk of pedestrian road accidents, and what can be done to reduce the number and severity of such accidents? Given that the DfT (2010b) reported that 58% of pedestrians that were seriously injured or killed in pedestrian accidents failed to look properly before crossing the road, the looking behaviour of pedestrians is likely to be of great importance when attempting to understand why children and adults are more likely to be involved in pedestrian accidents. In this thesis it is assumed that certain looking behaviours, such as fixating on approaching vehicles, are more likely to result in safe crossing than attending to non-traffic relevant features, such as buildings and trees. All the participants in this thesis crossed the road without being involved in a pedestrian accident, so it is not possible to state with complete certainty that certain looking behaviours are responsible for pedestrian accidents. However, it is likely that at least some of the increased risk is attributable to still-developing perceptual, cognitive and motor skills in children and to the decline of these skills in older age, which may be investigated through the study of gaze behaviour at the roadside. This chapter will provide a summary of current understanding of the development and decline of perceptual and cognitive abilities assumed to be involved in road crossing. It will be explained how the study of gaze behaviour can give insight into road-crossing strategies adopted by pedestrians. In the vast majority of studies of gaze behaviour a laboratory setting has been used. However, it is becoming increasingly clear that behaviour in the laboratory may not be comparable to that exhibited in the real world, which is much less constrained. The ecological validity of such laboratory-based studies will be critically discussed in light of current understanding of the functioning of the visual system. This chapter will conclude with an overview of the thesis' aims.

## *1.1 Pedestrian accidents*

In 2010, the DfT published its annual report on road accidents in the UK showing that the number of people killed on Britain's roads in 2008 had fallen by a record 14% compared to 2007, to its lowest level ever, and that government targets for reducing the number of people killed and seriously injured on the roads had been met two years ahead of schedule (DfT, 2010c). However, the Audit Commission subsequently suggested that these reports were misleading: although the casualty rates for motorists had seen a significant fall, the reductions in casualty rates for more vulnerable road users – in particular, pedestrians – were significantly less marked. Indeed, comparative reports show that although the UK demonstrates among the lowest rates of child road casualties in the industrialised world, rates of child pedestrian casualties are comparatively high (Bly *et al*., 2005).

In the UK, children cross the road less often than young and middle-aged adults, but are more than four times more likely to be involved in a pedestrian accident (Thomson *et al*., 1996), while adults over the age of 65 are underrepresented in the total number of pedestrian accidents in relation to percentage of the population that older adults account for, but overrepresented in pedestrian fatalities (DfT, 2004a; Zegeer *et al*., 1993). In other words, older adults are less likely to be involved in a pedestrian accident than younger adults, but are more likely to die if they are involved in a pedestrian accident than other groups. This suggests that older adults are able to cross the road just as safely as younger adults but are at greater risk of death because of physical frailty. However, by using only percentages of the population to calculate the risk of pedestrian accidents of certain age groups, the frequency of roads crossed is not taken into account. Ward *et al*. (1994) conducted a survey on pedestrians and noted that older adults (over the age of 65) on average crossed 4.9 roads per day; this figure was 11.5 roads per day for young adults (aged between 16 and 19). Fontaine and Gourlet (1997) suggested that the number of roads crossed was the most appropriate measure of risk for older pedestrians and when this was taken into account older pedestrians had a greater chance of being involved in pedestrian accidents than younger pedestrians. Older adults in the UK are at greatest risk of being seriously injured or killed when distance travelled is taken into account (DfT, 2010b). Adults aged 25-59 are at the lowest risk of being involved in pedestrian accidents, whereas adults aged 16-24 are at a much greater risk, particularly males (DfT, 2010b). Young adults' increased exposure to road crossings may account for their relatively high involvement in pedestrian accidents (Holland & Hill, 2010). Given young adults' sensory and cognitive capabilities (discussed in the following sections) and the importance of these abilities when crossing the road, the relatively high incidence of pedestrian accidents in this group is likely related to the fact that 17–24-year olds walk more in terms of total distance and frequency than all other age groups (DfT, 2010b).

Most pedestrian accidents occur away from signalised crossings, but that is not to say that these crossings do not pose a threat to pedestrians. In Edinburgh around 25% of all pedestrian accidents occur at or within 50 metres of a signalised road crossing (Al Naqbi, 2009). More pedestrians are involved in accidents at a signalised crossing than 10-30m away from the crossing, although this is probably a result of the increased number of crossings that occur at signalised crossings.

Older and Grayson (1974) believed that crossing the road could be divided into four phases: observation, perception, judgement and decision. The psychological processes were specified in more detail by van der Molen (1981) who stated that the ability to selectively attend to pertinent information, coordinate multiple sources of information, accurately estimate the time of arrival of an approaching vehicle, accurately predict crossing time and an appropriate visual search were the most important skills required to cross the road safely. A reduced ability to perform these tasks may increase the risk of being involved in a pedestrian accident. In the following sections potential factors that may predispose people to pedestrian accidents are discussed.

## *1.2 Life span approach*

This thesis aims to enhance our understanding of the factors that contribute to the overrepresentation of children and older adults in serious pedestrian accidents. In the first study of this thesis (Chapter 3), the gaze behaviour of children, adults and older adults at a signalised pedestrian crossing will be investigated using an eye-tracker. No previous study has compared the gaze behaviour of children, adults and older adults at a road crossing. Based on the findings of this study, the subsequent studies will focus on children, further investigating attentional control in this group at real-world and simulated crossings (Chapters 4 and 6) and evaluating the effectiveness of two road crossing interventions aimed at improving children's pedestrian behaviour (Chapter 5). Finally, Chapter 8 aims to assess the ecological validity of the simulated road crossing environment. Thus, whilst children's gaze behaviour will be the main focus of this thesis, the first study takes a life-span approach, investigating the gaze behaviour of children, adults and older adults at a real-world signalised pedestrian crossing. Therefore, changes in sensory, perceptual and cognitive abilities across the life span will be discussed below.

It would appear that groups displaying sub-optimal sensory, perceptual or cognitive abilities are at greater risk of being involved in a pedestrian accident. The overrepresentation of children and older adults in pedestrian accidents may be at least partially explained by a combination of sensory, perceptual and cognitive factors (Barton, 2006; Holland & Rabbitt, 1992; Roberts & Norton, 1995), predisposing these groups to pedestrian accident. Numerous studies discussed in the following sections have investigated sensory (Atchison *et al.*, 2008; Coch *et al.,* 2005; Glasser & Campbell, 1999; Haegerstrom-Portnoy *et al.*, 1999; Leat & Wegmann, 2004; Lord, 2006; Tran *et al.*, 1998; Weale, 1963; Wright & Drasdo, 1985) and cognitive (Bedard *et al.*, 2002; Dempster, 1992; Fuster, 1997; Span *et al.*, 2004; West, 1996) abilities, road-crossing behaviour (Oxley *et al.*, 1997; Zeedyk *et al.*, 2002) and gaze behaviour (Underwood *et al.*, 2003, 2005) at different stages across the life span. These studies often indicate an improvement in performance from childhood to adulthood and a decline in later life. However, few studies have looked at performance across the entire life span and as tasks, measures, stimuli and age ranges often differ between studies, drawing conclusions about performance across the life span must be done with care. The data from these studies will be presented to give an indication of abilities across the life span. In the following sections "children" are defined as 6-11 year olds and "older adults" are defined as adults over the age of 65, unless otherwise specified.

## *1.3 Sensory processing*

### *1.3.1 Vision*

Static visual acuity in children is similar to that of adults by the age of six (Pan *et al.,* 2009). Significant differences exist between the contrast sensitivity of adults and that of six-year-old children, but these differences disappear in children over the age of eight (Leat & Wegmann, 2004). Colour perception in children aged six is comparable to that of adults, while motion perception may take longer to fully develop (Coch *et al.,* 2005). These studies suggest that many aspects of vision are fully developed by the age of eight and it is unlikely that the increased predilection to pedestrian injury of healthy children can be explained in terms of underdeveloped visual abilities.

The vision of older people is affected by natural physiological changes to the eye and may partially explain older adults' involvement in pedestrian accidents (Lord, 2006). During the ageing process the eye's shape changes and the mass and size of the lens increase (Atchison *et al.*, 2008) and the lens becomes less elastic (Glasser & Campbell, 1999; Weale, 1963). The yellowing of the lens that occurs with old age filters shorter wavelengths, meaning that blues and greens appear dull or grey (Haegerstrom-Portnoy *et al.*, 1999). The retina of older adults receives less light than the retina of younger adults because of a reduction in pupil diameter that older people experience (Weale, 1963). In older adults, spatial and temporal contrast sensitivity decline due to a reduction in retinal illuminance caused by the decreased pupil diameter (Wright & Drasdo, 1985). The level of darkness adaptation in adults over the age of sixty reduces, making it more difficult to see under low light conditions (Jackson *et al.,* 1999). It also takes older adults longer to recover from dark adaption than younger adults (Jackson *et al*., 1999). Depth perception begins to deteriorate between the ages of 40 and 50 (Holland & Rabbitt, 1992), probably due to changes in the power of accommodation and convergence that occur at this age (Hirsch & Wick, 1960). Older adults are also more sensitive to glare (Carter, 1982) and take longer to recover from glare than younger adults (Holland & Rabbitt, 1992; Schieber, 1992; Tran *et al*., 1998), making it more difficult to see when looking under brightly lit conditions. Motion detection and perception thresholds also deteriorate with age (Schieber, 1992; Tran *et al*., 1998). In sum, many important visual capabilities that can aid safe road crossing, such as depth perception, motion perception and recovery from glare, are often reduced in older adults. It is possible that these reduced visual capabilities predispose older adults to accidents at the roadside (Lord, 2006).

### *1.3.2 Hearing*

It is unlikely that hearing difficulties play a significant role in the overrepresentation of children in pedestrian accidents as the prevalence of hearing problems in children under the age of 10 is relatively low in the UK (Fortnum *et al.*, 2001). However, there appears to be a link between sensory problems and pedestrian accidents; Roberts and Norton (1995) collected data from parental reports and found that of the children killed or seriously injured in pedestrian accidents, 6.8% had vision problems and 8% had hearing problems compared to only 1.7% and 4% of the control group. The decline in sensory abilities of older adults is not limited to vision. Hearing is often impaired in older adults (Browning, 1998). Older adults experience a decline in hearing acuity (Willott, 1991) and are less able to determine the location of sounds (Dobreva *et al.*, 2011; Noble *et al.*, 1994). An inability to hear traffic or identify the location of the sound of a vehicle when deciding to cross the road places the pedestrian at greater risk of being involved in an accident with vehicles approaching from behind (Bailey *et al.*, 1992, cited in Dunbar *et al.*, 2004) or turning vehicles (Dewar, 1995, cited in Dunbar *et al.*, 2004).

### *1.3.3 Interim summary: Sensory factors*

The predisposition of children to pedestrian accidents is unlikely to be due to underdeveloped sensory systems, although children with visual and/or hearing impairments are more likely to be involved in pedestrian accidents than children without such impairments (Roberts & Norton, 1995). However, the decline in sensory abilities with age may contribute to the overrepresentation of older adults in pedestrian accidents (Holland & Rabbitt, 1992). Dunbar *et al*. (2004) noted that there is little direct evidence that sensory decline is responsible for the overrepresentation of older adults in pedestrian accidents. However, they also noted that there appears to be an association between sensory decline and driving accidents that indicate the importance of sensory abilities in safe behaviour in traffic environments. It is difficult to assess exactly how much of an impact the decline in vision and hearing experienced by older adults has on the predisposition of this group for pedestrian accidents, as sensory decline is typically accompanied by cognitive decline (Li & Lindenberger, 2002). The covariation in sensory and cognitive decline observed in older adults (correlationally and experimentally) may be due to general physiological decline, such as degraded white matter integrity reducing conduction speed and slowing down cognitive and motor activity (Raz, 2000), an increase in resource overlap, compensatory trade-offs (in the form of the sub-optimal sensory processing observed in older adults placing greater demand on the prefrontal cortex responsible for executive functions), or a combination of these factors (Li & Lindenberger, 2002).

### *1.4 Cognitive factors*

In addition to sensory factors, cognitive factors such as attentional control, dual-tasking, task switching and working memory may also contribute to the increased prevalence of pedestrian accidents in certain population groups (Barton, 2006; Thomson *et al*., 1996). In order to cross the road safely, a number of cognitive skills are required, including the ability to search for relevant information, such as vehicles

(Thomson *et al*., 2005), select a safe crossing place (Ampofo-Boateng & Thomson, 1991; Tabibi & Pfeffer, 2003; Zeedyk *et al*., 2001), estimate time-to-contact (Barton, 2006), ignore irrelevant information and attend to pertinent sources of information (Hill *et al*., 2000), switch attention (Barton, 2006) and understand the traffic regulations and the intentions of drivers (Foot *et al*., 2006).

### *1.4.1 Executive function*

Whilst there is no universal agreement on the definition of executive function (Jurado & Rosselli, 2007), the concept is not completely nebulous; it is generally agreed that executive function is a concept that describes the cognitive processes that modulate and control fundamental cognitive skills (McCarthy & Warrington, 1990) through the utilisation of information from various cortical sensory systems (Baddeley & Wilson 1988; Goethals *et al*., 2004; Lezak, 1995; Yogev-Seligmann *et al*., 2008). Executive function is important for decision making or "trouble shooting" in unfamiliar and/or difficult situations and situations that require a habitual response to be suppressed (Shallice & Burgess, 1991). Many studies investigating executive function have proposed that executive function comprises different components, such as attentional control, cognitive inhibition, task switching, binding of numerous sources of information and monitoring ongoing actions (Baddeley, 2003; Cabeza *et al*., 2004; Friedman *et al*., 2007; Healey & Miyake, 2009; Lezak, 1995; Reuter-Lorenz *et al*., 2000; Raz, 2000; Rypma *et al*., 2001; Shallice & Burgess, 1991; Stuss & Levine, 2002).

Whether or not all executive functions can be explained by one underlying mechanism remains a topic of some debate. It has been suggested that goal neglect (a condition where task requirements are ignored despite the ability to describe these requirements), common in patients with lesions in the prefrontal cortex indicates that one area is responsible for all executive functions (De Frias *et al*., 2006; Duncan *et al*., 1996; Parkin & Java, 1999). The prefrontal cortex plays a major role in planning, decision making and other executive functions and is essential for organising intellectual activity (Craik & Bialystok, 2006; Luria, 1973) although executive processes are unlikely to exclusively occur in the frontal areas, as these processes involve links between different areas of the brain (Baddeley & Wilson, 1988). Godefroy *et al*. (1999) stated that no one ability or area is responsible for all aspects of executive control. This statement was supported by varying performance on a variety of executive function tasks by frontal lobe patients. It is presently unclear if one or several areas are responsible for executive function (see Jurado & Rosselli, 2007, for a more detailed debate).

Regardless of the unity or non-unity of executive functions, they are imperative for many activities of daily living (Lezak, 1995; Reuter-Lorenz, *et al*., 2000; Stuss & Levine, 2002; Yogev-Seligmann *et al*., 2008). Sub-optimal executive function could lead to deterioration in the performance of tasks that require multi-tasking and decision making (Craik & Bialystok, 2006; Yogev-Seligmann *et al*., 2008), such as crossing the road.

Indeed, increasing evidence suggests that executive functions are compromised in both children and older adults compared with young adults. Many aspects of executive function are often not fully developed until the age of 15 (Cepeda *et al*., 2001; Span *et al*., 2004; Van der Molen, 2000) and seem to decline sooner in older adults than other, more basic cognitive functions (Craik & Bialystok, 2006; Kramer *et al*., 1994; Ridderinkhof *et al*., 2002). One possible reason for the decline of executive functions in older adults may be the increased demand on the prefrontal cortex due to reduced activity in occipital lobes. Imaging studies have revealed that reduced activity in the occipital regions (responsible for sensory processing) in older adults is often accompanied by increased activity in the prefrontal cortex, suggesting that older adults use cognitive processing to compensate for poor sensory processing (D'Esposito *et al*., 1999; Li & Lindenberger, 2002; Rypma *et al*., 2001). During perception older adults appear to recruit processes in the prefrontal cortex to mediate sensory deficits as a result of reduced occipital activity, which reduces the resources available for executive functions (Grady *et al*., 1994).

Younger adults perform better than children and older adults on executive function tasks that have been linked with road crossing such as attentional control, dual-tasking, task switching (Span *et al*., 2004; West, 1996) and working memory (Bedard *et al*., 2002; Dempster, 1992; Fuster, 1997; Span *et al*., 2004; West, 1996). The performance on these tasks varies across the lifespan and how changes to these functions may affect road crossing is discussed below.

*1.4.2 Attentional control and visual search*

Attentional control describes the mechanism that limits processing to information that is relevant to the task at hand (e.g., Milham *et al*., 2002). The amount of information in the visual field far surpasses our ability to process the information (Brockmole & Henderson, 2006). This has been demonstrated in many "inattentional blindness" studies where observers often fail to report the presence of unexpected events and objects when attending to other events and objects (Mack & Rock, 1998; Most *et al.*, 2005; Rensink, 2000). For instance, Simons and Chabris (1999) noted that some observers, when watching a video, failed to notice the introduction of a woman in a gorilla suit while they were counting basketball passes.

Despite the abundance of information in the visual field, adults rarely have difficulties functioning in busy environments and have developed the ability to selectively attend to "task-relevant" information to such a degree that irrelevant information is often unattended (Brockmole & Henderson, 2006). Attentional control is needed for many situations, such as at the road side (Thomson *et al.*, 2005; Zeedyk *et al.*, 2002). Pedestrians are presented with a large amount of both pertinent and irrelevant visual cues and stimuli in the pedestrian setting; it is therefore necessary to process some information and not process other information (Itti, 2005). Proposed mechanisms responsible for attention, how attentional control changes with age and the implications of sub-optimal attentional control on road crossing are discussed below.

It has been proposed that the allocation of visual attention can be driven both endogenously and exogenously (Posner, 1980). Endogenous attention is voluntary and goal-directed. For example, when searching for keys on an untidy desk, attention may be directed to a place that the keys would usually be or underneath a recently moved paper. If they are not found, then the visual search for the keys may start from the left-hand side of the desk and progress slowly towards the right-hand side of the desk until the keys have been found. This endogenous attention is often referred to as "top-down" control (Yantis, 1998).

In contrast, exogenous attention is momentary, occurs rapidly (Cheal & Lyon, 1991) and is thought to be guided by external stimuli such as the flashing lights of an ambulance or the honking of a car horn. Exogenous attention is often referred to as a "bottom-up" process and is considered a more primitive mechanism that directs the observer towards salient objects or events (Posner, 1980).

One task commonly used to probe how we allocate visual attention in time and space is that of visual search (e.g., Treisman & Sato, 1990; Wolfe, 1992). In typical visual search tasks, participants are required to search for a target that differs from distractors in certain parameters such as size, orientation and colour. When the target differs from the distractors in only one parameter, such as colour, it often appears to "pop out" of the display, and reaction times are not affected by the number of distractors (e.g., Donnelly *et al.*, 2007; Treisman & Gelade, 1980). This is known as "efficient", "parallel", or "feature" search. When the target differs from the distractors in more than one dimension (e.g., colour and orientation), reaction times increase with increasing numbers of distractors. This is known as "inefficient", "serial", or "conjunction" search. Treisman and Gelade (1980) argued that during conjunctive searches, attention is directed serially to each stimulus in the display.

Children are less proficient than adults in visual search tasks, with performance on such tasks continuing to improve throughout childhood. Children take considerably longer to find target objects compared to adults (particularly when there are more distractors, and if they need to look for more than one characteristic at once), and take longer to decide if there is no target present at all (e.g., Donnelly *et al.*, 2007; Hommel *et al.,* 2004; Trick & Enns, 1998). The presence of moving objects creates additional difficulty (Trick *et al*., 2003). Younger children (aged 6-8 years) have more difficulty than older children (aged 10-12 years) when identifying and tracking a moving target surrounded by distractors, and experience even greater difficulty accurately tracking multiple moving targets (Trick, *et al*., 2005). The improvement in visual search abilities of older children may be a result of an improved ability to switch the focus of attention (Pearson & Lane, 1991) and divide visual attention (Kaye & Ruskin, 1990); this is discussed further in 1.4.3 *Dual-task performance*. Further, young children (around 7 years old) tend to guide their eyes around a scene much less systematically than adults and take longer to decide whether it is safe to cross the road (Whitebread & Neilson, 2000). These tendencies suggest that children are more likely than adults to miss opportunities for safe crossing, and to miss potential dangers (such as oncoming vehicles) in their environment, which may partially explain why in 72% of child pedestrian accidents the child had reportedly failed to look properly before crossing the road (DfT, 2010a).

When comparing the performance of children, adults and older adults during visual search tasks Hommel *et al*. (2004) noted that the reaction times of children and older adults were longer than the search times of adults; this is even more striking during conjunctive searches. Older adults take longer than young adults to voluntarily move their attention, which may explain their poorer performance in visual search tasks (D'Aloisio & Klein, 1990; Trick & Enns, 1998). The poorer performance of older adults during visual search tasks may also be attributed to a reduced useful field of view (UFOV). The UFOV is able to predict problems in vision better than standard visual field assessments as it measures processing speed, divided attention and selective attention (Ball & Owsley, 1993). Older adults' performance on the UFOV test reveals that it takes them longer to discriminate stimuli in the central field than younger adults (Sekuler *et al*., 2000). Poor performance on the UFOV test has been linked with reduced ambulatory ability (the ability to successfully navigate in the environment) and driving competence (Ball *et al*., 1993; Broman *et al*., 2004; Myers *et al*., 2000; Owsley *et al*., 1998; Stalvey *et al*., 1999), indicating that reduced inability to discriminate stimuli, divide attention between multiple target or ignore distractors has a negative effect on performance in traffic environments.

The poor visual search abilities of children and older adults are relevant to the pedestrian setting as pedestrians must attend to multiple moving vehicles, and perhaps other pedestrians, before deciding to cross the road, particularly at unsignalised crossings, but also at signalised crossings. An inability to systematically search the environment may mean safe crossing opportunities are missed and unsafe crossing opportunities are identified as safe ones.

Wolfe (1994) has argued that attention is almost always determined by an interaction between endogenous and exogenous factors, which produces a ranking of the most important stimuli to be attended. Much of the evidence to support the use of top-down and bottom-up attentional control comes from laboratory-based studies which tend to rely on the passive viewing of stylised visual images on a computer monitor (e.g., Bergen & Julesz, 1983; Braun, 1998; Braun & Julesz, 1998; Braun & Sagi, 1990; Nakayama & Mackeben, 1989; Treisman, 1988; Treisman & Gelade, 1980). However, more recent research suggests that in active tasks, conducted in "real-world" environments, attention is driven predominantly by a top-down process. When making a sandwich, for example, Hayhoe *et al*. (2003) found that task-relevant information such as the knife, bread and peanut butter, were attended almost exclusively. Land and Lee (1994) noted that the tangent of a corner is fixated when driving on a bending road and that drivers' steering movements are tightly coupled with their eye movements, suggesting that the drivers actively sought information that would help them steer the vehicle. Occasionally, attention would be driven exogenously in the real world, for example when the sound of a police siren in the distance may cause pedestrians at a road crossing to look in the direction of the sound.

It appears that children are less able than adults to selectively attend to the most pertinent sources of information in the real world. Certain cues such as particular colours, textures (Donnelly *et al*., 2007) and spatial orientations (Nardini *et al*., 2006) are more salient than others to children and this contributes to attentional problems (Schiff & Knopf, 1985). When learning a route, older children and adults made effective use of landmarks, attending to corners where a change of direction is necessary, while younger children attended to interesting, but task-irrelevant information, such as seeing a cat (Allen *et al*., 1979). More evidence of children's propensity to be easily distracted from task-relevant information by salient information can be found in a study by Tagg (1990, cited in Thomson *et al*., 1996). In that study children aged 5 and 7 years old, were required to memorise the location of animal pictures in a room. The children attended more to the physical properties of the animal pictures than the task-relevant spatial features. The lesser ability to attend exclusively to the most pertinent sources of information may be a result of cognitive factors rather than a lack of experience, as when the animal pictures were replaced by less interesting simple targets the children were able to focus on the spatial features of the targets and successfully memorise their location. This indicates that the children have some understanding of what visual information is important to complete the task, but have difficulties in ignoring salient but irrelevant information. This disparity between knowing what information is relevant and attending to that information is revisited in relation to improving children's road-crossing behaviour (see 1.7 *Training/adapting gaze behaviour*).

A reduced capacity to selectively attend to task-relevant information could have implications for children when crossing the road. Young children (between 5 and 7 years old), are easily distracted by task-irrelevant information in a traffic environment (Foot *et al*., 1999). It has also been noted that children who are better at focusing their attention in the presence of distracting task-irrelevant information attend more to traffic during a road crossing (Dunbar *et al*., 2001).

At the opposite end of the life spectrum the ability to perform visual search declines in older adults with conjunctive search particularly affected (D'Aloisio & Klein, 1990; Plude, 1990; Rabbitt, 1965; Trick & Enns, 1998). This decrease in visual search performance may be partially explained by reduced peripheral acuity (Scialfa 1990) and possibly a lesser ability to disengage attention from one target (D'Aloisio & Klein, 1990).

Another test of attentional control is the Stroop test (Stroop, 1935) in which observers are presented with a series of colour names in different colours, for example red, blue, green and are asked to ignore the meaning of a presented word and identify the colour the word is presented in. Generally, identifying the blue colour in the word red takes longer than identifying the blue colour in the word blue (Tabibi & Pfeffer, 2003). Children (Tabibi & Pfeffer, 2003) and older adults (Milham *et al*., 2002; Uttl & Graf, 1997; Verhaeghen & De Meersman, 1998) exhibit a reduced ability to inhibit the processing of task-irrelevant information compared with younger adults. Interestingly, Tabibi and Pfeffer (2003) noted that faster and more accurate processing on the Stroop test was related to safer pedestrian behaviour in 6-year-olds: the authors found that children who performed well on the Stroop test were significantly better at ignoring information irrelevant to the task at hand, which in turn allowed for faster and more accurate identification of safe and dangerous road crossing sites. Recently, Barton and Morrongiello (2011) found no link between Stroop-test performance and safe pedestrian behaviour in children, but noted that children (aged 6-9 years old) that performed better on the Contingenecy Naming Test (a similar test to the Stroop test, but unaffected by reading proficiency) also displayed safer pedestrian behaviour at a simulated road crossing, by looking more frequently at the traffic and allowing for more time to cross when selecting crossing opportunities. Whilst no such studies have directly investigated performance on the Stroop test or Contingency Naming Test and its relationship with road-crossing behaviour in older adults, it is plausible the performance on attentional control tasks may be linked to pedestrian behaviour in older adults as well, since both groups display sub-optimal attentional control (Milham *et al.*, 2002; Tabibi & Pfeffer, 2003; Uttl & Graf, 1997; Verhaeghen & De Meersman, 1998). Future studies investigating the link between performance in laboratory-based tests such as the Stroop test and performance during real-world activities may increase our understanding of the cognitive processes being used in the real world and also reveal how useful laboratory-based studies are for explaining cognitive process outside of the laboratory (see 1.8 *Studying cognition under realistic conditions*).

Attentional control, like many other cognitive and sensory abilities, improves from childhood, peaks in young adulthood, and declines in older age (Plude, *et al.*, 1994; Trick & Enns, 1998). It has been suggested that this development and decline in attentional control is directly related to changes in basic information-processing mechanisms (e.g., Dempster, 1992). Others have argued that while some similarities between the developing cognitive processing capabilities of children and the declining cognitive processing capabilities of older adults may exist, the underlying mechanisms are likely to be task-specific: intellectual development across the lifespan is dynamic and older adults may experience greater deficits in executive functions than in non-executive functions, whereas children's reduced cognitive abilities are likely to be observed across a range of functions (e.g., Hommel *et al.*, 2004; Li *et al.*, 2004; Waszak *et al.*, 2009).

Differences in the speed of information-processing may account for age-related differences in certain other cognitive tasks, regardless of the specific demands of the task. For example, children's abilities to estimate their own crossing speed and effectively search for safe crossing opportunities may both be affected to the same extent by a general information-processing mechanism. Span *et al.* (2004), for example, noted that children's performance on a range of executive and non-executive function tasks supports the "global speed hypothesis" of information processing. Some older adults, however, perform better on non-executive function tasks (such as reading) than would be expected based on their performance during executive function tasks (such as dual tasks) (Span *et al.*, 2004), suggesting that ageing does not affect all cognitive functions to the same extent. This is in line with the finding that age-related deterioration of the brain occurs predominantly in the prefrontal cortex, considered responsible for many executive functions (Raz, 2000).

### *1.4.3 Dual-task performance*

Performance on a task often declines when a second task is added (Kahneman, 1973). It has been proposed that this reduced performance with the addition of a secondary task is due to either limited attentional resources being divided between the demands of the tasks (Kahneman, 1973; Wickens, 1991), a 'bottle-neck' effect where two or more processes must be completed at the same time (Pashler, 1994) or a result of cross-talk between parallel processing (Meyer & Kieras, 1997; Pashler, 1994). It is also possible that a combination of limited attentional resources and cross-talk results in reduced processing capabilities with added tasks (see Kramer & Larish, 1996, for a detailed review). Koch (2009) noted that performance on trials where strong cross-talk is present is significantly worse than when little cross-talk is present. Schwab (1954) observed that performance on motor tasks such as drawing was compromised with the addition of a secondary motor task (clenching the non-drawing hand). Regardless of the underlying processes it is important to divide attention efficiently between numerous tasks when crossing the road (Thomson *et al*., 2005). Estimating gaps in traffic, monitoring the walkway and maintaining balance all require cognitive processing at the roadside and may present problems for children and older adults who have been shown to perform worse than younger adults in dual-task studies.

Dual-task paradigms have been used extensively to assess cognitive resources (Irwin-Chase & Burns, 2000), although there is no standard secondary task that has been used in research investigating the effects of dual task on performance. Examples of secondary tasks are responses to auditory (Lajoie *et al*., 1993; Lajoie *et al*., 1996) and visual stimuli (Abernethy *et al*., 2002; Sparrow *et al*., 2002), counting back from 50 (Beauchet *et al*., 2005; Beauchet *et al*., 2007), mental arithmetic (Van Iersel *et al*., 2007), spelling words backwards (Hollman *et al*., 2007) and memorisation (Li *et al*., 2001; Lindenberger *et al*., 2000). Typically performance on a primary task is less efficient (i.e., takes longer or is less accurate) when a secondary task is added, providing that both tasks are sufficiently demanding (Sparrow *et al*., 2002).

As with other cognitive capabilities already discussed in this thesis, there appears to be an improvement from childhood to adulthood (Foley & Berch, 1997; Guttentag,

1989) and a decline in older age (Kramer & Larish, 1996; Ponds *et al*., 1988; Salthouse *et al*., 1995; Tsang & Shanner, 1998; Yogev-Seligmann *et al*., 2008) in the ability to efficiently divide attention between two concurrent tasks. Particularly relevant to the road-side setting is that older adults take longer to respond to visual and auditory cues whilst walking than younger adults (Sparrow *et al.,* 2002).

It is possible that an inability to effectively perform more than one task at once may result in pedestrians relying on one source of information to guide their road-crossing decisions which may increase the chances of a pedestrian accident. For example, relying solely on the distance of an approaching vehicle when deciding when to cross the road would be a sub-optimal strategy (see 1.5.2 *Ability to judge safe crossing gaps*). The effects of a secondary task are investigated in Chapters 4 and 6.

### *1.4.4 Task switching*

There are many different tasks required at a road crossing, such as predicting drivers' actions, monitoring traffic lights and estimating crossing gaps. The ability to switch between tasks is important for safe road crossing (Barton, 2006; Dunbar *et al*., 2001). The cost of task switching has been investigated in many laboratory-based studies. These studies often require participants to repeatedly perform one simple task, for example judging if a presented number is odd or even. At some point the participants will be required to complete a different task, such as judging if the presented number is higher than five (Altmann, 2007). It is generally found that performance on the trial that occurs at the switch is worse than the performance on trials where the previous task was the same as the current one. This is known as the "switch cost" and may be indicative of processes involved in cognitive control (Monsell, 2003). Whilst it is also possible that the switch cost is a result of differences in the cueing of the two tasks, recent research findings indicate it is the switching of the task and not the cueing that causes poorer performance on these tasks (Grange & Houghton, 2010).

Again, as in other executive functions, there is a clear pattern of improvement and then decline across the life span in task-switching abilities. Older adults display a relatively poor performance during switching tasks, when compared with younger adults, even when general age-related slowing is taken into account (Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005). Numerous studies have shown that children are less able to switch tasks than adults (e.g., Diamond *et al*., 2005; Rennie *et al*., 2004). Dunbar *et al*. (2001) noted that younger children had weaker concentration and task switching skills than older children when being asked questions whilst watching a cartoon. Poor performance in this task-switching test was related to less skilled, more reckless road-crossing behaviour, characterised by not stopping to look for traffic before crossing the road and running rather than walking across the road.

### *1.4.5 Working memory*

The term 'working memory' was first used by Miller *et al*. (1960) when drawing comparisons between the brain and a computer. Since then, the term has been used in computational modelling (Newell & Simon, 1972) and in animal learning to describe the retention of information over a series of trials (Olton, 1979). The concept of "working memory" applied to humans was appropriated by Baddeley and Hitch (1974) to describe a system comprising a central executive, aided by two subsystems, one dealing with acoustic and verbal information (the phonological loop) and the other with visual and spatial information (the visuospatial sketchpad). Working memory is different from short-term memory as short-term memory involves the recollection of very recent information, whereas working memory involves the processing and manipulation of information. Working memory can therefore be described as an executive function that is involved in the processing, disposal, and retrieval of short-term information (Best *et al*., 2009). This short-term storage and manipulation of information is believed to underlie human thought processes (Baddeley, 1998, 2003). Working memory is therefore critical in remembering information such as the location and direction of motion of moving vehicles, traffic lights and previous gaze directions during active road-crossing tasks.

The working memory of younger adults has been shown to have a greater capacity than that of both children and older adults in studies requiring participants to store and manipulate either auditory or visual information, or a combination of both (Cabeza & Nyberg, 1997; Cowan, 2001; Petrides, 1995; Span *et al*., 2004). One test of working memory is the *n*-back task (Jonides *et al*., 1997), in which participants make a judgement about a stimulus from a certain number (*n*) of trials ago. This requires the participants to keep information in working memory. Typically the task is more difficult and participants make more errors as the number of trials required to be stored and manipulated increases (Owen *et al*., 2005). Clancy *et al*. (2006) noted that impairments in working memory were linked to a reduced ability to learn road-crossing skills in a simulated environment.

Much of the research relating to working memory has revolved around thought and comprehension (Baddeley, 2007). Land (2009), however, has argued that the notion of working memory could be extended to incorporate gaze control and action as the gaze system automatically advances during search, apparently without recourse to consult a schema for explicit instructions, and the visual information is stored and manipulated to guide actions (for a more detailed discussion on working memory see Baddeley, 2008).

*1.4.6 Interim summary: Cognitive factors*

In sum, children and older adults often perform less well than younger adults across a range of tasks involving executive function such as dual-tasking, task switching and working memory. In addition, poorer performance in such laboratory-based tasks has been linked to poor road-crossing behaviour or an increased accident risk in a traffic environment in several studies (e.g., Barton & Morrongiello, 2011; Clancy *et al*., 2006; Dunbar *et al*., 2001; Owsley *et al*., 1991; Tabibi & Pfeffer, 2003). These studies suggest that cognitive functioning may play a role in child and older adults' pedestrian accidents. However, one of the criticisms of the tasks used in many of these studies is that some of the methods traditionally used to investigate executive functions are so far removed from real-world activities or tasks that their ecological validity must be questioned (Burgess *et al*., 1998; Kingstone *et al*., 2008a; 't Hart *et al*., 2009). Cognition is context-dependent (Clark, 2001) and poor performance in a laboratory-based study and unsafe road-crossing behaviour may not necessarily be a result of the same underlying mechanism (see 1.8 *Studying cognition under realistic conditions*). It has been noted that traditional laboratory-based methods often fail to generate valid theories of cognitive processes and behaviour in real-world settings (Kingstone *et al*., 2008a). Land and Lee (1994) and Hayhoe *et al*. (2003) observed people's gaze behaviour in real life as a way of building theories of cognition and behaviour (Kingstone *et al*., 2008a). In this thesis the focus will similarly be on observing natural gaze behaviour and allowing the many cognitive factors to interact, thus measuring the combined output of these cognitive factors rather than to attempt to determine the role of one specific cognitive function in crossing behaviour. The studies by Barton and Morrongiello (2011), Dunbar *et al*. (2001) and Tabibi and Pfeffer (2003) may have successfully identified important factors that contribute to children's increased risk of pedestrian accidents, but it is hoped that studying pedestrians' gaze behaviour at an actual road crossing may provide a more detailed understanding of the potential predisposing factors to pedestrian injuries than research conducted in a laboratory (see 1.8 *Studying cognition under realistic conditions*).

## *1.5 Road-crossing behaviour*

Different behaviours displayed by children, adults and older adults before crossing the road may relate to differences in the prevalence of pedestrian accidents. Much of our current understanding of roadside behaviour comes from observational studies of "real-world" crossing behaviour and experimental laboratory-based studies. Such studies have investigated the selection of safe places to cross (Ampofo-Boateng &

Thomson, 1991), the ability to judge safe crossing gaps in traffic (Holland & Hill, 2010; Lee *et al*., 1984; te Velde *et al*., 2005) and where pedestrians look before crossing (Holland & Hill, 2010; Oxley *et al*., 1997; Whitebread & Neilson, 2000; Zeedyk & Wallace, 2003). These are discussed in turn below.

### *1.5.1 Selecting a safe place to cross the road*

Selecting a safe place to cross the road is a vital aspect of safe road crossing. Even if a pedestrian is in excellent physical and mental condition, crossing the road in a location where oncoming traffic is obscured, for example near the top of a hill or near a sharp corner, potentially places the pedestrian in danger. Young children (5 and 7 year olds) often select dangerous places to cross the road, such as near a bend or close to the top of a hill (Ampofo-Boateng & Thomson, 1991). Young children also miss more safe crossing opportunities and are more likely to select unsafe gaps than older children (11 year olds; Ampofo-Boateng & Thomson, 1991). In a road-crossing simulation where child participants had to cross a purpose-built road that ran parallel to an actual road and pretend that the traffic on the actual road was on the replica road, Lee *et al*. (1984) noted that five-year-old children occasionally made unsafe decisions and missed more safe opportunities to cross the road than ten-year-old children.

### *1.5.2 Ability to judge safe crossing gaps*

Young children (5–9 years old) tend to be over-cautious in terms of judging the safety of “gaps” between themselves and moving cars in roadside simulations: they typically select larger gap sizes compared to adults (e.g., Lee *et al*., 1984; Plumert *et* *al*., 2007) and probably make their judgement on the basis of distance, not "time-to-contact" (Connelly *et al*., 1998); this is risky because this strategy does not take the vehicle's speed into account, and therefore children may be more likely to misjudge how quickly a vehicle will arrive at their location.

te Velde *et al*. (2005) suggested that pedestrians can cross the road safely without reaching a high level of cognitive development by purely relying on the ability to directly perceive time-to-contact. This suggestion must be interpreted with care as the experimental evidence to support this claim comes from a very simplified laboratory environment using only one bicycle on a pulley system moving at a relatively low velocity. Recently, Wann *et al*. (2011) noted that children's reduced sensitivity to looming (the expansion of the size of an approaching object on the retina used to perceive time-to-contact) may predispose them to pedestrian accidents involving vehicles travelling at over 20mph, as vehicles travelling faster loom less than slower moving vehicles. The actual traffic environment is much more complex, meaning the attenuation and computation of many different sources of information is essential to safe pedestrian behaviour.

It has been suggested that older adults are also less able to select safe crossing opportunities than younger adults. Oxley *et al*. (1997) covertly filmed the road-crossing behaviours of younger and older adults, and concluded that older pedestrians (assumed to be over 65 years old) were less able than younger adults to gauge the distance between cars and accurately perceive the time-to-arrival of oncoming vehicles as they left less room for error when crossing. Dunbar *et al*.

(2004) noted, however, that this reduced safety margin may be a result of older adults making full use of the time available when crossing. Dunbar *et al*. (2004) raised other issues regarding the presence of outliers and the lack of an independent measure of walking speed in the Oxley *et al*. (1997) study.

### *1.5.3 Looking strategies*

Another important factor in safe road crossing, and one which seems to be compromised in children and older adults compared with younger adults, is the looking strategy people use when at the roadside. A small number of studies have addressed looking behaviour at real-world or simulated road crossings, but almost all of these use inferred measures of gaze from gross head movements, rather than gaze location specifically (e.g., Holland & Hill, 2010; Oxley *et al*., 1997; Whitebread & Neilson, 2002).

Looking left and right at approaching traffic is an important aspect of judging when it is safe to cross the road. In 2008, "pedestrians failed to look properly" was assigned as a contributing factor in 60% of pedestrian accidents (DfT, 2010b). Several studies report that children and older adults may not scan their environment as broadly, or for as long, as younger adults (e.g., Holland & Hill, 2010; Oxley *et al*., 1997; Whitebread & Neilson, 2000; Zeedyk & Wallace, 2003). For example, young children (aged 5-6 years) seldom look left or right before crossing, and when they do, it is often in the wrong direction relative to approaching traffic (Whitebread & Neilson, 2000; Zeedyk *et al*., 2002), and older adults may look at the ground significantly more than younger adults (Oxley *et al*., 1997).

Whitebread and Neilson (2000) investigated the behaviour of children at a simulated road-crossing. A two-way road was filmed from the kerb with three cameras, one facing left, one facing the centre and the other facing right. The footage from the three cameras was displayed on three screens, which were angled in a way that required the participants to make the same head movements as they would at a real road crossing to see traffic from the left and the right. The participants had to watch the video and press a button to indicate that they had found a safe crossing opportunity. The authors concluded that pedestrian looking strategies improved in children between the ages of 5-6 and 7-8 years, and approached adult levels by 11 years. By counting head movements, they inferred that the younger children were not attending to as many sources of information as the adult participants. Adults and older children appeared to switch the focus of their attention to different areas of the display more frequently, especially in the final seconds before a decision to cross was made. While this study advanced our understanding of the development of pedestrian behaviour, there is a need to record eye movements to properly assess the gaze control of pedestrians as gaze behaviour is indicative of the underlying cognitive processes (see 1.6 *Eye movements, gaze direction and visual attention*). By using an eye tracker it would be possible to identify what the participants are attending to; by observing changes in head direction it is only possible to identify some of the instances when attention is switched and the research provides no indication of what the participant is attending to before deciding if it is safe to cross.

In their real-world covert observational study, Oxley *et al*. (1997) found that older adults spent a significantly longer time directing their attention to the ground and when they had made the decision to cross they fixated almost exclusively on the ground rather than monitoring vehicles or crossing signals. As a result, they were slow to react to approaching traffic. The data on pedestrian accidents typically exclude falls. If pedestrian injury data included falls, Jensen (1999) estimated that falling would account for between 70 and 75% of all pedestrian injuries in the traffic environment. Attending to the ground may predispose older adults to pedestrian accidents involving cars, but may also reduce the chance of tripping.

Holland and Hill (2010) also investigated head movements in younger and older adults when selecting safe crossing opportunities, but at a simulated, rather than real roadside. A two-way road was filmed from the kerb with three cameras and displayed as in the Whitebread and Neilson (2000) study. Participants were required to take a step forward and verbally indicate when they had selected a safe crossing opportunity. Head movements were recorded and the direction of last look before crossing, proportion of crossings where the participant looked both ways in the final 3 seconds before crossing, the time from when the last car passed to the selection of a crossing opportunity, the number of safe crossings made, the number of safe crossings missed and the number of unsafe crossings were used to identify differences in the crossing behaviour of male and female drivers and non-drivers at this simulated road crossing.

Holland and Hill (2010) reported that looking left (towards the direction of oncoming traffic on the far side of the road) was related to fewer safe crossings being missed and more safe crossings being selected and that looking to the right immediately before crossing was related to a higher percentage of unsafe crossings. This suggested that participants were more likely to make mistakes when the participants did not attend to the left (traffic approaching on the far side of the road) before crossing. In older adults, Fontaine and Gourlet (1997) noted that pedestrian accidents were more likely to occur in the far lane of a two-way road; this may be explained by the findings of Holland and Hill (2010).

The behaviours exhibited at the simulated road crossings in the Holland and Hill (2010) and Whitebread and Neilson (2000) studies have not been directly compared with behaviours at a real-world road crossing, but gender and age differences noted in unsafe gap selections (where there was not a sufficient amount of time to cross) in these simulated road crossing studies corresponded with accident statistics, suggesting that the findings from these studies were consistent with natural behaviour at real road crossings. In Chapter 8, gaze behaviours at a real-world road crossing and a simulated road crossing are compared.

### *1.5.4 Interim summary: Road-crossing behaviour*

Many factors potentially predisposing individuals to pedestrian accidents have been suggested by researchers investigating accident statistics and behaviour at real and simulated traffic environments. Looking strategy has frequently been proposed as an important factor when investigating the overrepresentation of children and older adult in pedestrian accidents. Children and older adults display behaviours and strategies at actual road crossings that may help explain their overrepresentation in such accidents. For older adults some of these behaviours, such as looking at the ground before crossing, may be a functional adaptation to increased fragility and reduced walking capacity. In the case of the children, behaviours that may predispose them to injury, such as looking the wrong way or not looking at all, suggest they are either inexperienced in the traffic environment and have not learnt what are the most pertinent sources of information or they are unable to assert sufficient top-down control of their attention.

The methods used in the real world and the laboratory are often different. Many of the real-world studies have secretly observed pedestrians (e.g., Oxley *et al*., 1997; Zeedyk *et al*., 2002; Zeedyk & Wallace, 2003), whereas in the simulated road crossing studies the participants are briefed and familiarised with the road-crossing simulation. The simulated crossings in the laboratory are controlled, but since no study has looked at both simulated and real-world crossing it is difficult to accurately estimate how behaviour at the simulated crossings reflects behaviour in the real world. Differences between real-world and laboratory-based studies may be a result of the measures, participants and/or traffic environment used (this is further discussed in 1.8.8 *Real-world vs. simulated displays*).

It is important to note that the above studies have used the direction of the pedestrian's head to infer what information is attended. Observing head movements provides information about the general location of the display or environment to which gaze is being directed; it does not indicate what is being attended and can only give indications to changes in attention. For example, if an observer tracks the movement of a vehicle from the left to the right, by monitoring only head movements it may be concluded that attention has been switched to different areas of the display/environment. By studying the gaze behaviour with eye movement recordings it would be clear that the attention had not switched from the moving vehicle. Thus, recording head movements alone provides only a limited picture of the allocation of attention and the use of eye tracking technology can further aid our understanding of what information is being attended at a traffic environment (e.g., Geruschat *et al*., 2003; Land & Lee, 1994).

## *1.6 Eye movements, gaze direction, and visual attention*

Many researchers now believe that eye movements act as a "*window into the operation of the attentional system*" (Henderson, 2003, p. 498). In order to attend to features of our visual environment, we typically move our eyes to allow the object of interest to fall on the fovea – a region of high photoreceptor density in the centre of the retina that allows us to resolve fine spatial detail. Recording eye movements can therefore provide useful information about what people are attending to, and how attentional resources may be allocated and divided in complex tasks such as walking. In order to be effective, the visual attentional system must be able to both guide our eyes to task-relevant areas of the world, and divert them towards things that are not immediately relevant to the task at hand, but which may otherwise require immediate action, such as an oncoming pedestrian. However, eye movement research investigating visually-guided movements has focused almost exclusively on reaching or grasping movements of the arm and hand rather than whole-body movements such as maintaining balance and walking. The few studies published in the vision literature relating to maintaining balance and walking are consistent with the idea that attention is directed to task-relevant objects during walking (Chapman & Hollands, 2007; Hollands & Marple-Horvat, 2001). Some research in the field of motor control has addressed "perception-action coupling" in walking, using treadmills or short walkways in laboratory settings. The findings are consistent with the ideas that people direct their attention towards task-relevant features just before motor actions are triggered (Land & Lee, 1994) and that older people spend more time fixating potential threats than younger adults (Underwood *et al*., 2005).

*1.6.1 The eye and eye movements*

It necessary to shift gaze fixations to gain a detailed representation of the environment, as only a small amount of visual information can be brought into clear focus during a single fixation. In this section a brief overview of the structure and functions of the eye is given, which provides support for the use of the monitoring of eye movements as a valid methodology for psychologists. The transparent tissue covering the front of the eye is known as the cornea (see Figure 1.1). Light passes though the cornea and the pupil. The lens is a transparent tissue controlled by the ciliary muscles that shape the lens in order to redirect the light onto the retina (Oyster, 1999). The shape of the lens is dependent on the distance of the object being viewed. The retina contains two types of photoreceptors (receptors that respond to light): rods and cones. Around 95% of the photoreceptors are rods (Oyster, 1999). Rods are responsive in low light conditions and the light that is directed onto them forms the peripheral vision. They are sensitive to movement, but unable to provided fine detailed information. Cones are responsive to colour and in good lighting conditions provide detailed information (Oyster, 1999). The area with the highest concentration of cones is known as the fovea and provides the highest acuity of visual information (Oyster, 1999). Most eye movements occur to position the fovea in line with reflected light from an object of interest (Findlay & Gilchrist, 2003).

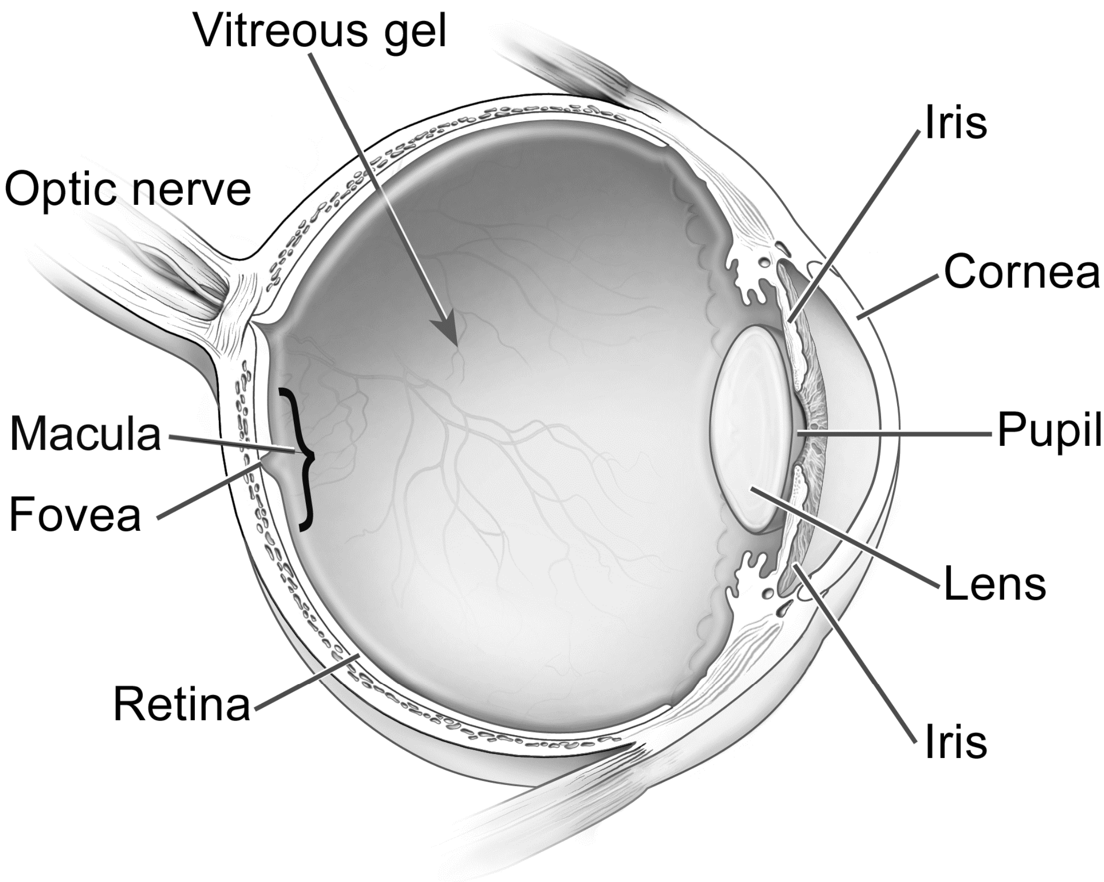


Figure 1.1. The Anatomy of the Human Eye (National Eye Institute, 2011).

Eye movements occur to track and fixate on visual stimuli (Martinez-Conde *et al*., 2004). The study of eye movements is of great importance to experimental psychologists as they are measurable behaviours that can provide indications of cognitive processes. There are many different types of eye movements (Rayner, 2009). The most common eye movement is the saccade. Saccades are sudden ballistic eye movements that last for 30-120 ms and are notably resistant to fatigue. Enderle and Wolfe (1987) proposed that the control of the saccade was based solely on a desire to minimise the time taken. More recently Harris and Wolpert (2006) noted the ‘bell shaped’ velocity curve of saccades and many other motor actions (such as reaching and grasping) were very stereotypical of human movement. They argued that in humans the neural circuitry of the saccade had evolved to optimize speed and accuracy. More specifically the typical trajectory of the saccade optimises visibility in the presence of motor noise because the signal noise around the signal of a fast saccade is greater than the noise around the signal of a slower saccade, although slower saccades result in a longer time without visual information.

During fixations slow gradual movements occur that result in the fovea drifting away from the point of interest. Microsaccades are very small saccades that act as a corrective mechanism to drifting by re-foveating the point of interest (Martinez-Conde *et al*., 2004). Smooth pursuit eye movements occur when tracking a moving object travelling at a constant velocity. The aim of these eye movements is to maintain foveation of the object during its motion. Smooth pursuit movements cannot be voluntarily replicated without an object to track (Rayner, 2009). Vergence eye movements keep an object of interest foveated in both eyes. There are two types of vergence movements: convergence and divergence (Cullen & Van Horn, 2011). Convergence occurs when viewing an object that is in close proximity to the eyes by rotating the eye inward. To keep the object foveated if it were to move away from the eyes, the eyes must diverge by rotating outwards. There are two reflexive eye movements that aim to foveate the point of interest during movement (Sadeghi *et al*., 2010). The vestibulo-ocular reflex allows the object of interest to remain foveated during head movements. The optokinetic reflex uses the velocity of a moving object in the retinal image to move the eye in the direction and at the same velocity to maintain foveation of the object. (Sadeghi *et al*., 2010)

### *1.6.2 Eye-tracking methods*

Eye trackers often shine infra-red light into the eye in order to get a high contrast image of the eye. The darkest part of the image is the pupil and the brightest part is the reflected infra-red light; once the system has been calibrated the relationship between the pupil and infra-red corneal reflections is used to calculate gaze direction (Merchant, *et al*., 1974). Traditionally, eye tracking has been used predominantly in research where participants are required to read or to perform a visual search task on a computer screen (e.g., 't Hart *et al*., 2009). Recently a range of portable eye trackers has entered the market and provide the opportunity to study gaze behaviour under more natural settings. The accuracy and speed of these portable eye trackers are typically inferior to larger eye trackers that require fixing the participants' heads in place, but they do allow for data to be collected in a more natural setting.

### *1.6.3 Eye-movement strategies*

Recent research in eye movement control suggests that during active real world tasks attention is primarily allocated to relevant parts of a visual scene in a "top-down", task-driven manner. Although it is possible that objects can be attended to covertly (Posner, 1980), and that certain forms of information can capture attention through a “bottom-up” process, researchers increasingly agree that such strategies are of limited relevance during purposeful action such as making a cup of tea or crossing a road (e.g., Land, 2009). Evidence for this idea has primarily been gathered from studies that record eye movements, which often draw different conclusions to those that record other measures such as reaction time. Eye movement studies have indicated the importance of short-term or working memory in selective attention, as gaze during active tasks is almost exclusively directed to task-relevant information and often temporally linked to the ongoing actions (Hayhoe, 2000; Henderson, 2003; Land *et al*., 1999). It has also been noted that eye-movement strategies depend on the instructions provided to the observer (Buswell, 1935; Yarbus, 1967).

The top-down control of eye movements is particularly evident during active, skill-based tasks that we perform regularly, such as making a sandwich or catching a ball. Land (2004), for example, noted that eye movement patterns during active tasks tend to be influenced by previous experiences. When making tea, attention is directed to the tip of the tea spout immediately prior to tea being poured into a cup. Land *et al*. (1999) argued that previous experience in pouring tea would have indicated that this area would provide the most relevant information about the flow of tea, and thus would be the most salient place to direct one’s gaze.

Other studies have shown a direct relationship between eye movements and associated motor actions. In a study by Johansson *et al*. (2001), for example, participants picked up a bar and moved it to a switch, avoiding an obstacle on the way. Eye movement data showed that as the bar circumvented the obstacle the edge of the obstacle was fixated; when the bar had passed the obstacle, gaze was quickly directed towards the switch. Patla and Vickers (2003) also showed that during a visually-guided stepping task (participants had to step on certain points of a walkway) the next stepping place was fixated on until about one second before it became the current standing place. In a driving study, Land and Lee (1994) noted that on winding roads participants fixated frequently on the tangent point of the upcoming bend. This tangent was fixated whether the curvature of the bend was constant or not. The authors reported that changes in the tangent point were accompanied by changes in the steering wheel angle with a one-second delay. In a sandwich-making study Hayhoe *et al*. (2003) observed that participants frequently fixated on objects just before they directed actions towards it. In all these studies, participants fixated on significant areas or objects immediately before the action. It appears the deployment of gaze is linked temporally to the activity, suggesting that gaze allocation is primarily under top-down control. In a dynamic environment, such as a road crossing, directing gaze towards task-relevant objects, such as vehicles, may cause difficulties for children as they are less able than adults to track multiple moving targets (Trick, *et al*., 2005).

Studies exploring *sequences* of eye movements reveal that people often fixate certain regions in repetitive patterns, or cycles of fixation, further confirming the role of higher-level, “top-down” cognitive processes in guiding visual attention where and when it is needed (Tatler, 2009; Tatler & Vincent, 2008; Underwood, 2007). For example, periods of local scanning may be interspersed with those of more global relocations to new regions of a scene in the free-viewing of static pictures (Tatler & Vincent, 2008), and regions of scanning may be wider and more efficient in experienced compared with novice drivers in simulated driving tasks (Underwood, 2007).

Overwhelming evidence, then, suggests that the control of eye movements depends critically on the nature of the stimulus presented, the task performed and the behaviour expected; this has led to a marked increase in research using more "real-world" contexts and "active" tasks, and calls for more to be conducted.

### *1.6.4 Gaze behaviour and the role of expertise*

Few studies have compared the eye movement behaviour of children, adults and older adults during active tasks, but studies investigating experience-related differences in eye movement behaviour provide a basis for understanding how experience affects the way in which individuals search the environment for useful information. Williams *et al*. (1994) investigated visual search strategies in experienced and inexperienced soccer players. The authors found that, when watching a video display of a football game, the experienced players anticipated the destination of the ball before it was kicked, whereas the inexperienced players were unable to predict the area the ball was to be played to until after the ball had been kicked. Analysis of visual gaze showed that inexperienced players 'ball-watched', following the position of the ball rather than specific players or the developing pattern of play. The authors concluded that an important distinction between experienced and inexperienced soccer players was the ability to make effective use of advanced information.

When viewing traffic footage from the perspective of a car driver, novice drivers made longer and fewer fixations than more experienced drivers did (Chapman & Underwood, 1998). Other driving studies, examining the effects of experience on the search strategies of drivers, have concluded that experienced drivers adopt a more extensive scanning strategy (displaying less central bias), making more and shorter fixations than novices do (Crundall & Underwood, 1998; Underwood *et al*., 2003).

These studies show that experience-related differences are observable through the examination of visual gaze behaviour. Experienced adults make more and shorter fixations than inexperienced adults do (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Underwood *et al*., 2003; Williams *et al*., 1994) and are able to make effective use of information that is not always fixated on by less experienced adults (Chapman & Underwood, 1998; Williams *et al*., 1994). In other words, experienced performers attend to different areas of the environment at different times than less experienced performers, often anticipating the location of important future events.

Experience-related differences, as noted in the studies above (Chapman & Underwood, 1998; Crundall & Underwood, 1998; Underwood *et al*., 2003; Williams *et al*., 1994), may also be found between children and adults. Differences in the gaze behaviour of younger and older adults are unlikely to be due to the greater experience of the older adults and may be the result of the different priorities of younger and older adults. Zietz and Hollands (2009) noted that during stair walking, older adults fixated more on the next stepping location before stepping than younger adults did; the authors suggested that this may be due to a greater reliance on visual information to maintain balance. Older adults have more experience crossing roads than younger adults, but, similar to the findings by Zietz and Hollands, their gaze behaviour may partly reflect altered priorities (in particular, the control of balance and walking). Furthermore, older adults' gaze behaviour is likely to be affected by reduced sensory and cognitive capabilities (see 1.3 *Sensory processing* & 1.4 *Cognitive factors*). Recent work comparing gaze behaviour at real-world and laboratory settings (e.g., Dicks *et al.*, 2010; 't Hart *et al.*, 2009) indicate that experience-related gaze-behaviour differences found in the laboratory may not necessarily exist in the real world (see 1.8 *Studying cognition under realistic conditions*), so conclusions drawn from laboratory-based studies should be interpreted with caution.

### *1.6.5 Gaze behaviour across the life span*

For the previously discussed cognitive abilities a reoccurring theme was noted: the skills develop from childhood to adulthood and decline from adulthood to old age. Few studies have investigated age-related differences in gaze behaviour during active tasks. Given the importance of attentional control in directing gaze towards task-related information and children's reduced capabilities in controlling attention (see 1.4.2 *Attentional control and visual search*) it is reasonable to assume that children may direct gaze in a less optimal fashion than adults. In a rare study comparing the gaze behaviour of younger and older adults detecting hazards in videos of traffic (from the perspective of a car driver) Underwood *et al.* (2005) found no evidence of age-related decline in terms of search behaviour or the ability to detect hazards. However, making judgements based on information in film clips may be very different from real-world tasks and activities (Underwood *et al*., 2005). Watching video footage is less demanding than performing real-world tasks, in which participants interact with the environment. Older adults are known to have greater difficulty in completing tasks that are more cognitively demanding (Sparrow *et al*., 2002; see 1.4.3 *Dual-task performance*). The older drivers' search behaviour may have been different if they were actually driving the car in the Underwood *et al*. (2005) study. Executive functions such as attentional control and working memory (see 1.4 *Cognitive factors*) have been shown to decline with age (Baddeley & Wilson 1988; Goethals *et al*., 2004; Lezak, 1995; Yogev-Seligmann *et al*., 2008). Although there is little actual evidence to suggest that this decline affects gaze behaviour during active, real-world tasks, older adults' sub-optimal performance on tasks requiring attentional control suggests that differences between adults and older adults may exist in gaze control during real-world active tasks.

### *1.6.6 Interim summary: Eye movements, gaze direction and visual attention*

Eye movements occur to track and fixate on visual stimuli (Land, 2009). They are indicative of underlying cognitive processes and the study of eye movements can act as a "*window into the operation of the attentional system*" (Henderson, 2003, p. 498). Advances in technology have made the study of gaze behaviour during active, real-world tasks more accessible to researchers. Studies investigating gaze behaviour during active tasks have provided insights as to how visual attention is controlled and suggest that the allocation of attention is controlled in a "top-down" manner.

The study of gaze behaviour in simulated environments (e.g., Crundall & Underwood, 1998; Underwood *et al*., 2003; Williams *et al*., 1994) has demonstrated a number of age-related and skill-related differences across a range of tasks, such as experts fixating on areas earlier than novices, or novices fixating on certain features for longer than experts. These findings suggest that "people who think differently also, to some extent, see differently" (Yarbus, 1967, p. 211).

### *1.7 Training / adapting gaze behaviour*

Considerable evidence, from both laboratory-based experiments and real-world observations, suggests that children and older adults perform differently across a range of cognitive, attentional and behavioural measures compared to younger adults, and that these differences may contribute to their overrepresentation in pedestrian accidents. If this is the case, it may be possible to develop targeted interventions to improve their performance on specific measures.

Various studies have investigated the effects of training on road-crossing behaviour of children. Traditional teaching methods such as classroom-based instruction, discussions and games have been associated with improvements in children's theoretical knowledge of road safety (e.g., Batu, *et al*., 2004; Miller & Davis, 1984; Padgett, 1975; Page *et al*.,1976; Singh, 1979). However, the extent to which this knowledge transfers outside the classroom is still a topic of debate: McKenna (2010) noted that few training programmes aimed at improving road safety are based on theory or evidence. The little research that has been conducted in this area reports no improvements in subsequent road-crossing behaviour (Padgett, 1975; Zeedyk *et al*., 2001).

More recently, several researchers have developed Virtual Reality (VR) training programs which require children to navigate an avatar across a road in a more active, skill-based approach (e.g., Bart *et al*., 2008; Goldsmith, 2008; McComas *et al*., 2002; Thomson *et al*., 2005; Tolmie *et al*., 2002; Tolmie *et al*., 2005). Generally, studies examining the efficacy of VR training report some improvements in roadside behaviour, such as standing in the appropriate place before crossing or making head movements towards areas of oncoming traffic.

Whilst the author of this thesis is unaware of studies investigating the effects of training on the road-crossing behaviour of older adults, there is some evidence that older adults can be "trained" to move their eyes in a way that is more conducive to safe walking and driving. Young and Hollands (2010), for example, reported that, when walking, older adults are able to display gaze behaviour similar to that of younger adults if they are verbally instructed to shift gaze from the current stepping location to the next stepping location before the current stepping action is complete. Attentional control training in older adults has been found to improve processing speed on the tasks analogous to the training task, but there is little evidence that the training benefit can be transferred to tasks outside of the training context (MacKay-Brandt, 2011). In a simulated driving task, Romoser and Fisher (2009) found that active training, in which the gaze behaviour of older adults was monitored and positively reinforced, significantly increased the number of eye movements to intersections compared with no training or passive eye movement training which involved general instructions on PowerPoint slides. This is consistent with basic research in reading and visual search, which shows that eye-movement training can generate significant, and often transferable, improvements in eye-movement strategies (e.g., Dewhurst & Crundall, 2008). After showing in Chapter 3 of this thesis that children display gaze behaviours at the roadside that could be considered sub-optimal and often unsafe, the availability of training programmes specifically aimed at improving children's pedestrian behaviour brings it within the scope of this thesis to subsequently focus on the training of road-crossing skills in children. To date, no research has examined the effects of training on the gaze behaviour of children at road crossings. One of the aims of this thesis is to investigate the effects of training on children's gaze behaviour at a road crossing and this is accomplished in Chapter 5.

### *1.8 Studying cognition under realistic conditions*

Although many laboratory-based experiments continue to use traditional line-and-dot stimuli, recently studies investigating gaze behaviour have used more "natural" stimuli such as photographs or pictures (Baddeley & Tatler, 2006; Krieger *et al.*, 2000; Parkhurst *et al.*, 2002; Peters *et al.*, 2005; Privitera & Stark, 2000; Reinagel & Zador, 1999; Tatler *et al.*, 2005), video footage (Underwood *et al.*, 2005; Williams *et al.*, 1994) or computer-based simulations (Jovancevic *et al.*, 2006; Jovancevic *et al.*, 2008; Land & Lee, 1994; Rothkopf *et al.*, 2007; Van Loon *et al.*, 2010). Despite these efforts to create more natural stimuli, the relationship between gaze behaviour demonstrated under real-world and laboratory-based conditions had been unaddressed until very recently (e.g., Dicks *et al.*, 2010; 't Hart *et al.*, 2009). It is unclear if many of the laboratory-based eye movement studies provide anything more than detailed descriptions of the way pictures are viewed (Tatler, 2009).

Dunwoody (2006) noted that research in psychology often neglects or ignores the environment in order to gain experimental control; traditional laboratory-based experiments investigating eye movement behaviour are typically conducted in a darkened laboratory with the participant seated and still (occasionally with the participant's head held still with the use of a bite bar), using stimuli presented on a relatively small computer monitor. However, the visual system has evolved under much less constrained conditions and in less degraded environments, with the purpose of providing information on objects and the environment that will aid future actions (Churchland *et al*., 1994; Findlay & Gilchrist, 2003). Cognitive processes such as memory have also evolved to aid perception and action in a three-dimensional environment (Glenberg, 1997). As such, the impoverished nature of the laboratory and the passive nature of many of the tasks are not necessarily conducive to the study of natural behaviour and the findings from studies that neglected the environment cannot easily be extrapolated to the real world (Araújo *et al*., 2007; Dhami *et al*., 2004).

The importance of studying cognition under natural conditions has been emphasised in methodological frameworks such as "representative design" (Brunswik, 1956, cited in Dhami *et al*., 2004), and "cognitive ethology" (Kingstone *et al*., 2008a). Brunswik (1956, cited in Dhami *et al*., 2004) stated that because organisms adapt to their natural environment, it is important that experimental stimuli are sampled from the organism's natural environment. This representative design is a more ecologically valid method than using simplified stimuli and the findings from such studies can be more easily generalised to real-world situations.

In the following sections, "cognitive ethology" and "embodied cognition", will be presented. These two complementary theoretical approaches emphasise the necessity to study and understand behaviour and cognition within the environment from which they have evolved and developed. These approaches provide a theoretical underpinning for this thesis. Following this, evidence that real-world environments differ from laboratory-based simulations in the way people perceive and interact with their visual environment is discussed.

### *1.8.1 Cognitive ethology*

Cognitive ethology advocates the studying of behaviour under realistic conditions. This theoretical approach was traditionally applied to the study of animal behaviour, but has more recently been applied to the study of human cognition. Kingstone *et al.* (2008a) argued that real-world observations were needed to develop theories capable of explaining cognitive processes in the real world. Researchers conducting laboratory -based studies often make two incorrect assumptions: (i) the processes that subserve cognition are invariant and regular across conditions and (ii) situational variability can be reduced or eliminated without affecting the nature of the process being measured (Kingstone *et al.*, 2008a). This approach does not advocate to do away with laboratory-based research altogether. There is still a place for laboratory-based research, as it is useful for testing hypotheses and theories generated from observations of real-world behaviour (Crundall & Underwood, 2008; Kingstone *et al*., 2008b).

Cognitive ethology questions the appropriateness of studying cognitive processes during abstract tasks under unnatural conditions. However, some have argued that because cognitive processes have developed under natural real-world conditions, studying them there can be uninformative and misleading (Watt & Quinn, 2008). Crundall and Underwood (2008) argued that laboratory-based studies alone can lead to wrong conclusions (e.g., drivers and passengers are unaware of the attentional demands and dangers that come with talking and driving). Watt and Quinn (2008) stated that because the visual system estimates the probable state of the environment based on previous experiences and sensory input, these estimations are usually correct. However, in the laboratory it is possible to create stimuli that do not occur in the real world and therefore present difficulties for the visual system: processes to deal with such stimuli have not developed, as there has been no need to process this information. Kingstone *et al*. (2008b) questioned the relevance of such an approach as studies using stimuli that do not occur naturally can only provide information about how vision responds to stimuli that never occur and are meaningless.

*1.8.2 Embodied cognition*

The mind has often been viewed as an abstract information processor and the connections between the mind and the environment have been considered of little theoretical importance (Wilson, 2002). If the mind is an abstract information processor, then investigating cognitive processes through traditional laboratory-based experiments using abstract stimuli would appear to be an appropriate way of investigating cognitive processes. However, it is clear that cognitive processes are "deeply rooted in the body's interactions with the world" (Wilson, 2002, p. 625). Humans have evolved from creatures whose neural networks dealt almost exclusively with perceptuo-motor tasks. Notions of cognitive embodiment or embodied cognition emphasise that "biological brains are first and foremost the control systems for biological bodies. Biological bodies move and act in rich real-world surroundings" (Clark, 1998, p. 506).

The general principles of embodied cognition revolve around the link between cognition and the environment. Cognitive activity occurs in the context of a real-world environment, and involves perception and action (Wilson, 2002). It has been argued that cognition is for action and that perception and memory must be understood in terms of their contribution to situation-appropriate behaviour (Churchland *et al.*, 1994; Findlay & Gilchrist, 2003; Wilson, 2002). One of the central views of embodied cognition is that cognition is situation specific: when interacting in the environment cognitive processes are strongly influenced by perceptual information and this information changes during motor activity (Chiel & Beer, 1997; Clark, 1998; Clark, 2001; Pfeifer & Scheier, 1999; Steels & Brooks, 1995; Wilson, 2002). Embodied cognition states that cognition is time-pressured and must be understood in terms of how it functions under temporal constraints during real-time interaction with the environment (Clark, 1998; Wilson, 2002). Real-time situated cognition is evident in activities that involve the continuous updating of plans in response to changes in the environment (Wilson, 2002). For example at a road crossing the decision to cross the road may be made and unmade based on the actions of drivers or changes in the traffic lights and the decision will be re-evaluated as the available information changes. Embodied cognition provides a rationale for studying behaviour in the real world. The study of eye guidance during active real-world tasks reveals the importance of and temporal link between attention and action (e.g., Hayhoe & Ballard, 2005; Land, 2006; Land & Tatler, 2009), as fixations on relevant objects or areas precede related actions by about 1 second (Hayhoe *et al.*, 2003; Land & Lee, 1994; Patla & Vickers, 2003; see 1.6.3 *Eye-movement strategies*). If cognition is context dependent and time sensitive, using eye-tracking methods during real-world activity appears to be an ideal way of collecting data that will allow the development of theories that can explain cognitive processes in the real world. In the following sections research will be presented that shows that people perceive and interact with real-world and laboratory-based simulated environments differently. These studies provide experimental support for the real-world approach to the study of cognition.

### *1.8.3 Central bias*

Regardless of the content of a scene displayed on a monitor there appears to be a strong tendency to fixate the centre of images (Tatler, 2007; Vincent *et al.*, 2009), possibly due to the framing effect of the monitor (Tatler *et al.*, 2011). It has been suggested that this bias to fixate the centre of the screen may account for up to 34–56% of eye movements (Vincent *et al.*, 2009). This central bias appears to be weaker when viewing continuous movies (footage filmed from the same perspective without cuts or edits) than when viewing static images (Tatler *et al.*, 2011). However, the bias still exists when viewing continuous movies and accounts for a considerable amount of eye movement behaviour (Cristino & Baddeley, 2009; Dorr *et al*., 2010; ’t Hart *et al*., 2009).

*1.8.4 Scale of the environment*

Smith *et al*. (2008) found that, when searching for a target in a large-scale environment, children were less likely to revisit a previously searched location than when performing the equivalent task on a computer. Searching a large area like a road crossing is likely to be more taxing than searching a still image or a video of a road crossing and may elicit different behaviours.

*1.8.5 Visual information*

Studies investigating eye movements during the viewing of static images or video clips of real-world environments are often constrained by suppressing head movements, which are essential in the real world for large gaze shifts (Stahl, 1999); this distorts the coupling of visual and vestibular feedback (‘t Hart *et al*., 2009). The visual array in the real world is much bigger and takes up more room on the retina than a computer screen (‘t Hart *et al*., 2009) and computer displays have limited resolution. To create a video-based simulation of a real-world environment requires the degradation of important visual information and as a result the information that is attended in the real world may not be present in the same form during simulations.

*1.8.6 Nature of the task (demands)*

Performing active tasks in the real world (e.g., walking across a road) is considerably more demanding than typical laboratory-based tasks (e.g., pressing a button). Active tasks in large-scale, complex environments typically require multi-tasking and task switching which we know tap into a central, limited-capacity attentional mechanism, and limit the resources available for the primary task. This is especially the case in children and older adults as they have reduced processing capabilities (Diamond *et al*., 2005; Dunbar *et al*., 2001; Foley & Berch, 1997; Guttentag, 1989; Kramer & Larish, 1996; Ponds *et al*., 1988; Rennie *et al*., 2004; Salthouse *et al*., 1995; Tsang & Shanner, 1998; Yogev-Seligmann *et al*., 2008; see 1.4.3 *Dual-task performance* and 1.4.4 *Task switching*). Importantly, the seemingly effortless task of walking (and perhaps even maintaining balance) appears to require not inconsiderable cognitive effort, particularly among older adults (see Yogev-Seligmann *et al*., 2008, for a review), suggesting that even the acts of standing or stepping require additional attentional resources compared with sitting in a laboratory.

### *1.8.7 The two visual systems*

Typical responses required in laboratory-based studies (verbal response or pressing a button) are often different to responses or actions in the real world. There is evidence to suggest that the underlying cognitive processes involved in perceiving (for example, verbally judging a safe crossing opportunity) and acting (for example, actually crossing the road) may be very different. Goodale *et al*. (1991) and Goodale and Milner (1992) proposed that two different cortical visual systems exist, one for perception, such as recognising objects (the ventral stream), and one for action, guiding movements (the dorsal stream). Many studies investigating cognitive processes use a paradigm that requires perceptual judgements and the results of such studies may be affected by the disproportionately high influence of ventral stream processing. Bootsma (1989) criticised the experimental paradigm often used to study motion prediction. He argued that asking participants to press a button in response to visual information disrupts the natural link between perception and movement and leads to a less accurate perceptual process. In his study, Bootsma presented participants with squash balls dropping from a tube placed vertically in front of the participants. The participants were asked to either i) hit the ball with their arm and a bat, ii) press a button to release a mechanical arm to hit the ball with, or iii) press a button to indicate when the ball would be at the appropriate height to be hit. Participants were significantly more accurate when performing the task with their own arm than when they used an artificial arm. Moreover, participants were found to be significantly more variable timing the pressing of the button (*SD* = 62 ms) than they were initiating the movement with the artificial arm (*SD* = 34 ms) or with their own arm (*SD* = 16 ms). Similarly comparing a functional action with a more abstract one, Davids *et al*. (2001) asked skilled volleyball players to accurately toss a volleyball to a certain height on repeated occasions and, in another condition, to serve the ball. The participants were able to place the ball at its zenith more accurately (i.e., with less variability between attempts), when they subsequently served it, than when they focused on placement only (Davids *et al*., 2001). These studies provide evidence to support the notion that visual information is processed differently depending on the required response. The main focus of this thesis is to investigate children's gaze behaviour before crossing the road; the findings from these papers emphasise the importance of the children actually crossing the road and support the experimental paradigms used in this thesis.

*1.8.8 Real-world vs. simulated displays*

Conducting research inside the laboratory has many advantages: a simulated, rather than real environment offers a greater degree of control in which to study gaze behaviour, and provides the means to manipulate variables independently of each other with few ethical difficulties. For example, the effects of dual-tasking on children's behaviour at an undesignated crossing area could be investigated in a simulated environment easily (by showing a video of a road crossing), without placing the child in danger.

Video displays have proven to be sufficient to demonstrate differences between skilled and less skilled performers (e.g., Williams *et al.*, 1994) and potentially explain trends in pedestrian accidents (e.g., Holland & Hill, 2010; Whitebread and Neilson, 2000): age-related differences (and gender differences in the Holland & Hill, 2010 study) in unsafe gap selections corresponded with accident statistics, suggesting that the simulated road crossings used in these studies may elicit behaviours in the laboratory that are used in the real world.

However, the constraints of video displays in simulated environments may present serious challenges for the ecological validity of measurements taken in the laboratory. Given the nature of the constraints imposed by laboratory-based simulations of real world environments, it would seem essential that differences in gaze behaviour between laboratory and natural settings are examined. 't Hart *et al.* (2009) compared gaze behaviour during unrestricted real-world free exploration of a variety of indoor and outdoor locations (such as hospitals and forests) and head-fixed free viewing of the footage from the scene camera in the real-world trial in video and static form. They found that gaze behaviour viewing video displays can to some extent predict gaze behaviour in the real world. It was also noted that the viewing of still images resulted in a much higher inter-observer consistency than was reported in the real world and video viewing conditions.

In 't Hart *et al.*'s study, the videos used in the laboratory conditions were taken from a head-centred camera from the free exploration study; this means that the gaze allocation during the video viewing conditions were much more restricted and gaze fixation was highly prescribed as the camera moved towards areas of the environment that the wearer of the camera looked. It is not clear to what extent these differences found between real world and laboratory-based simulations are the results of the participant being forced to attend to information from the scene camera. Further, participants in this study were required to view the footage passively without a goal or task, yet it has long been established that gaze behaviour is very different during an active task than during passive free viewing (e.g., Buswell, 1935; Yarbus, 1967). To date, only Dicks *et al.* (2010) have compared visual gaze behaviour in real and simulated environments during active tasks and the findings supported Kingstone *et al.*'s (2008a) views that traditional laboratory-based methods often fail to generate valid theories of cognition and behaviour in real natural settings. It would appear that even studies using video footage of real-world environments provide distorted and unrealistic gaze behaviour. For example, Savelsbergh *et al.* (2005) provided a detailed description of how experienced and less experienced soccer goalkeepers direct their gaze when facing a penalty kick. However, Savelsbergh *et al.* (2005) investigated gaze behaviour of goalkeepers during a video simulation of a penalty kick and provided nothing more than a detailed description of how goalkeepers direct their gaze during the particular video-based simulation used in that study. They incorrectly assumed that the behaviours observed during the simulation were invariant and therefore representative of real-world behaviour. Dicks *et al*. (2010) replicated Savelsbergh *et al*.'s (2005) study but with the inclusion of a real-world condition in which the gaze behaviour of goalkeepers when attempting to save a penalty kick was recorded. Dicks *et al*. (2010) observed similar behaviour in the simulation condition to that reported by Savelsbergh *et al*. (2005). However, when the data were compared to gaze behaviour data from the real-world condition, it was revealed that the simulated condition created an artificially high percentage of fixations towards the hips on the penalty taker whereas in the real world the goalkeepers fixated almost exclusively on the ball.

*1.8.9 Gaze behaviour during real-world tasks*

Traditionally, laboratory-based studies of gaze behaviour have predominantly used simple stimuli and required participants to read or to perform a visual search task on a computer screen (Findlay & Gilchrist, 2003). It is not clear if research from such studies has advanced our knowledge of the visual system beyond providing a detailed description of how static images are viewed (Tatler, 2009). Technological advances in eye tracking over the last 10 years have made it possible to record eye movement data quickly and easily outside the laboratory. During this time, eye movement data from active tasks such as tea making (Land *et al*., 1999), sandwich making (Hayhoe, 2000), avoiding oncoming pedestrians (Jovancevic-Misic & Hayhoe, 2009), crossing the road (Geruschat *et al*., 2003) and driving (Land & Lee, 1994) have indicated the importance of top-down control over visual gaze during active tasks in the real world (Land, 2009). These studies have provided information on eye movements during everyday activities that would not be possible to attain through a task using simplistic stimuli presented on a computer screen.

To the author's knowledge, no study to date has compared the eye movement behaviour of children, adults and older adults in pedestrian settings in the real world. One study has looked at the gaze behaviour of pedestrians at a real road crossing in the US. Geruschat *et al*. (2003) found that adults in their sample attended predominantly to "relevant" sources of information such as cars and traffic lights in the few seconds before they made the decision to cross the road. The participant group in the Geruschat *et al*. (2003) consisted of both young and older adults, but no comparisons were made between groups of different ages.

It is possible that the results from studies investigating eye movement behaviour at road crossings will vary depending on the traffic regulations of the country in which the study was conducted. For example, in some countries it is possible for vehicles to turn right (e.g., USA) or left (e.g., India) at junctions when a red light is shown and the pedestrian walk light is on, whereas in others (including the UK) it is not. It is also illegal to cross the road in some countries on a pedestrian red light (e.g., Australia, New Zealand, Singapore, USA), whereas in many others (including the UK) regulations for pedestrians are mostly recommendations and not legally enforced. These differences in traffic regulations are likely to produce different road-crossing behaviours. More research is needed in this field to identify cross-cultural differences in road-crossing behaviour.

Since laboratory-based studies using simplified displays may produce artificially distorted results (Tatler, 2009; ‘t Hart *et al*., 2009; see 1.8.6 *Real-world vs. simulated displays*) it is imperative that gaze behaviour is studied in the real world during active tasks.

*1.8.10 Interim summary: Studying cognition under realistic conditions*

To date only ‘t Hart *et al*. (2009) and Dicks *et al*. (2010) have compared gaze behaviour in simulated and real-world environments and they noted significant differences between the conditions in terms of the distribution of gaze. More research is needed as ‘t Hart *et al*. (2009) used passive viewing and previous studies have shown that gaze fixation behaviour is linked to the task at hand (e.g., Hayhoe *et al*., 2003; Land & Lee, 1994). At the moment, there is little evidence that gaze behaviours noted in studies using simulated environments are indicative of the gaze behaviour displayed in the real world. In fact, the little research that has compared gaze behaviour in real-world and simulated environments suggests that gaze behaviour in simulated environments are not representative of real-world gaze behaviour. It therefore appears imperative that studies comparing the gaze behaviour of children, adult and older adults (Chapter 3) or the effects of training on the gaze behaviour of children (Chapter 5) take place at actual road crossings. However, if it is possible to elicit natural real-world behaviour in the laboratory with a road-crossing simulation, the advantages of studying pedestrian gaze behaviour in a safe and controllable environment mean that children’s gaze behaviour could be studied at potentially dangerous crossings. In Chapters 6 and 7, road-crossing simulations are used and in Chapter 8 children's gaze behaviour at real-world and simulated crossings are compared.

### *1.9 General introduction summary*

Children and older adults are at greater risk when crossing the road than younger adults (Dunbar *et al.*, 2004; Holland & Hill, 2010; Thomson *et al.*, 2005). Older adults often experience sensory decline that may predispose them to accidents, as poor vision and hearing may result in them failing to perceive approaching vehicles (Holland & Rabbitt, 1992; Roberts & Norton, 1995). It has also been reported that children and older adults perform worse in a variety of cognitive tasks that are important for safe road crossing, such as attentional control and visual search (Milham *et al.*, 2002; Tabibi & Pfeffer, 2003; Uttl & Graf, 1997; Verhaeghen & De Meersman, 1998), dual-task performance (Guttentag, 1989; Foley & Berch, 1997; Kramer & Larish, 1996; Ponds *et al.*, 1988; Salthouse *et al.*, 1995; Tsang & Shanner, 1998; Yogev-Seligmann *et al.*, 2008), task switching (Diamond *et al.*, 2005; Dunbar *et al.*, 2001; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; Rennie *et al.*, 2004). It is likely that poorer cognitive capabilities may partially explain the overrepresentation of children and older adults in pedestrian accidents (Sparrow *et al.*, 2002; Thomson *et al.*, 1996).

A variety of studies have looked at the road-crossing behaviour of children and older adults at either real-world or simulated road crossings, although none have done both, meaning that there is uncertainty as to how well these simulations, which allow a greater degree of control than is possible in the real world, represent the real-world environments. These studies have suggested that younger children miss more safe-crossing opportunities and select more dangerous ones (Lee *et al*., 1984) than older children and adults. Children also often fail to look in the direction of oncoming traffic before crossing the road (Zeedyk *et al*., 2002) and make fewer head movements before crossing (Whitebread & Neilson, 2000) than adults. It has also been noted that children who performed poorly in task switching were more likely to display unsafe road-crossing behaviour (Dunbar *et al*., 2001). Older adults have been shown to look at the walkway more than younger adults do before crossing (Oxley *et al*., 1997). Many of the studies that report looking behaviour at road crossings have used head movements as a measure; few studies have recorded eye movement behaviour of pedestrians (with Geruschat *et al*., 2003 being the notable exception) and none have recorded the eye movement behaviour of children pedestrians. Eye movements provide a "*window into the operation of the attentional system*" (Henderson, 2003, p. 498) and provide a more accurate method of assessing looking behaviour than the study of head movements.

## *1.10 Thesis aims*

Despite the burgeoning research in the area of eye movements over the last 15 years, there are still many gaps in our understanding of how eye movements are related to behaviour within and outside the laboratory, particularly with regard to the dangerous task of crossing roads, and among the more vulnerable populations of children and older adults. To the author's knowledge no study has compared gaze behaviour across the lifespan during active road-crossing tasks or recorded the gaze behaviour of children outside of a laboratory setting. The studies in this thesis will be the first to do so. This thesis aims to identify differences in gaze behaviour across the life span that may partially explain the increased prevalence of pedestrian accidents in children and older adults, assess the effectiveness of interventions aimed at improving children's road-crossing behaviour and to compare gaze behaviour of children at real world and simulated crossings. The aims of the thesis initially involve investigating gaze behaviour across the life span at signalised road crossings and later focus on children; this is because the findings from the first study suggested that children were more in need of a road crossing intervention than the younger and older adults. Older adults did not fixate traffic irrelevant features to a greater extent than the younger adults and the high percentage of fixations on the walkway observed in the older adult group is likely a functional adaptation to reduce the risk of falling (for a more detailed discussion see 3.4.7 *Older adults would fixate more on the walkway*). Attempting to 'correct' behaviours that may be functional adaptations based on the specific needs of certain groups may be counterproductive (Latash & Anson, 1996). Other factors that lead to the focus being predominantly on children were (i) they were the only group that accepted the offer of an ice cream after crossing several roads at a junction (ice cream was intended as a reward; however, qualitative observations of children's behaviour walking back to the starting point whilst still wearing the eye-tracker caused the experimenter to make a post-hoc decision to examine the gaze behaviour of the pedestrians with ice cream), (2) the interventions designed to improve road crossing behaviour are aimed at children and (3) difficulties were experienced in capturing eye-movement data of older adults in the simulated environments (see 5.1 *Projector condition*).

*1.10.1 Aim 1*

The first aim of this thesis is to compare the eye-movement strategies of children, younger adults and older adults in a real-world, active road-crossing task, in a way that might explain their greater propensity for involvement in pedestrian accidents. This will be addressed in Chapter 3. A signalised crossing will be used in all real-world crossings for safety reasons and to create some standardisation across the trials in terms of traffic flow (see Chapter 2: *General Methods* for a more detailed description).

It is expected that visual search strategies will differ across the life span and that children and older adults will display behaviours that may explain their overrepresentation in pedestrian accidents. Specifically, the behaviours that may explain the overrepresentation of children are likely to centre around their comparative inexperience at the roadside or reduced cognitive capabilities, while those for older adults are more likely to relate to their prioritising of stepping location over oncoming traffic (e.g., Oxley *et al*., 1997; Young & Hollands, 2010), rather than an inability to effectively search for and identify potential hazards in the environment (e.g., Underwood *et al*., 2005).

### *1.10.2 Aim 2*

The second aim of this thesis is to explore whether established road-crossing training interventions using both traditional and VR methods can improve the gaze behaviour of children by leading to an increase in the percentage of fixations on the road and vehicles and a decrease in the percentage of fixations on traffic-irrelevant features at an actual road crossing (see Chapter 2: *General methods*). The VR environment does not require the participants to simply view the footage but to interact in the environment and make decisions on when it is safe to cross. This is important as differences have been observed in behaviours during passive (e.g., viewing an image) and more active tasks (making judgements regarding the image) that suggest that the cognitive processes involved in these tasks are very different (e.g., Buswell, 1935).

It is expected that the VR training in the ‘Crossroads’ intervention (Department for Transport, 2005) will improve children’s road-crossing behaviour in a way that will be evident in their gaze behaviour. The tasks the children are required to complete in the VR condition are more closely matched to those required during actual road crossing, such as predicting drivers’ actions, ignoring irrelevant events, directing search appropriately (both sides of the road before crossing) and selecting safe crossing opportunities between vehicles. Practising these skills should improve them and be useful in the real world. The traditional teaching methods in the ‘Safety Watch’ intervention that aim to improve theoretical knowledge of general safety are not expected to improve children’s road side behaviour to the same extent as the Crossroads intervention. Whilst some studies have found that traditional teaching methods improve children’s theoretical understanding of road crossing in a written test (e.g., Miller & Davis, 1984; Singh, 1979), the extent to which this theoretical knowledge transfers to behaviour in the real world is unclear and some studies have even shown that increasing young children’s knowledge of road crossing does not lead to an improved performance at actual crossings (e.g. Padgett, 1975; Zeedyk & Wallace, 2003). The Safety Watch training is used as it shares several features with the Crossroads training programme (e.g., freely available to schools, aimed at children aged 8-9, requires the use of a computer, aimed at improving safety), making it ideal as an additional control condition. The road crossing interventions will be the topic of Chapter 5.

*1.10.3 Aim 3*

The main aim of the final experimental chapter (Chapter 8) is to compare gaze behaviour at real-world and laboratory-based, simulated road crossings using (i) a small-scale display and passive task; and (ii) a large-scale display and active task. Gaze behaviour will be compared across all three conditions with the aim of providing an insight into the usefulness of using a large-scale display to reproduce real-world road crossing environments in a laboratory.

From 't Hart *et al.*'s (2009) findings, it is expected that sitting in front of a computer monitor, viewing a relatively small video display of a traffic environment and pressing a button to signify a safe crossing opportunity (the monitor condition) will produce different gaze behaviours than the real-world crossing. Standing in front of a large projection of a road crossing and taking a step forward when a safe crossing opportunity is identified (the projector condition) may also produce some different gaze behaviours than the real world, but it is likely that the gaze behaviour at the projection crossing produces more realistic gaze behaviour than sitting in front of a monitor.

*1.10.4 Aim 4*

A further aim of this thesis is to assess the effects of specific task constraints under which the road crossing takes place. In particular, this thesis reports on the effects of a spatial task on children's gaze behaviour at a signalised real-world road crossing (Chapter 4) and a non-spatial task at signalised laboratory-based road crossings (Chapter 6). Furthermore, the signalised and unsignalised road crossing conditions will be compared with regards to their effect on children's gaze behaviour (Chapter 7). These studies will be the first to investigate the effects of cognitive load on the gaze behaviour of children performing an active task. As previous studies have shown that performance on a task often declines when a second task is added (Kahneman, 1973) and that young children in particular, have difficulties in efficiently dividing attention between two concurrent tasks (e.g., Foley & Berch, 1997), it is predicted that children will attend more to irrelevant information when performing a secondary task as attentional control will be compromised by the extra cognitive load.

# **CHAPTER 2**: GENERAL METHODS

The general method, for all experiments, was to record the eye movements of individual participants while they waited at a real signalised road crossing, or watched video footage of a real road crossing (either signalised or unsignalised). The participant's task in each case was to indicate when it was safe to cross, either by actively stepping out (Chapters 3, 4, 5, 6 & 8), or passively indicating via a button press on a computer keyboard (Chapters 6, 7 & 8). In the real-world road crossing study data were collected from children, younger adults and older adults. In the training intervention and simulated crossings data from only the children group were used. For each trial, gaze position was coded manually, frame-by-frame, according to both location-based ("where") and object-based ("what") categories in order to derive proportion of total time fixating certain regions and objects.

## *2.1 Participants*

The total number of participants recruited for the study is reported in the following sections. Whilst no participants withdrew from the study, data loss as a result of the eye tracker being unable to track the eye at the road crossings (typically as a result of bright sunlight directed at the eye) meant that many of the participants' data were unusable. The number of participants reported in each study is stated in the appropriate experimental chapters' method section.

*2.1.1 Inclusion criteria*

In order to be selected for inclusion in the study, participants had to (**1**) have been living in the UK for the last four years to ensure that the participants were familiar with crossing UK roads, as cars drive on the left side of the road whereas in the vast majority of countries cars drive on the right side of the road, (**2**) be familiar with the road crossings used in the studies, to help standardise the procedure, (**3**) be within the stated age range for one of the three experimental groups (8-9 years for children; 18-30 years for young adults or 65 years plus for older adults), (**4**) have normal or corrected-to-normal visual acuity, and (**5**) not need to wear glasses when walking and crossing roads.

The age groups were chosen for a variety of reasons, the 8-9 age group was selected as many of the children's parents reported that the children recently began crossing the road independently and pilot studies had shown that at this age children were patient enough to go through the calibration procedure. Whilst children aged 11 years old are more likely to be involved in pedestrian accidents than younger children (DfT, 2010a) this is likely to be related to the number of roads crossed independently. Younger children (8-9 years old) typically display poorer performance than older children and adults on cognitive tests (Cepeda *et al*., 2001; Van der Molen, 2000) which has been linked to poor road-crossing behaviour in several studies (e.g., Clancy *et al*., 2006; Dunbar *et al*., 2001; Tabibi & Pfeffer, 2003). Initial pilot studies with younger children (aged 5-6) suggested that the eye tracker was too large to comfortably fit and that the children lacked the required patience for the calibration procedure. The 18-30 year old age group was selected as at this age cognitive capabilities are fully developed (Cepeda *et al*., 2001; Craik &

Bialystok, 2006) and this group was highly accessible. While there appears to be a sharp increase in the risk of pedestrian accidents when over the age of 70 (DfT, 2010b), the lower age limit for the older adult group was set at 65 years to aid the recruitment process as one of the conditions was that the participants could not wear glasses. The latter criterion was deemed necessary because the eye tracker used infra-red corneal reflections to track the eye's direction of gaze, and the presence of glasses created a lens reflection that rendered tracking difficult or even impossible. No problems were noted with the capture of gaze for participants wearing contact lenses.

*2.1.2 Children*

A total of 30 children (16 males, 14 females; $M$ = 8.8, $SD$ = 0.4 years) took part in the "real world" studies (Chapter 3, 4, 5 & 8). All the children were recruited from Bruntsfield Primary School Edinburgh, chosen for its close proximity to the signalised road crossing used in the study. A further 12 children (six males, six females; $M$ = 8.5, $SD$ = 0.5 years) took part in the laboratory-based simulation studies. The children in this group were recruited from Bruntsfield Primary School (as before) or from Craiglockhart Primary School, Edinburgh, chosen for its close proximity to the laboratory.

*2.1.3 Younger Adults*

Fourteen younger adults (seven males, seven females; $M$ = 24.1, $SD$ = 4.5 years) took part in the study in Chapter 3. Of these 14 adults, 11 were recruited from the BA (Hons) Psychology programme at Edinburgh Napier University and the remaining three participants were undergraduates on different courses.

### *2.1.4 Older adults*

Fourteen older adults (six males, eight females; $M = 70.7$, $SD = 4.1$ years) took part in study in Chapter 3. They were recruited through a mixture of advertisements in local community centres and older people's groups under the umbrella of the City of Edinburgh Council, and personal contacts. There were more females than males in this study, which is a fairly accurate representative of the population from the age of 65 onwards (Office for National Statistics, 2010).

### *2.1.5 Rewards*

Children in the real world road crossing studies were given an ice-cream of their choice after the completion of the road crossings. The children involved in the laboratory-based simulation were given a chocolate egg. The adults involved were given the choice of an ice cream or a drink; one adult chose an ice cream, the others chose a drink. The older adults were offered drinks and biscuits, and given £10 to cover any expenses they may incur in getting to the laboratory.

## 2.2 Apparatus

### *2.2.1 "Mobile Eye™" eye tracker*

The Mobile Eye™ (Applied Science Laboratories) was used to record gaze behaviour in all experiments presented in this thesis, including at real world road crossings (Chapters 3, 4 & 5) and the projected simulated crossings (Chapters 6 & 7).

The Mobile Eye™ is a head-mounted system equipped with a small video camera that captures the visual field (50º horizontally and 40º vertically) and another camera that records the corneal reflections from three infra-red lights aimed at the right eye (see Figure 2.1). The Mobile Eye™ system detects the position of the pupil and the infra-red corneal reflections and uses the relationship between line of gaze and pupil and corneal reflection separation to calculate gaze direction once it has been calibrated. The optics are mounted just above eye-level on glasses that are worn by the participants and head movements are not restricted. Data are recorded onto digital tapes in a modified Sony GV-D1000E Camcorder that is carried in a waist bag by adults and in a back-pack with safety harness by children.

The footage from both cameras is interlaced onto the digital tape at a combined frequency of 25 Hz. The interlaced footage is then transformed into a combined video file showing the visual scene as viewed by the participant, with the centre of gaze fixation superimposed as a red circle (see Figure 2.2). The spatial resolution is 0.1º, and system accuracy is 0.5º.

The Mobile Eye™, and other head-mounted eye trackers like it, is generally less accurate and records at a lower frequency than remote eye trackers, but is fully portable and can be used outside of the laboratory.


Figure 2.1. Mobile Eye Optics and recording device


Figure 2.2. Gaze fixation data overlaid onto the scene camera footage

*2.2.2 iView X*

The SMI iView X RED was used to collect eye movement data during the simulated road crossing experiments using a monitor (rather than projected) display (Chapters 6, 7 & 8).

The iView X RED is a remote, non-invasive and unobtrusive remote eye tracking device (see Figure 2.3). An infra-red camera is mounted on the desk directly below the monitor display (TV) and emits an infra-red light. An image of the participant's eye is obtained from an infra-red camera and processed by the iView X software. As with the Mobile Eye™, the iView X records the position of the pupil from corneal reflections to determine the centre of gaze after the system has been calibrated. The spatial accuracy of the iView X is better than 0.5 degrees. The head position is recorded to compensate for movements in order to accurately calculate gaze fixation. As a result the head is free to move naturally and a chin rest or bite bar is not required. Greater spatial and temporal resolution can be achieved by systems that use bite bars but fixing the head may restrict natural behaviour (Tatler, 2009).

*2.2.3 Calibration*

The eye tracker (Mobile Eye™, or iView X) was calibrated before each experiment using a 9-point calibration frame and the system's own calibration routines to translate eye position data into x and y coordinates relative to the scene being viewed. For the Mobile Eye™, this scene is the video footage from the scene camera and for the iView X this is the road crossing video displayed on the monitor.

#### 2.2.3.1 *Calibrating the Mobile Eye™*

Calibrating the Mobile Eye™, is a manual procedure in which footage from the scene camera is displayed on a computer monitor and the experimenter clicks on the point of gaze fixation. The calibration protocol differed slightly between the participants groups and studies due to the location where the calibration took place. These variations in calibration are discussed below.

Figure 2.3. iView X RED eye tracker. The infra-red emitters and camera are housed in the device highlighted.

In Chapter 3, calibration for adult participants took place in the laboratory with the windows open to better approximate the lighting conditions where the road crossing would take place. Nine Xs printed on separate sheets of A4 paper were placed on the wall and the participants were asked to fixate on the centre of a specific X while the experimenter defined that area as the centre of gaze in the Mobile Eye™, software. When all nine Xs had been successfully entered as the centre of gaze the accuracy of the calibration was assessed by asking the participants to fixate each calibration marker again and then to pick an object in the room at random and fixate on it.

Calibration for older adults took place in a temporary office in a University building situated closer to the road-crossing location to minimise the walking distance for some of the older participants. The procedure was otherwise the same as that described above, for adult participants.

The calibration of the Mobile Eye™ for the children participants took place at their school. The procedure was the same as the one describe above for the adults in the laboratory except that the calibration points were drawn on a wall-mounted whiteboard rather than printed on A4 paper. Calibration at the school occurred for all the children in real world road crossing studies (Chapters 3, 4, 5 & the real world condition in Chapter 8).

In Chapters 6 and 8 (video-based simulation experiments), the calibration of the Mobile Eye™ also took place in the laboratory. On these occasions the black-out blinds were drawn to replicate the conditions in which they would view the road crossing video footage projected onto the wall. The calibration points were projected onto the wall and children were asked to look at each one in turn while the experimenter defined these areas as the centre of gaze.

2.2.3.2 *Calibrating the Remote Eye Tracker (iView X)*

The iView X eye tracker has an automated 9-point calibration procedure in its Experiment Centre software. In all cases, participants were asked to direct their heads towards the centre of the calibration frame but no form of head restraint was used. A target appeared in different areas of the display and the participants were required to look at the centre of the target.

### *2.3 Stimuli: real world road crossings and video simulations*

In the real-world studies, all participants crossed at a preselected signalised junction (approved by the City of Edinburgh Council for the purposes of this study) in order to ensure some degree of standardization between participants and across conditions. Signalised crossings were deemed worthy of study as a substantial proportion of pedestrian accidents occur at or near (within 50 m) signalised crossings. In Edinburgh, for example, where this study took place, 25% of all pedestrian accidents occur at or within 50 metres of signalised crossings (Al Naqbi, 2009).

Gaze behaviour at signalised crossings may not be indicative of gaze behaviour at other crossings: in fact Geruschat *et al.* (2003) found that when crossing a signalised road pedestrians changed their gaze behaviour depending on the presence of a crossing signal. Chapter 8 explores the gaze behaviour at simulated unsignalised road crossings.

### *2.3.1 Road-crossing location*

This area was positioned close to both the university and the school and was familiar to all participants. This area is in a 30mph zone and is a relatively affluent residential and retail area 2.9km from Edinburgh city centre (see Figure 2.4).

## *2.4 Development of road crossing footage*

Video footage of the signalised road crossing (see Figure 2.5) and an unsignalised road crossing (see Figure 2.6) location in a nearby area was generated for use in the laboratory-based simulation study (Chapter 7). In each case, the site was filmed by five video cameras mounted on a custom-made frame positioned on the pavement. The five cameras were positioned in a way that they would capture all the traffic present at the road crossing. When the footage from five cameras was combined, approximately 190° horizontally of the traffic environment was captured (see Figure 2.5). When this footage was displayed by the projector it measured 79° of the visual angle horizontally.

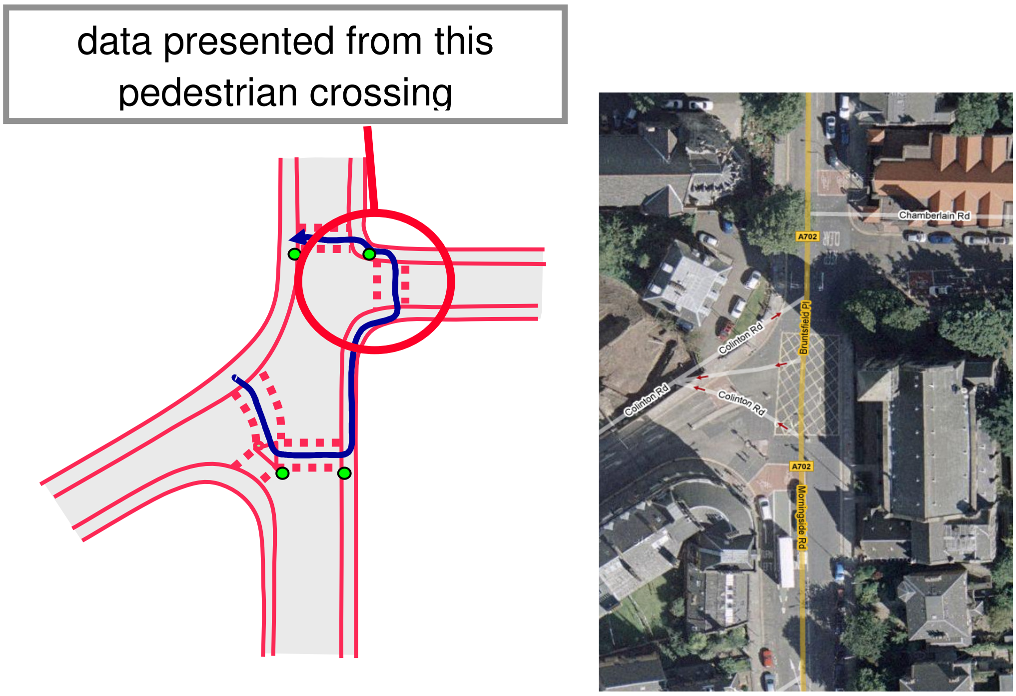


Figure 2.4. Signalised road crossing location

Previous attempts to capture the traffic at the road crossing with three cameras at various elevations (e.g., approximately head height and at the top of a street lamp) were not deemed of sufficient quality to be used for a road-crossing simulation as parts of the environment were useful information could be found were missed or the high elevation did not represent the kind of visual information that would be available in real world when crossing a road. It was decided that five cameras were sufficient to film the entire road from the perspective of a pedestrian without missing sections of the crossing.

Figure 2.5. Still from video of signalised road crossing used in the road-crossing simulations

Figure 2.6. Still from video of an unsignalised road crossing used in the road-crossing simulations

Rather than display each video on separate, appropriately angled displays like Whitebread and Neilson (2000) and Holland and Hill (2010), the decision was made to stitch videos together using the video editing software packages Adobe Premiere Pro and Adobe After-Effects, and to present the video on one display to ensure there were no gaps between the footage from the five cameras. This method also allowed for a direct comparison between projector and monitor conditions as the same video could be used on both. The iView X (remote) eye tracker is only able to track eye movements on one display monitor, so displaying the road crossing over more than one would mean that only a fraction of the eye movements would have been recorded. The disadvantage of this method of displaying the footage is that all information is presented on one plane; angled displays would require participants to turn their head to the left or right to watch the traffic as they would at a real world crossing. Head movements were necessary for the large projection condition but it was not necessary to make head movements of the same amplitude as those needed to fixate approaching vehicles from both sides at the real world crossing. It is unclear if this scaling of the natural movement patterns will disrupt the participants' gaze behaviour. Initial experiments with three angled displays also resulted in issues with synchronising the play back of the individual videos which were avoided by stitching the five road crossing videos together. Merging the footage from five cameras into one video required the spatial and temporal alignment of the videos. Spatial alignment was achieved by lining up road markings and vehicles on the road, previous attempts using background scenery produced areas of over-lap where the videos were joined together when vehicles and pedestrians came close to the cameras. Temporal alignment was achieved by directing all the cameras towards a traffic signal at the beginning of the recording until the lights changed the frame in which the lights changed was used as a reference point when editing the videos. Creating the videos proved to be difficult due to bugs that caused crashes during the rendering process. The SMI iView X RED is only able to produce gaze fixation data for MPEG4 videos with an XVID decompression which seemed to present even more problems for Adobe Premier Pro. In the end, the videos were first created as high quality MOV files which were used for the simulated studies with the Mobile Eye and the projector and then converted to MPEG4 files for the iView X RED monitor based simulations.

Four 2-minute videos were made for the signalised crossing. Each video represented one traffic cycle: starting with the red pedestrian light and ending as the green pedestrian light became red again. Four 2-minute videos were also created for the unsignalised crossings (see Figure 2.6). No obvious starting points such as the onset of a traffic light were available so the appearance of an approaching vehicle was used to create some standardisation across all trials.

Both videos were of roads in a 30mph zone in Edinburgh: the signalised crossing was the same crossing that the participants crossed in the real-world studies (to ensure greater standardization across conditions and tasks), and the unsignalised crossing was made in a nearby street, to ensure comparable overall layout and architecture.

When selecting traffic cycles to use in the simulation studies care was taken to avoid periods when direct sunlight hit a camera, pedestrians stared directly at the cameras or obstructed the camera view of the traffic scene. Adobe After-Effects was used to reduce some of the differences in lighting between the footage from the five cameras.

## *2.5 Procedure*

Participants were told that the purpose of the study was to see what they are looking at before they cross the road. Informing the participants of the nature of the study may have affected their behaviour but disguising the purpose of this study would have been very difficult as an eye tracker was fitted and calibrated and then the participants were taken to a series of signalised road crossings. Even if it was possible to hide the nature of the study from some of the participants it is unlikely that all the participants, particularly the psychology undergraduates would not have realised the purpose of the study. Specific instructions are detailed in the relevant experimental chapters.

Participants (and their parent / guardian in the case of the children) were asked to read the information sheet and sign the consent form if they agreed to take part.

### *2.5.1 Real world crossings*

After the mobile eye was fitted and calibrated, the participants were accompanied to the signalised road crossings. In the case of children they were accompanied by two adults (the experimenter and either a research assistant or a volunteer helper from the school;

the volunteers that accompanied the children to the crossings were not the parents of the participants). At the road crossing the participants were given instructions regarding which roads to cross. They were also told they were responsible for deciding when to cross and that they should pretend that they are not wearing the eye tracker and cross as they normally would. All participants were informed that the experimenter would not engage in conversation during the road crossings. However, when participants asked for confirmation of the road they should cross it was given. The experimenter remained behind the participants at the road crossings to avoid entering their field of view. When the children were at the road crossing the experimenter held on to the back-pack via a sturdy handle as he stood or walked behind the participant so that it was possible to prevent children from crossing if they had made an unsafe decision to cross. The participants completed a total of four signalised road crossings. Data from only one crossing are presented due to direct sunlight resulting in extensive data loss from the other crossings for many participants.

Data at the real world crossings was collected between 9.30am and 12.15pm and 1.45pm and 3pm, to avoid elevated traffic due to the ‘school run’. This measure helped to ensure that the amount of traffic and the amount of light was reasonably standardised for all the participants. No measurements of the traffic density or the type of vehicles were made other than the coding of vehicles that the participants fixated.

*2.5.2 Simulated crossings*

After the eye tracker was set up the participants were shown two practice videos to become familiar with the display. The participants were asked to imagine that they were on the pavement at the road crossing on the video and to act as they normally would at the actual crossing when looking for a safe crossing opportunity. The children would then either take a step forward (in the projected display condition) or press a button (in the monitor display condition) when they felt that it was safe to cross.

*2.6 Coding of gaze position*

The coding of gaze fixation for both 'what' and 'where' categories was done manually for data from the Mobile Eye and iView X eye trackers. Both eye tracking systems produced footage of the traffic environment that the participants had seen in the trials and on each frame overlaid a circle indicating the centre of gaze, which indicated what the participants were looking at.

Data from the last 3 seconds before crossing (defined as the frame at which participants stepped forward to cross the road or by identifying a safe crossing opportunity by pressing the space bar) were analysed using the observational software package INTERACT 8 (Mangold). Analysing what was fixated in the moments before crossing was expected to give an indication of what information is attended to immediately before making the decision that it is safe to cross. The dynamic nature of the traffic environment means that information used to guide a decision to cross the road may no longer be valid a few seconds later as the state of the vehicles and lights and signs can change very quickly. The time frame of 3 seconds was chosen because previous research has suggested that this interval may be representative of the information used to guide the decision to cross. Whitebread and Neilson (2000) noted an increase in the number of head movements in the 3-5 seconds before making a decision to cross the road; Geruschat *et al*. (2003) examined the gaze behaviour of pedestrians during the final 4 seconds before crossing the road. Holland and Hill (2010) found that looking to the left during the final 3 seconds before crossing the road was found to be associated with safer road-crossing decisions.

### *2.6.1 Object-based ("what") categories*

A fixation was coded when the centre of gaze fixated on an object. As was the case in Geruschat *et al*. (2003), in the event that two objects occupied the centre of gaze, the centre of gaze on the next frame was used to decide what was being fixated; if the centre of gaze on the next frame was on a different object then the frame that preceded the uncertain fixation was used. Twenty-five unique codes were used (26 including ice cream only relevant to Chapter 4). Gaze position on each frame was collapsed into a 5-category coding system, based on the coding scheme used by Geruschat *et al*. (2003) for data analysis (1 Road and vehicles; 2 Pedestrians; 3 Walkway; 4 Lights and Signs; 5 Non traffic relevant features) as pilot studies revealed the comparison of each coded fixation between participants were overly complex and influenced too much by uncontrollable factors such as the presence of a particular vehicle type (e.g., a bus) in one trial.

If a fixation occurred on a car that was moving from the participant's left to the participant's right then it was coded as 'car left to right'; this was the case for buses and bikes (see Table 2.1). If a fixation occurred on a car that was moving from the participant's right to the participant's left then it was coded as 'car right to left'. When a vehicle was stationary, either waiting at the lights or parked it was coded as being stationary. Vans were classed as cars and HGV vehicles as buses. The 'road' was coded when a fixation fell on the road outside of the 'walkway' area, signified by a series of metal studs.

When a pedestrian was fixated, the pedestrian's location and actions were used to determine the subsequent code. If the pedestrian was not at the road crossing then "pedestrians distant" was coded; if the pedestrian was at the crossing and walking towards the side of the street the participant was standing, "pedestrian approaching" was coded; if the pedestrian was standing at the same side of the street and walked in the intended direction of travel for the participant, "pedestrian same direction" was coded; if the pedestrian was at the road crossing but was waiting to cross, "pedestrian stationary" was coded.

Table 2.1 Individual codes in the five category coding system

| Road and Vehichles | Pedestrians | Walkway | Lights and Signs | Other |
|---|---|---|---|---|
| Road | Pedestrians Distant | Walkway Stepping | Pedestrian Lights | Buildings |
| Car left to right | Pedestrians Oncoming | Walkway Approaching | Traffic Lights | Trees and Bushes |
| Car right to left | Pedestrians Stationary | Pavement Stepping | | Sky |
| Car Stationary | Pedestrians Same Direction | Pavement Approaching | | Animals |
| Bus left to right | | Pavement Distant | | |
| Bus right to left | | | | Ice Cream |
| Bus Stationary | | | | |
| Bike left to right | | | | |
| Bike right to left | | | | |
| Bike Stationary | | | | |

Most of the individual codes are self-explanatory although the walkway overlaps with the road. If the centre of gaze is fixated on the part of the road that is specified by road markings as the walkway then the fixation on the walkway is coded. The road and vehicles are grouped together as when looking for vehicles the road will often be fixated in the absence of vehicles. This method of using fixations towards the road to indicate search for vehicles was also used by Geruschat *et al*. (2003). In the projection condition, if the participants fixated on an area outside of the projected image it was coded as 'non-traffic', unless it occurred on the ground in which case it was coded as 'pavement'. Pavement stepping was coded when a fixation occurred on the pavement that the participant could reach within approximately three steps. Pavement distant was coded for fixations that occurred on the pavement outside of the participants intended direction of travel.

Pedestrian lights were coded when gaze fixation occurred on the pedestrian lights and traffic lights were coded when the traffic lights (intended for vehicles) were fixated.

Buildings, trees, bushes and the sky were coded when gaze fixation occurred on these features. In Chapter 4, ice cream was coded when ice cream was fixated. The ice cream code was grouped with non-traffic relevant as it provided no useful information regarding the state of the traffic environment.

### *2.6.2 Location-based ("where") categories*

The term 'general gaze direction' refers to the general direction of the participant's gaze in relation to the intended direction of travel (the other side of the road crossing). General gaze direction does not specifically indicate what is being fixated, but roughly where attention is being directed; this is tantamount to 'looking behaviour' described in studies (Holland & Hill, 2010; Oxley *et al.*, 1997; Whitebread & Neilson, 2000) that have used head movements to determine what areas of the environment are being attended. The term 'looking behaviour' is not used here to avoid confusion as the 'gaze fixation' provides information as to what was being fixated, which is a description of what is being looked at.

For the real world experiments, general gaze direction was defined as in Geruschat *et al.* (2003): if both sides of the crossing were in view, the head direction was classified as 'centre'. If only the left or right of the pedestrian crossing was in view, the head direction was classified as 'left' or 'right', respectively.

For the laboratory-based conditions, general gaze direction was determined by dividing the video into three equal sections (left, centre and right). This is because large head movements sufficient enough to remove the walkway from the scene camera are not required to fixate upon the extremes of the display, also there is no scene camera on the iView X RED that used in the monitor display simulations.

### *2.7 Data analysis*

The data collected in the studies in this thesis were gaze fixations. The percentages of fixations on object-based categories and location-based categories in the final three seconds before crossing the road were analysed. The sub categories (e.g. the walkway, traffic irrelevant features) within object-based categories were not independent, for example fixating more on one category the road and vehicles means fixating less on other categories. This lack of independence between the sub categories violates assumptions needed for the use of parametric statistics to investigate differences between the sub categories within groups (Field, 2000). Parametric tests are not ideal for analysing proportional data as they can attribute probability to values that cannot exist (values below 0 and over 100 for the percentage data collected in these studies) for example a 95% confidence interval around a mean percentage fixation of 80% would range from 52% to 108%. By attributing probability to impossible events (a percentage over 100%) it is likely that possible events (percentage between 0 and 100) are underestimated producing spurious results beyond Type I and Type II errors (Jaeger, 2009). Despite this problem parametric statistics may be useful to compare the percentage of fixations on the road and vehicles between groups or as a result of an intervention (provided that the confidence intervals would not take the range outside possible boundaries). Shapiro-Wilk tests were carried out on the gaze data from each group and condition and revealed the majority of the data to be abnormally distributed. Attempts to transform the abnormally distributed data into normally distributed sets were made by square rooting and cube rooting the data. Whilst there were some data sets that were normally distributed (or could be transformed to meet the assumptions for parametric tests), parametric statistics were not used to analyse these sets as the comparable sets between groups or conditions were not normally distributed. Data sets that were normally distributed are highlighted in the results section of the relevant studies. As a result, non-parametric statistical tests were used throughout the thesis to estimate the probability that any differences between groups arose by chance. The specific tests used to analyse the data are reported in the data analysis section in the methods section in each study. All the $p$ values reported in *post-hoc* tests have been adjusted to compensate for multiple tests. As the data are a percentage of fixations on objects or areas the mean of the data is presented in the Figures and text as the combined mean fixation data on each category for each group and condition is equal to 100%. As the combined median fixation data did not equal 100% it was felt that presenting the median data did not fully represent the data collected.

To indicate the strength of the relation between the two or more variables effect sizes are reported in the result sections. Partial eta squared ($\eta^2$) effect size are given for Kruskal-Wallis and Friedman's Analysis of Variance and Cohen's $d$ effect sizes are provided for *post-hoc* tests such as Mann-Whitney $U$ and Friedman's pairwise comparison. *Post-hoc* power analyses have been conducted when hypothesised findings failed to reach statistical significance but large effect sizes were reported. These power analyses are presented in the relevant results sections.

## *2.8 Ethical Practices*

All research was conducted according to the Code of Conduct of the British Psychological Society and was approved by Edinburgh Napier University's Research Ethics Committee. The experimenter (CDE) was cleared to work with vulnerable pedestrian groups by Disclosure Scotland. All participants were accompanied by the experimenter who stayed one step behind on actual road crossings. In the case of children a second adult (either one of the children's parents or a second researcher) was present throughout the data collection. The roads chosen to cross were approved by Edinburgh's Road Safety Team and informed consent (and assent where appropriate) was given by the participants and/or their legal guardians.

To ensure anonymity for the participants, the data from the participants were given codenames so they were only identifiable to the experimenter. The participants were informed that they were free to pull out of this study at any time without giving a reason and would not experience any negative consequences as a result.

## **CHAPTER 3:** GAZE BEHAVIOUR OF CHILDREN, YOUNGER ADULTS AND OLDER ADULTS AT A SIGNALISED ROAD CROSSING

Part of the data from this study was presented at the European Conference on Visual Perception (ECVP) under the title "Visual gaze behaviour of children and adult pedestrians at a signalised road crossing" (Egan *et al.*, 2008), and at the Applied Vision Association's Christmas meeting in 2009 under the title "Visual gaze behavior of adults and older adults at a pedestrian crossing" (Egan & Willis, 2010).

### *3.1 Introduction*

Gaze fixation is widely believed to be indicative of underlying cognitive processes such as attentional control (Land, 2009; Henderson, 2003; Wilkie & Wann, 2003). Previous research has found differences in the cognitive capabilities across the life span (D'Aloisio & Klein, 1990; Donnelly *et al.*, 2007; Trick & Enns, 1998; see 1.4 *Cognitive factors*) such as the ability to carry out more than one task at the same time (e.g., Foley & Berch, 1997; Kramer & Larish, 1996). It is likely that differences will be observable in the gaze behaviour across the lifespan during a cognitively demanding situation such as at a signalised road crossing as cognitive capabilities change across the lifespan. An increasing amount of evidence suggests that movement decisions are preceded in a highly predictable way by gaze fixations to task-relevant features of the environment (e.g., Hayhoe & Ballard, 2005; Henderson, 2003; Land & Lee, 1994; Land, 2009; Wilkie & Wann, 2003). However, although several studies have recorded behaviours of children, adults and / or older adults at real or simulated road crossings (Holland & Hill, 2010; Oxley *et al.*, 1997; Tolmie *et al.*, 2005; Whitebread & Neilson, 2000; Zeedyk *et al.*, 2002), very few studies have attempted to examine gaze behaviour in road crossing directly. The few studies that have looked at gaze behaviour at a road crossing have focused on healthy older adults (Geruschat *et al.*, 2003) and older adults with visual impairments (Geruschat *et al.*, 2006). In the Geruschat *et al.* (2003) study, three young adults were grouped (aged 27.7 ± 5.9) with nine older adults (aged 72.2 ± 7.0) to indicate what was being fixated by pedestrians at the road crossing. Given the difference in behaviours (head movements) displayed by older and younger adults in other studies such as Oxley *et al.* (1997), the inclusion of three younger adults in the study makes it difficult to evaluate the potential impact of ageing on eye movement behaviour at road crossings. In this thesis, the gaze behaviour of children, adults and older adults were recorded at a signalised road crossing with the aims of providing information on the way gaze is directed during road crossing across the life span, and whether differences in gaze behaviour exist between the three groups that may, at least in part, explain the over-representation of children and older adults in pedestrian accidents.

### *3.1.1 Aim & predictions*

The aim of this study was to explore the gaze strategies of children, young adults and older adults as they waited to cross a real road at a signalised junction. Gaze direction is highly related to the current focus of attention (Henderson, 2003) and as such can be used to reveal differences in the strategies used by children, younger adults and older adults during road crossing. In adopting principles from representative design (Brunswick, 1956, cited in Dhami *et al.*, 2004) and cognitive ethology (Kingstone *et al.*, 2008a) to explore real behaviour in a real environment, I hoped to provide a more ecologically-valid description of road-crossing behaviour.

Although no study, to the author's knowledge, has explicitly tested these predictions, there may be good reason to expect children and older adults to exhibit quite different eye movement behaviours compared with younger adults. Children, for example, may be more likely to fixate irrelevant features due to a reduced capacity to prioritise the most important information in a scene, or ignore irrelevant information (Allen *et al.*, 1979; Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al.*, 1996; see 1.4.2 *Attentional control and visual search*). Given children's poorer performance on tasks that require attentional control (Tagg, 1990, cited in Thomson *et al.*, 1996), children may fixate more potent sources of information (such as the walk light) more often, than attempt to monitor the roads and vehicles that requires the pedestrian to divide attention, and attend to multiple sources of information such as the size of a gap between two vehicles approaching from the right and the interaction between two vehicles at the pedestrian's left when one is about to turn. We might also expect children to look in the directions of oncoming traffic less compared with the centre, as young children often do not look in the direction of oncoming traffic before crossing the road (Zeedyk *et al.*, 2002) and may search the scene less systematically than older children and adults (Whitebread & Neilson, 2000).

At the other end of the life span, older adults, like children, have been shown to perform worse than adults on tasks that require attentional control and other aspects of executive functioning (e.g. Craik & Bialystok, 2006; Plude, *et al.*, 1994; Span *et al.*, 2004; Trick & Enns (1998); see 1.4.1 *Executive function*), and find walking and maintaining balance more cognitively demanding than younger adults (see Yogev-Seligmann *et al.*, 2008). It is therefore reasonable to predict that older adults will attend to traffic-irrelevant features significantly more than younger adults do. We might also expect older adults to direct their gaze more often towards (a) pedestrian walk lights as this information is a good indicator of when it is safe to cross and requires less cognitive effort; and (b) the ground ahead of them (the "walkway") compared with younger adults: Oxley *et al.* (1997) noted that older adults direct their heads towards the ground more than younger adults, perhaps reflecting increased concerns about tripping or falling, so it is likely that their eyes (and attention) will be directed here also.

## *3.2 Methods*

### *3.2.1 Participants*

For this study, 30 children, 12 adults and 14 older adults were recruited. A combination of factors such a direct sunlight, the eye tracker slipping and breeches in protocol from an accompanying adult (these and other factors are detailed in 9.2.3 *The Mobile Eye: Problems and data loss*) resulted in the data from a selection of the participants being unusable. Data from 18 children (*M*= 8.8, *SD*= 0.4 years), 10 adults (*M*= 24.1, *SD*= 4.5 years) and 10 older adults (*M*= 70.7, *SD*= 4.1 years) are presented in this study.

*3.2.2 Design*

This study used a mixed design. The independent variables were age (with three levels: children, adults and older adults) and object or location categories (with five and three levels, respectively). The two dependent variables were the percentage of fixations on object-based and location-based categories in the final 3 seconds before crossing.

*3.2.3 Procedure*

The mobile eye tracker was fitted and calibrated indoors as outlined in the General Methods (see 2.2.1 *Mobile Eye eye tracker*). Participants were accompanied by the experimenter as they walked to the road crossings and when they arrived at the crossings were asked to cross the signalised crossing as they normally would and to imagine that they were not wearing an eye tracker. The experimenter remained one step behind the participants and in the case of the children participants the experimenter held onto a strap on the bag pack/harness to prevent children from crossing in dangerous situations.

*3.2.4 Data analysis*

Gaze direction was coded according to five "what" categories and three "where" categories, as outlined in the General Methods. A series of Shapiro Wilk tests revealed that only the data relating to fixations on vehicles were normally distributed. None of the non-parametric data sets could be transformed in to parametric data. As all the data sets required non-parametric statistical tests, a series of Kruskal-Wallis tests was carried out to determine statistical differences between the data from the three groups. *Post-hoc* Mann-Whitney *U* tests were used to determine which, if any, age groups were statistically different from each other for each object or location category. Friedman's Analysis of Variance by Ranks statistical tests were used to determine statistical differences between percentage of fixations on categories and in the percentage of general gaze directions. Friedman's pairwise comparisons were used to identify between which specific categories or general gaze directions statistical differences were found.

## *3.3 Results*

There were quite pronounced differences in gaze behaviour between children, young adult and older adult groups: young adults directed their gaze mostly towards the road and vehicles (55%), and very little time looking at lights or signs (8%), while older adults spent much more of their time fixating the ground in front of them (38%), and children appeared to direct their gaze much more equally between different features of the road crossing but fixated mostly on non-traffic relevant features (27%) (see Figure 3.1).

### *3.3.1 Between groups*

Here the percentages of gaze fixations on object based categories between the three groups are compared. Kruskal-Wallis tests were sufficiently powerful to reveal statistical differences between groups in the fixation percentage of 'road and vehicles'

($\chi^2_{(2)}$=10.364; $p$=0.006; $\eta^2$=0.19). *Post-hoc* Mann-Whitney $U$ tests revealed, as predicted, younger adults fixated significantly more on the road and vehicles compared with both children ($U$=19; $p$=0.008; $d$=1.5) and older adults ($U$=7; $p$=0.003; $d$=1.98). The large effect sizes observed revealed the magnitude of these differences. It was further hypothesised that children and older adults would attend more to traffic-irrelevant information (such as buildings) than younger adults. This hypothesis was only partially supported by the results: differences in the proportion of time fixating traffic-irrelevant features were not significant across the groups ($\chi^2_{(2)}$=2.075; $p$=0.354; $\eta^2$=0.04), but a medium to large effect was found ($d$=0.69) in fixations to traffic-irrelevant objects in children compared to young adults. A *post-hoc* power analysis (1-β=0.452) indicated that the statistical test lacked the power to detect this medium to large difference.

The older adults directed 39% of their fixations towards the walkway, almost twice as much as the younger adults (21%). It was hypothesised that older adults would direct their gaze significantly more towards the walkway than younger adults would. This hypothesis was only partially supported as a Mann-Whitney $U$ tests revealed no significant differences between the older adults and younger adults in terms of fixations on the walkway ($U$=79.5; $p$=0.203), however a medium effect size was noted ($d$=0.66). A *post-hoc* power analysis (1-β=0.377) indicated that the statistical test lacked the power to detect this medium-sized difference. There was little difference in the percentage of fixations on the walkway between the children and younger adults.

Overall no significant differences were found between the three groups in terms fixations to the walkway ($\chi^2_{(2)}$=1.882; *p*=0.39; $\eta^2$=0.03).

It was also hypothesised that older adults would fixate the traffic lights more than younger adults would. Again, this hypothesis was not confirmed by the statistical significance (*U*=84; *p*=0.123; *d*=0.78), however the medium to large effect size suggests that the difference may be meaningful. A *post-hoc* power analysis (1-β=0.472) indicated that the statistical test lacked the power to detect this medium to large difference.

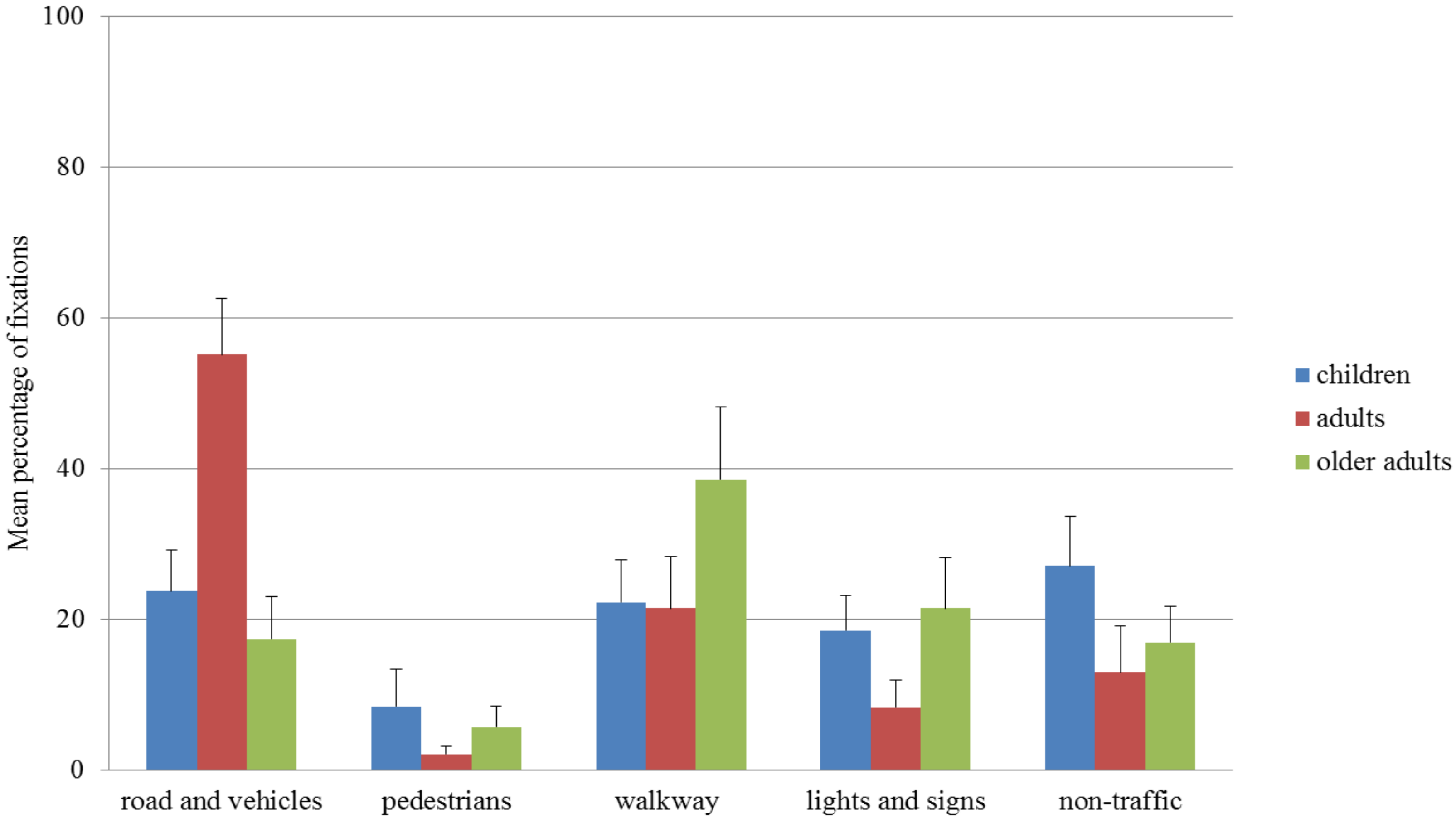


Figure 3.1. The mean percentage of gaze fixations on object-based categories by children, adults and older adults at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean

Children and older adults tended to fixate on the pedestrians and the lights and signs more than the younger adults did. However, no statistically significant differences were found between the three age groups in terms of the percentage of gaze fixations on pedestrians ($\chi^2_{(2)}$=0.155; $p$=0.925; $\eta^2$=0.003), lights and signs ($\chi^2_{(2)}$=2.636; $p$=0.268; $\eta^2$=0.048).

The general gaze direction data (see Figure 3.2) showed that the children and older adults fixated mostly in the centre (63% and 77% respectively) whereas the adults directed their gaze to the right (47%) slightly more than the centre (43%). All participants directed their gaze to the left less than the centre and right. It had been hypothesised that children would direct their gaze towards the centre more than adults. Again this hypothesis was only partially supported as a Mann-Whitney $U$ test revealed no significant differences ($U$=44; $p$=0.325; $d$=0.64), but a medium effect size was found, suggesting that children's greater percentage of fixations in the centre than the younger adults' may be meaningful. A *post-hoc* power analysis (1-$\beta$=0.409) indicated that the statistical test lacked the power to detect this medium-sized difference. No significant differences were noted between the groups in the general gaze direction towards left ($\chi^2_{(2)}$=3.701; $p$=0.157; $\eta^2$=0.067), centre ($\chi^2_{(2)}$=3.895; $p$=0.143; $\eta^2$=0.071) and right ($\chi^2_{(2)}$=2.576; $p$=0.276; $\eta^2$=0.047).

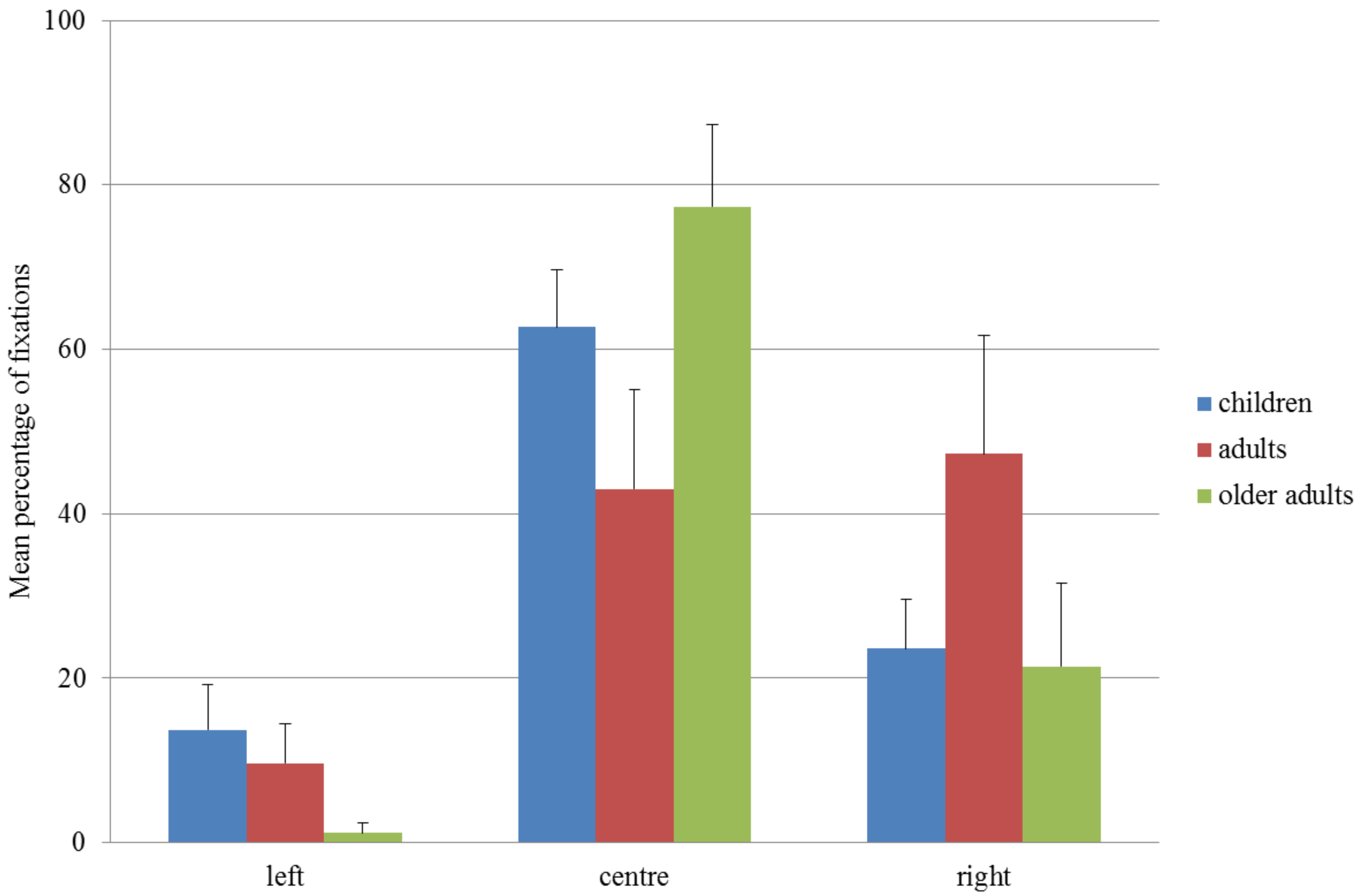


Figure 3.2. The mean percentage of gaze fixations in each direction by children, adults and older adults at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean

*3.3.2 Within groups*

*3.3.2.1 Children*

In the children group, Friedman's Analysis of Variance by Ranks revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=11.075; $p$=0.026; $\eta^2$=2.769) and in the percentage of general gaze directions ($\chi^2_{(2)}$=10.194; $p$=0.006; $\eta^2$=5.097). Friedman's pairwise comparisons revealed that children fixated on traffic irrelevant features significantly more than on pedestrians ($\chi^2_{(1)}$=2.907; $p$=0.037; $d$=0.81) and more to the centre than to the left ($\chi^2_{(1)}$=3.005; $p$=0.008; $d$=2). The children fixated more often to the centre than the right, although when correcting the $p$ value to accommodate for multiple testing (by multiplying the $p$ value by 5: the number of pairwise comparisons needed for the Friedman's Analysis of Variance by Ranks) this difference failed to reach statistical significance ($\chi^2_{(1)}$=2.298; $p$=0.065; $d$=1.54). However the large effect size noted suggests that this may be a meaningful difference. All other pairwise comparisons failed to reach statistical significance ($p$>0.05).

*3.3.2.2 Younger adults*

In the younger adult group, Friedman's Analysis of Variance by Ranks also revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=26.88; $p$=0.001; $\eta^2$=6.72) and in the percentage of general gaze directions ($\chi^2_{(2)}$=6.865; $p$=0.032; $\eta^2$=3.425). Pairwise comparisons revealed adults fixated on the road and vehicles significantly more than traffic irrelevant features ($\chi^2_{(1)}$=2.1; $p$=0.03; $d$=1.89) and pedestrians ($\chi^2_{(1)}$=3.15; $p$<0.001; $d$=2.67) and more on the walkway than pedestrians ($\chi^2_{(1)}$=2; $p$=0.047; $d$=1.05) and lights and signs ($\chi^2_{(1)}$=2.6; $p$=0.002; $d$=0.78). Pairwise comparisons of the general gaze direction did not result in significant differences after the adjustments for multiple tests were made. Although large effect sizes were found that indicate fixations occurred less towards the left than they did in the centre ($\chi^2_{(1)}$=2.124; $p$=0.101; $d$=1.1) and towards the right ($\chi^2_{(1)}$=2.236; $p$=0.076; $d$=1.04), *post-hoc* power analyses indicated that the statistical analyses just lacked the power to detect these differences (1-β=0.734 and 0.687, respectively).

*3.3.2.3 Older adults*

Friedman's Analysis of Variance by Ranks revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=16.94; $p$=0.002; $\eta^2$=4.235) and in the percentage of general gaze directions ($\chi^2_{(2)}$=14.28; $p$=0.001; $\eta^2$=7.14) in the older adult group. Pairwise comparisons revealed that older adults fixated significantly more on the walkway than on pedestrians ($\chi^2_{(1)}$=2.542; $p$=0.001; $d$=1.2). This was the only significant difference that survived the adjustment for multiple tests. The percentage of fixations on the walkway was higher than fixations on roads and vehicles ($\chi^2_{(1)}$=2.259; $p$=0.24; $d$=0.8) and the percentage of fixations on the lights and signs was higher than on pedestrians ($\chi^2_{(1)}$=2.647; $p$=0.13; $d$=0.85): the large effect sizes found for these differences suggest that they may be meaningful. *Post-hoc* power analyses indicate that the statistical tests for these non-significant fixation differences lacked the power to detect these large differences (1-β=0.591 and 0.642, respectively). All other comparisons between fixations of objects failed to reach statistical significance

($p$>0.05). Pairwise comparisons of the general gaze direction revealed that older adults fixated significantly more in the centre than did to the left ($\chi^2_{(1)}$=3.57; $p$=0.001; $d$=2.57). All other comparisons between the general gaze directions failed to reach statistical significance ($p$>0.05).

## 3.4 Discussion

This experiment was the first, to the author's knowledge, to use eye tracking techniques to explore gaze behaviour at a real road crossing in children, younger and older adults. The differences in gaze behaviour between the groups must reflect, to some extent at least, differences in the strategies used by children, young adults and older adults to cross the road. Numerous age-related hypotheses were made that may, to some extent, explain the increased prevalence of children and older adults' involvement in pedestrian accidents. In this section these hypotheses and general themes are discussed in relation to the findings of this study.

### 3.4.1 Children would fixate less on the road and vehicles

It was hypothesised that children would fixate the road and vehicles less than younger adults. Although this was the first study to record children's gaze behaviour at a road crossing data, pedestrian accident reports indicate that failing to look for vehicles before crossing the road is cited more often in accidents involving children than other age groups (DfT 2010a, 2010b). Support for the hypothesis that children would look at the vehicles less can be found in studies investigating attentional control. Previous studies have shown that young children have a reduced capacity to prioritise the most important information in a scene (e.g., Allen *et al*., 1979; Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al*., 1996; Tolmie *et al*., 2005a) and given that a pedestrian accident involves a collision with a vehicle, at a road crossing vehicles could be considered as the most important source of information.

As hypothesised, children did attend significantly less to the road and vehicles before crossing the road than younger adults did and this may provide support for previous research that found children have difficulties prioritising the most important sources of information (e.g., Allen *et al*., 1979; Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al*., 1996; Tolmie *et al*., 2005a). However, even though children attended to vehicles significantly less than adults did, they still crossed the road safely without the need for intervention from the accompanying adults. Children's lower percentage of fixations to the road and vehicles may not be due to an inability to prioritise important information but due to children's lesser ability to process the information from the road and vehicles. Previous research has found that younger children have more difficulty tracking a moving target surrounded by distractors than older children (Trick *et al*., 2003), and experience even greater difficulty when attempting to track multiple moving targets (Trick, *et al*., 2005). Therefore children are likely to find it difficult to track multiple vehicles and use this information to guide their road-crossing decision, which may explain the lower percentage of fixation on the road and vehicles observed in the children compared to the younger adults.

It could therefore be argued that directing attention to the vehicles is unnecessarily demanding when simpler forms of information relating to safe crossing opportunities are available such as pedestrian lights. It may be that attending less to the road and vehicles is a functional strategy of children aimed at reducing cognitive demands.

Even if attending less to the road and vehicles ($p<0.05$) is a functional strategy aimed at reducing the cognitive effort of crossing the road this behaviour may still partially explain the increased prevalence of children in pedestrian accidents. Attending less to approaching vehicles before stepping into the road is likely to increase the chance of a pedestrian accident, however from the data collected in this study it cannot be concluded with complete certainty that the differences observed between the groups relate to contributing factors to pedestrian accidents as all participants crossed the road safely. However, it is likely that attention to vehicles is a critical part of road crossing that is linked to accident rates as failing to look properly for vehicles is the most frequently cited cause for pedestrian accidents and this cause is more frequently cited in children pedestrian accidents than in other groups (DfT, 2010a;b).

Studying the percentage of fixations that children direct to the road and vehicles in a safe simulated environment may indicate how likely the lower percentage of fixations on the vehicles is the result of a functional adaptation or a lesser ability to prioritise important task-relevant information. This is investigated in Chapter 8.

*3.4.2 Children would fixate more on the traffic lights*

It was hypothesised that children would fixate more on potent sources of information such as the walk light, more often than younger adults would. Children directed 18% of their gaze towards the lights whereas younger adults directed only 8% of their gaze to the lights. No significant effect of group was noted when investigating the percentage of fixations on lights and signs; however, a medium to large effect size was found and the subsequent power analysis revealed that 28 children and 28 younger adults would be needed to find a significant difference. At a signalised road crossing the most pertinent sources of information for pedestrians before crossing the road are almost certainly the movement and location of vehicles and traffic and pedestrian lights. A medium to large effects size indicates that children's higher percentage of fixations the younger adults' to the lights is probably meaningful. Children's strategy of fixating the lights before crossing appears to be prudent as monitoring the pedestrian lights to base a road-crossing decision is much simpler than monitoring traffic flow and children appear to have difficulty with the necessary capabilities to accurately judge safe crossing opportunities based solely on the vehicle movement. It has been reported in previous research that young children have difficulty in tracking multiple moving targets (Trick, *et al*., 2005) and miss more crossing opportunities than older children and adults (Connelly *et al*., 1998; Lee *et al*., 1984; Plumert *et al*., 2007). Although attending to a potent source of information such as the pedestrian lights appears to be a wise strategy for children, it is unclear why children do this. It may be due to an awareness of their lesser capacity to accurately track moving objects or safe crossing opportunities or it may be that they are following parental instructions. In a later study children's gaze behaviour will be investigated at a signalised road crossing; if the children direct their gaze towards the pedestrian lights less in a safe environment this may indicate that their fixations on the pedestrian lights in the real world reflects uncertainty in their ability to cross the road based on information from the vehicles.

### *3.4.3 Children would fixate more on traffic irrelevant features*

It was hypothesised that due to a reduced capacity to ignore irrelevant information noted in previous research (e.g., Allen *et al*., 1979; Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al*., 1996; see 1.4.2 *Attentional control and visual search*) children would fixate more on traffic irrelevant features than other features. In the present study, children attended significantly more to traffic irrelevant features than to pedestrians. It had been hypothesised that children would attend to traffic irrelevant features more than younger adults would. The trend in the data suggested that this was the case and although the difference was not statistically significantly, a medium effect size was noticed ($d$=0.69). The percentage of fixations on traffic irrelevant features ranged from 0 to 81% in the children participants, indicating a large amount of variability. This high inter-participant variability may have contributed to the lack of statistical significance between the children's and younger adults' fixations on traffic irrelevant features. Collecting data from a larger sample of participants may address this issue, in fact the post-hoc power analysis ($1-\beta=0.452$) indicated that the test lacked the required power to detect the difference and that to achieve sufficient power ($1-\beta=0.8$), 33 children and 33 younger adults would be needed. Variability is discussed later in this discussion (see 3.4.8 *Variability*) and again in the *General Discussion* (see 9.2.3 *Variability in gaze behaviour*).

The trend observed in this study, although not statistically significant, is in line with other studies that have reported that children often attend to non-task relevant features. Children's preponderance to pay attention to task-irrelevant features is well demonstrated in the literature (e.g., Allen *et al*., 1979; Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al*., 1996; Tolmie *et al*., 2005; see 1.4.2 *Attentional control and visual search*). For example, when learning a route, younger children attended to interesting, but task-irrelevant information, such as seeing a cat whereas older children and adults attended to attended to corners where a change of direction was necessary (Allen *et al*., 1979). When required to memorise the location of animal pictures in a room, young children attended more to the task irrelevant physical properties of the animal pictures than the task-relevant spatial (Tagg, 1990, cited in Thomson *et al*., 1996). Children's attention to task irrelevant features has also been reported when viewing traffic simulations. In a study by Tolmie *et al*. (2005a), whilst viewing a road crossing, children were required to give a verbal account of what they thought was important information for crossing the road. The young children frequently reported traffic irrelevant information; in fact 50% of the features reported by children were traffic irrelevant such as the colour of cars and seeing a man on a ladder. Children's attention to irrelevant features noted in this study (27%) concurs with other research but the extent to which children attended irrelevant features differs substantially from that reported by Tolmie *et al*. (2005a). Differences in the methodology and participants probably explain this disparity; the participants in the Tolmie *et al*. (2005a) study were 6 years old the task involved verbally reporting events whereas the present studied investigated real world gaze behaviour during a task that required action in children aged 8-9 years old. The mechanisms used to verbally recall events and those used for acting in real time are unlikely to be the same (Milner & Goodale, 1992; 2008). Also, younger children have been shown to perform worse than older children in tasks that require attentional control (e.g., Donnelly *et al.*, 2007; Hommel *et al.,* 2004; Trick & Enns, 1998).

At the road side, pedestrians are presented with more visual information (task relevant and irrelevant) than can be processed; it is therefore necessary to selectively process some information and not process other information (Itti, 2005). Increased attention to traffic irrelevant features, as observed in children pedestrians in this study, may be indicative of poorer attentional control noted in other studies (e.g., Trick *et al*., 2003; see 1.4.2 *Attentional control and visual search*) and may partially explain their involvement in pedestrian accidents. Attending to irrelevant information may potentially have negative consequences for road crossing: if the limited attentional resources of children (Donnelly *et al.*, 2007; Hommel *et al.,* 2004; Trick & Enns, 1998) are occupied with irrelevant information it is likely that task relevant information will not be processed efficiently and this could lead to missed crossing opportunities or unsafe crossing decisions. Previous research has indicated that young children are more likely to miss safe crossing opportunities and select unsafe gaps than older children (Ampofo-Boateng & Thomson, 1991; Lee *et al*., 1984). However, it is important to note that even with the relatively large percentage of fixations to irrelevant information observed in children; all participants crossed the road safely.

### *3.4.4 Children would fixate less in the directions of oncoming traffic*

It had been hypothesised that children would look in the directions of oncoming traffic less compared with the centre. As hypothesised, children attended in the centre significantly more than they did to the left or the right. This finding concurs with other studies that have noted that young children often do not look in the direction of traffic before crossing the road (Zeedyk, *et al*., 2002) or search the scene less systematically than older children and adults (Whitebread & Neilson, 2000). Failing to look towards the direction of oncoming traffic could be a predisposing factor in children's overrepresentation in pedestrian accidents. Whilst children looked in the centre more than the left it is interesting to note that children directed their gaze towards the left more than the other groups (again not statistically significant). It is unclear if this trait in children's behaviour is a factor that may predispose children to pedestrian accidents. Attending towards the left was associated with safe road-crossing behaviour in adults and older adults in the Hollands and Hill (2010) study, as pedestrian accidents often occur on the far side of the road. However, Zeedyk *et al.* (2002) found that young children were equally as likely to look in the direction of immediate oncoming traffic (to the right) as they were the opposite direction (to the left) and postulated that this may reflect uncertainty of the direction of oncoming vehicles. The differences in the interpretation between these studies could be a result of the participants, methods and traffic environment used. Whether this behaviour is an indication of uncertainty as to which direction the vehicles will be approaching from, a skilled strategy to reduce the risk of pedestrian injury or simply the following of a set of basic rules such as the green cross code (look all around for traffic) is not known. Future studies that supplement the collection of real-world gaze data with interviews may clarify this situation (although children's theoretical knowledge does not always translate to behaviour). During the interview the video from the scene camera could be played back and the interviewer could ask the children why they looked to the left. Looking at children's gaze behaviour at a one way road may also help to answer this question. If vehicles only approached from the right and children attended to the left as much as the right it is likely that this reflects an uncertainty regarding the area that vehicles will approach from or the application of set rules such as the Green Cross Code to situations that are not appropriate.

*3.4.5 Older adults would fixate more on traffic irrelevant features*

It was hypothesised that older adults would attend to traffic-irrelevant features significantly more than younger adults would. Older adults have been shown to perform worse than younger adults on tasks that require attentional control and other aspects of executive functioning (e.g. Craik & Bialystok, 2006; Plude, *et al.*, 1994; Span *et al.*, 2004; Trick & Enns, 1998; see 1.4.1 *Executive Function*), and find walking and maintaining balance more cognitively demanding than younger adults (see Yogev-Seligmann *et al.*, 2008). However this hypothesis was not confirmed and the data did not indicate that older adults have difficulty ignoring irrelevant information as they fixated irrelevant information to a similar extent as younger adults.

Due to the large amount of visual information available in the environment, it is necessary to selectively process some information and not process other information (Itti, 2005). Adults have developed the ability to selectively attend to task-relevant information to such a degree that irrelevant information is often unattended (Brockmole & Henderson, 2006), although older adults appear to perform worse than younger adults at tasks that require attentional control (D'Aloisio & Klein, 1990; Hommel *et al.*, 2004; Plude, 1990; Rabbitt, 1965; Trick & Enns, 1998; see 1.4.2 *Attentional control and visual search*). The findings from the present study do not support the notion that older adults have difficulty ignoring irrelevant features, which may have been indicative of poor attentional control. One of the few studies that has compared the gaze behaviour of older adults and younger adults when searching a dynamic scene suggest that older adults are able to selectively attend to pertinent information in order to identify hazards equally as well as younger adults (Underwood *et al.*, 2005; see 1.2 *Life span approach*). The results from the present study seem to lend some support to the findings from Underwood *et al.* (2005) as younger and older adults fixated irrelevant features to a similar extent. It is possible that the findings from Trick and Enns (1998) who found older adults performed worse than younger adults in tasks requiring selective attention (see 1.4.2 *Attentional control and visual search*) differ from the findings from Underwood *et al.* (2005) and this current study, due to the nature of the tasks required in traditional laboratory-based experiments. The abstract tasks often required in laboratory-based studies are not representative of actual tasks the participants would normally perform (Burgess *et al.*, 1998). The differences may also be due to the measurements used to assess performance; reaction time studies and eye movement studies often draw different conclusions (Henderson, 2003). There is evidence to suggest that observing a stimulus and pressing a button to achieve a desired goal (as is often the case with traditional visual search tasks) is very different than acting upon real world visual information (Milner & Goodale, 2008), and that participants respond less accurately when pressing a button than when performing the natural action associated with the visual information (Bootsma, 1989).

The similar amount of fixations to irrelevant features noted the younger and older adults in the present study indicates that for these participants a reduced ability to ignore task irrelevant information is unlikely to explain the older adults' increased risk of pedestrian accidents.

*3.4.6 Older adults would fixate more on the traffic lights*

It was hypothesised that older adults would use less cognitively demanding sources such as the actions of other pedestrians or the predictable onset of a pedestrian walk sign. This hypothesis was only partially confirmed as no significant differences were noticed between the younger adults and older adults in terms of fixation on lights and signs but a large effect size ($d$=0.79) and the subsequent power analysis indicated that 22 participants in each group would be enough to find a statistical difference if one existed. The rationale for this hypothesis was based upon previous research that shows that older adults are less able to perform cognitively demanding tasks than younger adults (Craik & Bialystok, 2006; Kramer *et al.*, 1994; Ridderinkhof *et al.*, 2002) and it was speculated that the older adults may adopt a strategy that reduced the cognitive demands required to cross the road safely. Attending the lights requires little cognitive processing and as previous studies have shown that the frontal lobes, responsible for executive functions seem to compensate for reduced occipital activity in sensory processing in older adults (D'Esposito *et al.*, 1999; Li & Lindenberger, 2002; Rypma *et al.*, 2001) it would appear this may be a functional adaptation to changes in cognitive processing capabilities. The increased attention to the lights and signs may also be explained by a slower walking speed meaning that older adults need more time to cross the road and are guaranteed a set crossing time during the pedestrian walk phase of the traffic cycle.

To ascertain why older adults direct their gaze towards the lights and signs more than adults, future studies could implement interviews and also film the traffic environment at the time of the crossings and calculate safe crossing opportunities based on gaps in traffic and the pedestrian's walking speed. Such research may indicate whether the fixations to the pedestrian lights were an attempt to reduce the cognitive processing required or to allow sufficient time to cross.

*3.4.7 Older adults would fixate more on the walkway*

It was hypothesised that older adults would fixate on the walkway more than younger adults. A high percentage of fixations to the walkway was expected to reflect older adults' increased concerns about falling. Previous research has also noted that older adults direct their heads towards the ground more than younger adults (Oxley *et al.*, 1997). This hypothesis was only partially confirmed; as older adults directed their gaze more to the walkway than adults did although this difference was not statistically significant. However, there was a medium effect size for the differences between the groups suggesting that the difference may be meaningful. A power analysis ($1-\beta=0.377$) revealed that the current test lacked the power to detect this medium-sized difference.

Another hypothesis was that the older adults would fixate on the walkway more than the other object-based categories such as vehicles, as falling on the pavement or walkway is much more likely than being hit by a vehicle (Jensen, 1999). As predicted, older adults did direct their gaze towards the walkway more than any other category, although it was only statistically significantly more than pedestrians. It appeared that the older adults prioritised fixating on stepping location over fixating on vehicles, which may be a functional adaptation to decrease the risk of falling. After making adjustments for multiple tests this failed to reach statistical significance, however, a large effect size of $d$=0.8 was noted and a power analysis ($1-\beta=0.591$) suggested that more participants would be needed to reach statistical significance after the $p$ values were adjusted.

This variation in the gaze fixations towards the walkway observed may be a reflection of individual differences in the confidence of their ability to maintain balance while crossing the road and experiences of falling, which in turn is likely to be influenced by previous experiences of falling. In future studies, data about participants' history of falls could be collected through the implementation of interviews. Directing a large proportion of gaze on the walkway (39%) would allow older adults to attend to where they will be walking, potentially reducing the possibility of falling. The gaze behaviour of older adults seems to emphasise an importance of foot placement and whilst this may increase the chances of being involved in a collision it is possibly the most appropriate strategy for older adults when crossing the road, especially when additional information is available signifying a safe crossing opportunity (such as an auditory signal to indicate the pedestrian crossing phase at signalised crossings).

Previous studies have indicated that older adults can be trained to direct their gaze differently (Young & Hollands, 2010), however training older adults to fixate the walkway less may be inappropriate. The behaviours observed in individuals are likely to be the result of an interaction of many different constraints such as cognitive and sensory capabilities, the environment and task (Newell, 1985), and are as such not 'hard-wired'. The emergent behaviour will be based on the priorities of the central nervous system, which are often different in special and/or aging populations compared to the healthy, young population (Latash & Anson, 1996). For instance, the walking pattern of individuals with Parkinson's disease is often characterised by slowness of movement. This symptom (bradykinesia) is, however, not a primary defect but a functional adaptation of the central nervous system to changed circumstances. Individuals with Parkinson's disease are able to generate larger forces and faster movements than their slow, shuffling gait suggests, but these movements are highly inaccurate. Their nervous system has prioritised accuracy over speed or energy efficiency (Latash & Anson, 1996). Latash and Anson (1996) warn against focusing interventions on restoring such atypical movement behaviours back to 'normal' as they may represent optimal behaviours within a changed set of constraints. For the older adults in the present study the high percentage of fixations on the walkway is also likely to be a functional adaptation, representing optimal behaviour given their constraints. For them, the chances and consequences of falling are much greater than for younger adults (Jensen, 1999) due to reduced sensory (Atchison *et al.*, 2008; Glasser & Campbell, 1999; Haegerstrom-Portnoy *et al.*, 1999; Li & Lindenberger, 2002; Weale, 1963; Wright & Drasdo, 1985) and cognitive capabilities (D'Aloisio & Klein, 1990; Kramer & Larish, 1996; Li & Lindenberger, 2002; Ponds *et al*., 1988; Salthouse *et al*., 1995; Sekuler *et al*., 2000; Trick & Enns, 1998; Tsang & Shanner, 1998). Fixating more on the walkway and less on the road and vehicles may be a predisposing factor in pedestrian accidents but it is also functional as it likely reduces the risk of falling. Since older adults are more likely to fall than to be hit by a car (Jensen, 1999), this adaptation appears appropriate.

The altered gaze behaviour (i.e., fixations on irrelevant features) of children was not considered to be a functional adaptation, as focussing on irrelevant information has no obvious benefit. This gaze behaviour can be considered a sub-optimal, potentially dangerous, behaviour that should be corrected through training.

*3.4.8 Variability*

Variability in the data was a recurring theme throughout the results and warrants further consideration here. The nature of the variability observed in the study warrants further investigation; it was probably a combination of inter-participant variability and environmental factors but the relative contribution of individual and environmental differences are unknown.

A large amount of inter-participant variability in gaze behaviour has also been reported in other studies that have investigated eye movement behaviour in real world settings (Geruschat *et al*., 2003; Underwood *et al*., 2005). 't Hart *et al*. (2009), for example, found higher levels of variability in real world environments, as opposed to laboratory-based simulations. This is not surprising as 't Hart *et al.*'s (2009) laboratory-based video simulations used a scene camera from the eye tracker to capture the footage, which is only capable of recording 50°x40°. This meant that the participants' gaze fixation is restricted to objects and areas within this range. In the real world participants are free to move their heads around and direct their gaze in any direction they chose increasing the likelihood of variance between participants. While high levels of variability can prevent statistically significant differences being found between groups and conditions, the presence of large amounts of variability may be informative of the nature of gaze control in the real world; gaze behaviour may be very depend critically on the specific situational context and in the real world the specific context may be outside of the experimenter's control. Therefore variability should be seen not as a hindrance to statistical significance but a reflection of the nature of gaze control under natural settings. Gaze allocation may adapt to numerous different situations. Future studies investigating within-participant variability of gaze control would help to increase our understanding of the nature of variability in gaze control.

It is not possible to completely remove "situational variability without compromising the nature of process that is being measured" (Kingstone *et al.*, 2008, p. 319). However, attempts were made to standardise the protocol in an effort to reduce situational variability in a way that did not affect the process of road crossing. For example all of the data were collected during week days, during school hours. This measure, as well as being convenient for the participants, placed some constraints on (but did not control or guarantee) the amount of light and traffic as crossings took place during the day time and outside of “the school run” times and rush hours to avoid high levels of vehicular activity. The signalised crossings allowed for some measure of constraint on traffic flow as the predictable traffic flow sequence is repeated each traffic cycle. Originally it had been planned to analyse the gaze behaviour of the participants at four crossings and the start time of the first crossing in relation to the traffic cycle had been standardise across all the participants, however the relative time of the traffic phase of the subsequent crossings depended on the time taken to arrive at the next crossing. Due to data loss only data from the third crossing was analysed and therefore the start time was not standardised. All participants received the same information before crossing the road. Obviously it was not possible to recreate the same visual information available for each participant due to many uncontrollable factors such as traffic flow, weather and the behaviour of other pedestrians. It was hoped that these measure would to some extent reduce the situational variability without removing it completely and compromising the nature of road crossing. It is better to allow variance to occur naturally and accept that variability is a feature of the real world and measure it rather than trying to constrain it, as variability may reveal key characteristics of cognitive processing (Kingstone *et al.*, 2008a). From this study the variability observed suggests that eye-movement behaviour may be highly adaptive to dynamic environments. More research is needed to determine the contribution inter-participants differences and the dynamic nature of the environmental to the variability observed in this study.

*3.4.9 Sample size*

Given the large amount variability noted relatively large sample sizes were required for many of the differences observed to reach a level of statistical significance. There are numerous occasions when hypothesised results were not confirmed even though medium/large effects sizes were found. This study would have benefited from the use of power analyses before the data were collected rather than the *post-hoc* power analyses. However, the experimenter was unaware of this form of analysis until after the data were collected.

*3.4.10 Natural behaviour*

This study investigated gaze behaviour at a road crossing in a natural environment. There is no guarantee that all the participants displayed their natural gaze behaviour: it may be that the participants, all of whom were aware of the nature of the study, produced gaze behaviour that they thought they should rather than what they usually do. It is possible that the children adopted a more socially desirable road-crossing behaviour than their natural road-crossing behaviour for the study as they were aware that their eye movements were being recorded. It would have been difficult to keep children naïve to the tracking of their eye movements as an eye tracker was fitted and calibrated, even if it would have been possible to deceive the children it is less likely that would be possible with the adults and as the gaze behaviour across the lifespan was compared it was necessary for all participants to be given the same information before crossing. However, it is unlikely that the children were attempting to adopt more socially desirable and less realistic gaze behaviour as they attended to irrelevant features more than any other category, although gaze fixations on traffic irrelevant features were only significantly higher than fixations on pedestrians.

To avoid the well-known “observer effect”, the true nature of the experiment could be hidden from the participants. Zeedyk *et al*. (2002) carefully set up an experiment with controlled traffic flow where children’s road-crossing behaviour was being recorded. The children were unaware of this and believed the purpose of their class trip was to participate in a treasure hunt. In the current study it may have been possible to inform participants that the purpose of the study is to see what they look at in a shop (one which roads must be crossed to get to). If the participants were unaware that their gaze behaviour at a road crossing was of interest to the experimenter it may be that more realistic behaviour was exhibited. All the participants claimed that they were comfortable with the eye tracker on and confirmed that they crossed the roads in this study as they normally would have, although there is no objective way that this can be confirmed.

### *3.5 Conclusions*

The aim of this study was to compare the gaze behaviour of children, younger adults and older adults at a signalised road crossing. It was hypothesised that differences observed between the groups may partially explain the differences in pedestrian accident rates for the different age groups. All of the participants in this study crossed the road safely without the need for the accompanying experimenter to intervene meaning that it is not possible to state with certainty that differences found in the gaze behaviour between the groups are contributing factors in pedestrian accidents. However there are good reasons to believe that certain behaviours such as fixating on the road and vehicles and directing gaze toward the direction of approaching vehicles are conducive to safe road crossing. For example failing to look properly for vehicles is the most frequently cited cause of pedestrian accidents (DfT, 2010a). In the present study children and older adults attended significantly less to the road and vehicles in the final 3 seconds before stepping into the road than younger adults did; adults are also less likely to be hit by a vehicle when crossing the road. Younger adults also fixated on the road and vehicles significantly more than traffic irrelevant features indicating that they are able to selectively attend to task-relevant information to the extent that irrelevant information is often unattended (Brockmole & Henderson, 2006).

Older adults fixated mostly on the walkway and before adjustments were made to the *p* value they fixated significantly more on the walkway than on the road and vehicles. This was probably a functional strategy aimed at reducing the risk of falling; this was also noted by Oxley *et al*. (1997). Children fixated mostly on non-traffic relevant features. Tolmie *et al*. (2005a) also noted that young children frequently attend to traffic irrelevant features at the roadside. Attending to irrelevant features may increase the risk of missing safe crossing opportunities. It is possible that attending mostly to the walkway or irrelevant features before crossing the road are both predisposing factors for pedestrian accidents. However, older adults' attention to the walkway appears to be functional, whereas children's attention to irrelevant information seem to have no functional purpose. Based on these findings subsequent studies will investigate the effects of cognitive load on children's gaze behaviour and also the effects of training interventions designed to improve their road-crossing behaviour.

## **CHAPTER 4**: THE EFFECTS OF ICE CREAM ON THE GAZE BEHAVIOUR OF CHILDREN AT A SIGNALISED ROAD CROSSING

The data from this study were presented at the Vision Sciences Society annual meeting under the title "The effects of a distractor on the visual gaze behaviour of children at signalised road crossings" (Egan *et al*., 2009).

### *4.1 Introduction*

Kingstone *et al*. (2008a) highlighted the importance of making real-world observations in order to generate theories of psychology that actually explain real-world behaviour. Here in this study observations made during the data collection of the previous Chapter 3 resulted in the generation of the hypothesis that children would fixate the road and vehicles less when presented with an ice cream. This hypothesis is tested here in the present study.

After the children had completed the road crossing in Chapter 3 they were rewarded for their participation with an ice cream. The children were again given the opportunity to decide when to cross the roads on the way back to school while they eat their ice cream. Two children had to be prevented from crossing as they selected unsafe crossing opportunities that mostly likely would have resulted in a pedestrian accident if the drivers of the approaching vehicles were unable to break quickly enough. Another child failed to cross when the ‘green man’ appeared on three consecutive traffic cycles. Using the cognitive ethology approach of forming theories and hypotheses through observing real-world behaviour, it was hypothesised that the presence of an ice cream would negatively affect children’s gaze behaviour at a road crossing. The protocol for the study in Chapter 3 was adapted to include going to the ice cream parlour after the initial road crossings and then repeating the route with an ice cream. Adults and older adults were also offered an ice cream for their participation, although only one adult accepted.

Real-world observations suggested that ice cream affected children’s road-crossing behaviour at the road outside the ice cream parlour. Traditional laboratory based research can also be used to support the hypothesis that children’s road crossing performance will be negatively affected when given an ice cream. However, it is difficult to classify the effects of giving children an ice cream in terms of traditional psychology paradigms. The children were rewarded with an ice cream and asked to cross the roads on the way back to school: the children were not given instructions as to whether they should or should not eat the ice cream at the road side. All data in this study is from children who consumed ice cream at the road crossing: the children that did not eat ice cream at the road crossing had already finished their ice cream before they arrived at the road crossing. This study could therefore be seen as a dual-task experiment as the children undertook two tasks simultaneously. However, the ice cream could also be considered a distractor since the children were not asked to consume ice cream. Some of the children also reported that their hands were cold from holding the ice cream which fits with the notion that the presence of the ice cream distracted the children.

Both the dual-task and distractor interpretation of the ice cream condition can lead to same hypothesis of ice cream having a negative effect on children's road-crossing behaviour. Previous studies have shown that the addition of a secondary task can have a negative effect on the performance of the primary task (Foley & Berch, 1997; Guttentag, 1989), other studies have shown that the presence of salient task irrelevant information can also have a negative effect on the performance of cognitive tasks, particularly in young children (Donnelly *et al*., 2007; Nardini *et al*., 2006). It is likely that ice cream had affected executive functions such as working memory.

Previous laboratory-based studies have noted children have sub-optimal executive functioning (Bedard *et al*., 2002; Dempster, 1992; Fuster, 1997; Span *et al*., 2004; West, 1996; see 1.4.1 *Executive function*) particularly tasks that require divided attention (Foley & Berch, 1997; Guttentag, 1989; see 1.4.3 *Dual-task performance*) and attentional control (Schiff & Knopf, 1985; Tagg, 1990, cited in Thomson *et al*., 1996; see 1.4.2 *Attentional control and visual search*). These functions are required when crossing the road and eating an ice cream. As eye movements can provide a powerful insight into attentional processes (e.g., Henderson, 2003) it is expected that gaze behaviour at a signalised road crossing will change with the introduction of an ice cream.

The process of consuming ice cream can be aided by visual information making eating the ice cream a spatial task. Many traditional studies have used non-spatial tasks to investigate the effects of cognitive load on primary task performance (e.g. Beauchet *et al*., 2007; Hollman *et al*., 2007; Lajoie *et al*., 1996; Van Iersel *et al*., 2007). Spatial and non-spatial working memory are associated with activation in different cortical areas in the prefrontal cortex (D'Esposito *et al*., 1998) and studies have reported that visual search tasks are affected by spatial working memory tasks and not by non-spatial working memory tasks (Oh & Kim, 2004). This suggests that spatial information of searched items is more crucial than non-spatial information when searching a predefined target object efficiently (Oh & Kim, 2004). However, this is not a universally accepted view. Some have suggested that visual search efficiency is not affected by a "full" visual working memory (Woodman *et al*., 2001). Anderson *et al*. (2008) compared the effects of spatial and non-spatial tasks on efficient and inefficient visual search tasks and concluded that they had a comparable negative effect on inefficient visual search and that efficient visual search was not affected by either spatial or non-spatial tasks. Anderson *et al*. (2008) proposed that inefficient search recruits working memory processes used in spatial and non-spatial tasks.

The different results and interpretations lend support for the notion that cognition is not invariant (Kingstone *et al*., 2008a) and differs depending in the specific context in which they occur (Clark, 2001). In this study the effects of a spatial task (eating an ice cream) on the gaze behaviour of children at a road crossing will be observed.

In Chapter 3, children and older adults attended less to vehicles before deciding it was safe to cross the road than adults did, supporting previous findings that young children make fewer head movements than adults and older children when viewing a real or simulated traffic environment (Whitebread and Neilson, 2000; Zeedyk *et al.*, 2002). Studying children's eye movements while they cross the road may provide clues about what information they use to guide their decisions about when it is safe to cross. In Chapter 3, before crossing a road, children directed 27% of gaze towards irrelevant features. Attending to irrelevant information may indicate poor attentional control or be representative of an immature search strategy that has not had enough the opportunity to develop.

To understand eye guidance it is important to study eye movements in the natural environment in which they occur (Tatler, 2009). Presenting the children with ice cream when crossing the road under natural conditions may elicit a different behaviour to that seen in the Chapter 3. This may improve our understanding of how cognitive processes are affected in the real world by realistic distractions. Often methods used in traditional experiments investigating aspects of executive functioning have little relevance to tasks that participants would actually do in real life (Burgess *et al.*, 1998) for example in real life it is unlikely that it would be necessary to respond to a series of questions with answers that relate to previously asked questions as is the case in the n-back test. While this "quasi-experimental" study lacks counter balanced conditions (the ice cream condition always occurred after the 'control' condition), real world behaviour is being observed and this may lead to the generation of theories that can help explain cognition and behaviour in natural settings (Kingstone *et al*., 2008a), specifically the effects of secondary spatial tasks in a dynamic environment.

### *4.1.1 Aim & predictions*

This study was created to further investigate children's gaze behaviour at a road crossing when given an ice cream. As two children made unsafe road-crossing decisions and had to prevented from crossing by the experimenter and another child missed the pedestrian crossing phase on three consecutive traffic cycles when given an ice cream it was hypothesised that the ice cream had a negative effect on children's ability to select safe crossing opportunities. This was expected to be evident in the gaze behaviour of children as they were expected to fixate less on the road and vehicles, and lights and signs when given an ice cream. It is not possible to discriminate potential cognitive loading effects of eating an ice cream from potentially distracting effects of a visually salient ice cream. Previous studies have noted that children's sub-optimal attentional control at the road side results in children attending to irrelevant features (Tolmie *et al*., 2005a) or failing to look in the direction of oncoming traffic (Zeedyk *et al*., 2002). It is hypothesised that either or both the additional cognitive load of eating an ice cream or the visually distracting presence of the ice-cream will result in children directing their attention towards traffic irrelevant information more when they are presented with an ice cream and searching the environment less systematically resulting in more fixations in the central direction and fewer in the directions of oncoming vehicles.

## *4.2 Methods*

### *4.2.1 Participants*

Data from nine children (five males, four females) (*M* = 8.9, *SD* = 0.3 years), who took part in Chapter 3 are presented in this study. All the children who participated in this study received an ice cream for their participation: however, data from only nine children post-ice cream were recorded at the same crossing used in Chapter 3 as originally the children were not taken back to the crossing as the study in Chapter 4 had not been conceived when study in Chapter 3 began. Data sets were also lost due to the children either getting ice cream on the reflective lens of the eye tracker or the eye tracker slipping. Also, some of the children had eaten the ice cream before they arrived at the road crossing.

### *4.2.2 Design*

This study was not conventionally designed. However, it used a repeated measures design. The independent variable was the presence of ice-cream (not present or present). The dependent variables were the percentage of fixations on categories and directions in the final 3 seconds before crossing.

### *4.2.3 Procedure*

After the study in Chapter 3 had been completed, children were presented with an ice cream of their choice. The ice cream was in a tub (children were initially offered the choice of a cone or a tub, but the cone often resulted in children getting ice cream on the eye tracker), and children continued to eat it as they crossed the road (the same road, in the same direction as in Chapter 3) on the way back to school. The data for the ice cream free condition are part of the data used in Chapter 3. This data from Chapter 3 is compared with the gaze fixation data during the ice cream condition.

The decision to analyse the data from these studies came after the data had been collected in Chapter 3. For this reason, the order of conditions were not counterbalanced (the ice cream task always came after the ice cream free task), and the study lacked an appropriate experimental control; results must therefore be interpreted with caution.

*4.2.4 Data analysis*

After coding the data to the criteria discussed in general methods; fixations that occurred on the ice cream were coded as 'ice cream' and grouped in the non-traffic relevant category: creating a separate category for ice cream seemed unnecessary as it would not be possible to compare fixations between the two conditions as ice cream was not present in the first crossing. A Shapiro Wilk test revealed no matched data sets that met the assumptions required for parametric test (even after attempts to transform the data). As all the data sets required non-parametric statistical tests a series of Wilcoxon tests were applied to determine statistical differences between the non-parametrical data relating to proportion of total time fixating either object or location based categories from the two conditions.

Friedman's Analysis of variance by ranks statistical tests were used to determine statistical differences between percentage of fixations on categories and in the percentage of general gaze directions. Friedman's pairwise comparisons were used to identify between which categories statistical differences were found.

## *4.3 Results*

In general, children fixated all traffic-relevant features (road, walkway, traffic lights and signs) slightly less often during the ice cream condition compared with the ice-cream free condition (see Figure 4.1). However, Wilcoxon signed rank tests revealed no significant effect of ice cream in the percentage of fixation on the road and vehicles (Z=0; $p$=15; $d$=0.03); pedestrians (Z=-0.365; $p$=0.715; $d$=0.16); walkway (Z=-0.415; $p$=0.678; $d$=0.15); lights and signs (Z=-1.599; $p$=0.11; $d$=0.55); non-traffic relevant (Z=1.481; $p$=0.139; $d$=0.54). Children fixated more in the centre and less to the left and right when given an ice cream (see Figure 4.2). In fact, children's general gaze direction was significantly more in the centre ($M$=79%) than in control condition ($M$=62%) (Z=-1.96; $p$=0.05; $d$=0.6.1). Although the sum of fixations to the left and right showed that children fixated less in the directions of oncoming traffic when presented with an ice cream, statistical analysis on the individual components (fixations to the right and fixations to the left) revealed no significant effects of gaze fixations to the right (Z=-1.014; $p$=0.310; $d$=0.48) or left (Z=-1.483; $p$=0.138; $d$=0.4) as a result of the ice cream.

Friedman's Analysis of variance by ranks revealed no significant differences between the percentage of fixations on categories in the ice cream free condition ($\chi^2_{(4)}$=6.588;

$p$=0.159; $\eta^2$=1.647) or in the percentage of general gaze directions ($\chi^2_{(2)}$=4.514; $p$=0.105; $\eta^2$=2.257). Significant differences were noted between the percentage of fixations on categories in the distractor condition ($\chi^2_{(4)}$=12.93; $p$=0.012; $\eta^2$=3.233) and in the percentage of general gaze directions ($\chi^2_{(2)}$=7.548; $p$=0.023; $\eta^2$=3.774). Pairwise comparisons revealed that when presented with an ice cream, children fixated more on the traffic irrelevant features more than pedestrians ($\chi^2_{(1)}$=-3.28; $p$=0.01; $d$=1.61). They also fixated in the centre significantly more than to the left ($\chi^2_{(1)}$=2.475; $p$=0.04; $d$=2.96). No other significant differences were observed after the adjusting the $p$ values to accommodate for the multiple test ($p$>0.05).

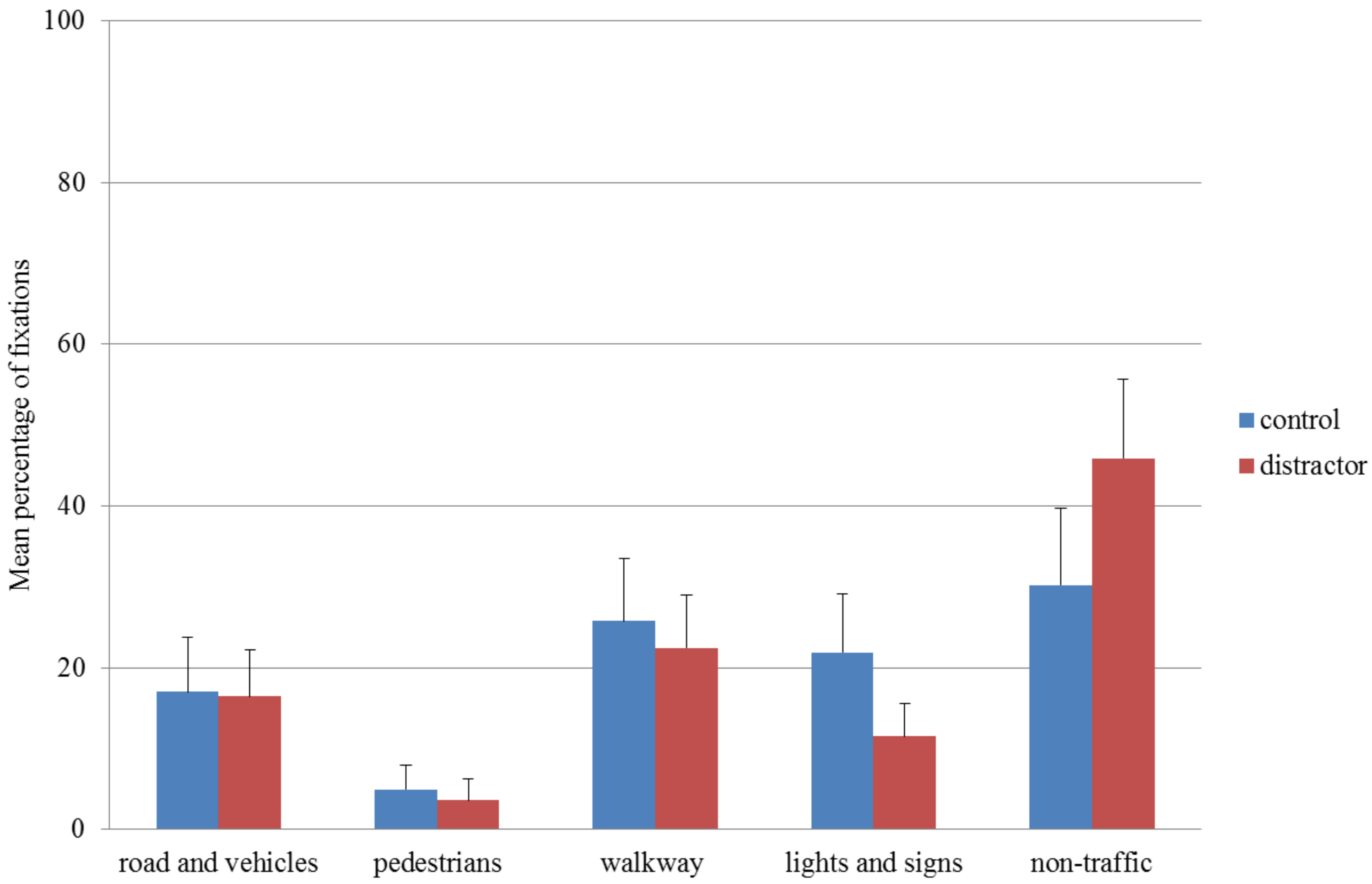


Figure 4.1. The mean percentage of gaze fixations on object-based categories by children with and without an ice cream at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

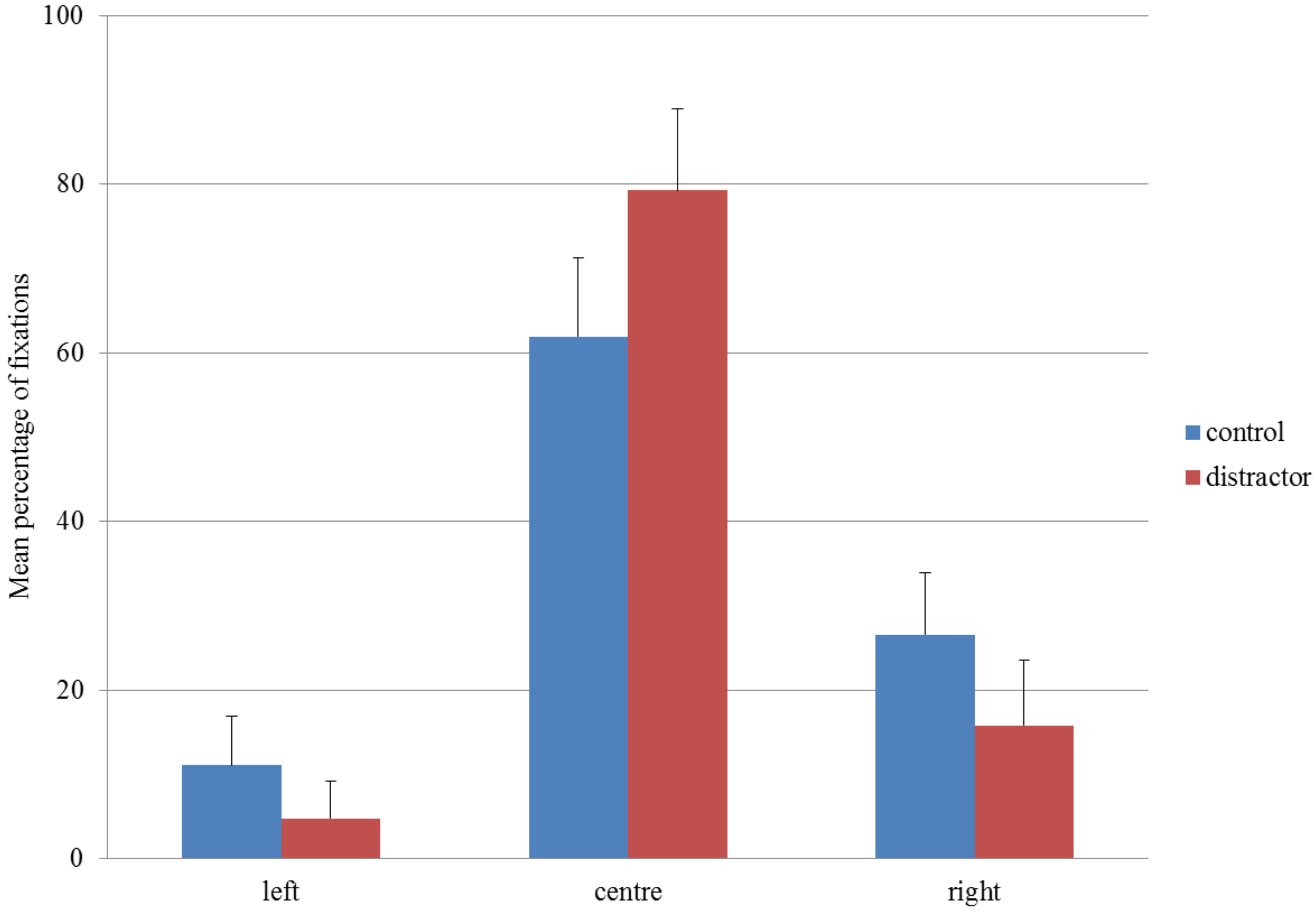


Figure 4.2. The mean percentage of gaze fixations in each direction by children with and without an ice cream at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

## *4.4 Discussion*

Based on observations made when children attempted to cross the road with an ice cream it was hypothesised that when presented with ice cream, children would fixate the road and vehicles, and lights and signs less and traffic irrelevant features more compared to when they did not have an ice cream. The children were also expected to look to the directions of oncoming traffic less during the ice cream condition than in the ice cream free condition. Subsequent analyses revealed that children did not gaze significantly less at the road and vehicles, or the traffic lights. No significant differences were found in terms of fixations to traffic irrelevant features, even though this category including the ice cream. However, they did direct their gaze significantly more towards the centre and less to the directions of oncoming traffic when presented with an ice cream. By focussing their gaze more in the central visual field the children attended less to the directions that traffic is likely to come from before crossing the road which may increase the number of missed safe crossing opportunities and the risk of being involved in a pedestrian accident. Making fewer looks to the left and right before deciding to cross was a trait of the youngest group of children in the Whitebread and Neilson (2000) study. The potentially debilitative effect the ice cream had on the gaze behaviour of children at a road crossing could be used to support findings from studies that reported children's reduced ability to prioritise the most important information to the task at hand (Allen *et al*., 1979; Tagg, 1990, cited in Thomson *et al*., 1996; Tolmie *et al*., 2005a; see 1.4.2 *Attentional control and visual search*). However it could be argued that children considered eating the ice cream as an additional task and divide their attention between the two tasks. Regardless, children fixated less to the direction of approaching traffic when they were presented with a task irrelevant to crossing the road and this may partially explain why in 72% of children pedestrian accidents the children failed to look properly before crossing the road (DfT, 2010a).

Although a number of studies have found that performance on a primary task is negatively affected by the demands of a secondary task in laboratory tasks (Beauchet *et al.*, 2005; Beauchet *et al.*, 2007; Hollman *et al.*, 2007; Van Iersel *et al.*, 2007), the study of a naturally occurring, realistic secondary task on gaze behaviour during real world tasks has rarely (if ever) been studied. The ice cream provides an optional secondary task that can be aided with visual attention and changes in gaze behaviour as a result of the introduction of the ice cream may be due to the participants attending to the ice cream to aid the secondary task rather than being indicative of the attentional system being overloaded by a secondary task. The effects of a secondary task that does not require visual attention on the gaze behaviour of children at a simulated road crossing are investigated in Chapter 6. It is clear that when given an ice cream, children's general gaze direction is aimed towards the centre even more.

The road and vehicles and the lights and signs present the most useful source of information when deciding to cross the road; it is interesting that children attended to these less than traffic irrelevant features when presented with an ice cream. However, the statistical significance of these differences did not survive the adjustment of the $p$ value for multiple tests the large effect sizes noted ($d$>1) suggests that they may be meaningful; a *post-hoc* power analyses indicated that a sample size of 14 would be enough to find significant differences after the adjustment for multiple tests.

Children spent less time looking in the direction of oncoming traffic before crossing when presented with a distractor, this indicates some attentional control is exerted over their search strategy under normal conditions. It has not been possible to attribute children's less developed gaze behaviour to a lack of experience or lesser cognitive capabilities, although a combination of these two factors seem plausible. It has also not been possible to discriminate the role of ice cream as a secondary task or a potent distractor. However, it is clear that children spend less time fixating in the directions of oncoming vehicles when given an ice cream and this may potentially predispose them to pedestrian accidents as failing to look for vehicles before crossing the road is cited as the number one contributing factor in pedestrian accidents (DfT, 2010b).

Due to the unbalanced conditions (the ice cream free condition always preceded the ice cream condition) it is possible that changes in gaze behaviour noted in the ice cream condition were not solely the result of eating ice cream and may be due to either a learning effect as the children had previously crossed the road or change in behaviour as the children became accustomed to wearing the eye tracker or a combination of these factors. Even though the children are relatively inexperienced compared to adults at crossing the road, given that the road crossing was familiar to all the participants and in a very familiar environment (close to their school), it is unlikely that children's gaze behaviour at a road crossing would change as the result of one extra road crossing experience.

The increase in fixations towards the centre may be to aid the secondary task rather than being indicative of the attentional system being overloaded by a secondary task. There is evidence to suggest that spatial and non-spatial tasks affect visual search performance differently (Oh & Kim, 2004). A non-spatial secondary task such a counting (although less realistic) may improve our understanding of the effects of a secondary task on gaze behaviour during real-world active tasks.

### *4.5 Conclusion*

The present findings suggest that children's attention can be diverted away from areas where oncoming vehicles may be approaching with potent distractors like ice cream. Reducing the percentage of time fixating in the direction of oncoming traffic, as the children did when presented with an ice cream, may potentially predispose them to pedestrian accidents as failing to look for vehicles before crossing the road is cited as the number one contributing factor in pedestrian accidents (DfT, 2010b). The results reported here suggest that eye movements can provide important clues about what visual information children use when deciding to cross the road. Training children to display a more appropriate search strategy before crossing the road may reduce their risk of pedestrian accidents. In the next study the effects of training tools aimed at promoting safe behaviour at the road side on children's gaze behaviour at signalised road crossings will be investigated.

# **CHAPTER 5**: THE EFFECTS OF TRAINING INTERVENTIONS ON CHILDREN'S GAZE BEHAVIOUR AT A SIGNALISED ROAD CROSSING.

## *5.1 Introduction*

The previous studies have shown that children look less at vehicles before crossing the road than do adults. They also make fewer eye movements to the directions in which traffic may be approaching when presented with a secondary task such as eating an ice cream (see 4.3 *Results*). It is possible that children's gaze behaviour may be a result of a lesser ability to ignore task irrelevant features or due to a lack of experience in road crossing resulting in little opportunity to develop mature gaze behaviour. Fixating less in the direction of oncoming vehicles before stepping on to the road probably increases the risk of being involved in a pedestrian accident. As children are involved in a greater number of accidents and the previous studies in this thesis have identified key differences between the gaze behaviour of children and adults, improvements in road-crossing behaviour as a result of training may be observed through the study of gaze behaviour.

In this chapter the effectiveness of two CD-ROM based training devices on the gaze behaviour of children at signalised road crossings will be compared. One training device aims at improving children's behaviour at road crossings through the use of virtual reality and the other aims to promote safety at road crossings (as well as general safety) through the use of classroom-based methods, such as informing children what they should do in certain situations.

*5.1.1 Training*

Given the fact that pedestrian accidents are the leading cause of accidental death for children in many developed countries (Thomson *et al*., 1996; see 1.1 *Pedestrian Accidents*), it is not surprising that many training tools, such as the Green Cross Code and the Arrive Alive scheme, have been developed with the aim of improving the road-crossing behaviour of children. Previous studies have looked at the effects of training on road-crossing behaviour (Thomson *et al*., 2005; Zeedyk & Wallace, 2003; see 1.7 *Training/adapting gaze behaviour*). The effectiveness of these training programs has often been assessed through the use of checklists to evaluate children's performance at the road crossing (see Bart *et al*., 2008 for example of a checklist). The checklist can produce a reasonably detailed account of what children did at the road side, but in terms of children's looking behaviour, it is limited to the general gaze direction and it is not possible by observing children to determine what they are fixating on. The study of gaze behaviour at the road crossing may provide evidence of the effectiveness of the training programmes as gaze fixations are strongly linked with future actions (Land, 2009; Tatler, 2009) and are indicative of the state of the attentional system (Henderson, 2003). Chapter 5 will be the first study to compare the effects of training on the gaze behaviour of children at road crossings.

Many of the training programs designed to improve the road-crossing skills of children that have been evaluated fit roughly into two categories: traditional learning materials aimed at improving children's knowledge of road crossing and most recently virtual reality (VR) games.

One example of a traditional training device currently used in some schools in the UK is the Safety Watch CD Rom. This program aims to improve children's (aged 6-11 years) knowledge of safety with the use of instructions on how to behave in specific situation, such as stopping before crossing the road and looking in both directions, through written instructions or a short cartoon and can be used on a computer at home or at school. The theory behind such programs is that telling children what they should do will increase their knowledge of what is appropriate behaviour when crossing the road. Studies that have used traditional learning techniques have noted improvements in children's theoretical knowledge of road safety. However, these did not lead to an improvement in actual road-crossing behaviour (Padgett, 1975; Zeedyk *et al*., 2002). The children in these studies knew what they should be doing at the roadside but did not apply this theoretical knowledge into practice. The lack of improvement in road-crossing behaviour following this sort of training is possibly due to children not being given the opportunity to actively practise the skills they were instructed on how to perform.

In the past eight years virtual reality (VR) games have been used as a tool to improve the road-crossing skills of children. Typically these VR games are bespoke computer programs that require children to guide an avatar safely across a road (the term VR should not be confused with fully immersive virtual reality that requires a helmet and powerful computer). One example of a virtual reality program currently used by some schools in the UK is Crossroads, developed by psychologists at Strathclyde University and freely available in the UK. The Crossroads program is designed to direct children's attention to important areas of the traffic environment and present children with the opportunity to practise skills required at actual road crossings such as switching attention, selectively attending to the most pertinent sources of information and predicting the actions of drivers (Tolmie *et al*., 2005b). Generally studies that have used VR training (Bart *et al*., 2008; Goldsmith, 2008; McComas *et al*., 2002; Thomson *et al*., 2005; Tolmie, *et al*., 1998; Tolmie *et al*., 2005a) report some improvements (such as reporting more traffic relevant information at the road crossing or an increased prevalence of pressing the pedestrian crossing button) in road side behaviour.

Studies that have examined the effects of training on the road side behaviour of children have reported contradictory findings. These contradictory findings may be a result of the training materials, the methods of the intervention, the age of the children, the amount of time that has passed since the intervention took place, the way in which road crossing performance was assessed (e.g., self-report, via a checklist, or more objective observations at road crossings) and many other factors. Making comparisons between different studies and training tools is difficult as few studies have directly compared the use of one training tool against another (Wright, 2010) with most studies implementing a control group and one intervention group, but studies that use VR interventions often report improvement in road-crossing behaviour (Wright, 2010) whereas studies that have investigated instruction based interventions often fail to improve actual road-crossing behaviour (e.g., Zeedyk & Wallace, 2003). Other studies that have investigated the effects of training, particularly VR and road side instructions have noted improvements in children's road-crossing behaviour. Bart *et al*. (2008) suggest that training programs that use VR can improve the looking behaviour (determined by head movements) and road side behaviour of children when crossing actual roads. Studies using traditional methods, similar to the activities in the Safety Watch programme, often fail to produce improvements in actual road-crossing behaviour (Zeedyk *et al*., 2002). The interactive nature of the VR based training tools allow children to practise important skills (such as judging safe gaps in traffic and actively looking towards areas where vehicles may be approaching from) necessary for actual road crossing with from the safety of their own home. It is interesting to note that even though the VR programmes are designed to guide children towards appropriate road-crossing behaviours Thomson *et al*. (2005) noted that the Crossroads CD-ROM was most effective when accompanied by adult-led discussions. With training tools that use more traditional teaching methods, where children are told what to do at the road crossings, there is no opportunity to practise these skills in a safe environment.

In this chapter, the effects of training with the Crossroads (VR based) and Safety Watch (instruction based) programmes on gaze behaviour at signalised road crossing are examined. These particular training programs were chosen as they are similar in terms of how they are accessed; they are both CD-ROMs that require children to sit in front of a computer and can be done at home and are sufficiently user friendly that the children will be able to complete the activities independently. These two training programs are also free and widely available to UK residents and are currently in use in some schools in the UK, although they are not part of any school curriculum and none of the participants were familiar with the training programs before the experiment began.

To the author's knowledge, no study to date has examined the effects of training on the gaze behaviour of children at road crossings. As gaze fixation is often linked with what information is being attended, the collection of gaze data when assessing interventions aimed at improving the road-crossing behaviour of children should provide important information as to the effectiveness of the intervention. In this experiment the effects of VR and traditional teaching methods on the gaze behaviour of children are examined.

*5.1.2 Aim & predictions*

The aim of this study was to evaluate the effect of training interventions on children's gaze behaviour at a signalised road crossing. It was hypothesised that training with the Crossroads intervention would develop cognitive skills such as attentional control and working memory as irrelevant information must be ignored and numerous moving objects required attention to make safe road-crossing decision in the Crossroads tasks (Tolmie *et al.*, 2005b). Improvements in these cognitive abilities were expected to be evident in children's gaze behaviour at the road crossing by increasing the percentage of fixations towards the road and vehicles and the direction of oncoming vehicles while also decreasing the percentage of fixations towards non-traffic relevant features such as buildings and the sky. It was also hypothesised that training with the Safety Watch intervention would be less effective at improving children's gaze behaviour as it did not provide children with the opportunity to develop active skills needed when road crossing actual roads: such as searching for and selecting safe crossing opportunities. The Safety Watch intervention provided instructions on how to behave at the road crossings and other studies investigating similar techniques have found no improvement in road-crossing behaviour (Padgett, 1975; Zeedyk & Wallace, 2003).

## 5.2 Methods

### 5.2.1 Participants

For this study, 30 children were recruited and randomly assigned to one of three groups. A combination of factors detailed in the Chapter 6 resulted in the data from a selection of the participants being unusable. After extensive data loss due to sunlight, the eye tracker slipping and other factors highlighted in Chapter 4 more children were recruited the following year and assigned to the group with the lowest number of complete data sets. One child that was initially assigned to the Crossroads group was placed in the control group because the participant had not attempted any of the tasks as the CD-ROM would not play on a MacBook computer. Data from 18 children ($M$= 8.8 $SD$= 0.4 years) is presented in this study. Each group consisted of six children.

### 5.2.2 Design

This study used a three (groups) x two (pre/post) mixed design. The independent variables were type of training intervention (VR-based “Crossroads”, instruction-based “Safety Watch” and nothing, to act as a control) and time of testing (pre/post training). The dependent variables were the percentage of time participants spent fixating object-based and location-based categories.

*5.2.3 Procedure*

The mobile eye tracker was fitted and calibrated as explained in the general methods section. The participants were taken to the road crossings and asked to imagine that they were not wearing the eye tracker and to cross the road as they normally would when it was safe to do so (see 2.5 *Procedure*).

After completing the road crossing, the children were accompanied to the school and subsequently assigned to either the “control” group, or the “Safety Watch” or “Crossroads” intervention groups at random by pulling the appropriate CD from a bag.

*5.2.4 Crossroads*

The Crossroads CD is part of a larger road safety training programme that includes adult-led group discussions. The children in this study were required to take the CD home and complete the road crossing games which included predicting drivers actions (see Figure 5.1), selecting safe gaps to cross the road (see Figure 5.2) and looking at areas where traffic would approach from before crossing (see Figures 5.3, 5.4 and 5.5). Figures 5.3, 5.4 and 5.5 give a sample of the kind of visual information and tasks that children in the Crossroads group encountered. In this experiment no adult or peer led group discussions took place because it allowed for direct comparison between the Safety Watch intervention. Time and resource constraints also made the implementation of group discussion prohibitive.


Figure 5.1. Still from the Crossroads intervention requiring children to predict a driver's actions. Here, the child views a short traffic sequence and the footage freezes, at this point the child must decide whether to cross (by clicking on the walking icon) or to wait (by clicking on the icon depicting a child standing still). To do this the children must predict which direction the red car will turn.


Figure 5.2. Still from the Crossroads intervention requiring children to select a safe crossing opportunity. Here, vehicles are constantly approaching from both directions and the child must select a safe gap in the traffic and then press the walk icon.


Figure 5.3. Still from the Crossroads intervention requiring children to look in the direction of oncoming traffic before crossing. Here, the child is able to control the avatar's walking and looking direction. If the child does not look at least twice to the right or once to the left before crossing, a vehicle will appear from that side while the avatar crosses causing an accident.

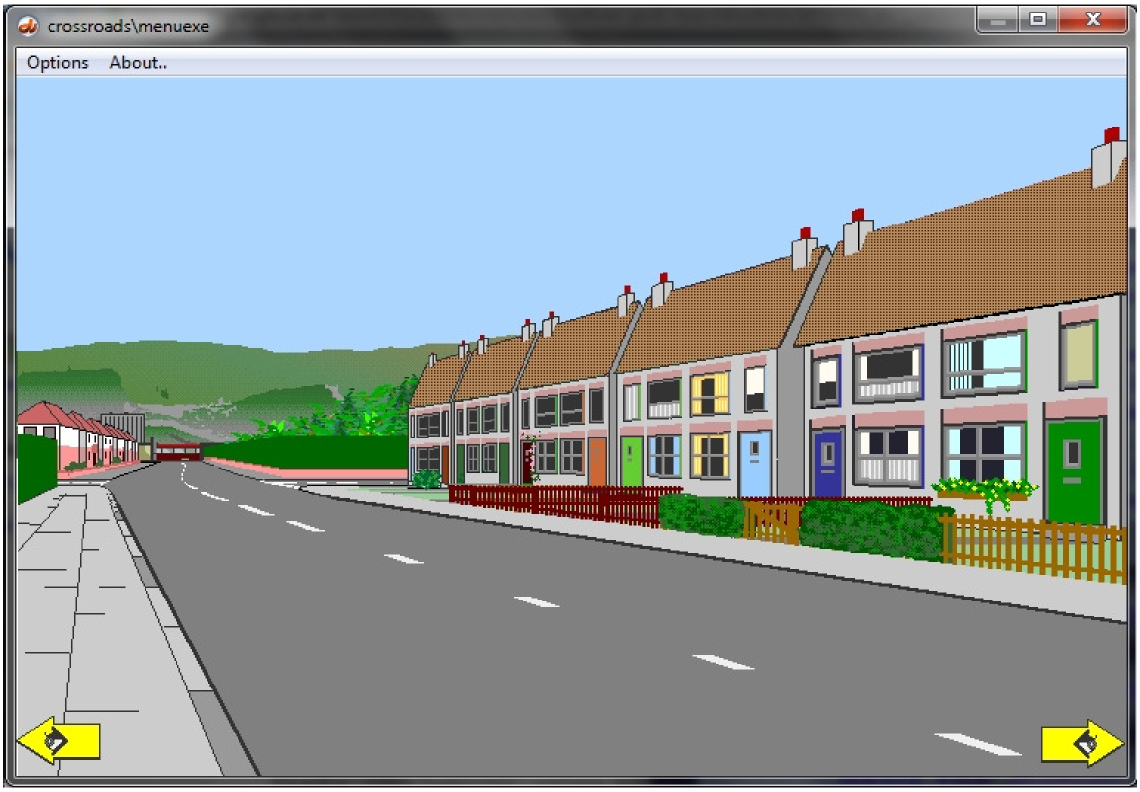


Figure 5.4. Still from the Crossroads intervention requiring children to look in the direction of oncoming traffic before crossing. Here, the view point of the avatar can be seen when the child has clicked on the look left icon.

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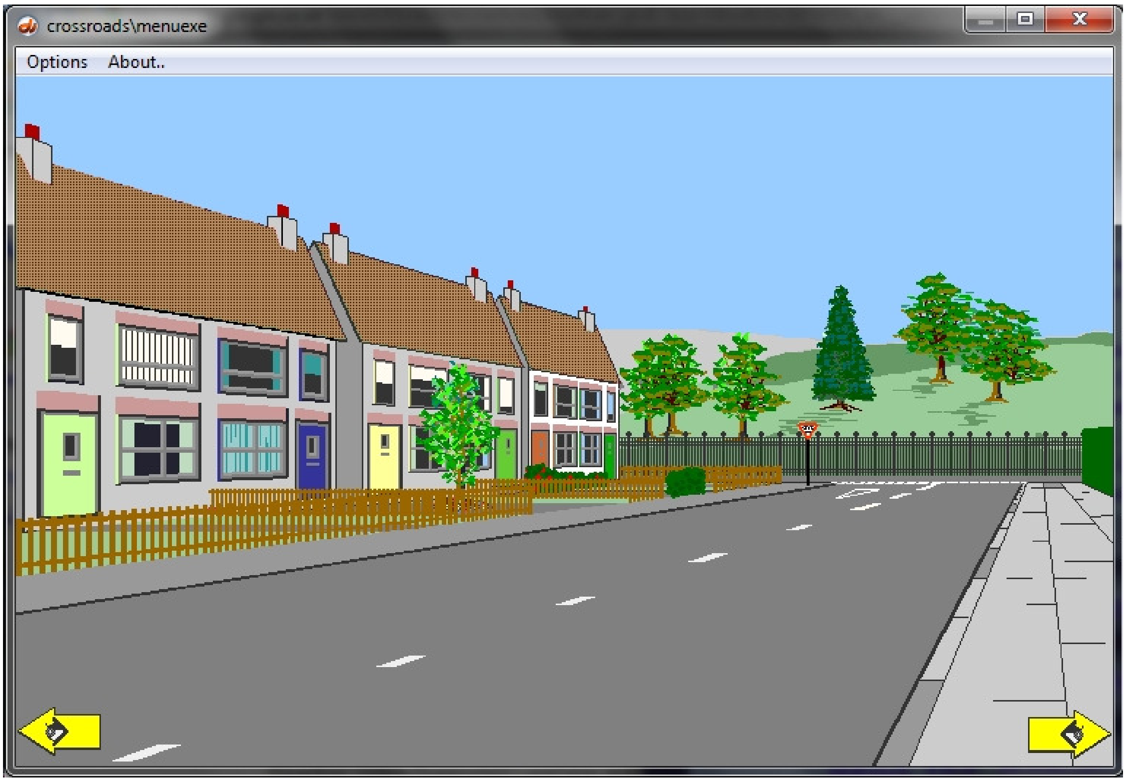



Figure 5.5. Still from the Crossroads intervention requiring children to look in the direction of oncoming traffic before crossing. Here, the view point of the avatar can be seen when the child has clicked on the look right icon.

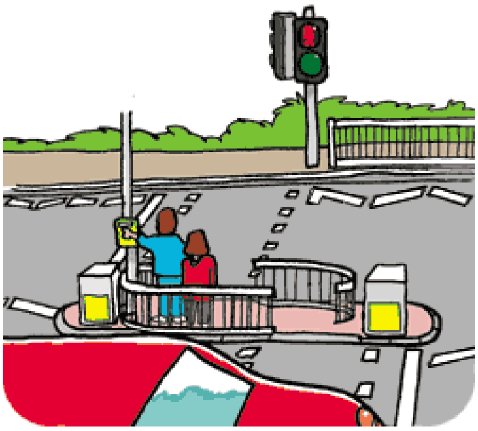
*5.2.5 Safety Watch*

The Safety Watch CD-ROM contains various materials aimed at improving awareness of dangers and the promotion of safe behaviour, including that during road crossing. Some of these materials are specifically aimed at improving road side behaviour, such as a list of appropriate and inappropriate road side behaviours (se Figure 5.6), a picture of pedestrians crossing the road that can be coloured in (see Figure 5.7), and a video of children behaving unsafely at the road side (see Figure 5.8). Other activities are aimed at highlighting other dangers, such as those relating to the use of electricity, and talking to strangers. None of the activities require any kind of interaction beyond selecting areas of picture that need to be coloured in.

The children assigned to the Crossroads and Safety Watch groups were asked to complete all the tasks and activities on the CD-ROM in the next five weeks, when the post-intervention data were collected. As a manipulation check the children were asked if they had completed all the tasks on the CD and given follow up questions regarding the activities, the names of the children avatar, who sang the song etc. This indicated that children were familiar with the tasks on the CD but gave no indication as to the children's proficiency on the tasks. There were no instructions as to how the children should manage their time regarding the completion of the tasks on the CD and no data was collected regarding this. The children were required to complete all activities before the second round of data collection began. The same procedure for collecting gaze data was undertaken five weeks after the initial pre intervention data collection.

## USING A CROSSING WITH TRAFFIC LIGHTS

**Some pedestrian crossings have a red and a green man either opposite or above the push button.**



Push the button and wait where you can see the signal and the traffic.

Once the green man shows and the traffic has stopped you can start to cross. There may be a **bleeper** sound at this time. You should still keep looking for traffic while you cross.

Do not start to cross if the **green** man is not showing. When the **green** man disappears there could be:

- A flashing **green** man
- A **red** man signal
- No signal

Figure 5.6. Using a crossing with traffic lights. This image is taken from the Safety Watch intervention. Here, written instructions are provided on what to do at a signalised crossing

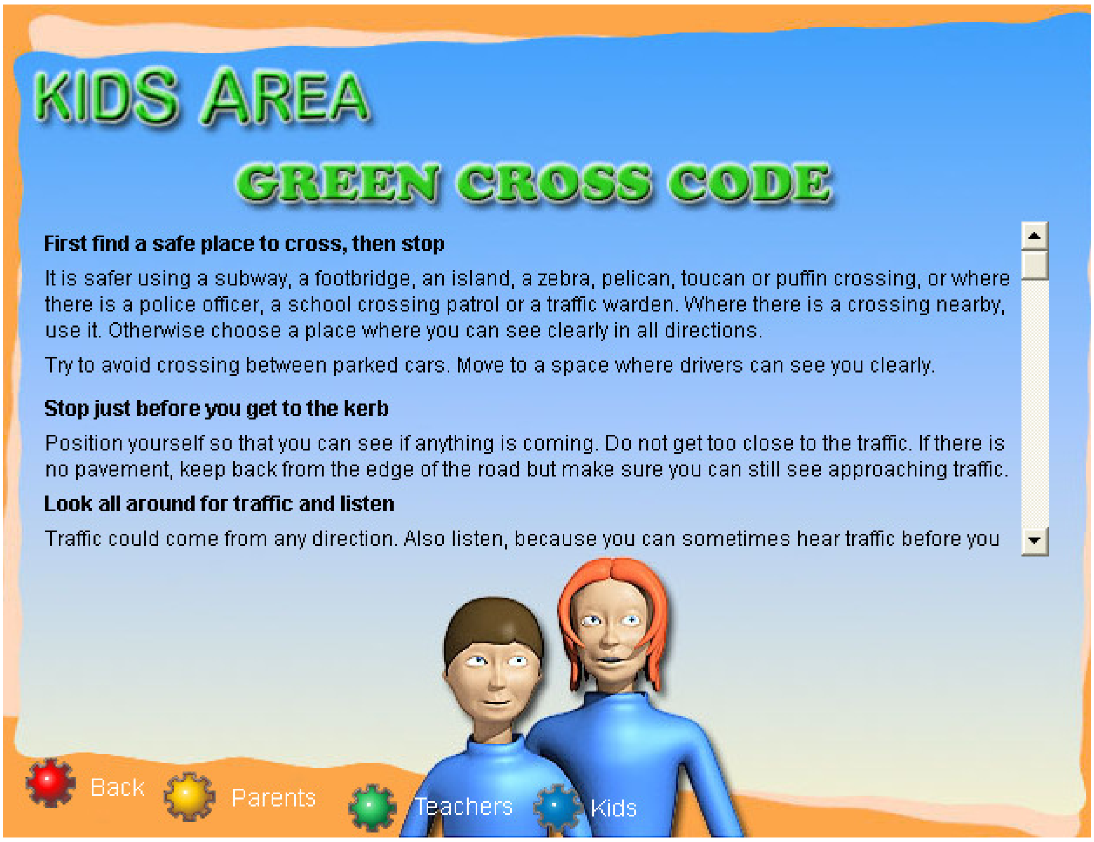



Figure 5.7. The Green Cross Code. This image is taken from the Safety Watch intervention and provides instructions on what to do before crossing the road.

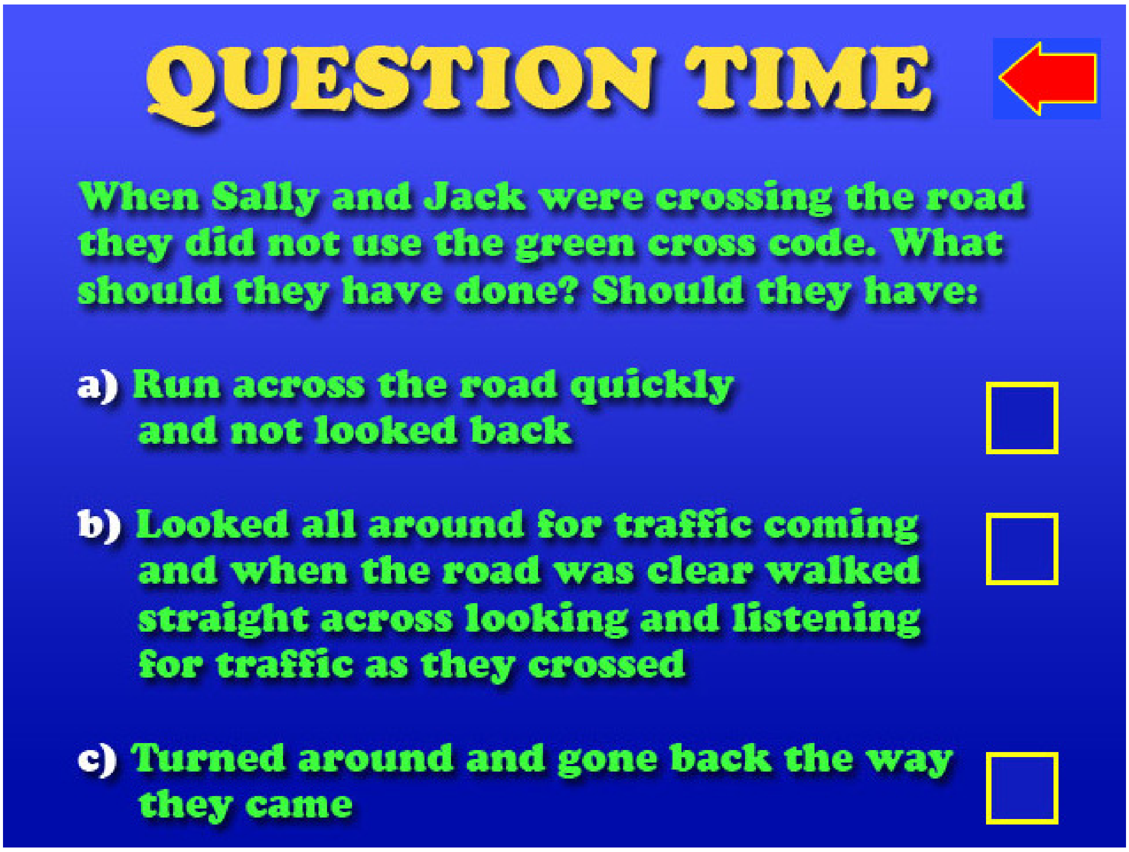



Figure 5.8. Question time. This image is taken from the Safety Watch intervention. Here, the children must answer questions on road safety after watching a short animated clip.

### *5.2.6 Data analysis*

After coding the data to the criteria discussed in general methods a Shapiro Wilk test was carried out to determine the suitability of the data for parametric tests. The Shapiro Wilk tests revealed that the percentage of fixations on the road and vehicles and in the centre from the Crossroads group in the pre-intervention condition was normally distributed as were the fixations on walkway in the control group during the "pre"-test. As no matched data sets met the assumptions required for parametric tests (even after attempts to transform the data), Wilcoxon signed rank tests were used to determine statistically significant differences between the percentages of fixations on object or location based categories from the two conditions (pre and post intervention). A Kruskal-Wallis test was carried out to determine statistically significant differences between the three intervention groups in terms of the change in fixation data from pre to post intervention. *Post-hoc* Mann-Whitney $U$ tests were used to determine which groups were statistically different from each other. The $p$ values were multiplied by three (the number of Mann-Whitney $U$ tests for each follow up to the Kruskal-Wallis test) to adjust for multiple test.

## *5.3 Results*

In this section the pre and post intervention fixation data are compared in each condition. Finally, between group comparisons are made.

### *5.3.1 Gaze behaviour before and after the VR-based "Crossroads" intervention*

Multiple Wilcoxon Signed Rank tests were used to compare the pre and post fixation data for each object-based and location-based category. The tests revealed no significant effect of training with Crossroads (see Figure 5.9) in the percentage of time fixating the road and vehicles ($Z=-0.943$; $p=0.345$; $d=0.51$); pedestrians ($Z=-1$; $p=0.317$); walkway ($Z=-1.572$; $p=0.116$; $d=0.92$); lights and signs ($Z=0.734$; $p=0.463$; $d=0.21$); non-traffic relevant ($Z=0.943$; $p=0.345$; $d=0.66$) or in the percentage of fixations in general gaze direction (see Figure 5.10) to the centre ($Z=1.214$; $p=0.225$; $d=0.2$); right ($Z=-0.405$; $p=0.686$; $d=0.2$); and left ($Z=-1.604$; $p=0.109$; $d=0.58$).

### *5.3.2 Gaze behaviour before and after the instruction-based "Safety Watch" intervention.*

Again, no significant differences before and after training were observed in terms of the percentage of time fixating the road and vehicles ($Z=-1.214$; $p=0.225$; $d=0.84$); pedestrians ($Z=-0.535$; $p=0.593$; $d=0.14$); walkway ($Z=-0.934$; $p=0.345$; $d=0.85$); lights and signs ($Z=1.153$; $p=0.249$; $d=0.8$); non-traffic relevant ($Z=0.105$; $p=0.917$; $d=0.03$); see Figure 5.11. Similarly, there were no differences in general gaze direction (see

Figure 5.12) in the centre (Z=1.483; $p$=0.138; $d$=0.89); right (Z=0.674; $p$=0.5; $d$=0.17) and left (Z=-1.214; $p$=0.225; $d$=0.9).

### *5.3.3 Control group*

The children in the control group directed their gaze towards the lights and signs (Z=-2.023; $p$=0.043; $d$=1.22) less in the 'post' test (see Figure 5.13). No other significant differences were noted between the two data collection sessions in terms of gaze direction towards the road and vehicles (Z=-1.826; $p$=0.068; $d$=0.92); pedestrians (Z=0.674; $p$=0.5; $d$=0.41); walkway (Z=-0.943; $p$=0.405; $d$=0.4); non-traffic relevant (Z=-0.674; $p$=0.5; $d$=0.14; or in general gaze direction (see Figure 5.14) towards the centre (Z=1.483; $p$=0.138; $d$=1.11); right (Z=-1.483; $p$=0.138; $d$=0.56); and left (Z=-1.342; $p$=0.18; $d$=0.6).

### *5.3.4 Between group comparisons*

The gaze fixation and general gaze direction of children at a signalised road crossing before and after the Crossroads (see Figures 5.9 and 5.10) and Safety Watch (see 5.11 and 5.12) intervention and the equivalent data from the control conditions (see Table 5.13) revealed no benefits of the interventions. A Kruskal-Wallis test was run on the changes between the pre and post intervention data (see Table 5.1). No significant differences were found between the groups for percentage for gaze fixations in any category; roads and vehicles ($\chi^2_{(2)}$=0.106; $p$=0.948; $\eta^2$=0.053), pedestrians ($\chi^2_{(2)}$=0.694; $p$=0.707; $\eta^2$=0.347), walkway ($\chi^2_{(2)}$=2.751; $p$=0.253; $\eta^2$=1.376), lights and signs ($\chi^2_{(2)}$=3.22; $p$=0.2; $\eta^2$=1.61) and non-traffic relevant features ($\chi^2_{(2)}$=1.162; $p$=0.559;

$\eta^2$=0.581), general gaze direction towards the centre ($\chi^2_{(2)}$=0.976; $p$=0.614; $\eta^2$=0.488), right ($\chi^2_{(2)}$=2.143; $p$=0.343; $\eta^2$=1.072) and left ($\chi^2_{(2)}$=0.331; $p$=0.848; $\eta^2$=0.166).

A Kruskal-Wallis test showed significant differences between the pre-intervention groups in terms of gaze direction to pedestrians ($\chi^2_{(2)}$=8.313; $p$=0.016; $\eta^2$=4.157). *Post-hoc* Mann-Whitney $U$ tests revealed that the control group fixated more on pedestrians than the Crossroads group ($U$=3.5; $p$=0.013; $d$=1.3) and the Safety Watch group ($U$=5; $p$=0.031; $d$=1.23).

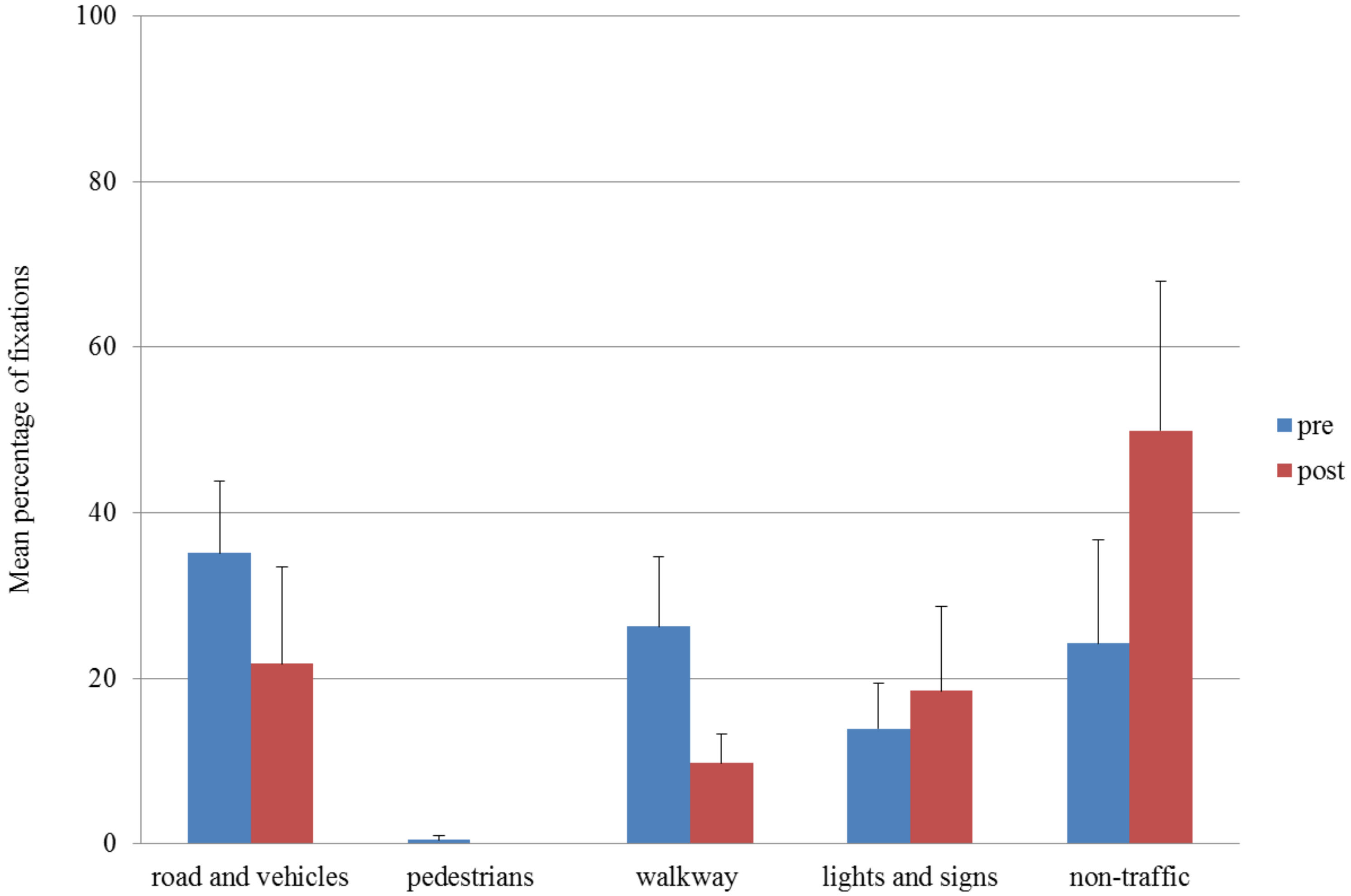



Figure 5.9. The mean percentage of gaze fixations on object-based categories by children in the Crossroads group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

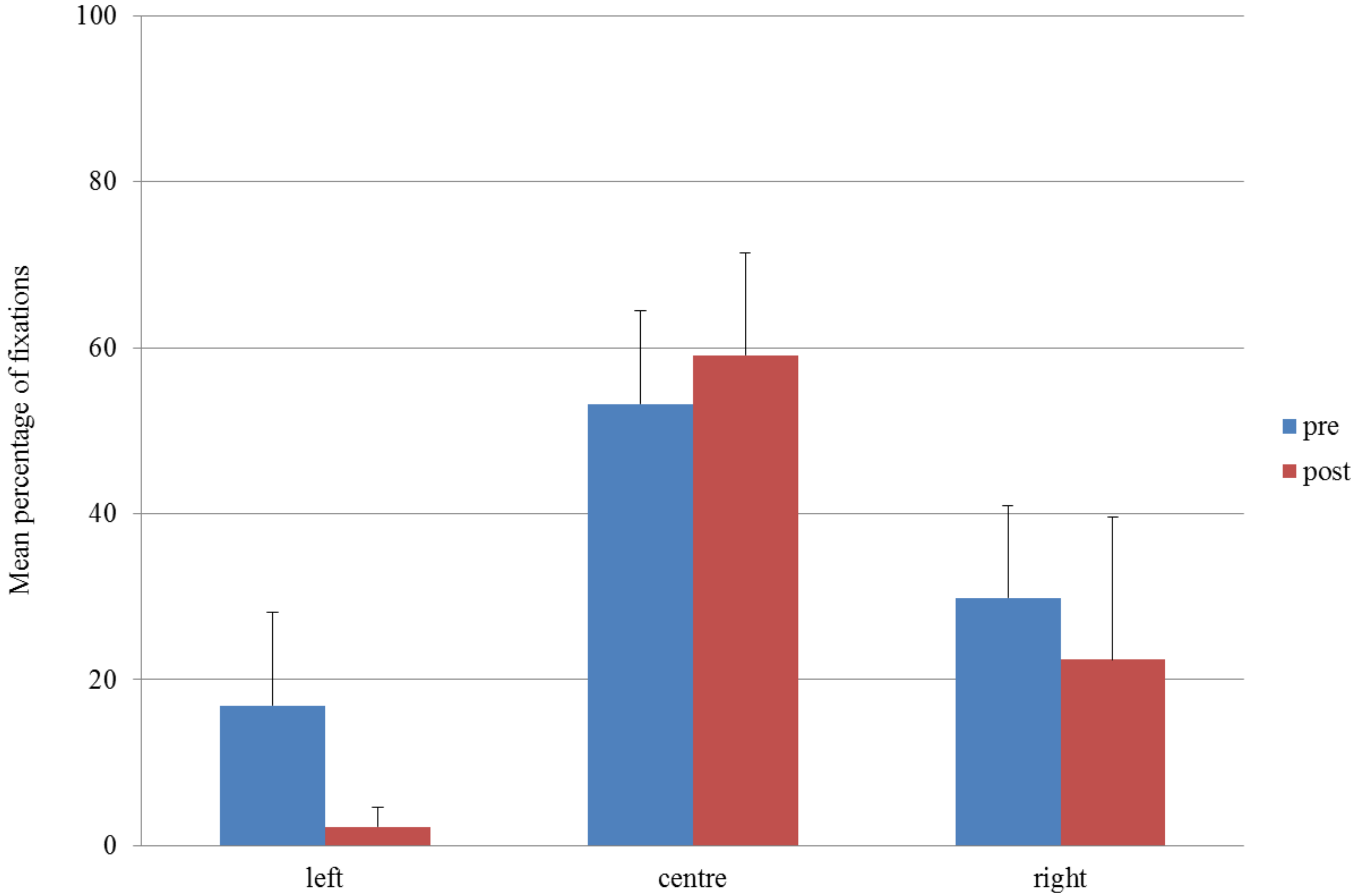



Figure 5.10. The mean percentage of gaze fixations in each general gaze direction by children in the Crossroads group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

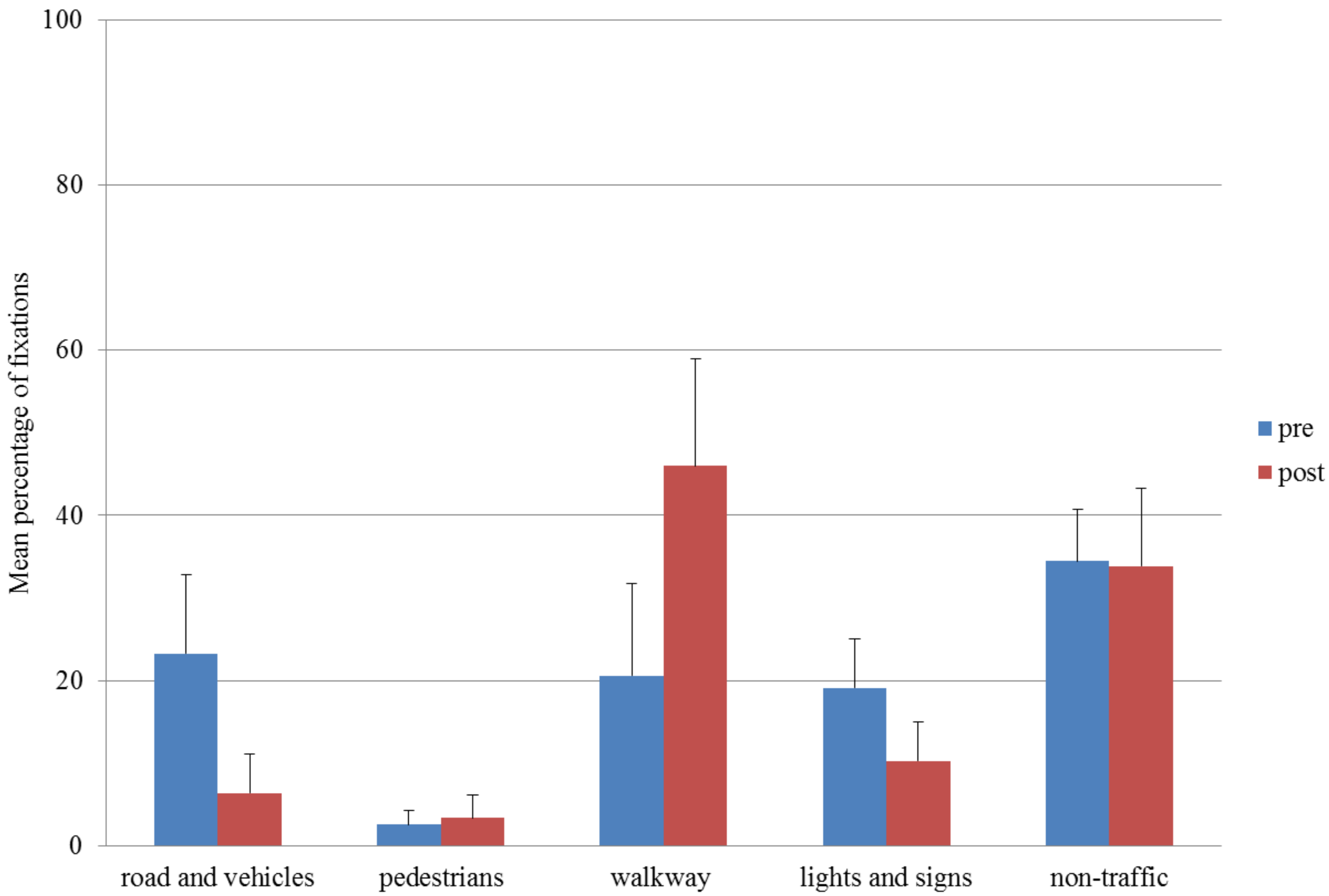



Figure 5.11. The mean percentage of gaze fixations on object-based categories by children in the Safety Watch group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

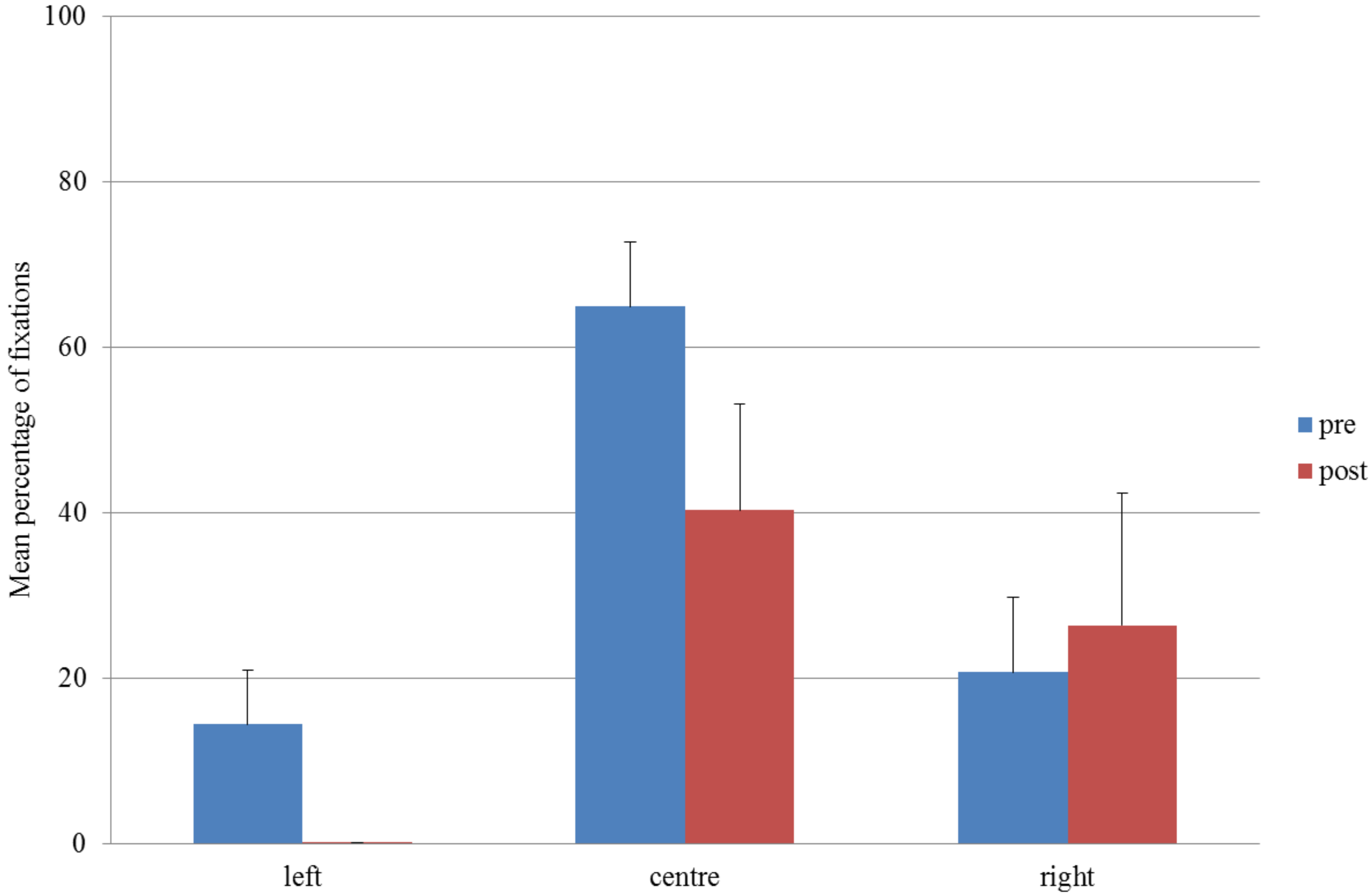



Figure 5.12. The mean percentage of gaze fixations in each general gaze direction by children in the Safety Watch group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

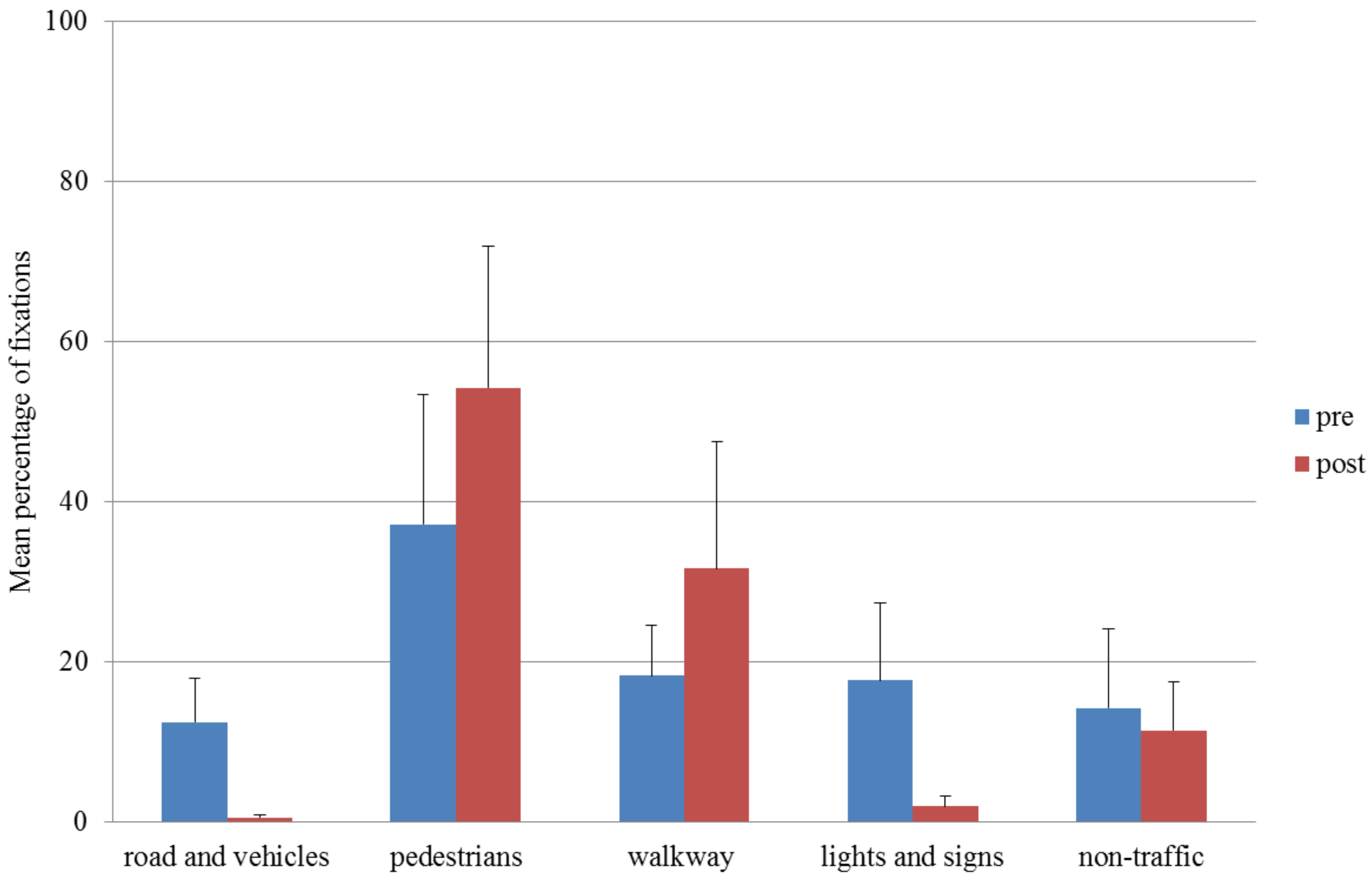



Figure 5.13. The mean percentage of gaze fixations on object-based categories by children in the control group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

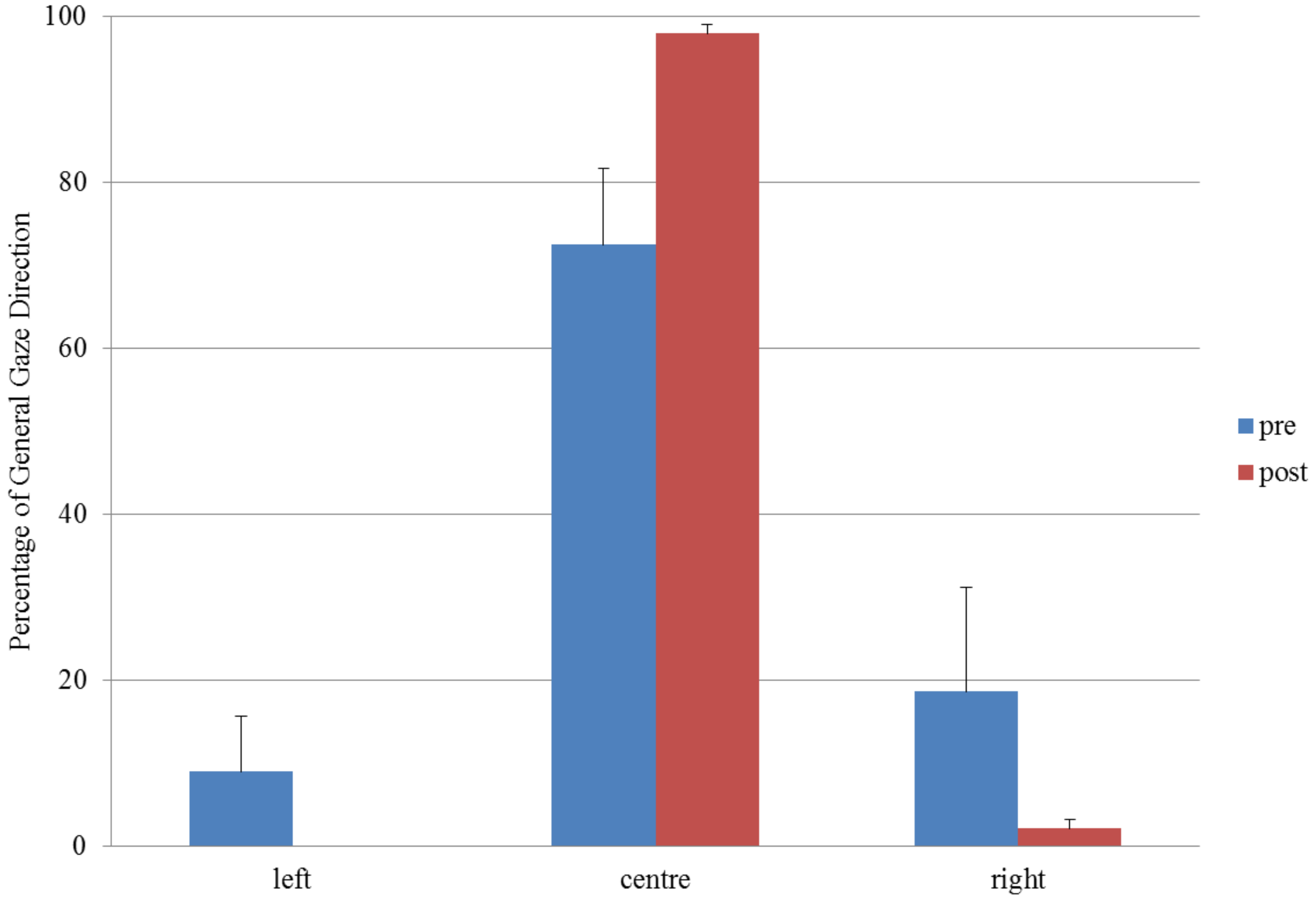



Figure 5.14. The mean percentage of gaze fixations in each general gaze direction by children in the control group at a signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

Table 5.1. Changes in the gaze fixation and general gaze direction of children at a signalised road crossing after 5 weeks of training.

| | Road and Vehicles | | Pedestrians | | Walkway | | Lights and Signs | | Other | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Crossroads | -13.3 | 29.4 | -0.5 | 1.3 | -16.5 | 22.9 | 4.6 | 13.6 | 25.7 | 46.9 |
| Safety Watch | -16.9 | 28.0 | 0.8 | 4.4 | 25.5 | 52.9 | -8.8 | 23.6 | -0.6 | 24.0 |
| Control | -11.9 | 12.6 | 17.0 | 60.3 | 13.5 | 39.0 | -15.7 | 24.6 | -2.8 | 25.8 |

| | Left | | Centre | | Right | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Crossroads | -14.6 | 29.7 | 21.6 | 43.3 | -7.4 | 39.7 |
| Safety Watch | -10.5 | 15.8 | 3.3 | 21.9 | 7.2 | 29.2 |
| Control | -9 | 16.5 | 25.4 | 31.4 | -16.5 | 22.5 |

## *5.4 Discussion*

It was hypothesised that training with the Crossroads intervention would improve gaze behaviour at the roadside by increasing the percentage of fixations on the road and vehicles and to the right (the direction of oncoming vehicles) and also reducing the percentage of fixations on traffic irrelevant features. This hypothesis was not confirmed as no improvements in gaze behaviour as a result of the Crossroads intervention were found in this study. It was also hypothesised that training with the Safety Watch intervention would not result in as much of an improvement in gaze behaviour as the Crossroads intervention as other studies using similar techniques have found no improvement in road-crossing behaviour (Padgett, 1975; Zeedyk & Wallace, 2003).

### *5.4.1 No improvements were noted after the interventions*

Neither of the training methods used in this study led to changes in gaze behaviour that could be associated with a more skilled road crossing strategy (greater percentage of fixations towards the road and vehicles and a lesser percentage of fixations towards traffic irrelevant features) or indeed any observable differences. It was hypothesised that the SafetyWatch training would not improve gaze behaviour at the road crossing as it implemented traditional teaching techniques designed to improve children's understanding of what is appropriate behaviour at the roadside but did not present the opportunity for the children to practise these behaviours. This concurred with the findings of Zeedyk et al. (2002) who noted that training with commercially available road crossing materials aimed at improving children's knowledge of the traffic environment did not improve road-crossing behaviour as they often did not look in the direction of oncoming traffic before crossing the road. Whilst the lack of improvement was expected for the control and Safety Watch group as previous studies using similar techniques have not reported an improvement after training, the failure of the Crossroads CD to change the gaze behaviour of children was surprising.

Whilst no other study has examined the effects of training on the gaze behaviour of children at road crossings, other studies have shown some improvements in roadside behaviour after VR training, and it was expected that improvements would be observable in the present study through the study of gaze behaviour (greater percentage of fixations on the road and vehicles and a lesser percentage of fixations on non-traffic relevant features). Thomson *et al*. (2005) found that the Crossroads programme was more effective at improving children's road-crossing behaviour when accompanied by adult-led discussion than when it was accompanied by peer-led discussions. The Crossroads CD-ROM is designed to guide children to the most appropriate road-crossing behaviours and provide them with an opportunity to practise some necessary skills such as judging gaps in traffic (Tolmie *et al*., 2005b). It may be that the children needed certain cues, behaviours or skills such as ignoring non-traffic relevant events to be emphasised by adults to fully benefit from the training. It is possible that the inclusion of adult-led discussions in this current study may have resulted in observable differences in the gaze behaviour of the children at actual road crossings.

The relative contribution of dorsal and ventral processing may also partially explain the differences between the Tolmie *et al*. (2005b) study and the present study. Tolmie and colleagues (2005b) used a combination of computer and real world report tasks and a road crossing decision task to assess the effectiveness of the VR training intervention. The report tasks required children to view a computer generated or real-world traffic scenario and report what they had seen and heard that was important for crossing the road safely. The road crossing decision task took place at an actual road crossing and the children were required to stand at the road crossing and shout when they would cross but not actually cross the road. It is likely that all of the tasks used by Tolmie *et al*. (2005b) relied more on ventral stream processing as the tasks all required a perceptual judgement over action (Dicks *et al*., 2010; Goodale & Milner, 1992; Milner & Goodale, 2008). This is in contrast to the methods used in the present study where the children had to cross an actual road which would require dorsal stream functioning. It is likely that the tasks used in the present study and the Tolmie *et al*. (2005b) tested performance that are subserved by different processes and as such are unlikely to be affected by training in a similar manner.

It is also possible that the Crossroads and/or Safety Watch training caused changes in the behaviour of children that were not picked up during the coding of the eye movement behaviour. Whilst the recording of gaze behaviour has been sufficient for identifying differences across the lifespan at a signalised crossing the implementation of a check list that recorded a variety of behaviours (such as pressing the button at the pedestrian crossing) may have resulted in observable differences as a result of training.

### *5.4.2 Significant findings?*

This study employed numerous statistical tests to determine differences within and between groups as a result of training. Oddly the significant differences found in this study were not the result of training with the Crossroads or Safety Watch interventions. A significant change had occurred between the pre and post-tests in the control group, with participants fixating on lights and signs less in the post-test than in the pre-test. As this was the control group it is not clear what has caused this change. It is possible that this is a Type I error due to the number of statistical tests run in this study. Significant differences existed between the control group and the two intervention groups in terms of fixations towards pedestrians before any intervention occurred. It appears to be the result of chance as most of the children blindly selected their own intervention and the others were assigned to a group based on a quota system (aimed at achieving groups with the same number of male and female participants). The children were assigned to their groups before data on their gaze behaviour had been coded. Coding all the children's data before assigning children to groups would have increased the homogeneity of the pre-intervention groups. However this would considerably increase the time between the pre and post intervention data collection sessions increasing the possibility that other factors, outside of the intervention may have influenced their road-crossing behaviour.

*5.4.3 Future directions for pedestrian training*

McKenna (2010) noted that few training programmes aimed at improving road safety are based on theory or evidence. The Crossroads intervention was developed by psychologists and has a theoretical underpinning; it gives children the opportunity to practise skills relevant for actual road crossing, such as judging the speed of approaching vehicles in relation to the capabilities of the avatar child to cross the road, predicting the actions of drivers and performing appropriate searches before crossing. It was hoped that these skills, practised in a safe environment in the Crossroads intervention, could be transferred to actual road crossings. The transfer of skills developed by the Crossroads intervention was not evident through the study of gaze behaviour in this thesis. One of the possible reasons for the lack of improvement in gaze behaviour may be due to the stimuli and responses that are presented and required are representative of the visual information and actions required at a real world road crossing.

The visual stimuli and amount of control that the Crossroads intervention offers are impoverished compared to those available in the real world and modern video games. The Crossroads intervention required children to attend to certain areas of the display (where traffic may approach from) but this did not result in changes to real-world gaze behaviour; one possible reason for this is that the pressing of a symbol in order to display the visual information from the right may not have been a familiar or natural behaviour for children. Computer games that are played on gaming consoles often require active, continuous control of the ‘camera’ that allows the gamer to inspect the avatars visual environment, this technique of monitoring a virtual environment is much closer to the way humans direct their gaze in the real world. If a road crossing programme was developed that gave children complete control over the visual images that are presented it is possible that training with such a programme may result in changes to the way children direct their gaze at actual road crossings. However, producing such a training device may be too costly and it is unlikely that children would be interested in playing a road-crossing simulation for an extended period of time.

Playing action games has been linked to an increased UFOV (Green & Bavelier, 2003) and UFOV has been shown to predict traffic accident risk in older adults (Ball *et al.*, 1993; Broman *et al.*, 2004; Myers *et al.*, 2000; Owsley *et al.*, 1998; Stalvey *et al.*, 1999; see 1.4.2 *Attentional control and visual search*). It is possible that playing action games, where multiple targets have to be tracked and attentional control is challenged will improve skills useful for safe road crossing. However the games that have been shown to improve UFOV scores are action games, such as Unreal Tournament (Green & Bavelier, 2003) that are not age appropriate for young children.

As cognition appears to be context dependent it may be useful to train children’s road-crossing skills at the roadside. This training could involve an adult accompanying the child to the road crossing and asking the child to cross when it is safe to do so. For safety the adult should have some mechanism to prevent the child from making an unsafe decision. Providing children with the opportunity to practise road crossing in the real world and asking them to act upon this visual information is likely to develop context dependent cognitive skills. Principles related to the study of psychology such as representative design and cognitive ethology (see 1.8 *Studying cognition under realistic conditions*) could usefully be applied to interventions aimed at improving children's road-crossing behaviour. It is possible that the children involved in this study have had the opportunity to practise road crossing with their parents or guardians under similar conditions to this described above. Collecting a range of data about road crossing experiences could be used for the formation of sub-groups within the children participants that could be useful to investigate relationships between gaze behaviour and the type or frequency of road crossing of experience.

## 5.5 Conclusion

In terms of how children direct their gaze, the training interventions were ineffective with this group of children. No improvements were noted in the gaze behaviour of children after the training, one possible reason for this is that the children did not complete the training but this seems unlikely as all the children in the Crossroads and Safety Watch groups were able to answer questions specifically about the tasks in the training programme. The effects of virtual reality have previously shown an improvement in road-crossing behaviour (Thomson *et al*., 2005; Tolmie *et al*., 2005b), although gaze behaviour had not been previously examined. It may be that the

Crossroads training was not effective without adult-led discussions that highlight important behaviours for safe road crossing. Future studies could include adult-led discussions; they were not included in this study to allow for a more direct comparison with the Safety Watch CD-ROM and also due to time restrictions (imposed by the time taken to collect data and the amount of time children were allowed to miss from class to take part in this study).

Future studies could pre-test children before assigning them to groups and adopt a matched-pairs design to ensure homogeneity across the pre intervention groups. The time taken to complete the initial data collection and to code and analyse the data made this difficult to implement in this study as all the data collection and analysis was conducted by one researcher. A combination of the collection of gaze behaviour and other measures such as checklists may also improve future studies. In retrospect this could have been included in this study as a second adult was always present when the children were accompanied to the road crossing. The inclusion of the check list used by Thomson *et al*. (2005) would have allowed for a more direct comparison of the studies and may have given indications as to the role adult-led discussions have in the Crossroads training programme.

The low number of participants in each group may also have contributed to the lack of significant differences between the pre and post test data sets, however the trend appears to be negative with the mean percentage of fixations on the road and vehicles reducing after the Crossroads and Safety Watch interventions. The number of participants required to find an effect of training on gaze behaviour is unknown as conducting a *post-hoc* power analysis was therefore not appropriate as it assume the direction of the differences observed is not the opposite direction of the hypothesis. It is likely that children would benefit from interventions that more closely resembled the act of crossing the road in terms of visual information and task. Previous studies have suggested that different mechanisms are used to process information for acting on (such as at an actual road crossing) than during a perceptual judgement task that requires a less active response such as sitting in front of a monitor and pressing a button (e.g., Dicks *et al*., 2010). Training interventions that take place at actual road crossings may be more successful in improving children's gaze behaviour and warrant research further attention. It is likely that children receive this kind of training from their parents, particularly those who walk to school with their parents. By encouraging walking to school children may receive more opportunities to practise crossing with their parents and this may improve their road crossing abilities.

The studies in this thesis have all been conducted at a relatively safe signalised pedestrian crossing. It is possible for children to attend only to the walk light (which does not require constant attention) and still be able to cross safely; attempting to judge safe crossing opportunities by monitoring the traffic as opposed to waiting for a green light is more cognitively demanding and may be against specific instructions that the children have been given by other adults before crossing the road. Further investigations into children's gaze behaviour at road crossings may benefit from the inclusion of unsignalised road crossings, although this type of crossing may be more dangerous. In the next chapter, I examine this by creating a simulated roadside environment to explore gaze behaviour at both signalised and unsignalised crossings.

# **CHAPTER 6:** THE EFFECTS OF A NON-SPATIAL TASK ON THE GAZE BEHAVIOUR OF CHILDREN AT A SIMULATED SIGNALISED ROAD CROSSING

## *6.1 Introduction*

### *6.1.1 Cognitive ethology approach*

Cognitive ethology necessitates the observation and description of real-world behaviour before beginning laboratory based studies testing hypotheses generated from real world observations. Specifically testing theories generated from real-world observations may allow us to develop theories that actually explain real world behaviour (Crundall & Underwood, 2008; Kingstone *et al*., 2008a). In Chapter 4, children looked significantly less to the direction of coming traffic when presented with an ice cream. The cause of this change is however uncertain, it could be the visual nature of the distractor (having to look at the ice cream in order to eat it), or because the secondary task is cognitively more demanding in terms of allocating attention. In this chapter the effects of a non-spatial task that does not require visual attention will be explicitly tested, by using a standard counting task (using non-spatial attentional mechanisms) in simulated environments. This approach, consistent with cognitive ethology, allows the testing of theories generated from the observations of real-world behaviour. However, it cannot be assumed that cognitive processes are invariant across conditions and the behaviour during the laboratory studies are compared with real-world behaviour in the final study (Chapter 8) of this thesis.

*6.1.2 Video based simulations of road crossings*

The previous studies have investigated gaze behaviour at real-world road crossings in order to provide a good understanding of how pedestrians of all ages allocate their gaze in realistic situations. Although this approach is high in ecological validity, there are aspects of road-crossing behaviour that are not practical or ethical to study at the roadside. Unsignalised, or very fast roads, may be too dangerous to study safely – particularly among vulnerable pedestrian groups. Probing the effects of an attentionally-demanding secondary task can be similarly dangerous. Performing research in a laboratory provides the potential to explore such behaviour in a safe environment, and allows a greater degree of experimental control to test specific hypotheses generated from the previous real-world studies than is possible in the real world.

Video-based road-crossing simulations have been used in two studies investigating age related differences in road-crossing behaviours. In the first, Whitebread and Neilson (2000) inferred through head movements that at a simulated road crossing younger children shift their attention less before selecting a safe crossing opportunity than older children and adults. In that study a two-way road was filmed from the kerb with three cameras, one facing left, one facing the centre and the other facing right. The footage from the three cameras were displayed on three screens, that were angled in a way that required the participants to make the same head movements as they would at a real road crossing to see traffic from the left and the right. Looking and changes in attention were inferred from the direction the participants' heads were facing. This measure is comparable with the "general gaze direction" measure described in the *General Methods*. The children sat in front of the monitors and watched the videos of the traffic environment and called out 'cross' when they had selected a safe crossing opportunity. In the second study to use a video based simulation of a road crossing, Holland and Hill (2010) investigated gender differences across the lifespan (17-75+) when selecting safe crossing opportunities. The video footage was captured by three cameras and displayed on three monitors in a similar way to Whitebread and Neilson (2000). Participants were required to take a step forward and verbally indicate when they had selected a safe crossing opportunity. Head movements were recorded and the direction of last look before crossing, and the proportion of crossings where the participant looked both ways in the final 3 seconds before crossing, amongst other measures were used to identify differences in the crossing behaviour of male and female drivers and non-drivers.

The authors found that older adults made more unsafe selections than younger adults. They also noted that looking left (towards the direction of oncoming traffic of the far side of the road) was related to fewer safe crossings being missed and more safe crossings being selected and that looking to the right immediately before crossing was related to a higher percentage of unsafe crossings. This suggested that participants were more likely to make mistakes when the participants did not attend to the left (traffic approaching the far side of the road) before crossing. In older adults, Fontaine and Gourlet (1997) noted that pedestrian accidents were more likely to occur in the far lane of two way road; this may be explained by the findings of Holland and Hill (2010).

Whitebread and Neilson (2000) and Holland and Hill (2010) used very similar methods to create a video-based road-crossing simulation and both studies found that behaviour at these simulations could explain greater risk of pedestrian accidents in particular age groups. Whilst the methods for the creation and display of the videos used for the road-crossing simulation were very similar, the response required to indicate that a crossing opportunity had been selected was very different. Holland and Hill (2010) used a more realistic set up than Whitebread and Neilson (2000) that required participants to stand while watching the video and take a step forward when they felt it was safe to cross. These requirements are much closer to the behaviours necessary to cross an actual road than the behaviours required in the Whitebread and Neilson (2000) study. There is evidence to suggest that coupling an unnatural response to a specific situation may result in poorer performance due to the way visual information for perception and action are processed (Bootsma, 1989; Davids *et al*., 2001).

### *6.1.3 Two visual systems*

Goodale *et al*. (1991) and Goodale and Milner (1992) proposed that two different visual systems exist, one for perception such as recognising objects (the ventral stream) and one for action, guiding movements (the dorsal stream). Even though there is some evidence to suggest that the two streams are not completely independent, evidence from studies investigating movements such as intercepting a ball suggests that when verbal judgements are required over active responses regarding the timing of the initiation of the action accuracy drops and variability increases (Bootsma, 1989). In other words when asked to verbally respond to visual information that normally requires an action adults' judgements are different than when they are required to act on the visual information. By getting participants to take a step forward rather than press a button when they have selected a safe crossing opportunity more natural behaviours may be observed.

### *6.1.4 Two video-based simulations*

In this chapter, two custom-developed video-based road-crossing simulations are used to investigate the effects of a secondary task on the gaze behaviour of children when selecting a safe crossing opportunity. One simulation will use methods similar to many traditional laboratory-based studies where the participants are sat in front of a monitor where stimuli are displayed and they are required to press a button to indicate a selection has been made. The other simulation will use more realistic conditions: the size of the video will subtend a greater area of the visual field and the participants will have to stand and maintain balance whilst viewing the footage and make an active realistic response to the visual information (take a step forward). A comparison of the validity of these simulations will be made in Chapter 8.

### *6.1.5 Non-spatial task*

The results from the Chapter 3 show that children direct their gaze less towards the road and vehicles than adults do. It has been suggested (Thomson *et al*., 1996; Zeedyk &

Wallace, 2003) that this may be due to difficulties in selectively attending to the most relevant sources of information. Initially the gaze behaviour of the children, when compared to that of adults, suggested that children did not selectively attend to relevant information as they failed to attend to the road and vehicles as often as adults did before crossing the road and fixated mostly on traffic irrelevant features. Further, the study in Chapter 4 showed that when presented with a secondary task, such as holding and eating an ice cream, children direct their gaze away from the direction of oncoming vehicles, suggesting that this real world distractor caused problems for the efficient allocation of attention.

In the current study the extent to which children devote attention to the road crossing task in the presence of an additional task will be investigated. Dual-tasking is traditionally used to determine the amount of resources given to a task (Yogev-Seligmann *et al*., 2008) as extra cognitive load in the form of a secondary task should have a negative consequence on the performance of the initial task if the initial task required a certain amount of cognitive processing, providing that the secondary task is sufficiently demanding. The secondary task challenges attentional capacities and requires the ability to divide attention (Yogev-Seligmann *et al*., 2008; see 1.4.3 *Dual-task performance*).

In this experiment the secondary task is a non-spatial counting task as changes in gaze behaviour are likely to be a result of the additional cognitive demand rather than to acquire visual information important for the completion of the secondary task as was the case in Chapter 4. Other advantages of this approach are that previous studies have found that counting tasks to be effective as a secondary task when investigating cognitive processing (Beauchet *et al.*, 2005; Beauchet *et al.*, 2007; Van Iersel *et al.*, 2007; see 1.4.3 *Dual-task performance*) and it is very easy for young children to understand what is required. The participants were asked to count up in 3's. An initial pilot study suggested that counting in 3's was taxing enough to challenge children's attentional capabilities but not too difficult that the children would lose motivation.

There is some debate regarding the effectiveness of spatial and non-spatial tasks on visual search tasks. Anderson *et al*. (2008) compared the effects of spatial and non-spatial tasks on efficient and inefficient visual search tasks. They concluded that spatial tasks and non-spatial tasks had a comparable negative effect on inefficient visual search and that efficient visual search was not affected either spatial or non-spatial tasks. Anderson *et al*. (2008) proposed that inefficient search recruits working memory processes used in spatial and non-spatial tasks. However, spatial and non-spatial working memory is associated with activation in different cortical areas in the prefrontal cortex (D'Esposito *et al*., 1998) and other studies have found that visual search tasks are affected by spatial working memory tasks and not by non-spatial working memory tasks (Oh & Kim, 2004). This suggests that spatial information of searched items is more crucial than non-spatial information when searching a predefined target object efficiently (Oh & Kim, 2004). Others have suggested that visual search efficiency is not affected by a "full" visual working memory (Woodman *et al*., 2001).

### *6.1.6 Aim and predictions*

It was hypothesised that children would attend less to relevant information when presented with a secondary task. Even though maintaining balance requires cognitive processing (Sparrow *et al*., 2002; Yogev-Seligmann *et al*., 2008) it was expected that the effects of a distractor will be even more pronounced during the monitor condition as cognition is context dependent (Clark, 2001) and the required actions (stepping forward) and scale of the visual information available in the projector task are much closer than the monitor condition to those available at an actual road crossing where children have (to some extent) previously practised selecting safe crossing opportunities. As practised skills require less cognitive processing (Fitts & Posner, 1967) it is expected that less cognitive resources will be required when searching for safe crossing opportunities in the projector condition as the projector simulation more closely resembles the context in which these children have previously been practised. Children in the projector condition may use less cognitive processing to select safe crossing opportunities the additional load from counting (and also maintaining balance) should have less of an effect on the primary task than when the children are performing a more abstract and less practised task such as siting at a computer screen and pressing a button to indicate when it is safe to cross.

## *6.2 Methods*

In this study two different road crossings simulations are used. Both simulations use the same video footage, but the size of the display, the way the video is displayed, the position that the video is viewed from and the actions required to signify a safe crossing differ between conditions. Two different simulations are used in this study; one represents a traditional approach to recreating real-world stimuli in a laboratory, while the other attempts to create a more realistic environment.

*6.2.1 Participants*

For this study, 12 children (*M* = 8.5, *SD* = 0.5 years) were recruited. Due to data loss only nine cases are presented in the data set here.

*6.2.2 Design*

This study used a two (cognitive load) x two (simulation type) repeated measures design. The independent variables were cognitive load (with and without the counting task) and simulation (monitor + passive task, or projector + active task). The dependent variables were the percentage of fixations on categories and directions in the final 3 seconds before crossing.

*6.2.3 Equipment*

*Mobile Eye*

The eye tracker was fitted and calibrated for the **projection** simulated road crossings as described in the general methods chapter.

*Tracksys iView X remote eye tracker*

The Tracksys iView X was set-up and calibrated for the **monitor** display simulated road crossings as described in the general methods chapter.

*Video footage*

Four videos (a, b, c & d) of the road crossing were produced for the simulated conditions. Each video represented a different 2 minute traffic cycle, beginning with the onset of the red pedestrian crossing light and ending as the green pedestrian crossing light ends. The production of the simulated signalised crossing is described in the General Methods section (see 2.4 *Development of road crossing footage*).

*6.2.4 Procedure*

After the eye tracker (Tracksys iView X for the monitor condition and Mobile Eye for the projector condition) was set-up and calibrated the participants were shown a practice video. The participants were asked to imagine that they were on the pavement at the road crossing on the videos and to act as they normally would at the actual crossing when looking for a safe crossing opportunity. After the practice video the children were shown the road-crossing simulation and asked to select a safe crossing opportunity. During the cognitive load task they were also asked to count aloud upwards in 3's. The order of simulation (projector/monitor), the video clips (a, b, c & d: each video represented a different 2 minute traffic cycle, beginning with the onset of the red pedestrian crossing light and ending as the green pedestrian crossing light ends) and cognitive load (control/counting) was counter-balanced across all participants.

*6.2.5 Monitor condition*

During the monitor condition, the participants were required to sit in front of a large monitor and watch a video (70cm x 8.75cm) that represented 47° horizontally and 6° vertically of the visual of a road crossing and select a safe crossing opportunity by pressing the space bar on the key board in front of them. This set up is typical of many traditional laboratory-based experiments and the visual information and task required are not representative of the real world.

*6.2.6 Projector condition*

In the projection condition participants stood in front of a large projection (3.6m x 0.45m) that represented 79° horizontally and 12° vertically of the visual angle at a distance of 2.2m. A marking on the floor indicated the 'kerb' in the simulated study. The participants were asked to take a step forward when they felt that it was safe to do so. This set up was designed to more closely recreate the conditions that would be found in the real world than the more traditional laboratory-based set up. In the projector condition the footage of the road crossing was not backlit as in the monitor condition which meant the room had to be very dark to prevent the road crossing footage from looking "washed out". The dark room resulted in the pupil expansion for the participants and in the case of older adults it made it difficult to track the eye using the Mobile Eye. This was the main reason that the experiments in this chapter focus on children.

### *6.2.7 Data analysis*

After coding the data to the criteria discussed in the General Methods, Shapiro Wilk tests revealed no matched data sets that met the assumptions required for parametric test (even after attempts to transform the data). As the entire data sets required non-parametric statistical tests, Wilcoxon signed rank tests were applied to determine statistical differences between the percentage of fixations on object and location based categories in each simulation condition, to determine the effects of cognitive load. Wilcoxon signed rank tests were also used to test the hypothesis that the additional cognitive load will have less of an effect during the more realistic projector condition by comparing the change in gaze behaviour as a result of the cognitive load between the two simulations.

## *6.3 Results*

In this section gaze fixation data from the control and non-spatial secondary task condition are compared for the monitor and projector road crossing simulations.

### *6.3.1 Effect of cognitive load during the monitor condition*

Wilcoxon tests revealed that in the monitor condition (see Figure 6.1), the walkway was attended to more in the distraction condition than in the control condition ($Z=2.38$; $p=0.017$; $d=1.36$) and that lights and signs were fixated more in the control condition than in the distraction condition ($Z=-2.023$; $p=0.043$; $d=1.3$). No significant differences were found between the control and distraction conditions in the gaze allocation for vehicles and roads (Z=-1.26; *p*=0.208; *d*=0.7); pedestrians (Z=2.08; *p*=0.779; *d*=0.39); non-traffic features (Z=1.4; *p*=0.161; *d*=0.37) or general gaze direction (see Figure 6.2) in the centre (Z=0.84; *p*=0.401; *d*=0.72); right (Z=0; *p*=1; *d*=0.06); and left (Z=-1.23; *p*=0.208; *d*=0.9).

*6.3.2 Effect of cognitive load during the projector condition*

Wilcoxon tests revealed no significant differences in the projector condition (see Figure 6.3) between the control and distraction conditions in the gaze allocation for vehicles and roads (Z=-0.73; *p*=0.465; *d*=0.24); pedestrians (Z=-1.363; *p*=0.173; *d*=0.65); walkway (Z=-0.405; *p*=0.686; *d*=0.58); lights and signs (Z=-1.342; *p*=0.18; ; *d*=0.6); non-traffic features (Z=-0.943; *p*=0.345; *d*=0.41) or general gaze direction (see Figure 6.4) in the centre (Z=-0.105; *p*=0.917; *d*=0.1); right (Z=-0.524; *p*=0.6; *d*=0.4); and left (Z=-0.73; *p*=0.465; *d*=0.28).

*6.3.3 Effect of simulation type*

During the cognitive load condition children increased their fixations on the lights and signs in the projector condition and reduced their fixations on the lights and signs in the monitor condition, this difference was found to be significant (Z=-2.201; *p*=0.028; *d*=0.76). Wilcoxon tests revealed no significant differences between the change in gaze behaviour as a result of the additional cognitive load in the projector condition and monitor condition in terms of fixations on the road and vehicles (Z=-0.734; *p*=0.463; *d*=0.38); pedestrians (Z=0.314; *p*=0.753; *d*=0.22); walkway (Z=1.153; *p*=0.249; *d*=1.04); non-traffic features (Z=1.363; *p*=0.173; *d*=0.81) or general gaze direction (see

Figure 6.4) in the centre (Z=0.734; *p*=0.463; *d*=0.45); right (Z=-0.734; *p*=0.463; *d*=0.26); and left (Z=-734; *p*=0.463; *d*=0.41). However, large effect sizes were noted for some of these differences indicating that these differences may be meaningful.

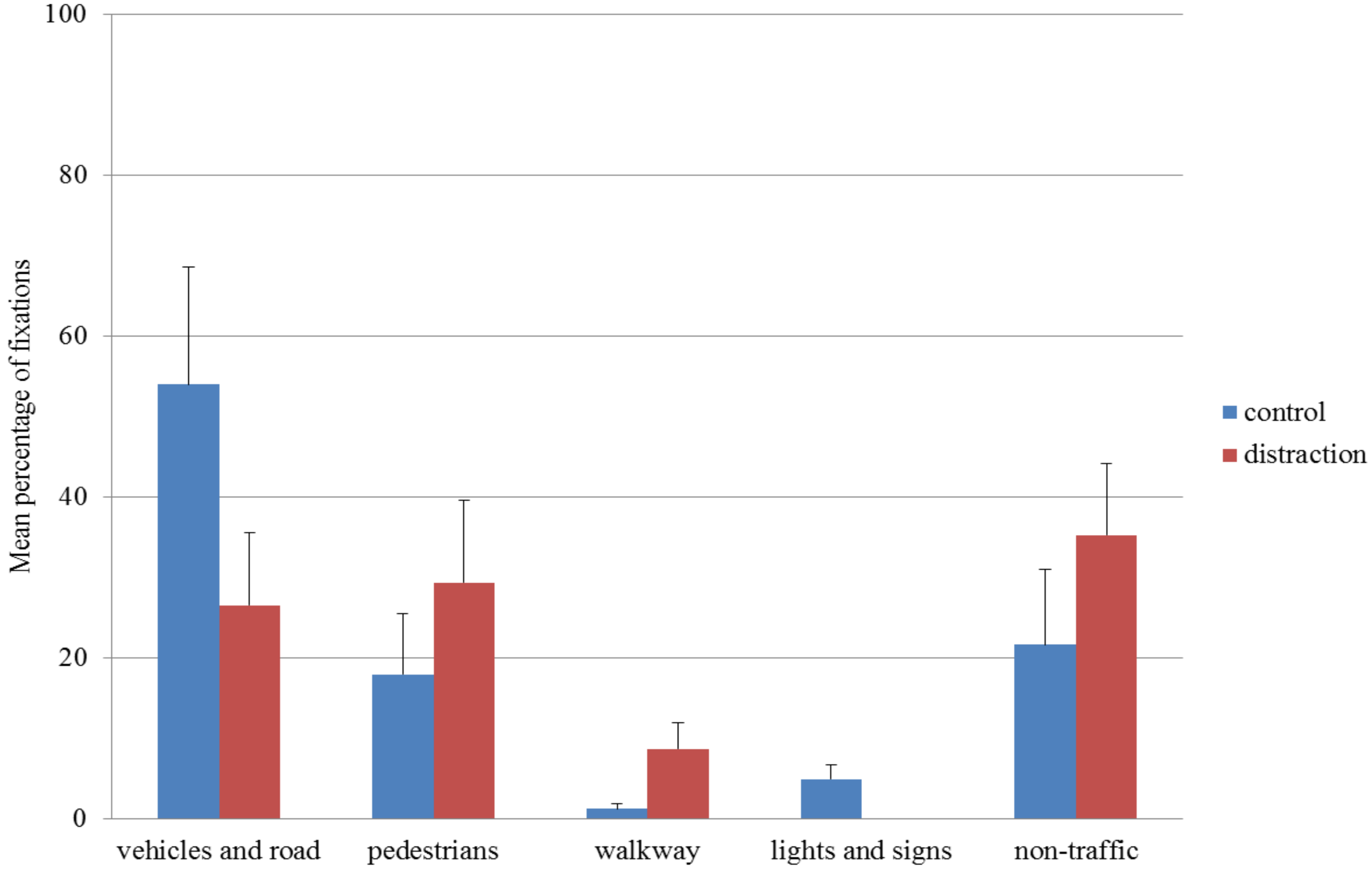



Figure 6.1. The mean percentage of gaze fixations on object-based categories by children during the control and distraction conditions at the monitor simulation of the signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

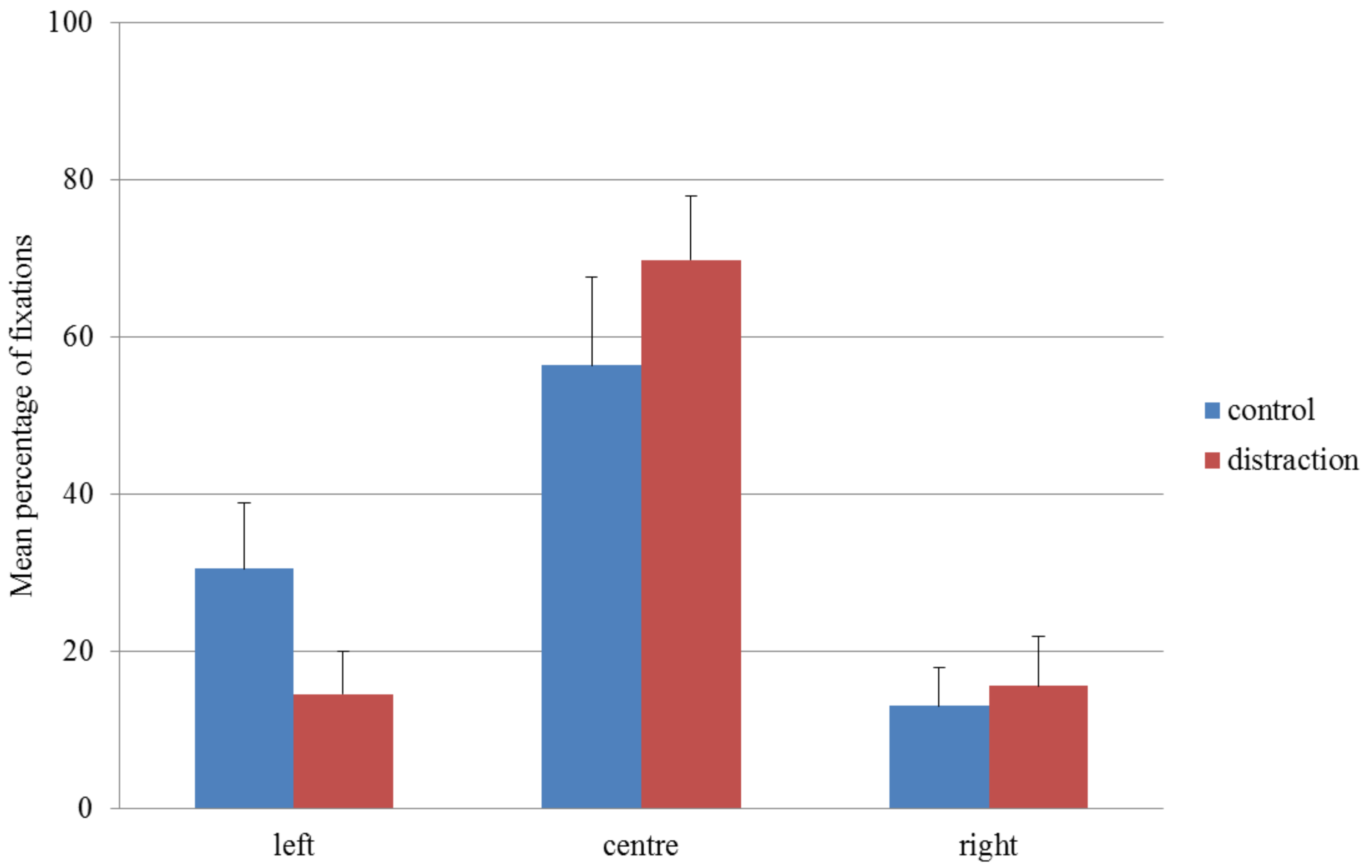



Figure 6.2. The mean percentage of gaze fixations in each general gaze direction by children during the control and distraction conditions at the monitor simulation of the signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

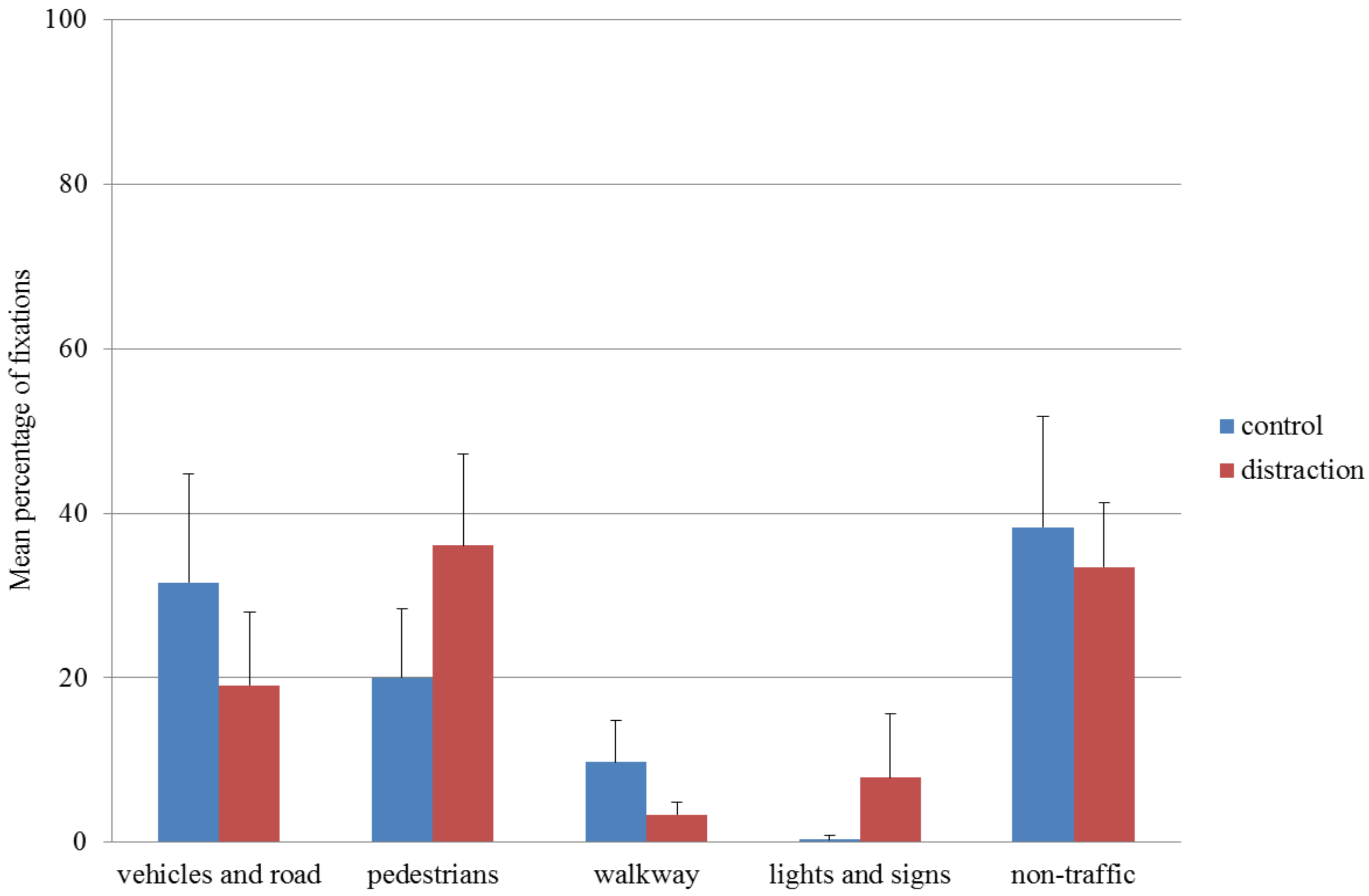



Figure 6.3. The mean percentage of gaze fixations on object-based categories by children during the control and distraction conditions at the projector simulation of the signalised two-way road crossing. The error bars represent + 1 standard error of the mean.

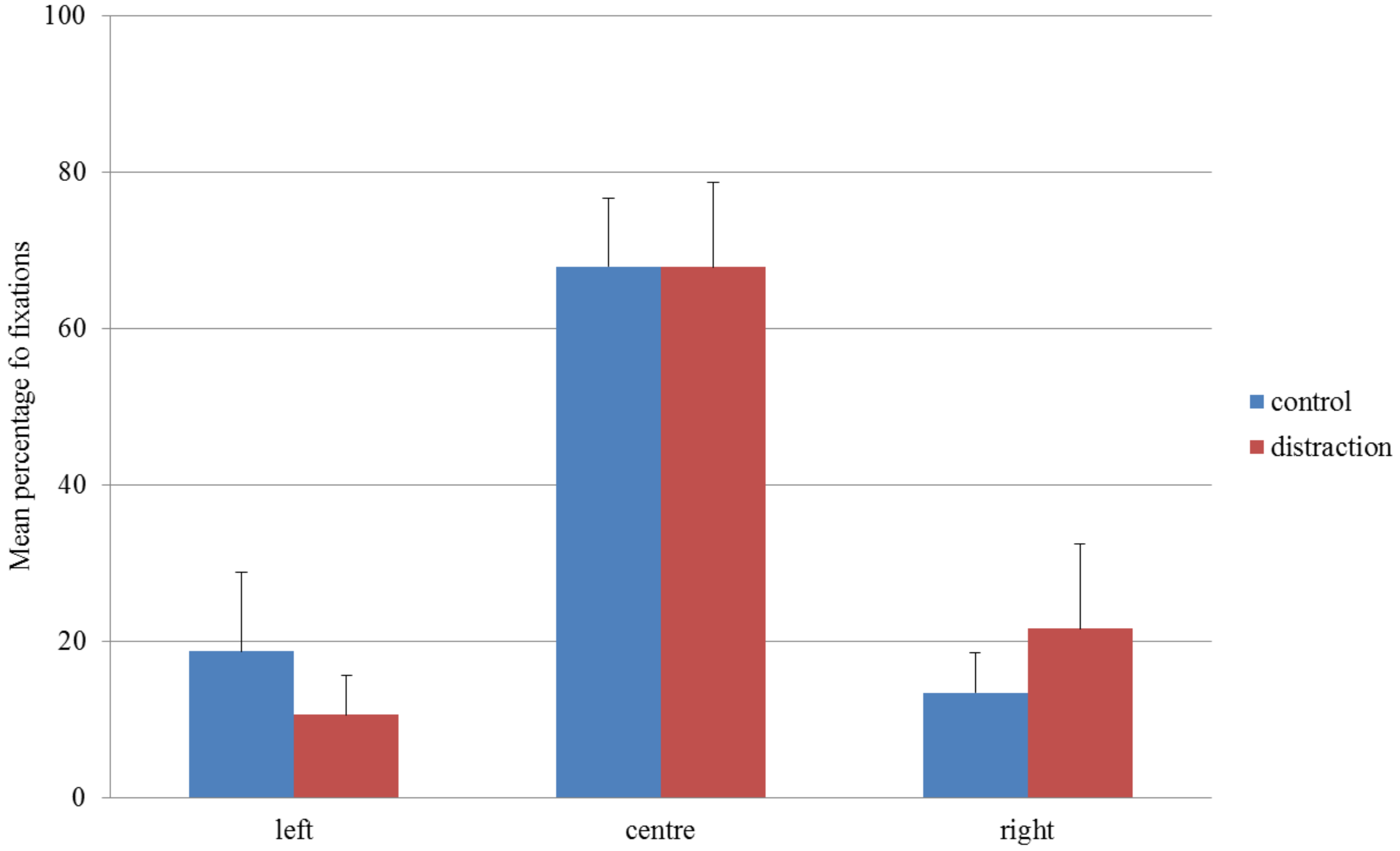



Figure 6.4. The mean percentage of gaze fixations in each general gaze direction by children during the control and distraction conditions at the projector simulation of the signalised two-way road crossing. The error bars represent standard error.

## *6.4 Discussion*

It was hypothesised that a secondary task such as counting would have a negative effect on children's gaze behaviour when searching for a crossing opportunity at a simulated road crossing. This negative effect on gaze behaviour would be observed by a reduced percentage of fixations on the road and vehicles and an increase in fixations traffic irrelevant features. It was also hypothesised that the effects of a distractor would be less pronounced during the projector condition of the two simulations the required actions (stepping forward) and scale of the visual information available in the projector task are more like those at an actual road crossing where children have (to some extent) previously practised selecting safe crossing opportunities.

### *6.4.1 Monitor*

In the monitor condition the walkway was attended to more and the lights and signs less in the dual-task than in the control condition. It was hypothesised that during the dual-task condition, gaze would be directed more often towards irrelevant features. For the purposes of the simulated study information from the walkway can be seen as irrelevant as information from this area is needed to guide walking and the participants will not actually walk there in the simulation. Attending more to the walkway during the dual-task condition may suggest that the participants were less able to prioritise the most pertinent sources of visual information in the display. The attention to irrelevant information (such as the walkway in this simulated study) when presented with a distracting task was also found in the real world ice cream distractor study (Chapter 4).

These findings provide support for numerous studies that have reported that task performance deteriorates when an additional task is added (e.g., Abernethy *et al.*, 2002; Beauchet *et al.*, 2005; Beauchet *et al.*, 2007; Sparrow *et al.*, 2002; see 1.4.3 *Dual-task performance*). At the monitor simulation, children also fixated less on the road and vehicles during the dual task condition than in the control condition and although this failed to reach a statistically significant level, the medium to large effect size noted suggested that this difference may be meaningful.

### *6.4.2 Projector*

No significant differences were found between the control and dual-task conditions during the projection condition. It was hypothesised that the secondary task may have a *lesser effect* in the projector condition than in the monitor condition as cognition is context dependent (Clark, 2001) and the required actions (stepping forward) and scale of the visual information in the projector condition are more similar to those at an actual road crossing where road-crossing skills have been developed. Practised skills require less cognitive processing (Fitts & Posner, 1967) meaning that more attentional resources were available for the processing of the secondary task. Whilst a *lesser effect* of the secondary task was expected in the projector condition, it was surprising that *no effect* was found as many studies (e.g., Foley & Berch, 1997; Kramer & Larish, 1996; Salthouse *et al.*, 1995; Tsang & Shanner, 1998) have demonstrated that primary task performance is affected by the addition of a secondary task. Indeed, this was seen in the current study when participants were in the monitor condition. It may be that the children prioritised searching for a safe crossing opportunity over the mental arithmetic additional task and therefore devoted more processing to selecting a safe crossing opportunity. It is also possible that the counting up in threes was not sufficiently demanding for the participants. Both of these possibilities seem unlikely as this was not the case in the monitor condition. Another possibility is that children are using information from the lights and other pedestrians to guide their decision making process which requires little cognitive processing and therefore less likely to be affected by a secondary task.

### *6.4.3 Context dependent cognition*

As hypothesised, the addition of the dual-task (counting upwards in threes) was associated with differences in gaze behaviour in the monitor condition, but not the projection condition. The findings from the present study, strongly support Kingstone *et al.*'s (2008a) views that cognitive processes are not invariant and regular across conditions. Varying the size of the display (small or large), the posture of the observer (seated or standing) and the response required (step or button press) when viewing a video of a road crossing and counting in threes, resulted in different cognitive processes observed through changes in gaze behaviour. If the effects of cognitive load on eye-movement behaviour during the monitor simulation condition are not invariant during the projector simulation it certainly cannot be assumed that the behaviour observed in the monitor condition is representative of that in the real world. The assumption that cognitive processes are invariant and are unaffected by the specific situational context in which they occur is pathological (Broadbent, 1991).

*6.4.4 Dorsal stream involvement duirng the projector simulation condition may mediate the effects of the secondary task*

It could be argued that the projector condition would be more cognitively demanding as the “active” tasks of standing up and taking a step forward require greater cognitive effort (Yogev-Seligmann *et al.*, 2008; see 1.4.3 *Dual-task performance*) as such, performance during this condition should be more susceptible to the effects of an additional cognitive task. However, one possible explanation for this is that the projector condition was similar to real world crossing and the skills children have developed at real world crossings were easily transferred. The contribution of the dorsal stream is likely to be high for well-practised skills requiring perceptuo-motor control (Milner & Goodale, 2008), such as looking for a crossing opportunity and stepping forward, and are less cognitively demanding than unfamiliar tasks (Fitts & Posner, 1967), such as pressing a pressing the space bar on a keyboard to identify a safe crossing opportunity, which is likely to involve mostly ventral stream processing. It is not possible to conclude that differences between the two conditions are the result of the response required as other factors such as the scale of the display may have contributed to this difference.

It was noted as during the cognitive load condition children increased their fixations on the lights and signs in the projector condition and reduced their fixations on the lights and signs in the monitor condition. An interaction effect indicates that either the size of the display, the required action or a combination of the two are responsible for changes in gaze behaviour. This provides further support for Clark’s (2001) assertions that cognition is context dependent and Kingstone *et al.*'s (2008a) views that cognitive processes are not invariant across conditions and environments.

*6.5 Conclusion*

The addition of a non-spatial secondary cognitive task may have caused problems in the children's ability to control attention during the monitor condition as they attended more to the walkway and less to the traffic lights than during the control condition. This finding supports the numerous laboratory-based studies that have shown the addition of a secondary task has a negative effect on the processing of the primary task, provided that the tasks are sufficiently cognitively demanding (e.g., Abernethy *et al.*, 2002; Beauchet *et al.*, 2005; Beauchet *et al.*, 2007; Hollman *et al.*, 2007; Lajoie *et al.*, 1993; Lajoie *et al.*, 1996; Sparrow *et al.*, 2002; Van Iersel *et al.*, 2007). It is interesting that this non-spatial task resulted in differences in the fixations on object-based categories whereas in Chapter 4 the spatial secondary task did not. However as this effect of a non-spatial secondary task was found not to be invariant across conditions the extent to which this finding can explain behaviour outside of the specific context of the test is questionable and may have little relevance to the processes that occur at an actual road crossing. It is possible that the visual information and active nature of the task in the projector condition allowed the children to use well-practised context specific skills that are less cognitively demanding than those required in more abstract tasks. The differences between the two simulations and their relevance to real-world road crossings is further investigated in Chapter 8.

# **CHAPTER 7:** THE GAZE BEHAVIOUR OF CHILDREN AT SIMULATED SIGNALISED AND UNSIGNALISED ROADS BEFORE SELECTING A CROSSING OPPORTUNITY

## *7.1 Introduction*

In Edinburgh it may be that as many as 25% of pedestrian accidents occur at or within 50 metres of a signalised crossing (Al Naqbi, 2009). Most pedestrian accidents, therefore, occur outside these zones. For safety reasons it is difficult to study road-crossing behaviour at these areas with children. A simulated environment offers a greater degree of control and safety in which to study gaze behaviour of children at an undesignated crossing area.

In the real-world study (Chapter 3) children attended less to the road and vehicles than did adults. It is possible that children were simply waiting for the green man to appear (see Chapter 3) before crossing the road, relieving them of much of the cognitive processing required to judge gaps in traffic. At unsignalised crossings, information from traffic lights is not available so the strategy of waiting for the green man to appear is not option. To cross the road safely at unsignalised crossings a strategy based on vehicles and the road is needed.

Geruschat *et al*. (2003) compared the gaze behaviour of pedestrians at real world signalised and unsignalised road crossings. To the author's knowledge, no other group has investigated real-world gaze behaviour at a road crossing and no one has investigated children's gaze behaviour at signalised and unsignalised crossings. Geruschat *et al*. (2003) found that pedestrians direct their gaze towards vehicles more at unsignalised crossings than they did at signalised crossings, perhaps because the traffic lights provided a pertinent, extra source of information that could be used to guide future actions.

### *7.1.1 Aim and predictions*

In this experiment, the gaze behaviour of children at a simulated signalised and unsignalised crossing will be compared. It is expected that children will fixate on vehicles more during the unsignalised road crossings than during the signalised road crossings, because at the unsignalised crossing the road and vehicles provide the only useful source of information to base crossing decisions whereas at the signalised the traffic lights can be used to guide crossing decisions. Geruschat *et al*. (2003) also noted that gaze is directed at vehicles more at unsignalised crossings than at signalised crossings. It is also expected that their general gaze direction will be in the centre more during the signalised crossings and in the right and left more during the unsignalised crossings. At the signalised crossing useful information such as the pedestrian traffic lights can be found in the centre of the display, whereas during the unsignalised crossing most of the information pertinent to road crossing such as approaching cars can be found towards the left and right of the display.

## *7.2 Methods*

### *7.2.1 Participants*

For this study, 12 children (*M* = 8.5, *SD* = 0.5 years) were recruited. Due to excessive data loss for the unsignalised crossing in the projector condition only the signalised and unsignalised data, only seven cases of data from the monitor condition are presented here.

### *7.2.2 Design*

This study used a repeated-measures design. The independent variable was road crossing type (signalised or unsignalised). The dependent variables were the percentage of fixations on categories and directions in the final 3 seconds before crossing.

### *7.2.3 Equipment*

The Tracksys iView X was set up and calibrated for the monitor display simulated road crossings as described in the general methods chapter.

*Video footage*

Both videos were of two-way roads in a 30mph zone in Edinburgh. The simulated signalised crossing described in the General Methods was used in these simulations. An unsignalised road crossing was developed in the same manner as the signalised crossings described the General Methods.

*7.2.4 Procedure*

After the Tracksys iView X eye tracker was set up, the participants were shown two practice videos to become familiar with the display. The participants were asked to imagine that they were on the pavement at the road crossing on the videos (signalised and unsignalised) and to act as they normally would at the actual crossing when looking for a safe crossing opportunity. The children would then press the space bar on a keyboard in front of them when they felt that it was safe to cross. The order of unsignalised and signalised crossings was counter balanced across the participants.

*7.2.5 Data analysis*

After coding the data to the criteria discussed in the *General Methods*, a Shapiro Wilk test revealed no matched data sets met the assumptions required for parametric test (even after attempts to transform the data). Wilcoxon signed rank tests were used to determine statistical differences between the data from the signalised and unsignalised simulated road crossings. Friedman's Analysis of variance by ranks statistical tests were used to determine statistical differences between percentage of fixations on categories and in the percentage of general gaze directions. Friedman's pairwise comparisons were used to identify between which specific categories or general gaze directions statistical differences were found.

## 7.3 Results

Due to excessive data loss for the unsignalised crossing in the projector condition only the signalised and unsignalised data for the monitor condition are presented here. This was possibly due to the lighting conditions. In each experiment in this thesis data loss was a reoccurring theme. Refinements in the projector condition may reduce data loss, this is discussed in depth in the *General Discussion* (see 9*.2.4 The Mobile Eye: Problems and data loss*).

### 7.3.1 Signalised vs. unsignalised crossings

Wilcoxon tests showed that in the monitor condition gaze was directed significantly more towards lights and signs at the signalised crossings compared with the unsignalised crossings (see Figure 7.1) (Z=-2.023; *p*=0.043; *d*=1.3) and pedestrians (Z=-2.201; *p*=0.028; *d*=0.76). This was not surprising, as there were no lights and signs and fewer pedestrians at the unsignalised crossings. Children fixated on non-traffic features more at the unsignalised crossings than at the signalised crossings (Z=-2.028; *p*=0.043; *d*=0.9). Significant differences were also noted in the general gaze direction (see Figure 7.2): children fixated significantly less towards the centre (Z=-2.197; *p*=0.028; *d*=1.21), and significantly more to the right (Z=-2.366; *p*=0.018; *d*=2.06) at the unsignalised crossing than the signalised crossings. No significant differences were found between the signalised and unsignalised crossings in terms of the percentage of gaze fixations on the road and vehicles (Z=-1.187; *p*=0.237; *d*=0.42), the walkway (Z=-0.943; *p*=0.345; *d*=0.46), or general gaze direction towards the left (Z=-0.105; *p*=0.917; *d*=0.03).

*7.3.2 Within signalised crossings*

Friedman's Analysis of variance by ranks revealed significant differences between the percentage of fixations on categories in the simulated signalised condition ($\chi^2_{(4)}$=12.296; $p$=0.015; $\eta^2$=3.074) but no significant differences were found in the percentage of general gaze directions ($\chi^2_{(2)}$=4.667; $p$=0.097; $\eta^2$=2.334). Pairwise comparisons revealed that children fixated the road and vehicles significantly more than the walkway ($\chi^2_{(1)}$=3.3; $p$=0.01; $d$=1.52). No other significant differences in the fixation of objects were observed after the adjusting the $p$ values to accommodate for the multiple test ($p$>0.05). However a large effect size was found for a greater percentage of fixations on the road and vehicles than the lights and signs ($\chi^2_{(1)}$=2.282; $p$=0.11; $d$=1.148). A *post-hoc* power analysis (1-β=0.688) indicated that the test lacked the power to detect this large difference and that 13 participants would be required to find a significant difference.

*7.3.3 Within unsignalised crossings*

Friedman's Analysis of variance by ranks revealed significant differences in the simulated unsignalised condition between the percentage of fixations on categories ($\chi^2_{(2)}$=6.741; $p$=0.015; $\eta^2$=3.3705) and the percentage of fixation in general gaze direction ($\chi^2_{(2)}$=6; $p$=0.05; $\eta^2$=3). Pairwise comparisons failed to report significant differences between fixations on objects after adjustments to the $p$ values were made for multiple tests ($p$>0.05). However, the large effects sizes observed suggest that meaningful differences may exist in the data as children fixated more on the road and vehicles than the walkway ($\chi^2_{(1)}$=2.138; $p$=0.083; $d$=1.43) and more on traffic irrelevant features than the walkway ($\chi^2_{(1)}$=2.028; $p$=0.107; $d$=1.3). *Post-hoc* power analyses indicate that the statistical tests between the fixations on the road and vehicles and walkway (1-β=0.768) and the traffic irrelevant features and walkway (1-β=0.69) just lacked the power to identify these large differences, and that 13 participants may be sufficient for both of these differences to reach a statistically significant value after adjustments to compensate for multiple test. A significant difference was found between the percentage of general gaze directions ($\chi^2_{(2)}$=2.272; $p$=0.023; $\eta^2$=1.136). Pairwise comparisons revealed that children fixated to the right more than in the centre ($\chi^2_{(1)}$=2.405; $p$=0.048; $d$=1.34). No other significant differences between general gaze direction were found ($p$>0.05). No fixations occurred on pedestrians or lights and signs and as a result these data sets were unsuitable for Friedman's Analysis of variance by ranks.

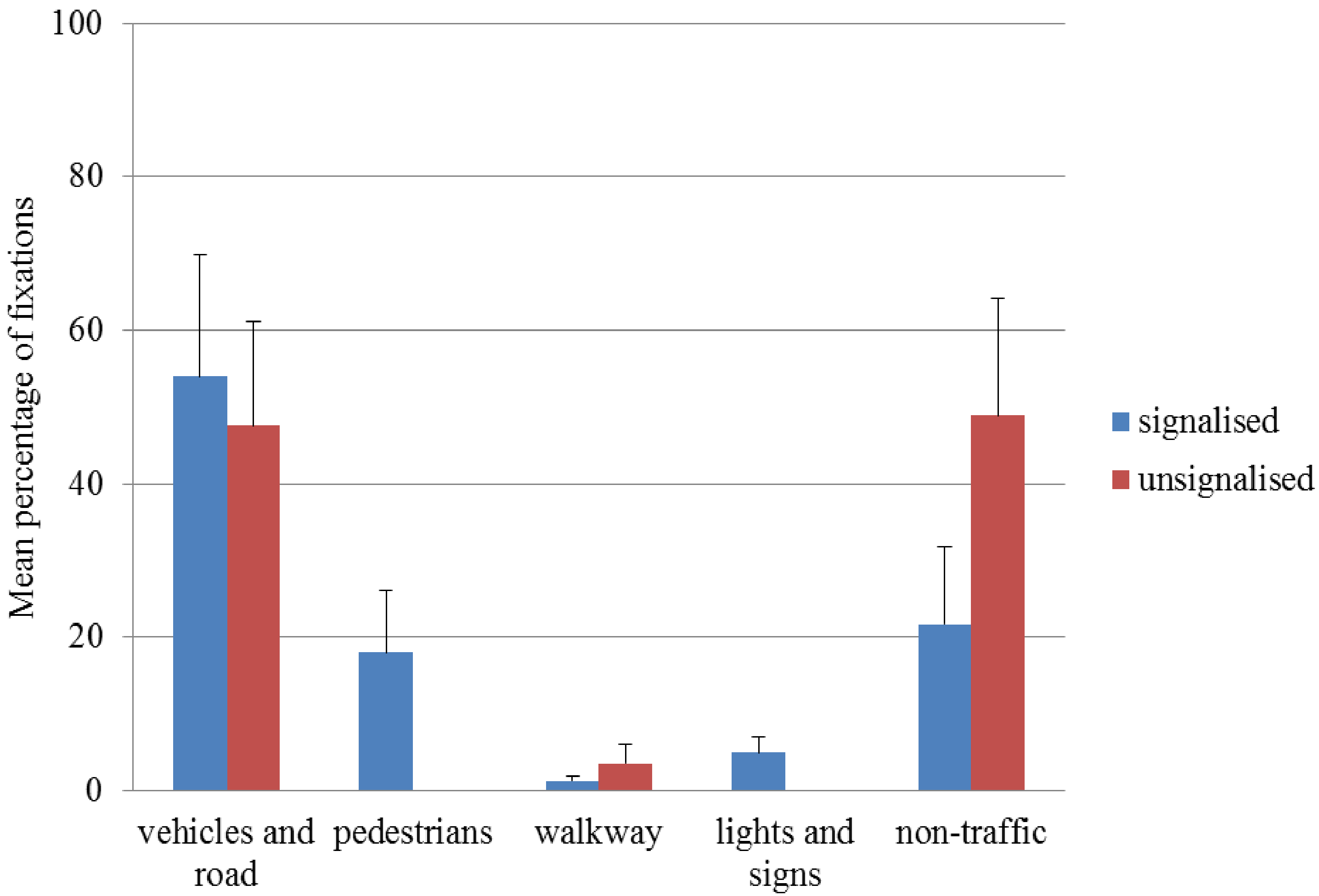



Figure 7.1. The mean percentage of gaze fixations on object-based categories by children during the monitor simulations of the signalised and unsignalised two-way road crossings. The error bars represent + 1 standard error of the mean.

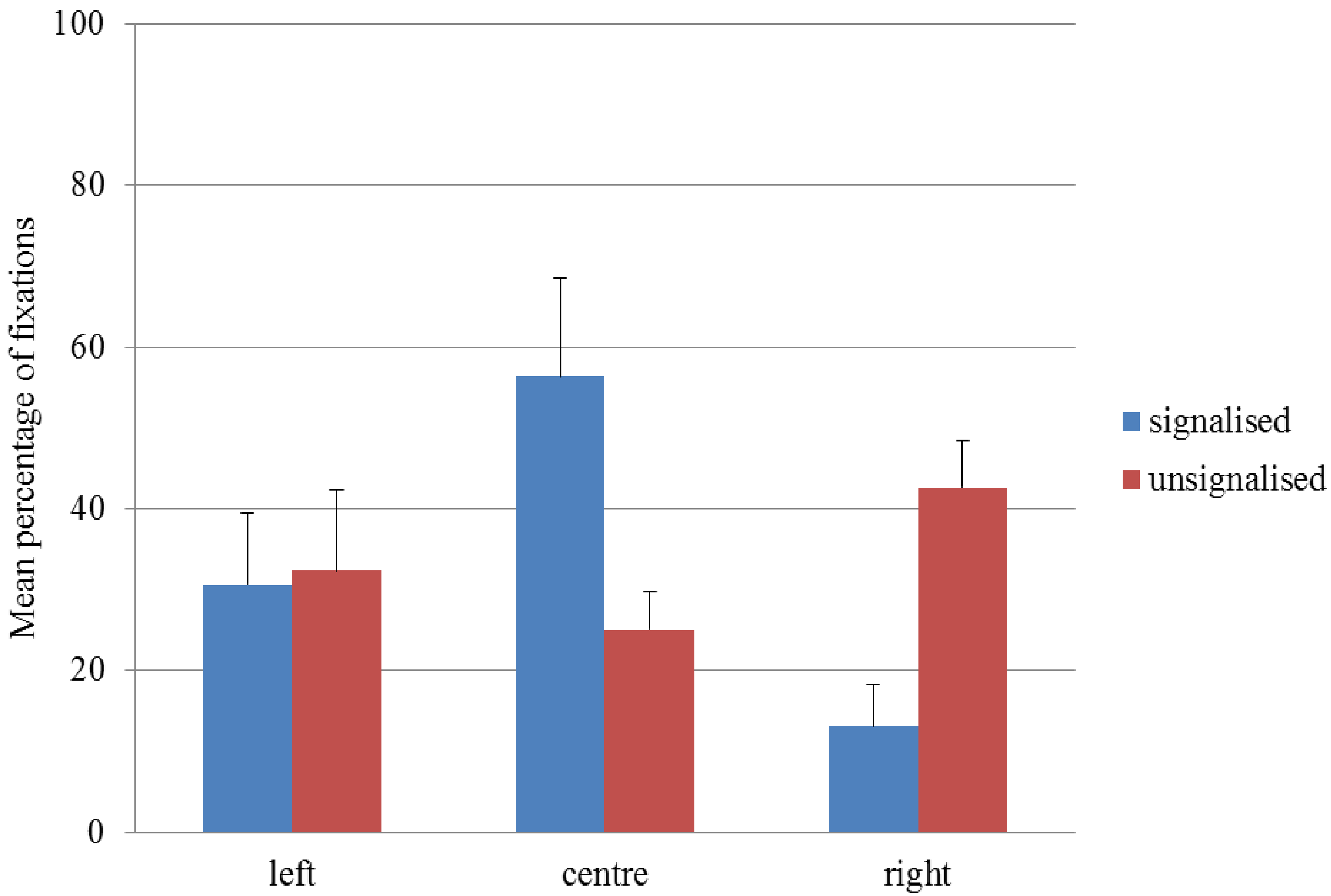



Figure 7.2. The mean percentage of gaze fixations in each direction by children during the monitor simulations of the signalised and unsignalised two-way road crossings. The error bars represent + 1 standard error of the mean.

## *7.4 Discussion*

It was hypothesised that children would direct their gaze towards the road and vehicles significantly more at the unsignalised simulated crossing than at the signalised simulated crossing. However, this was not the case in this study. Given the lack of other features such as lights and pedestrians in the unsignalised condition, it is surprising that a significant difference was not found. It could be argued that this failure to increase fixations towards the direction of oncoming vehicles during the unsignalised crossings may explain children's increased risk of pedestrian accidents in the real world. However, it must be noted that during this simulated signalised crossing, the children directed a much larger percentage of fixations towards the road and vehicles than the children at the actual road crossing in Chapter 3, suggesting that the simulated road crossings used here did not elicit real-world gaze fixation behaviour. This explanation of the data is further supported by the fact that the gaze fixation data at the signalised and unsignalised simulated crossings did not mirror the findings from the real-world comparison of older adults' gaze behvaiour at signalised and unsignalised road crossings reported by Geruschat *et al*. (2003). Geruschat *et al*. noted that gaze fixation on vehicles (the coding system used by Geruschat *et al*. combined the road with vehicles) was 39% at the signalised crossings and 65% during the unsignalised crossings. The fact that no significant differences were found between children's fixation of gaze at signalised an unsignalised crossings may suggest that children and older adults direct their gaze differently, but could also point, as mentioned above, to the simulated road crossings used here not eliciting real-world gaze behaviour. A combination of both of these factors seems likely.

Significant differences did exist between the simulated signalised and unsignalised crossings in terms of general gaze direction. As hypothesised the children attended towards the right significantly more and the centre significantly less in the unsignalised conditions than they did during the signalised crossings. This appears to be consistent with an approach that emphasises the importance of searching for oncoming vehicles, which in the UK, emerge from the right. At the signalised crossing, it is reasonable to expect that the most useful information in the centre would be the pedestrian lights, and the most useful information towards the right would be the road and vehicles. At the unsignalised crossing, no pedestrian lights were present straight ahead, so attending more to the right, where vehicles would be approaching, seems to be an appropriate looking strategy. These differences were not reflected in the object-based analyses (i.e. more fixations on the road and vehicle at the unsignalised crossing).

The major findings in this study appear to be at odds with each other. It was expected that children would attend to the traffic more in the unsignalised condition. This was not evident by the percentage of fixations on the road and vehicles as hypothesised. However, the percentage of fixations in the direction of oncoming traffic (right) did support the notion that children would actively seek information from traffic more in the unsignalised condition. One possible explanation for this may be that the procedure for coding gaze behaviour used in the real world and projector condition is unsuitable for small scale simulations. The size of the features in the simulated studies were much smaller than in the real-world condition and therefore in the simulated crossings a greater percentage of the traffic environment could be foveated in one fixation; as the centre of gaze was used to determine the object being fixated it is possible that other objects and features were the focus of attention and were fixated on but the display size of the simulated environment was not sufficient to accurately observe what information was being fixated.

Significant differences were also observed between the two crossing types as the children fixated the lights and signs and pedestrians more in at the signalised crossing than at the unsignalised crossing. This was not surprising as there were no lights and fewer pedestrians at the unsignalised crossing.

This study has raised questions regarding the validity of this simulation as a tool to investigate gaze behaviour at road crossings. Here, as in many other laboratory-based eye movement studies, it is unclear if the results provide anything more than detailed descriptions of how videos are viewed (Tatler, 2009). To increase our understanding of the relationship between gaze behaviour observed in a laboratory and in the real world the next study will compare the gaze fixation of children at simulated and real world signalised crossings.

## *7.5 Conclusion*

It is possible that limitations in the size of the display are responsible for the gaze fixation not corresponding with the findings of Geruschat *et al*. (2003). The different age groups used in the current study and the Gersuchat *et al*. (2003) study may also be partially responsible for the differences in gaze behaviour observed. Given the importance of context during cognition (see 1.8 *Studying cognition under realistic* *conditions*) and as previous studies have noted that gaze behaviour during laboratory-based simulation may not be representative of gaze behaviour in the real world (e.g., Dicks *et al*., 2010; 't Hart *et al*., 2009) the validity of this simulated environment must be questioned. In the next study children's gaze behaviour at a real world signalised pedestrian crossing in Chapter 3 will be compared to the children's gaze behaviour at a simulated road crossing in Chapter 8. If the gaze behaviours at the real-world and simulated road crossings are similar it will validate the use of the simulated road crossings as a tool to further investigate road-crossing behaviour in a safe environment. However if significant differences in gaze behaviour are found between the real-world and simulated road crossings, then the results from the simulated crossings must be questioned in terms of their ability to explain real-world behaviour.

# **CHAPTER 8:** THE GAZE BEHAVIOUR OF CHILDREN AT REAL-WORLD AND SIMULATED SIGNALISED CROSSINGS

## *8.1 Introduction*

In Chapters 6 and 7, video-based simulations were used to examine the effects of a distractor on the gaze behaviour of children and gaze behaviour at an unsignalised road in a safe, controllable environment. These studies produced unexpected results as no differences were found in the percentage of fixations on vehicles at simulated signalised and unsignalised road crossings. Differences in gaze behaviour were observed between the two types of simulated road crossings, as a non-spatial secondary task affected gaze behaviour in the monitor condition but not in the projector condition. In this study comparisons are made between children's gaze behaviour at a real-world signalised crossing (collected in Chapter 3) and two simulated signalised crossings (collected in Chapter 6) to test the ecological validity of the simulated crossings.

Whitebread and Neilson (2000) and Holland and Hill (2010) used general gaze direction as an indication of looking behaviour at simulated road crossings. These two studies produced results that could potentially explain trends in accident statistics (see 1.1 *Pedestrian accidents*) and fit with what was expected from the age groups (see 1.4 *Cognitive factors*). The general gaze direction data in Chapter 7 also produced results that would be expected with the addition of a distracter, however, the object-based gaze fixation data did not. Currently little is known regarding the ecological validity of studies investigating gaze behaviour when inspecting natural scenes inside a laboratory.

In the last 15 years researchers investigating gaze behaviour at more complex, realistic environments in the laboratory have often used photographs or pictures (Baddeley & Tatler, 2006; Krieger *et al*., 2000; Parkhurst *et al*., 2002; Peters *et al*., 2005; Privitera & Stark, 2000; Reinagel & Zador, 1999; Tatler *et al*., 2005), video footage (Underwood *et al*., 2005; Williams *et al*., 1994) or computer-based simulations (Jovancevic *et al*., 2006; Jovancevic *et al*., 2008; Land & Lee, 1994; Rothkopf *et al*., 2007; Van Loon *et al*., 2010). Despite these efforts to create real-world stimuli for laboratory-based eye-movement studies, the relationship between gaze data from real-world and laboratory-based studies has been mostly unaddressed ('t Hart *et al*., 2009). It is unclear if much of the laboratory-based eye-movement studies provide anything more than detailed descriptions of the pictures or videos viewed (Tatler, 2009). It is unlikely that it is possible to transform rich, real-world environments into static two dimensional images without affecting how observers will direct their gaze. Real-world eye-movement studies have caused a shift from the focus of the visual properties of objects in the scene to the behavioural goals of the observer (Hayhoe & Rothkopf, 2010; Tatler *et al*., 2011) and the lack of a natural goal in many of the laboratory based studies may alter individuals' natural real-world behaviour.

There also appears to be a framing effect of the monitor when images and footage is viewed under traditional laboratory based settings. Tatler and colleagues have reported that when viewing images on a monitor there is a strong tendency to fixate the centre of images regardless of the content of a scene displayed (Tatler, 2007; Tatler *et al*., 2011; Vincent *et al*., 2009). Vincent *et al*. (2009) estimated that this bias to fixate the centre may account for up to 56% of eye movements. This central bias can also be found when viewing continuous movies (Cristino & Baddeley, 2009; Dorr *et al.*, 2010; ’t Hart *et al.*, 2009) although the bias appears to be weaker than when viewing static images (Tatler *et al.*, 2011). If the laboratory setting distorts behaviour, the extent to which the results from studies conducted in such conditions can explain real-world behaviour must be questioned.

Studies investigating eye movements during the viewing of static images or video clips of real-world environments are often constrained by suppressing head movements, which are essential in the real world for large gaze shifts (Stahl, 1999); distorting the coupling of visual and vestibular feedback (‘t Hart *et al.*, 2009); and the limited resolution of the display (‘t Hart *et al.*, 2009). As cognitive processes are likely to be context dependent (Clark, 2001) it is not appropriate to assume that behaviours observed during laboratory-based tasks are invariant across a range of conditions (Kingstone *et al.*, 2008a). Given the nature of the constraints imposed by laboratory-based simulations of real-world environments it is essential that differences in gaze behaviour between laboratory and natural settings are examined (‘t Hart *et al.*, 2009).

‘t Hart *et al*. (2009) were the first to directly compare gaze behaviour at real settings and in the laboratory (see 1.8.8 *Real world vs. simulated displays*). They found that gaze behaviour differs in the laboratory and the real world, although no task was given to the participants other than to view the presented videos and still images. However, we know that eye movements are critically dependent on the task at hand (e.g. Yarbus, 1967). Eye movements are often goal directed (Land, 2009), therefore it is important to study gaze behaviour during goal directed tasks (see 1.8 *Studying cognition under realistic conditions*). To date, only Dicks *et al*. (2010) have compared gaze behaviour at real-world and simulated environments during an active task and they found that gaze behaviour in the real world during an active task was different from gaze behaviour in a laboratory-based simulator. In that study participants fixated almost exclusively on the ball when attempting to save the penalty whereas during the simulated study the participants directed an artificially high percentage of their gaze towards the hips and non-kicking foot. The findings from Dicks *et al*. (2010) highlight the importance of comparing the results from laboratory-based studies to the actual real-world conditions which the laboratory setting is supposed to represent.

Chapter 6 reported significant differences in gaze behaviour between monitor-based and projector-based simulations, providing further evidence that the size of the display (small or large) and the conditions under which the participants must respond to signify a safe opportunity crossing (sitting and pressing a button or standing and then taking a step forward), may be important in determining where children look in a simulated road-crossing task.

In this study, the gaze behaviour of children at a real-world, signalised road crossing (from Chapter 3) is compared with gaze behaviour at the projector and monitor simulations of the same signalised road crossing (Chapter 7) in order to establish whether gaze behaviour in simulated conditions is different to those in real-world conditions.

*8.1.1 Aims and predictions*

It is hypothesised that the gaze behaviour at the real-world road crossing will be different than during the laboratory-based simulations. Only two previous studies have compared eye-movement behaviour in the real world and laboratory and concluded that the laboratory condition did not elicit the same eye-movement behaviour found in the real world (Dicks *et al.*, 2010; 't Hart *et al.*, 2009). It is hypothesised that children will direct their general gaze direction towards the centre more in the simulated crossings than at the real-world crossing as 't Hart *et al.* (2009) noted that when viewing footage on a monitor there is a central bias for fixations that is not present during the real world. It is also hypothesised that children will direct their gaze more towards the walkway during the real-world crossing as fixations of objects are often temporally linked with subsequent actions, in the laboratory simulation children will not actually be crossing the road so fewer fixations should be directed at the walkway.

In the previous study hypothesised differences were not confirmed regarding the percentage of fixations on the road and vehicles at signalised and unsignalised crossings and it appears the high percentage of gaze fixations towards the road and vehicles during the signalised simulated road crossing in the monitor condition contributed to this unexpected result. As the video footage used in this experiment was unable to capture all the visual information available at the actual road crossing (such as the sky and the top of some buildings), it did capture most of the information relevant to make a crossing decision, such as the road and vehicles and traffic lights. It was expected that children's gaze would be directed towards the most relevant information more during the simulated road crossings than at the actual road crossing. It is therefore hypothesised that children will direct their gaze towards the road and vehicles more during the laboratory based simulations than at the real world.

Finally it is hypothesised that the gaze behaviour at the real-world and monitor simulation crossings will be the most disparate. The differences in the scale of the visual information (large vs. small) and task (active vs. passive) are greatest between the real-world and monitor simulation conditions. Context-dependent processes that have been trained at real-world crossings are more likely to be transferred to the projection condition than the monitor condition as the scale of the visual information and stepping task in the projector simulation is closer to those at the real world. It is likely that the visual information is processed very differently in laboratory-based simulations that do not require a natural response and the real world which requires natural behaviours (Milner & Goodale, 2008). For example, the pressing of a button to signify a crossing opportunity has been selected requires a greater ventral stream contribution as perceptual judgements are required whereas in the real world dorsal stream functioning would play a larger role as action is required. These factors are hypothesised to produce differences in gaze behaviour between the road crossing conditions studied here.

## *8.2 Methods*

In this study data presented earlier is re-analysed to investigate differences in real world and laboratory based gaze behaviour. As such this chapter does not have a conventional design, although one is presented to indicate the independent and dependent variables used in the analysis. Within this section the methods used in the Chapters 3 and 6 are presented.

*8.2.1 Participants*

In this study, data from the 18 children (*M*= 8.8 *SD*= 0.4 years) who took part in the real-world crossings (Chapter 3), and a different group of 12 children (*M* = 8.5, *SD* = 0.5 years) who took part in the simulation studies (Chapters 6 & 7) were compared.

*8.2.2 Design*

The independent variable was road crossing (real world, monitor simulation or projector simulation). The dependent variables were the percentage of fixations on object-based categories ("what" information) and general gaze direction ("where" information) in the final 3 seconds before crossing.

*8.2.3 Equipment*

*Mobile Eye*

The eye tracker was fitted and calibrated for the real-world and projection simulated road crossings as described in the general methods chapter.

*Tracksys iView X remote eye tracker*

The Tracksys iView X was set-up and calibrated for the monitor display simulated road crossings as described in the general methods chapter.

*Video footage*

In the simulated crossings the video of the signalised crossing described in the General Methods was used.

*8.2.4 Procedure*

The order of simulation (projector/monitor), the video clip was counter-balanced across all participants.

*Monitor condition*

During the monitor condition, the participants were required to sit in front of a large monitor and watch a video (70cm x 8.75cm) that represented 47° horizontally and 6° vertically of the visual of a road crossing and select a safe crossing opportunity by pressing the space bar on the key board in front of them.

*Projector condition*

In the projection condition participants stood in front of a large projection (3.6m x 0.45m) that represented 79° horizontally and 12° vertically of the visual angle at a distance of 2.2m. A marking on the floor indicated the 'kerb' in the simulated study. The participants were asked to take a step forward when they felt that it was safe to do so.

*Real-world condition*

In the real-world condition children were accompanied to the crossing and crossed the road when they felt it safe to do so as described in the general methods section and Chapter 3. The data from this condition are from Chapter 3.

*8.2.5 Data analysis*

After coding the data according to the criteria discussed in Chapter 2: General Methods, Shapiro Wilk tests revealed children's fixations on the road and vehicles and their general gaze direction to the centre in the real-world condition were normally distributed as was the percentage of fixation on pedestrians in the projector condition. However no matched data sets met the assumptions required for parametric test (even after attempts to transform the data). As one group of children that took part in the real-world road crossing and another group took part in the simulated crossings independent and related samples difference tests were used in this study. Mann-Whitney *U* tests were used to compare the gaze behaviour from the children at the real-world crossing to the gaze behaviour of the children at the simulated crossings. Wilcoxon signed rank tests were used to compare the gaze behaviour of the children at the projector and monitor simulations.

Friedman's Analysis of variance by ranks statistical tests were used to determine statistical differences between percentage of fixations on categories and in the percentage of general gaze directions within conditions. Friedman's pairwise comparisons were used to identify between which specific categories or general gaze directions statistical differences were found.

## *8.3 Results*

### *8.3.1 Real-world vs. simulated road crossings*

Comparisons between the gaze behaviour of children in real-world and simulated conditions (see Figures 8.1 and 8.2) revealed a number of important differences between behaviour in real world compared with simulated conditions.

Mann-Whitney *U* tests revealed that children fixated significantly more often on lights and signs at real road crossings than during equivalent, signalised crossings under both the passive, monitor condition ($U$=19.5; $p$=0.02; $d$=1.08) and the active, projector condition ($U$=4.5; $p$=0.001; $d$=1.42) (see Figure 8.1). They also fixated the walkway significantly more often in the real-world condition compared with the passive, monitor condition ($U$=5.5; $p$=0.01; $d$=1.35), though not with the active, projector condition ($U$=22.5; $p$=0.079; $d$=0.73): although the medium to large effect size suggests that the difference may be meaningful. A post-hoc power analysis (1-$\beta$=0.605) revealed that the statistical test lacked the power to detect this difference and that 23 participants in each group would be sufficient for finding a statistical difference if one exists. On the other hand, children looked significantly less often at other pedestrians in the real world compared with those in both the passive, monitor simulation ($U$=24.5; $p$=0.04; $d$=0.55) and the active, projector simulation ($U$=21.5; $p$=0.05; $d$=0.51).

Children in the real-world condition also looked less, on average, at vehicles and the roadway compared with those in the passive, monitor simulation ($U$=31.5; $p$=0.138; $d$=0.82) and the active, projector simulation ($U$=40; $p$=0.7; $d$=0.05): however, the differences failed to reach statistical significance. A *post-hoc* power analysis (1-$\beta$=0.369) revealed that test lacked the power to detect a medium difference between the percentage of fixations on the road and vehicles between the real-world condition and the monitor simulation condition.

No significant differences were found between the real-world condition and projector condition for the gaze allocation of non-traffic features ($U$=27; $p$=0.16; $d$=0.38) or general gaze direction in the centre ($U$=43; $p$=0.876; $d$=0.21); right ($U$=41.5; $p$=0.783; $d$=0.54) and left ($U$=44; $p$=0.934; $d$=0.22). No significant differences were found between the real-world condition and monitor condition for non-traffic features ($U$=52; $p$=0.972; $d$=0.21) or general gaze direction in the centre ($U$=47; $p$=0.698; $d$=0.22); right ($U$=44; $p$=0.543; $d$=0.55) and left ($U$=31; $p$=0.116; $d$=0.78).

*8.3.2 Projector vs. monitor simulations*

Although children's gaze in the active, projector condition tended to be directed more often, on average, towards the right, and on vehicles, lights and signs compared with the passive monitor condition, these differences failed to reach statistical significance. Wilcoxon signed rank tests showed there were no significant differences in where children looked between the two simulation conditions for fixations on the vehicles and roads (Z=-1.214; $p$=0.225), although a medium effect size was found ($d$=0.62). A *post-hoc* power analysis (1-$\beta$=0.491) indicated that the test lacked the statistical power to identify this medium-sized difference. Wilcoxon signed-rank tests also showed no significant differences between the two simulation conditions for fixations on pedestrians (Z=-0.734; $p$=0.463; $d$=0.1); walkway (Z=-0.674; $p$=0.5; $d$=0.78); lights and signs (Z=-1.826; $p$=0.068; $d$=1.12); non-traffic features (Z=-1.153; $p$=0.249; $d$=0.5) or in general gaze direction (see Figure 8.2) towards the centre (Z=-1.153; $p$=0.249; $d$=0.43); right (Z=-0.135; $p$=0.893; $d$=0.02); and left (Z=-1.153; $p$=0.249; $d$=0.5).

*8.3.3 Within groups*

*8.3.3.1 Real world*

In the children group, Friedman's Analysis of variance by ranks revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=11.075; $p$=0.026; $\eta^2$=2.769) and in the percentage of general gaze directions ($\chi^2_{(2)}$=10.194; $p$=0.006; $\eta^2$=5.097). Friedman's pairwise comparisons revealed that children fixated on traffic irrelevant features significantly more than on pedestrians ($\chi^2_{(1)}$=2.907; $p$=0.037; $d$=0.81) and more to the centre than to the left ($\chi^2_{(1)}$=3.005; $p$=0.008; $d$=2). The children fixated more in the centre than the right although when correcting the $p$ value to accommodate for multiple testing this value failed to reach statistical significance ($\chi^2_{(1)}$=2.298; $p$=0.065; $d$=1.54), however as it was hypothesised that children would fixate predominately in the centre there is some justification for using an unadjusted $p$ value which was significant ($\chi^2_{(1)}$=2.298; $p$=0.022; $d$=1.54). All other pairwise comparisons failed to reach statistical significance ($p$>0.05).

*8.3.3.2 Projector*

Friedman's Analysis of variance by ranks revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=11.481; $p$=0.022; $\eta^2$=2.87) and in the percentage of general gaze directions ($\chi^2_{(2)}$=6.333; $p$=0.042; $\eta^2$=3.167). Friedman's pairwise comparisons revealed that children fixated on traffic irrelevant features significantly more than lights and signs ($\chi^2_{(1)}$=-3.012; $p$=0.026; $d$=1.17). Children fixated more in the centre than to the right ($\chi^2_{(1)}$=2.309; $p$=0.063; $d$=2.95) and left ($\chi^2_{(1)}$=2.021; $p$=0.129; $d$=2.12) and although these differences failed to reach a significant level the large effect sizes indicate that they may be meaningful; power analyses (1-β=0.798 and 0.72 respectively) showed that the tests were just lacking the power to detect these large differences after adjustments to the $p$-value were made. All other pairwise comparisons failed to reach statistical significance ($p$>0.05).

*8.3.3.3 Monitor*

Friedman's Analysis of variance by ranks revealed significant differences between the percentage of fixations on categories ($\chi^2_{(4)}$=10.545; $p$=0.032; $\eta^2$=2.636) although not in the percentage of general gaze directions ($\chi^2_{(2)}$=5.407; $p$=0.067; $\eta^2$=2.704). After adjustments were made to the $p$ values due to the number of test Friedman's pairwise comparisons revealed no significant differences between the fixations between categories. However, large effects size were found that indicate children fixated on the road and vehicles more than the walkway ($\chi^2_{(1)}$=2.535; $p$=0.055; $d$=1.39) and lights and signs ($\chi^2_{(1)}$=2.197; $p$=0.14; $d$=1.34) they also fixated more on traffic irrelevant features than the walkway ($\chi^2_{(1)}$=2.028; $p$=0.215; $d$=0.85). Power analyses (1-β=0.589, 0.542 and

0.136 respectively) indicated that the statistical tests lacked to the power to detect these large differences after adjustments were made to compensate for multiple tests. All other pairwise comparisons failed to reach statistical significance ($p>0.05$).

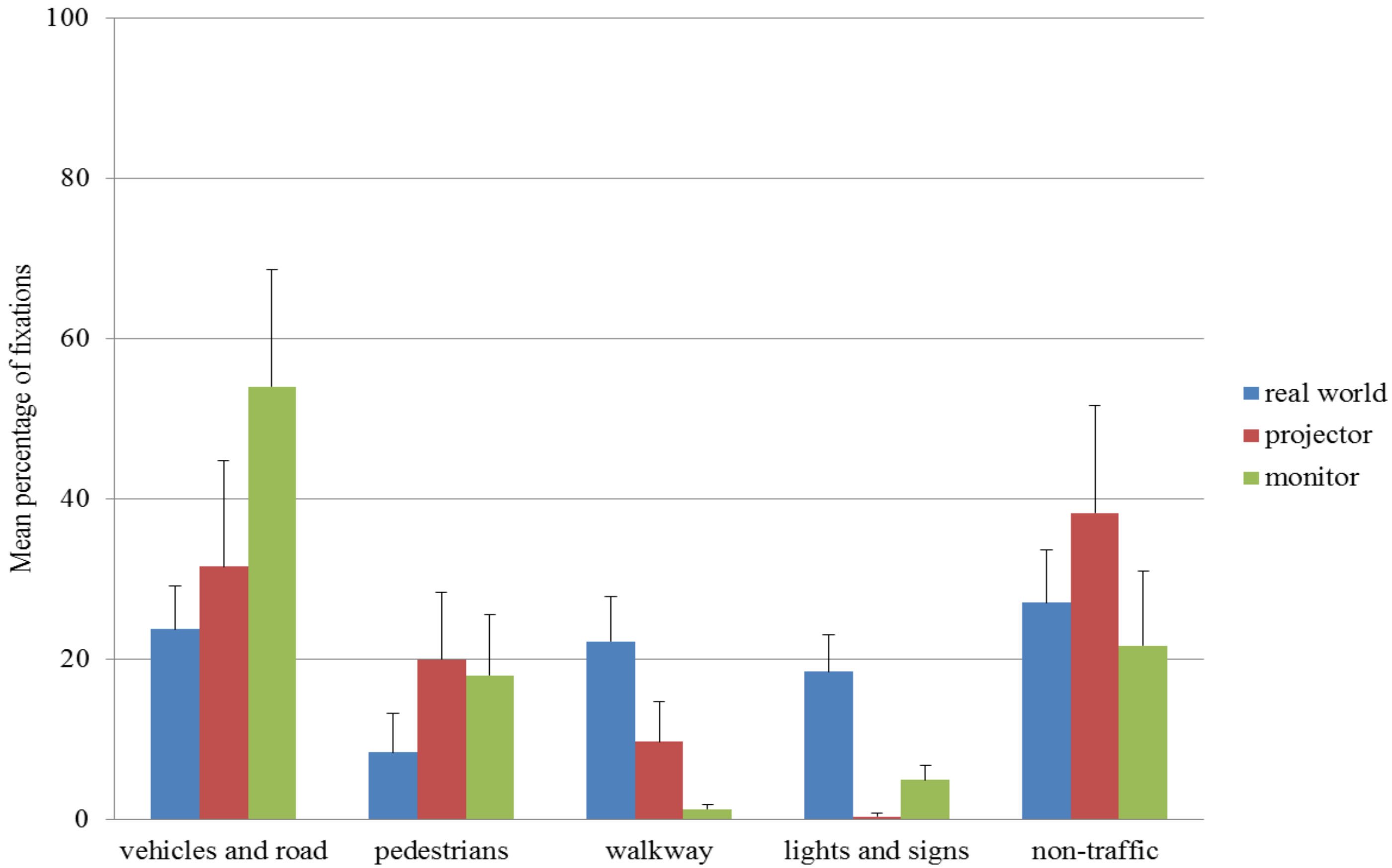



Figure 8.1. The mean percentage of gaze fixations on object-based categories by children during the real-world two-way road crossing and the projector and monitor simulations of the two-way road crossings. The error bars represent + 1 standard error of the mean.

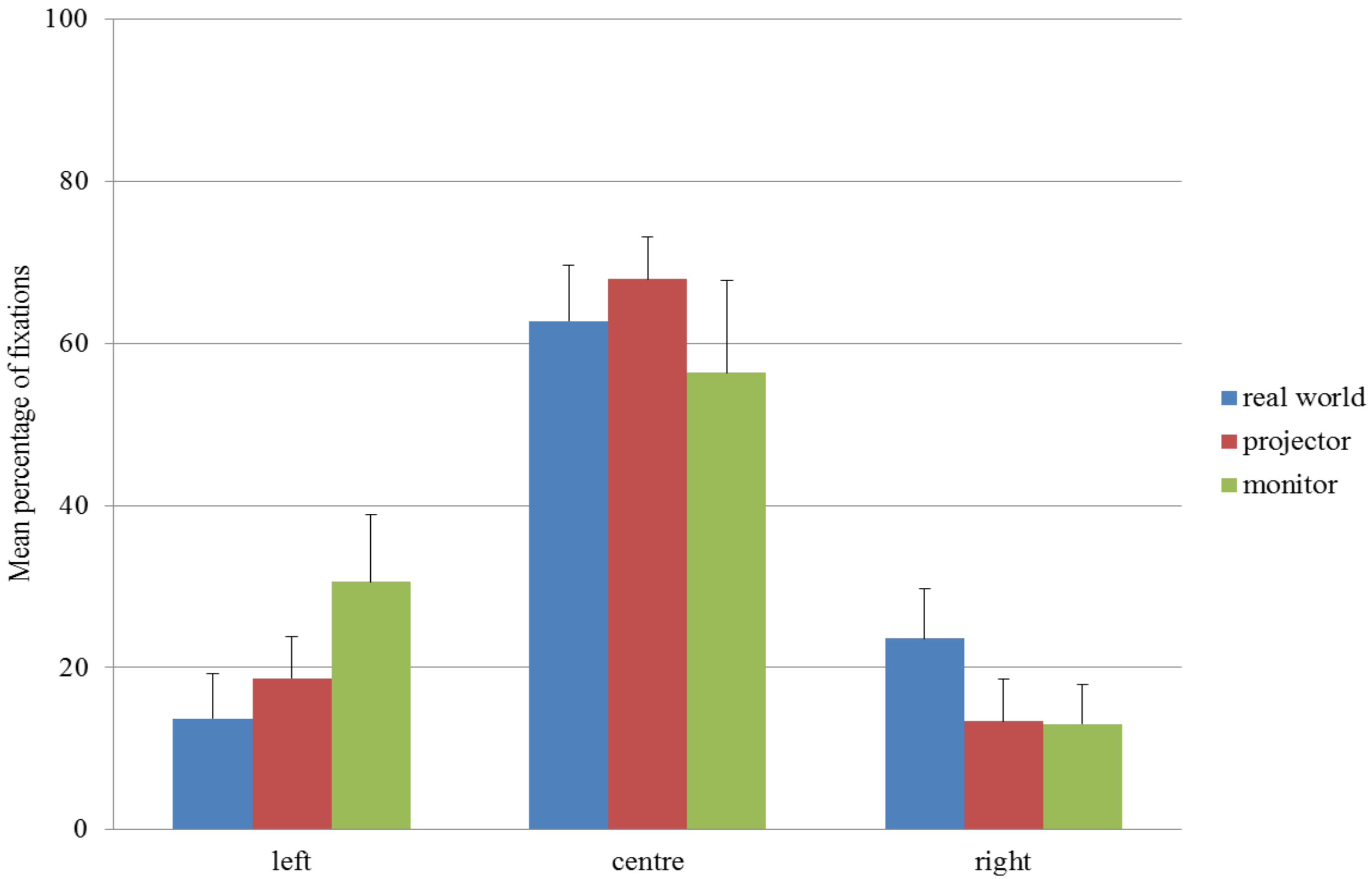



Figure 8.2. The mean percentage of gaze fixations in each direction by children during the real-world two-way road crossing and the projector and monitor simulations of the two-way road crossings. The error bars represent + 1 standard error of the mean.

## *8.4 Discussion*

It had been hypothesised that gaze behaviour would differ between real-world and laboratory-based simulation crossings, with children fixating more on the road and vehicles and less on the walkway during the simulations than during the real-world road crossing. It was also hypothesised that the projector condition would elicit more realistic gaze behaviour than the monitor condition because it mimicked the real-world task more closely in terms of its large display size and active task.

### *8.4.1 Comparison of gaze behaviour in real-world and. simulated environments*

This study was only one of a handful carried out so far to compare real-world and laboratory-based gaze behaviour, and the first to examine children. The results lent further weight to the argument that behaviour is context specific (e.g. Clark, 2001), and that cognitive processes may not be invariant across conditions and environments (e.g. Kingstone *et al.*, 2008a). Specifically, they showed that eye movement behaviour in the real world can differ markedly to that observed in the laboratory (e.g. Dick *et al.*, 2010; t'Hart *et al.*, 2009). The analysis presented here showed that in real road-crossing situations, children looked significantly more often at the ground ahead of them (walkway) and at lights and signs, than when performing in the "monitor" or "projector" simulations. This is consistent with ideas that the real world requires more physical and cognitive effort, and that behaviour differs as a result. Looking more often at the walkway is necessary to ensure that the ground ahead is suitable for taking a step, for example, and looking more often at lights and signs reduces the need for complex decision making in judging when it is safe to cross.

It may be that children spent more time looking at lights and signs in the real-world condition because there are important consequences for making a mistake, such as getting hit by a vehicle. This is consistent with Smith *et al*. (2008)'s argument that there are large differences in the levels of motivation and risks for participants at real-world environments and at the laboratory. The risks involved in crossing an actual road is likely responsible for some of the significant differences between the real-world and laboratory-based studies. The tendency for 8 and 9 year-old children to look more at signs at lights in the real world may suggest they are aware of the risks involved in crossing, and possibly also of a level of uncertainty or potential error in their own judgements regarding whether it is safe to cross.

However, although there were clear differences in what children in the real world vs. simulated tasks looked in terms of object-based ("what") categories, there were no differences in terms of "where" they looked, according to direction-based categories. This suggests that differences in eye-movement behaviour between real-world and simulated environments may not be inferred by monitoring only head movements.

A second aim of this study was to explore the possibility that behaviour in more "realistic" simulations, in terms of display size and nature of the task, might better mimic real behaviour than standard, monitor-based tasks. This hypothesis was not borne out by the current results, as no significant differences were found in terms of gaze fixation between the "monitor" and "projector" conditions. However, effect size and subsequent power analyses suggested that important differences may exist between these conditions, but that number of participants in this study was insufficient to reach statistical significance. For example, a large and medium effect size was found for the greater percentage of fixations on the walkway ($d$=0.78) and traffic irrelevant features ($d$=0.5) in the projector than the monitor condition. A large and medium effect size were also noted for the higher percentage of fixations on the lights and signs ($d$=1.12) and road and vehicles ($d$=0.62) in the monitor condition than in the projector condition. Power analyses indicated that tests lacked sufficient power to detect the large ($1-\beta=0.76$) and medium ($1-\beta=0.491$) differences noted above.

The differences between gaze behaviour in the real world compared to that in video-based simulations means that researchers using video simulations should consider the relevance of their findings to the real world very carefully. It is still not clear why gaze behaviour is different in the real world compared with the laboratory: however, differences may be due to the scale of the environment, and therefore its complexity and necessity for greater cognitive effort (Smith *et al*., 2008), the contribution of ventral and dorsal stream functioning (Dicks *et al*., 2010; Milner & Goodale, 2008) the resolution of the images (‘t Hart *et al*., 2009) or a combination of all these factors. This will be discussed in more detail in the *General Discussion* (see 9.1.3 *Gaze behaviour of children at real-world and laboratory-based simulated road crossings*).

### *8.4.2 Central bias*

It had been hypothesised that children would direct their gaze behaviour to the centre more in the laboratory based studies than during the real world condition as previous studies have shown that the way images and videos are presented in a laboratory may elicit a strong bias to fixate the centre (Cristino & Baddeley, 2009; Dorr *et al.*, 2010;; Tatler, 2007; Tatler *et al.*, 2011; 't Hart *et al.*, 2009; Vincent *et al.*, 2009). While there was a higher percentage of fixations in the centre than the left and right during the simulated road crossings this was also the case for the real world data. No differences were found in terms of the percentage of fixations directed to the centre between the real world and simulated conditions.

't Hart *et al.* (2009) noted that when viewing footage of the real world on a monitor participants fixated the centre more than when acting in the real world. The difference between the findings of 't Hart *et al.*'s (2009) study and the present study may be explained by the capture and presentation of the footage and tasks required in the studies. In 't Hart *et al.*'s study, the videos used in the laboratory conditions were taken from a head-centred camera from the free exploration study; this means that the gaze allocation during the video viewing conditions were much more restricted and gaze fixation was highly prescribed as the camera moved towards areas of the environment that the wearer of the camera looked. In the simulated road crossing used in this thesis the road crossing was filmed by five video cameras positioned in a way that they would capture all the traffic present at the road crossing. The footage from five cameras was combined, providing approximately 190° horizontal field of view of the traffic environment. The differences found between the two studies may be due to the amount of visual information available during the video viewing conditions. It is also possible that the difference is due to tasks required in the laboratory settings: the participants in 't Hart *et al.*'s study were required to view the footage passively without a goal or task and the participants in the present study were actively looking for crossing opportunities. It has long been established that gaze behaviour is very different during an active task than during passive free viewing (e.g., Buswell, 1935; Yarbus, 1967). The other explanation for the difference in findings is that cognition depends critically on the context (Clark, 1997, 2001) and as the stimuli that was presented was different the behaviours observed were also different.

### *8.4.3 Possible improvements to the simulation conditions.*

Although gaze behaviour was different in real-world compared to both projector and monitor simulation conditions, it is still possible that the projector simulation was superior than the monitor simulation in terms of eliciting more realistic behaviour: although differences between the two simulation conditions did not reach statistical significance in this study, the effect sizes were such that further research, with more participants, may be warranted. This would be advantageous in terms of setting up a realistic, yet more controlled and safer version of the real-world road crossing task in a laboratory environment.

It is also possible that the simulation conditions were not sufficiently realistic to permit realistic behaviour during the experiments. The inclusion of a longer walkway, for example, which required participants to take more than one step, might better mimic the more active task carried out in the real world This may result in the children directing their gaze towards the ground ahead of them, and therefore mimic this finding observed in the real world.

Another issue with the video display was that the entire road crossing footage was displayed on one plane. Holland and Hill (2010) used angled monitors in their video based road crossing simulation and this more closely represents a 180° expanse of visual field. This single plane display was considered to be preferable to having gaps in the display but may not be realistic enough to elicit real world behaviour. A curved projector screen with two projectors synchronised and aligned to provide a wide, curved display of road crossing footage may be able to elicit more realistic gaze behaviour.

It may be possible to create a situation where children have something to lose at the simulated road crossings. If children were told that they would not receive a reward if they selected an unsafe crossing opportunity it may result in children attending more to the lights and signs before crossing. This does not replicate the same risk present at an actual road crossing but could elicit a more natural behaviour in the lab.

It is necessary for the laboratory to be very dark so that the projection can be clearly seen. The mobile eye tracker used in this study did not function particularly well under these conditions, and as a result a large amount of data was lost. Very large backlit displays or a mobile eye tracker that is able to track the eye under dark conditions would reduce the amount of data loss during studies like this.

#### *8.4.4 Possible use for the monitor simulation in training children's road side behaviour.*

Many training interventions aimed at improving children's road crossing exist, although there is little evidence that many of them actually work (Zeedyk *et al.*, 2002). In the simulated studies children directed their gaze more towards the road and vehicles than in real world. Although this difference was not statistically significant, the gaze behaviour at the children's simulated signalised road crossing looks more like the gaze behaviour of adults at the actual signalised crossing. The monitor condition may be useful as a training aid as it directs children's gaze towards the road and vehicles. Previous studies have shown that manipulating visual information to direct children to the most pertinent sources of information can aid the learning of skills (e.g., Williams *et al.*, 2002). This simulation provides similar (although degraded) information to that present in the real world and appears to guide children's gaze towards the road and vehicles before crossing. It is possible that this simulation may be useful for training purposes. Training in the monitor simulation may reinforce attending to vehicles before crossing the road and this may be transferred to real-world crossings.

### *8.4.5 Importance of eye tracking*

Studying only the general gaze direction to indicate children's attention at these real world and simulated crossings would suggest that both the simulated road crossings are capable of producing very similar behaviour to the real-world conditions, as no significant differences were found in the general gaze direction between conditions. However, coding where children looked according to object-based categories (walkway, lights, vehicles, etc.) highlighted significant differences in the distribution of gaze fixation; this emphasises the importance of collecting eye-movement behaviour when investigation attention in real-world settings with active tasks. The use of eye-movement recording during real-world activities has shifted the emphasis in psychological research away from the properties of objects and towards their behavioural relevance (Hayhoe & Rothkopf, 2020).

## *8.5 Conclusion*

Studying gaze behaviour inside the laboratory using simulated road-crossing scenarios allows a greater degree of experimenter control and a safe environment; however, the findings presented here suggest that although gaze behaviour in simulated conditions was similar to that in the real world in terms of general gaze direction, patterns of fixation were often quite different between real world and simulated conditions for object-based categories. This suggests that examining head direction alone during real world road crossing may not be fully representative of actual looking behaviour.

The video displays used in this study did not produce the same gaze behaviour but it is possible that a revised methodology incorporating a more realistic video, longer walkway and an element of risk may be suitable for studying gaze behaviour inside the laboratory. It should not be assumed that cognitive processes observed in a laboratory setting are invariant of context (Kingstone *et al*., 2008a), researchers investigating real-world issues in the laboratory should strive to ensure that the simulated environment is capable of eliciting behaviours similar to the ones produced in the real world.

# **CHAPTER 9**: GENERAL DISCUSSION

## *9.1 Overview of the aims*

The primary aim of this thesis was to explore whether an active eye-tracking method could be useful in exploring why children and older adults may be over-represented in pedestrian accidents. The specific aims of this thesis were to:

1) compare the eye-movement strategies of children, younger adults and older adults in a real world, active road-crossing task, in a way that might explain their greater propensity for involvement in pedestrian accidents;

2) explore whether established road-crossing training interventions using both traditional and VR methods can improve the gaze behaviour of children at an actual road crossing;

3) compare gaze behaviour at real-world and laboratory-based, simulated road crossings using (a) small-scale display and passive task (the "monitor" condition"); and (b) large-scale display and active task (the "projector condition");

4) assess the effects of a secondary task on the gaze behaviour at a road crossings

The scope of this thesis covered pedestrian accident statistics, the development and decline of road-crossing skills across the lifespan, the effects of secondary tasks on gaze behaviour, and comparing gaze behaviour within real-world and simulated environments. The thesis was ambitious and includes the first experiments to investigate the gaze behaviour of children, adults and older pedestrians during an active, real-world task, and to compare gaze behaviour in real-world and simulated roadside conditions. The results from these experiments have provided valuable insights about what children, adults and older adults look at just before they make the decision to cross the road, the effects of a secondary task (such as eating an ice cream, or counting upwards in threes) on children's gaze behaviour, the effects of two training interventions designed to improve road safety, and the effectiveness of video-based simulations in eliciting real-world gaze behaviour.

This final section summarises what was discovered for each of these aims, identifies and draws together a number of key themes to emerge from across the experimental chapters, and further discusses the successes, limitations, and implications of the research in terms of both the methodology, and its wider theoretical and practical contexts.

### *9.1.1 The eye-movement strategies of children, younger adults and older adults a signalised road crossing*

The first aim of this thesis was to compare the eye-movement strategies of children, younger adults and older adults in a real world, active road-crossing task, in a way that might explain their greater propensity for involvement in pedestrian accidents. It would have only been possible to conclude for certain that particular gaze behaviours were linked to pedestrian accidents if the participants had crossed the road unsafely. This was not the case and all the participants crossed the road safely. However, failing to look for vehicles before crossing a road is the most cited cause of pedestrian accidents in official accident statistics (DfT, 2010b), so it would seem reasonable to assume that gaze direction is a valid construct with which to probe the efficacy of road-crossing skills.

It was expected that visual search strategies would differ across the life span and that children and older adults would display looking behaviours that may explain their over-representation in pedestrian accidents. The behaviours that may explain the overrepresentation of *children* were hypothesised to centre around attending to traffic irrelevant information rather the road and vehicles, due either to their comparative inexperience at the roadside (i.e. lack of skill) or poorer attentional control (Barton & Morrongiello, 2011; Tabibi & Pfeffer, 2003; Tolmie *et al*., 2005a). Indeed, the results showed that children fixated on irrelevant features of the road crossing environment more than adults and although this failed to reach statistical significance the medium effect size and a *post-hoc* power analysis suggested that more participants were required for this difference to become statistically significant.

Potential factors that may predispose *older adults* to pedestrian accidents were hypothesised to relate to their prioritising stepping location ahead of oncoming traffic (e.g., Oxley *et al*., 1997; Young & Hollands, 2010). As such, older adults' fixations on the walkway may be a functional adaptation to decrease the risk of a fall. It appeared that this was the case in this study, as older adults directed their gaze towards the walkway significantly more than any other category, including the road and vehicles. This difference was not significant after adjustments were made to the *p* value for multiple tests but the large effect size indicates that this difference may be important. Fixating more on the walkway and less on the road and vehicles may be a predisposing factor in pedestrian accidents but it may also be a functional strategy to reduce the risk of falling. Due to this perceived functional, adaptive behaviour of the older adults and children's relatively high percentage of fixations on irrelevant features the future studies in this thesis focused on children's gaze behaviour at road crossing.

*9.1.2 Improving children's gaze behaviour at road crossings*

The findings from Chapter 3 indicated that children's attention to irrelevant information may explain, at least in part, their overrepresentation in pedestrian accidents. The second aim of this thesis was to explore whether established road-crossing training interventions using both traditional and virtual reality (VR) scenarios improved the looking behaviour of children at real road crossings. It was hypothesised that the instruction-based "Safety Watch" intervention would not improve gaze behaviour at the road crossing to the same extent as the "Crossroads" intervention, as previous research had indicated that increasing young children's knowledge of road crossing does not lead to an improved performance at actual crossings (Zeedyk *et al*., 2002). On the other hand the VR-based "Crossroads" intervention was expected to improve children's gaze behaviour as the intervention allowed the children to practice skills such as predicting drivers' actions and looking for vehicles at a road crossing. However, neither of the training methods used in this study led to the hypothesised changes in gaze behaviour that could be associated with a safer road crossing strategy. The lack of improvement following the "Crossroads" intervention was surprising, as other studies have shown some improvements in roadside behaviour after virtual reality training (Thomson *et al*., 2005). However, it was noted by Thomson *et al*. (2005) that Crossroads was more effective at improving children's road-crossing behaviour when it was accompanied by adult-led discussion than when it was accompanied by peer-led discussions.

It may be that children require certain cues, behaviours or skills to be emphasised by adults to fully benefit from the VR-based training. Alternatively, it is possible that training road-crossing skills in front of a computer is an ineffective way of improving gaze behaviour in the real world as it is likely that cognition is context dependent (Chiel & Beer, 1997; Clark, 1998; Clark, 2001; Pfeifer & Scheier, 1999; Steels & Brooks, 1995; Wilson, 2002) and tasks that require button presses over realistic actions may be training perceptual skills related to ventral stream processing that do not play a significant role when acting in the real world (Dicks *et al*., 2010).

### *9.1.3 Gaze behaviour of children at real-world and laboratory-based simulated road crossings*

The experiments outlined in this thesis were based on the assumption that cognitive processes are not invariant across tasks or environments (e.g. Kingstone *et al*., 2008a), and that gaze behaviour during laboratory based simulations may not be representative of gaze behaviour in the real world (e.g. Dicks *et al*., 2010; 't Hart *et al*., 2009). It was hypothesised that gaze behaviour in the real world would differ from that in laboratory simulations because (a) the display sizes tend to be smaller in the lab; and (b) the tasks are typically more passive in laboratory tasks; and (c) the "cost" of getting things wrong is much higher in the real world. As predicted, the gaze behaviour of children at a simulated road crossing was significantly different to that at a real-world road crossing. Specifically, children directed their gaze towards the road and vehicles more and the walkway less at the simulated crossings than at in the real-world crossing. This supports the findings of Dicks *et al*. (2010) and ‘t Hart *et al*. (2009) and questions the use of laboratory simulations in studies that intend to investigate realistic gaze behaviour. The general gaze direction fixations appeared to consistent across each condition.

### *9.1.4 Secondary task and the gaze behaviour at a road crossings*

The fourth aim of this thesis was to assess the effects of a secondary task on the gaze behaviour at road crossings. Chapter 3 indicated that children’s higher percentage of fixations on traffic irrelevant features (higher than other categories but not significantly higher than adults’ although the effect size suggest that the difference between children and adults in terms of fixations on traffic irrelevant features may be meaningful) may be indicative of lesser attentional skills. To further assess the attentional capabilities of children the effects of ice cream on the gaze behaviour of children at a signalised road crossing and the effects of a counting task on children’s gaze behaviour at a simulated signalised crossings were studied. It was hypothesised that the presence of an ice cream or the additional cognitive load of eating the ice cream would have a negative effect on gaze behaviour before crossing the road. The negative effect on gaze behaviour would be observed by a reduced percentage of fixations on the road and vehicles and an increased percentage of fixations on traffic irrelevant features and in the general gaze direction in the centre (away from approaching vehicles). However there were no significant effects of ice cream on fixation to the road and vehicles or traffic irrelevant features. As hypothesised the percentage of fixations in the centre was significantly higher during the ice cream condition. Fewer looks to the direction of oncoming traffic before deciding to cross was a trait of the youngest group of children in the Whitebread and Neilson (2000) study.

The ice cream condition differed from many of the task traditional used to assess the effects of a dual task on primary performance. Eating the ice cream requires visual attention and it was not possible to attribute changes in gaze behaviour to the effects of an additional cognitive as the changes may have been to secondary task. To further investigate the effects of a secondary task on the primary task of crossing the road a non-spatial secondary task was used in a simulated road crossing study. It was hypothesised that gaze behaviour at a simulated road crossing would be negatively affected by a counting task as children's limited attentional capabilities will be overloaded by the additional task and this will result in poorer gaze control (Foley & Birch, 1997). As hypothesised in the counting condition children directed their gaze significantly less at the road and vehicles during the monitor simulation of the road crossing. This study supported the findings of many dual task studies (e.g., Abernethy *et al*., 2002; Beauchet *et al*., 2007; Hollman *et al*., 2007; Irwin-Chase & Burns, 2000; Lajoie *et al*., 1996; Li *et al*., 2001; Lindenberger *et al*., 2000; Sparrow *et al*., 2002; Van Iersel *et al*., 2007) in that performance on a primary task was negatively affected by the addition of a secondary task.

### *9.2 General themes*

The idea that cognition is context specific, the variability in gaze behaviour and data loss were recurrent themes in most of the studies in this thesis and are discussed in turn.

### *9.2.1 The context of cognition: Embodied Cognition and Cognitive Ethology approaches*

Throughout the studies of this thesis the importance of context in cognition was apparent. The decision to cross at actual roads for the majority of the studies was based on principles of cognitive ethology (Kingstone *et al*., 2008a), representative design (Brunswik, 1956, cited in Dhami *et al*., 2004) and embodied cognition (Clark, 2001). Cognitive processes are context specific (Clark, 2001) and are unlikely to be invariant across are range of tasks and environments (Kingstone *et al*., 2008a). The lack of improvement noticed at real-world crossings as a result of training that takes place on a computer was also linked to the cognitive processes being context specific and the recommendations for future interventions to be conducted at actual road crossings was based on the theory of cognitive embodiment (Clark, 2001). The final study in which gaze behaviour in the real world and laboratory were compared supported the cognitive ethology (Kingstone *et al*., 2008a) as the behaviour noted in the real world was not invariant across conditions. To understand natural behaviour it is important to study behaviour under natural conditions.

### *9.2.2 "What" versus "Where" Looking*

The studies in this thesis were specifically designed to increase our understanding of behaviour during complex real-world situations. The active nature of the tasks played an important role, because to understand behaviour it must be studied under natural settings (Brunswik, 1956, cited in Dhami *et al*., 2004; Kingstone *et al*., 2008a). There is evidence to suggest that the dorsal stream of visual processing in the human cortex makes a much more significant contribution when the visual information is processed to guide actions than to generate perceptual judgements (Milner & Goodale, 2008). By studying active tasks it is therefore likely that the dorsal stream will play an important role. Differences found between the laboratory-based conditions, which differed in the extent to which they required an active response or perceptual judgment, may have been due to the relative contribution of the dorsal and ventral pathways. Moreover, it is likely that the contribution from the dorsal stream is reduced for actions that have received little practice and that the ventral stream makes a considerable contribution to actions during the early stages of learning (Milner & Goodale, 2008). This may to some extent have affected laboratory-based conditions, as they attempted to replicate the natural situation but still may have been novel tasks to participants. If, in the early stage of learning, the ventral stream plays a much more prominent role than when a skill has been mastered (Milner & Goodale, 2008), the relative contribution of the ventral and dorsal streams may partially explain the differences in gaze behaviour found between young adults and children at the roadside. In young adults the dorsal stream may have contributed more to their gaze behaviour and processing of visual information than the ventral stream, whereas in children the ventral stream may have played a dominant role.

The notion of two visual systems was first proposed by Ungerleider and Mishkin (1982). They proposed that the dorsal stream is responsible for processing “where” objects are, whereas the ventral stream is responsible for processing “what” the object is. In the studies in this thesis fixations on object-based categories and location-based categories were measured. These dependent variables represented “what” the participants were looking at and “where” it was. It is probable that dorsal and ventral stream contributions influenced the fixation behaviour during the road crossing studies. When comparing "where" children looked at real-world and simulated road crossings no differences were found, although differences were found in terms of "what" the children were looking at. Conversely during the real world spatial secondary task (ice cream), the addition of a secondary task had no effect on "what" the children fixated, but it did affect "where" children looked. As cognition appears to be context dependent it is not surprising that some situations affect some cognitive processes and not others. Here it appears that the dorsal stream may be less affected by the degraded visual information presented in the laboratory but more affected by a spatial distractor than the ventral stream. If this is the case, then studies that monitor only head movements during active tasks (e.g. Holland & Hill, 2010) may be observing the effects of dorsal stream functioning, which would seem appropriate give the important role of action in most real-world activities.

### *9.2.3 Variability in gaze behaviour*

It is not possible to reduce situation variability without affecting the nature of the process being observed (Kingstone *et al.*, 2008a). In the real-world studies in this thesis a degree of experimental control has been sacrificed in order to study how pedestrians actually behave in the real world. It is likely that reducing experimental control has produced higher levels of variability than typically found during laboratory-based studies.

Inter-participant variability was high throughout the studies reported in this thesis. The high variability made it more difficult to uncover statistically significant differences in gaze behaviour, which in turn meant that more participants than originally expected may have been advantageous. However, variability (as estimated by standard error) was very similar between each of the age groups, even though the “children” group contained many more participants. This suggests that the use of larger groups may not necessarily have increased the probability of finding differences between conditions and groups at real-world crossings.

It is unclear at the moment if the variability in gaze behaviour observed at the real-world signalised road crossings is due to inter-participant differences or the result of the participants' gaze behaviour being highly adaptable and context sensitive. Kingstone *et al*. (2008a) noted that it is important to let variance occur naturally and measure it, rather than trying to control every setting in the environment (which is not possible in the real world) as variance may reveal important characteristics of cognitive processing. Variability in gaze behaviour (e.g. ‘t Hart *et al.,* 2009), for example, may reveal important differences between behaviour in real-world vs. laboratory settings (see 1.8.8 *Real-world vs. simulated displays*). Variability in motor control, too, can be seen as a reflection of a skilled and highly adaptable system (Egan *et al*., 2007). Variability in gaze behaviour in the real world should therefore not be considered necessarily as a hindrance, but a reflection of the nature of gaze control under natural settings.

Of course, the down side of exploring behaviour as it occurs naturally is not without its difficulties, not least the sacrificing of experimental control for ecological validity. It was not possible to completely recreate the same visual information available for each participant in real-world tasks due to many uncontrollable factors such as traffic flow and the behaviour of other pedestrians: as such, at least some of the variability between participants would have been due to differences in the traffic environment when the data were collected. Indeed, the handful of studies which have explored eye movement behaviour in real-world settings has also reported large amounts of inter-participant variations in gaze behaviour has also been reported (Geruschat *et al*., 2003; Underwood *et al*., 2005).

Future studies investigating within-participant variability of gaze control would help to increase our understanding of the nature of variability in gaze control more widely. The variability in gaze behaviour may also reflect differences in development in the children group and variation in the cognitive capabilities in the older adults.

### *9.2.4 The Mobile Eye: Problems and data loss*

The Mobile Eye is adjustable and can fit a reasonable variety of face shapes; however, the eye tracker could not be rested on the face of some children as either the nose of the child was not large enough for the eye tracker to rest on or the weight of the eye tracker was too much to be supported by the children's ears which resulted in the eye tracker slipping. Other reasons for data loss in the real-world condition were the participants (children) touching the eye trackers' lens when trying to rub their eye. Some children also knocked the reflective lens with a chocolate 'flake' in their ice cream and other children smeared ice cream onto the lens accidentally when eating their reward.

To prevent data loss due to sun light on the reflective lens of the mobile eye a baseball hat and later a cowboy hat was used. Unfortunately these methods were ineffective. Other studies had used a film on the lens to filter out infra-red light (e.g., Geruschat *et al*., 2003). This was not attempted in these studies as the lens was positioned in a prominent area of the visual field.

It was originally planned that data would be collected from four signalised crossings. The onset of the red pedestrian light at the first signalised road crossing was chosen as a standardised starting point. However, sun light often prevented eye-movement tracking at this and two other signalised road crossings. The participants arrived at the signalised crossing used in this thesis at different stages in the traffic cycle. If these experiments were to be repeated then the starting point from this crossing would be standardised.

When data were collected from children at the real-world crossings a second adult was present. Four sets of data from the children's real-world road crossings were discarded due to a breach of protocol from an accompanying adult. The experimenter and second accompanying adult were not to engage in conversation with the child at the roadside and were to stand behind the child, out of the child's peripheral view. At some of the crossings the second accompanying adult was a school road crossing guard and he occasionally prompted the children to cross with questions and entered the child pedestrian's peripheral view and on two trials stepped into the road before the child (as he would normally do). Due to these breaches of protocol the data affected was discarded.

Other difficulties with tracking gaze seemed to be more prevalent with the older adults. Often with older adults the image of the eye appears to be very cloudy and tracking was less consistent than with the younger adults. On reflection this may have been due to cataracts. In the laboratory the dark conditions in which the projection simulation occurred caused the pupil to expand beyond the range the eye tracking software accepted.

The entire fitting and calibration of mobile eye trackers is now possible on the site of the road crossings due to the recording and calibration equipment being on a netbook. This means the eye tracker can be worn for a much shorter time and the calibration of the eye tracker is less likely to be effected by a long walk or drive.

### *9.3 Critical evaluation*

The studies in this thesis are novel and there are numerous improvements that could have been made. First, power analyses could have been conducted before the studies began (rather than *post-hoc*) to determine how many participants would be needed to minimize the likelihood of Type II errors occurring. The reason this did not occur was due to the author being unaware of this procedure at the start of studies. In many of the studies (1, 2, 3, 4 & 6) medium to large effect sizes were found for non-significant differences. If a power analysis had been conducted on the intervention study (Chapter 5) the Safety Watch condition may have been dropped to increase the number of participants in the Crossroads and control condition.

During the initial data collection sessions at the school, children were shown the video from the scene camera and asked to describe what they were thinking and looking for as the video played. This was dropped due to children reporting that they were always looking for cars or the red light (which was clearly not the case). At the time it was felt that the children were giving socially desirable answers that did not reflect what they were actually doing at the crossing and therefore their answers were considered of little relevance. In retrospect, children's assertions of their road-crossing behaviour may have indicated that they are aware of what they should be doing at the road crossing and further strengthened the argument against training interventions that hope to improve road-crossing behaviour by increasing their theoretical knowledge (e.g., Safety Watch). The differences in what children say they were doing when watching a video and what they did at the crossing may also be relevant to the two visual systems section and add more support for the use of eye tracking techniques during real-world activities as an accurate way of measuring behaviours.

Had the road-crossing simulations been created before the real world crossings data had taken place it would have been possible to have used the same group of children for the real world and simulated crossings. The reason that they were not ready in time was due to a trial and error process in collecting the footage (various elevations, angles and number of cameras were experimented with) and the stitching of the video footage proved to be difficult for a then novice video editor.

*9.4 Implications of the Thesis*

In this section the implications of this thesis to road safety and general psychology are discussed. The experiments in this thesis, while often not perfect, have provided sufficient impact to go forward with more research and potentially make a difference to the number of children involved in pedestrian accidents and how research investigating eye-movement behaviour is conducted.

It appears that CD-based training programmes on their own do not make any difference to the way children move their eyes at the roadside. Children may require additional reinforcement about their road-crossing behaviour from an adult. The simulated crossing used in this thesis seemed to direct children's gaze towards traffic-relevant features such as vehicles. It is possible that training children's road crossing skills with this road-crossing simulation may improve their gaze behaviour at real-world road crossings. Future studies that investigate training methods have been proposed and these may be an effective training intervention. However, the findings from this thesis suggest that practising at an actual road crossing (under adult supervision) is likely to be the most efficient way of developing children's road crossing skills as cognitive skills are likely to be context specific.

Considerable effort was put into making the road-crossing simulations used in this thesis. The dynamic nature of the footage and the field of view captured replicates real-world visual information better than using a static image of a real world environment. However, despite this effort to create a realistic simulation it appears that such a simulation is unable to elicit real-world behaviour. Two studies (Dicks *et al.*, 2020 and the study in Chapter 8) have compared eye-movement behaviour during active tasks in the real world and in the laboratory. Both of these studies used a video-based simulation of a task that in the real world requires the observer to stand still while making a decision (saving a penalty in soccer and waiting to cross the road). Both studies found that these simulations do not elicit gaze behaviour found in the real-world. If laboratory-based studies using dynamic footage of events that would normally be viewed from the same position as they are presented in the laboratory are unable to elicit real world behaviour, it seems unlikely that studies using static images of real-world scenes are able to explain real-world behaviour. More real-world research is needed in order to develop theories about cognition that can explain real-world behaviour (Kingstone *et al.*, 2008a). Many real-world studies could build up descriptions of real-world behaviour and over time common patterns may emerge that are relevant to cognitive processes in rich, dynamic environments, in which these processes have evolved and developed.

### *9.5 Future Studies*

In this section, further studies are outlined which would address some of the issues raised in this discussion. The contribution of dorsal and ventral functioning in the real-world and simulation road crossings and the variability of gaze behaviours are two prominent themes throughout this thesis. However, the proposed research in the following sections could further inform our understanding of both of these themes. Suggestions are also made for research evaluating the monitor road-crossing simulation as a training tool aimed at improving children's gaze behaviour. Finally additional measures of executive function are proposed as supplementary measures to future eye-guidance research.

### *9.5.1 Contribution of dorsal and ventral stream for differences in gaze behaviour*

There were clear differences in the gaze behaviour of children at the real-world road crossing and at the simulated monitor road crossing. It has been noted that the contribution of the dorsal and ventral stream processing of visual information depends on the nature of the task (Goodale *et al*., 1991; Goodale & Milner, 1992; Milner & Goodale, 2008). The dorsal stream plays a prominent role during practised real-world activity (such as crossing an actual road) and a less active role in tasks that require perceptual judgements where unnatural responses to the stimuli are required (such as pressing the space bar when viewing a video of a road crossing). However, it is not possible to conclude that differences in gaze behaviour observed at the real-world and simulated crossings to the contribution of dorsal and ventral stream processing as other factors (such as the size and quality of the visual information available) may have influenced the behaviours in these conditions. To further investigate the effects of dorsal and ventral stream processing on eye guidance at a road crossing it would be possible to conduct an experiment that takes place at a road crossing where the dependent variable would be the response when a safe crossing opportunity is selected (verbally identify or cross). The verbal indication would be predominantly influenced by ventral stream processing whereas actual crossing would be mainly influenced by dorsal stream processing. Any differences observed in gaze behaviour between the two conditions would likely be as a result of the contribution of dorsal and ventral stream processing.

### *9.5.2 Investigating variability*

A large amount of inter-participant variability in gaze behaviour has also been reported in this thesis and in other studies that have investigated eye-movement behaviour in real world settings (Geruschat *et al*., 2003; Underwood *et al*., 2005). In this thesis the nature of the variability observed is unclear. The variability may have been due to inter-participant differences or due to the dynamic nature of the environment. Future studies collecting gaze behaviour from each participant crossing the same road on numerous occasions can improve our understanding of gaze behaviour in the real world. It may also be possible to reduce environmental variability in the real world by regulating traffic. Zeedyk *et al*. (2002) investigated children's road crossing behaviour at an actual road in which the traffic flow was being regulated by a police officer. Such a measure may reduce some of the environmental variability meaning that the variability observed is more likely to be a result of individual differences.

### *9.5.3 New road crossing training tool and training at road side*

During the monitor simulation road crossings, children directed their gaze more towards the road and vehicles than in real world. It can be argued that because the dynamic visual information used in this simulation was sampled from a real-world road crossing the monitor simulation provides much more realistic road crossing scenario than those present in the Crossroads and Safety Watch interventions. As the monitor simulation appears to guide children's gaze towards the road and vehicles before crossing the efficacy of the simulation as a training intervention warrants investigation.

As cognition appears to be context dependent (Clark, 2001; Kingstone *et al*., 2008a) it may be useful to train children's road-crossing skills at the roadside. This training could involve an adult accompanying the child to the road crossing and asking the child to cross when it is safe to do so. For safety the adult should have some mechanism to prevent the child from making an unsafe decision. Providing children with the opportunity to practise road crossing in the real world and asking them to act upon this visual information is likely to develop context dependent cognitive skills. Principles related to the study of psychology such as representative design and cognitive ethology (see 1.8.1 *Cognitive ethology*) could usefully be applied to interventions aimed at improving children's road-crossing behaviour.

McKenna (2010) noted that few training programmes aimed at improving road safety are based on theory or evidence: training with the monitor simulation road crossing or at the roadside would respectively be based on evidence and theory.

### *9.5.4 Inclusion of traditional EF measures alongside real-world gaze behaviour approach*

The issue of attentional control versus overall cognitive load versus inexperience was considered in Chapter 4. Due to the real-world approach it is was not possible to control each of these variables and just as in the real world these and many other variables were free to interact. Therefore it was not possible to state that differences in gaze behaviour between groups or conditions were the result of one particular process. The supplementary use of traditional executive function measures or the

UFOV could enrich eye-movement data collected in the real world and may indicate the importance of some cognitive factors over others in their contribution to the observed gaze behaviour. For example, collecting Stroop test data in addition to gaze behaviour at actual road would allow correlations to be made between the Stoop test performance and the percentage of fixations on traffic irrelevant features would increase our understanding of the contribution of attentional control during real-world behaviour. If a negative correlation was found that would indicate the processes investigated in the laboratory are also involved in selective attention during a dynamic complex environment. If no correlation was found it may indicate that the requirements of the Stroop test are so far removed from naturally occurring tasks that they are not sub-served by the same underlying mechanisms.

### *9.6 Conclusions*

Collecting eye-movement data at an actual road crossing provided information on what children, younger adults and older adults fixated before crossing the road. It is plausible that the lower percentage of fixations on vehicles observed in the children and older adults compared to younger adults is related to unsafe crossing in children and older adults. This observation fits with accident report data, but as all participants crossed safely it cannot be concluded with certainty that fixating less on the road and vehicles is linked to pedestrian accidents.

Perhaps the most important finding from this thesis was that eye-movements observed in the children when selecting a safe crossing opportunity appeared to depend critically on the specific context in which they occurred. This has huge implications for those interested in explaining real-world behaviour. Many researchers incorrectly assume that the processes they investigate in the laboratory are invariant across conditions (Kinsgtone *et al*., 2008a). The effects of a non-spatial secondary task on the gaze behaviour of children required to select a safe crossing opportunity by pressing the space bar on a keyboard when viewing footage of a road crossing on a monitor whilst seated were not found when the children were required to take one step forward when they had selected a safe crossing opportunity when the footage was projected onto a wall and viewed whilst standing.

Another incorrect assumption that researchers often make is that it is possible to reduce situational variability without affecting the nature of the process being observed (Kinsgtone *et al*., 2008a). A comparison of gaze behaviour data collected in the complex real world and the simplified laboratory setting shows that children direct their gaze differently during these conditions. This raises questions about the validity of other studies that have investigated gaze behaviour when viewing simulations of real-world scenes in a laboratory. It has been proposed recently that much of the research investigating eye-movement behaviour when viewing real-world images may only be informative to how pictures are viewed (Tatler, 2009). The use of dynamic footage and active tasks used in the simulations in this thesis are arguably much more realistic than stimuli (still images) and tasks (passively viewing a scene) used in many other studies (e.g., Henderson, 2003) but despite this effort to make the simulated conditions realistic, they are still unable to elicit gaze behaviour observed in the real world. Based on these findings it is proposed that Tatler's (2009) concerns regarding the implementation of traditional laboratory methods (e.g. passively viewing images) to increase our understanding of eye guidance in the real world are well founded.

Conducting real-world eye-movement research is difficult with many issues regarding experimental control and variability. The coding of the data by hand can also be arduous. However, the challenge of investigating complex processes in dynamic environments (which humans have evolved to do) is exciting. Real-world research is vital to advance our understanding of how people actually behave in the real world. The results from simple laboratory-based studies allow us to generate theories that can explain cognitive processes in the real world (Kingstone *et al*., 2008a), but these theories require careful verification in the real world before they can be accepted as describing meaningful, real behaviour.

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