A NOVEL PARADIGM TO IDENTIFY AGE- AND STROKE-RELATED CHANGES TO GAZE BEHAVIOUR ASSOCIATED WITH FALLS RISK DURING WALKING

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Abstract

This thesis aimed to investigate a novel way to explore changes in gaze behaviour, whilst walking, in frail populations. Initially three studies were conducted to establish how similar gaze behaviour recorded during walking was to that recorded whilst scene viewing. Duration of time and number of times different features were fixated were found to be similar in the three experiments. Older adults were assessed for falling risk and split into higher risk of falling (HROA) and lower risk of falling (LROA) groups. Their gaze behaviour was recorded whilst scene viewing along with a group of young adults. HROA were found to fixate the travel path longer than LROA and younger adults. HROA were slower at completing the incongruent Stroop task, suggesting a relationship between response inhibition and increased falling risk. A group of stroke patients were assessed for falling risk and split according to lesion location (parietal, occipital or frontal-temporal); gaze behaviour was recorded during scene viewing and compared to controls. Observable differences, which related to falling risk and lesion location, were shown in the gaze behaviour of the stroke patients compared to the controls. The findings of this thesis suggest that scene viewing could be used to better inform us about the changes in gaze behaviour which occur in frail populations that led to an increased risk of falling and the cognitive mechanisms which underlie these changes than laboratory studies.

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List of Abbreviations

MMSE: Mini Mental State Examination

TMT: Trail Making Task

HROA: Higher Risk Older Adults

LROA: Lower Risk Older Adults

ABC: Activities Balance Confidence Scale

GHQ: General Health Questionnaire

TUG: Time Up and Go

Chapter 1

General Introduction

Vision is crucial for human locomotion as it is the only sensory modality which provides information about the future travel path necessary for safe and efficient travel through our cluttered environment. In order to understand how humans use vision during locomotion it is important to investigate the cognitive control of eye movements during different tasks.

1.1: Cognitive control of vision

A number of studies have demonstrated that participants' gaze behaviour is influenced by the demands of the current task. DeAngelus and Pelz (2009) revisited Yarbus' classic work on how task demand shapes the eye movement behaviour of participants when viewing a photograph. They showed that asking participants to report on the age of the subjects in the picture produced a different pattern of eye movements to those produced by asking participants to report on the clothing worn by the subjects in the picture. Their findings suggested that eye movements are influenced by the goal of the participant and past experiences. In addition, sandwich (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003) and tea making (Land, Mennie, & Rusted, 1999) studies demonstrate a strong temporal link between eye movements and action with participants fixating objects such as the kettle, mug or knife moments before they use the object and then maintaining fixation until they have completed the action. The sandwich and tea making studies also showed that participants fixated objects not relevant to the current task for only 5% of the time indicating that fixation behaviour is driven by the goals of the current task. During sporting activities visual fixation behaviour is dependent on a number of factors which include prior knowledge of the situation gained through practise, the physical state of the player (level of fatigue and anxiety) and environmental distractions such as auditory and visual interfere (Williams, Janelle, & Davids, 2004).

Understanding how gaze behaviour is influenced by different activities is important for understanding human behaviour. The focus of the current thesis is to examine gaze behaviour during the everyday activity of walking.

1.2: Visual and cognitive control of walking in young adults

Hollands *et al*. (1995) were the first to record gaze behaviour whilst young adults walked along a predefined stepping stone route. They demonstrated that participants usually fixate the next stepping stone in the travel path during the stance phase of the targeting foot and then maintain fixation until the step has been completed at which point gaze is transferred to the next target in the route. Their findings demonstrated little variability between looking and stepping to the next target in the travel path. The observation of a temporal link between looking and stepping has also been observed by Patla and Vickers (2003) who investigated how far ahead participants fixated as they walked along a pathway with irregularly or regularly placed targets. They observed that participants fixated about two steps ahead in both conditions. The temporal link has also been demonstrated by Patla and Vickers (1997) during obstacle interaction. They explored how young adults use vision when stepping over an obstacle in the travel path. They found that participants' fixated higher obstacles with a greater frequency compared to the smaller obstacles suggesting that participants require more visual information about higher obstacles in order to safely negotiate them. Their participants fixated the obstacles as they approached them but not as they stepped over them, suggesting that young adults are able to obtain the visual information they require in order to safely step over an obstacle during the approach phase.

Hollands, Patla and Vickers (2002) investigated how gaze is used during direction change. They cued young adults to change direction as they walked along a straight travel path. They observed that participants made co-ordinated eye and head movements to the new direction of travel prior to orientating their body to the new direction. Their findings also supported the observations of Grasso *et al.* (1998) who found that participants make anticipatory eye and head movements to the new direction of travel when walking around a 90° corner in both light and dark conditions.

The temporal link between eye movements and locomotion indicates substantial coordination between the areas of the central nervous system responsible for moving the eyes and generating stepping actions. Understanding the neural mechanisms which enable this temporal link is crucial for understanding the factors that contribute towards falls in frail individuals.

1.3: Falling in older adults

The population of adults aged 60 and over is on the increase in the UK and falling risk increases with age (Scuffham, Chaplin, & Legood, 2003). The likelihood of death resulting from a fall increases for both men and women as they age and falls are one of the leading causes of accidental death in the over 75s (Lilley, Arie, & Chilvers, 1995; Blake et al., 1988). Older adults who survive a fall suffer pain, loss of confidence, (Tinetti & Williams, 1997), risk of hip fracture (Myers, Young, & Langlois, 1996), increased frailty and reduced levels of physical activity for at least 6 months following the fall (Lilley et al., 1995). Falls are also a good predictor for long term admission into a care home and place large financial pressure on the NHS and Social Services in the UK (Scuffham et al., 2003). Due to the increasing age of the UKs population, the detrimental effect that falling has on quality of life and the cost to the NHS and Social Services it is important to understand and treat the reasons why older adults are more likely to fall with age.

1.4: Visual decline in older adults

As part of normal healthy ageing there is decline in the visual system. Healthy older adults have reduced visual acuity, and contrast sensitivity, loss of accommodative amplitude, decrease in pupil size and thickening and yellowing of the lens (Spear, 1993). There is also a high prevalence of visual field loss, which is present in about 20% of community-dwelling older adults (Ramrattan et al., 2001). The leading cause of visual field loss is glaucoma, followed by optic disc diseases and stroke (Ramrattan et al., 2001). Visual field loss and visual impairment is associated with increased falling risk and reduced quality of life in older adults (Lord & Dayhew, 2001; Harwood, 2001; Ramrattan et al., 2001).

1.5: Cognitive decline, walking and older adults

Executive functions refer to the role of the prefrontal cortex in ensuring that the correct action is selected at the right time and place (Kolb & Whishaw, 2003). Executive functions comprise working memory, inhibition, planning, visuomotor skills, and selective attention (Kolb & Whishaw, 2003; Yogev-Seligmann, Hausdorff, & Giladi, 2008). It has long been accepted that as part of normal healthy ageing there is decline in the ability of older adults to perform executive function related activities (Verhaeghen & Cerella, 2002; Yogev-Seligmann et al., 2008). For example older adults are significantly slower when responding to the incongruent Stroop than young adults (Cohn, Dustman, & Bradford, 1984), which is a measure of a person's ability to deliberately inhibit a dominant response in order to complete the required task (Miyake et al., 2000).

In recent years a number of studies have demonstrated that cognitive decline in healthy older adults is associated with changes in gait. Ble *et al.* (2005) used the Mini Mental State Examination (MMSE) and the Trial Making Task (TMT) to assess cognitive function in a group of older adults and compared the cognitive function scores to performance on walking tasks. They observed that in the fast paced condition, which was more cognitively demanding, participants with low TMT scores had slower gait velocity. The findings of Ble *et al's* (2005) was also supported by Holtzer *et al.* (2006) who investigated whether IQ level and decline in specific cognitive abilities, which are affected by ageing, such as memory and attention, would be related to gait velocity. They found that verbal IQ, processing speed, attention and memory did predict gait velocity and that decline in cognitive function could contribute to falling risk in older adults. Springer *et al.* (2006) observed the effect of completing a dual task whilst participants walked; they found that the attentional demands of the dual task had a destabilising effect on the postural control of the older adults at a high risk of falling. They also found that fallers performed significantly worse on tests of executive function compared to non-fallers. Studies of normal cognitive decline in healthy older adults and walking indicate that poor cognitive function affects postural stability in older adults and increases falling risk.

1.6: Changes in eye movement behaviour during walking in older adults.

In recent years a number of studies have explored changes in eye movement behaviour, during locomotion, which develop as part of normal healthy ageing. When healthy older adults stepped onto and off of a platform they demonstrated a significantly longer lag between fixation of the target and stepping to the target compared to young adults (Di Fabio, Zampieri, & Greany, 2003). The lag suggested a delay in the time it takes older adults to convert visual information into an accurate step compared to the young adults. During obstacle interaction some older adults were observed to maintain fixation on an obstacle as they stepped over it, unlike young adults who directed their gaze to the future travel path (Di Fabio, Greany, & Zampieri, 2003) The authors concluded that some older adults find it hard to keep the size of the obstacle in their memory so need to maintain fixation.

King *et al.* (2009) explored the ability of young and healthy older adults to grasp a handrail, whilst in an unfamiliar environment, in response to an unexpected loss of balance caused by the floor moving. They reported that the younger adults were more likely to fixate the handrail on entering the unfamiliar environment than the older adults; which means that the reach to grasp response in the older adults had to be elicited using peripheral vision which is often impaired as a result of normal ageing (King et al., 2009). Older adults who failed to accurately grasp the handrail managed to maintain balance by executing compensatory steps; however, older adults with reduced ability to make compensatory steps would be at a risk of falling. The loss of peripheral vision, the decreased likelihood to fixate the handrail and the reduced ability to make compensatory steps could be an explanation for the increased risk of falling in otherwise healthy older adults (King et al., 2009).

There are also changes in when and where older adults visually sample information about the future travel path. Chapman and Hollands (2006b) showed that older adults looked to future targets significantly sooner and for longer than younger adults. Older adults classified as at a higher risk of falling were found to walk slower than younger adults, showed significantly greater step width variability and made less accurate steps than lower risk older adults and young adults. The changes in foot placement accuracy and precision shown by higher risk older adults caused an increased risk of falling (Chapman & Hollands, 2006b). As the number of targets was increased the higher risk older adults were shown to transfer their gaze to future targets before they had completed the ongoing step (Chapman & Hollands, 2006b). This could be an indication that in a cluttered environment higher risk older adults prioritise the planning of future foot placements over stepping to the current target which places them at a greater risk of falling (Chapman & Hollands, 2006b). An intervention which encouraged one group of higher risk older adults to maintain fixation on the current target until they have made heel contact and then move their gaze to a future target showed that the trained group presented with significantly reduced stepping error and gaze behaviour similar to that observed in lower risk older adults compared to the non-trained group (Young & Hollands, 2010).

These studies demonstrate that studying the eye movements of older adults during walking can provide evidence of age-related changes in the neural control of walking that contributes towards elderly trips and falls. It is therefore conceivable that similar techniques could be applied to understanding increased falls prevalence in other individuals with compromised neural processing e.g. stroke patients.

1.7: Prevalence of stroke and falling risk.

In recent years mortality rates as a result of stroke have reduced but the prevalence of milder strokes, which leave some degree of deficit have increased (Corriveau, Hébert, Raîche, & Prince, 2004). In the UK it is estimated that there are 100,000 new stroke cases every year and the prevalence of stroke rises with age (Poole, Reeve, & Warburton, 2002). Stroke patients in acute care and undergoing rehabilitation are at a higher risk of falling than community dwelling age and sex matched controls, and falls which do not result in injury still cause fear of falling and have an impact on quality of life (Jorgensen, Engstad, & Jacobsen, 2002). Fallers also tend to be more depressed and less socially active and these trends are more pronounced in repeat fallers (Hyndman, Ashburn, & Stack, 2002). More than 90% of falls are reported to occur in a familiar environment and 80% occur in the home. Falls most commonly occur during walking, turning and rising from sitting to standing and patients reported misjudgement, lack of concentration and loss of balance as factors that contributed to falling (Hyndman et al., 2002). Due to the increased prevalence of mild stroke in an ageing population and the resulting disabilities which led to falling it is important to explore the factors which cause falling in stroke patients.

1.8: Effect of stroke on visual areas of the brain

A large proportion of the brain is involved in visual processing (Manly & Mattingley, 2003) and therefore, unsurprisingly, visual problems following stroke are extremely common. The type of visual impairment which manifests following a stroke depends on the area of the brain where the stroke has occurred and include oculomotor deficits, spatial and perception problems and visual field loss (Rowe et al., 2009).

Hemispatial neglect generally results from a stroke in the middle cerebral artery which affects the posterior parietal lobes (Ting et al., 2011). Patients often demonstrate an inability to attend to stimuli presented to the contralateral side of the body to which the stroke has occurred (Ting et al., 2011). Patients are unaware that they are not attending to the neglected side so are unable to compensate for the deficit (MacIntosh, 2003). Hemispatial neglect is prevalent in about 43% of right hemisphere strokes and about 20% of left hemisphere strokes (Ringman, Saver, Woolson, Clarke, & Adams, 2004) and patients who have a stroke in the right hemisphere have a worse prognosis compared to left hemisphere stroke (Ting et al., 2011).

Visual field deficits following stroke are common and occur in about 50% of patients (Cassidy, Bruce, & Gray, 2001). Hemianopia is the most common form of visual field loss (MacIntosh, 2003) and is characterized by complete loss of vision in one half of the visual field (Nelles et al., 2007). Hemianopia results from a stroke in the posterior cerebral artery which supplies the occipital lobe (Kolb & Whishaw, 2003). Visual hallucinations usually occur in conjunction with severe visual loss and normally manifest as an image of a face or person

(Menon, Rahman, Menon, & Dutton, 2003). Patients are generally aware of the visual hallucinations and are not bothered by them (MacIntosh, 2003).

Stroke patients can have a number of eye movement problems which include deviation of the eye to the affected hemisphere, along with squints, double vision and blurred vision which manifest depending on the affected cranial nerves (Jones & Shinton, 2006). Stroke patients often have problems making saccadic eye movements and smooth pursuit and sometimes have reduced stereopsis which can result in problems with depth perception (Jones & Shinton, 2006). The eye movement problems observed in stroke patients are likely to have an adverse effect on stepping performance during walking and potentially result in an increased risk of trips and falls.

1.9: Changes in co-ordination during locomotion following stroke

Stroke patients demonstrate a number of changes in behaviour during locomotion compared to healthy age and sex matched controls. These changes include altered voluntary head movements during standing (Lamontagne, Paquet, & Fung, 2003), changes in the coordination of the head, thorax and pelvis when walking and turning (Lamontagne, De Serres, Fung, & Paquet, 2005) and changes in the coordination of gaze and posture during pre-planned turns in spatial and temporal domains (Lamontagne, Paquette, & Fung, 2007). Voluntary head movements are used to track targets, orient the body to a new direction of travel and scan the environment during standing and walking (Lamontagne et al., 2003). In stroke patients voluntary head movements are found to be significantly slower and take longer to initiate compared to healthy controls (Lamontagne et al., 2003). Accurate coordination of the head, thorax and pelvis during walking is important for the maintenance of balance. The poor coordination observed in stroke patients can cause changes in walking trajectory and result in loss of balance (Lamontagne et al., 2005). Lamontagne and Fung (2009) found that the degree of alteration in the coordination of postural and oculomotor behaviour during locomotion in stroke patients was affected by the level of disability and the direction of the turn. Changes in coordination were more pronounced in stroke patients who walked slower and when turning to the non-paretic side. To date stroke studies have only investigated changes in head and body coordination during locomotion and there have been no studies which explore the effect of stroke on gaze behaviour.

1.10: Summary

Studies which investigate changes in eye movements during walking, in stroke patients and older adults, indicate changes in the coordination of gaze and body movements which lead to instability and an increased risk of falling (Lamontagne et al., 2007; Lamontagne & Fung, 2009; Chapman & Hollands, 2006b; Chapman & Hollands, 2007).

To date most of the studies which have investigated the changes in gaze behaviour during locomotion have been conducted in the laboratory and do not reflect real-life situations. Participants are often expected to repeat the same activity over a number of trials in a very sterile environment causing problems when generalising the findings to real-life situations.

1.11: Using virtual techniques to explore eye movements during walking

In recent years a number of studies have compared gaze behaviour in the real-world to behaviour which is observed in a virtual reality environment. Reed-Jones *et al.* (2009) explored the steering behaviour of participants who walked on the spot in front of a large screen displaying a computer-generated video. The scene was displayed from a first person perspective and depicted a visual simulation of walking along a corridor and turning a corner at the end. Participants displayed similar steering behaviour to that normally observed when people turn in the real-world; characterised by a distinct pattern of postural alignment initiated by a rotation of the eyes, followed by head, trunk, body and finally the feet (Reed-Jones, Reed-Jones, Vallis, &

Hollands, 2009). Schoch *et al.* (2005) investigated the similarities between gaze behaviour measured from participants walking along a corridor in the real-world and gaze behaviour measured from the same participants navigating a computer simulation of the same corridor using a joystick. They found no significant differences between the number of times objects were fixated in the real-world and virtual conditions. Cristino and Baddeley (2009) explored the gaze behaviour of participants whilst they watched first person perspective movies of someone walking along a street. They found that, despite using different filters which emphasised either spatial or temporal characteristics of the video image, participants consistently made fixations to objects relevant for safe locomotion through the environment. For example, participants were observed to fixate kerbs and people's feet but did not look at a flock of seagulls; a salient but irrelevant visual event. These findings indicate that viewing a moving scene can elicit the same visual and postural behaviour as produced whilst walking around a real environment and raise the possibility of using virtual visual environments as a substitute for real-world experiences in probing gaze behaviour during walking tasks. There are currently only a limited number of published studies which directly and quantitatively compare gaze behaviour measured from participants passively viewing video scenes designed to emulate a visual walking experience with gaze behaviour measured during real walking. 't Hart *et al* (2009) compared gaze behaviour collected while a single participant walked around the real-world with that measured from two groups of participants during scene viewing under continuous replay and during random presentation of a single video frame at a frequency of 1Hz. The authors found that the gaze behaviour during continuous replay was a better predictor of where participants looked during the real-world compared to the 1s frame replay condition. However, the experimenters compared data from different groups of participants in the laboratory conditions to data from a single “observer” in the real-world walking condition. In addition the experimenters did not explicitly analyse fixations due to confounding factors introduced by their use of a between-groups statistical design. Droll and Eckstein (2009) studied gaze behaviour during walking in a real-world environment; however, their primary research question and corresponding analyses was aimed at characterizing participants’ ability to recall objects within the travel path and how the knowledge that they would be given a memory test at the end of the study affected their gaze behaviour. Stanley and Hollands (2010) and Foulsham, Walker and Kingstone (2011) compared the eye movement behaviour of participants walking around a real environment compared to scene viewing in the laboratory. They reported that the fixation behaviour of the participants was significantly similar between the two conditions.

Scene viewing has been demonstrated to evoke similar gaze behaviour to that observed during real-world walking. As a result recording gaze behaviour during scene viewing could help us to better understand the changes in gaze behaviour observed in frail populations which may contribute to falling.

1.12: Conclusions

We live in a society with an ageing population (Scuffham et al., 2003), where survival from stroke is on the increase (Poole et al., 2002). As a result there is an increasing proportion of the population who are at risk of falling. Older adults at a higher risk of falling have altered gaze behaviour which is causally linked to instability during walking (Chapman & Hollands, 2007). Stroke patients have a high prevalence of visual problems (Rowe et al., 2009) which could also be a factor in increased falling risk. In order to decrease falling risk amongst older adults and stroke patients it is important to explore the effect that ageing and stroke has on eye movements during walking. The logical approach to this is to record the eye movement behaviour of older adults and stroke patients has they walk around; however, this approach would be hard to standardise, impractical to implement and potentially unsafe for frail individuals. A possible alternative would be to use virtual reality environments to explore changes in eye movement. There is growing evidence that scene viewing evokes eye movement behaviour which is similar to that produced when participants walk around the same environment (Stanley & Hollands, 2010; Foulsham, Walker, & Kingstone, 2011; 't Hart et al., 2009).

1.13: Aims

The aims of the current thesis were to:

1. Develop a novel paradigm to evoke naturalistic gaze behaviour during walking that can be used with frail individuals.
2. Explore if measurable differences in gaze behaviour are evoked during scene viewing between older adults at a high risk of falling compared to older adults at a low risk of falling and young adults and establish if these differences are related to increased falls risk.
3. Compare the eye movement behaviour evoked, whilst scene viewing, in a group of chronic stroke patients to a group of age and sex matched controls and ascertain if measurable differences are observed which relate to falling risk.
4. Explore the cognitive mechanisms which underlie changes in gaze behaviour in older adults and stroke patients.

Chapter 2

General Method

The experimental methods detailed in this chapter were applied across all the experiments contained within this thesis.

2.1: Test battery to assess falling risk

To assess falling risk in the group differences study and stroke study, participants took part in a number of screening measures. These screening measures were selected based on criteria set out in previous research (Ble et al., 2005; Di Fabio, Emasithi, Greany, & Paul, 2001; Young & Hollands, 2010).

The Berg Balance Scale assesses participant's ability to complete 14 mobility related tasks. These tasks include standing on one leg, standing with eyes closed, getting into and out of a chair, etc. The scale is scored out of 56 and for each item participants can score a maximum of 4 (Berg, 1989).

The Activities Balance Confidence Scale (ABC) requires participants to report how confident they are (using a scale from 0 to 100%) that they will not lose their balance or become unsteady when completing certain tasks. The 16 tasks include activities of daily living such as walking around the house, sweeping the floor, and walking on an icy pavement. On completion of the test the mean score across all items is calculated to give an overall percentage representing a participant's confidence in their balance (Powell & Myers, 1995).

The Mini Mental State Examination (MMSE) is a test of the cognitive aspects of mental function with a maximum score of 30. The items test mental functions such as orientation, memory, recall and language. A score of over 25 is considered normal and anything less is considered to indicate some level of impairment (Folstein, Folstein, & McHugh, 1975).

The Trail Making Test (TMT) consists of two parts and requires participants to join 25 dots as quickly and accurately as possible. Part A tests the participant's ability to visually scan numbered dots and join them in numerical order. Part B requires the participant to alternate between connecting numbers to letters and tests cognitive flexibility.

Timed Up and Go (TUG) is a test of basic mobility skill. Participants start in an armchair and, when instructed, get out of the chair, walk 3 metres, turn and return to the chair. The time it takes the participant to complete this task is recorded. A time equal to or greater than 14 seconds is a good predictor of falling risk (Podsiadlo & Richardson, 1991).

A History of Falls from the past year was taken because studies have found that participants who have reported falling in the past year are more likely to fall again (Nevitt, Cummings, Kidd, & Black, 1989). In addition, participants who are repeat fallers have reduced mobility, reduced activities in daily living and higher anxiety and depression scores compared to non-fallers (Hyndman et al., 2002).

The General Health Questionnaire (GHQ) consists of 28 items which assess the general wellbeing of the participant. The questionnaire is split into four subscales which assess somatic symptoms, anxiety and insomnia, social dysfunction and depression (Goldberg & Hillier, 1979).

Visual Acuity was assessed using a Snellen Chart at a distance of 6 metres. The chart measures a person's ability to read black letters, which reduce in size, from a white background. The score is expressed as a fraction e.g. 20/20 with the numerator referring to the distance of the participant to the chart and the denominator referring to the size of the letter in millimetres.

Contrast sensitivity was assessed using the Pelli-Robson Contrast Sensitivity Chart which consists of triplets of letters, presented at a fixated height, on a white background, which gradually reduce in contrast. The chart is positioned at approximately eye height to the participant, at a distance of 1 metre. Contrast sensitivity was scored according to the faintest triplet of two which the participant was able to read.

2.2: Gaze tracker set up

Throughout this thesis a head mounted ASL 500 mobile eye tracker was used to record the fixation behaviour of each participant. In order to achieve a good calibrated image of the eye the eye tracker was adjusted so that when the participant looked straight ahead their eye was centred in the middle of the monitor. The eye tracker then shined an infra-red light on to the cornea and the light reflected back to the eye tracker forms the corneal reflection. The illumination was adjusted so it was at the lowest setting where the pupil was visible on the monitor. A white circle with cross hair was then stabilised around the pupil and the corneal reflection, which appeared as a white dot on the monitor, has a black circle stabilised around it with a black cross hair. The eye tracker then calculates the point of gaze by calculating the distance between the centres of each crosshair.

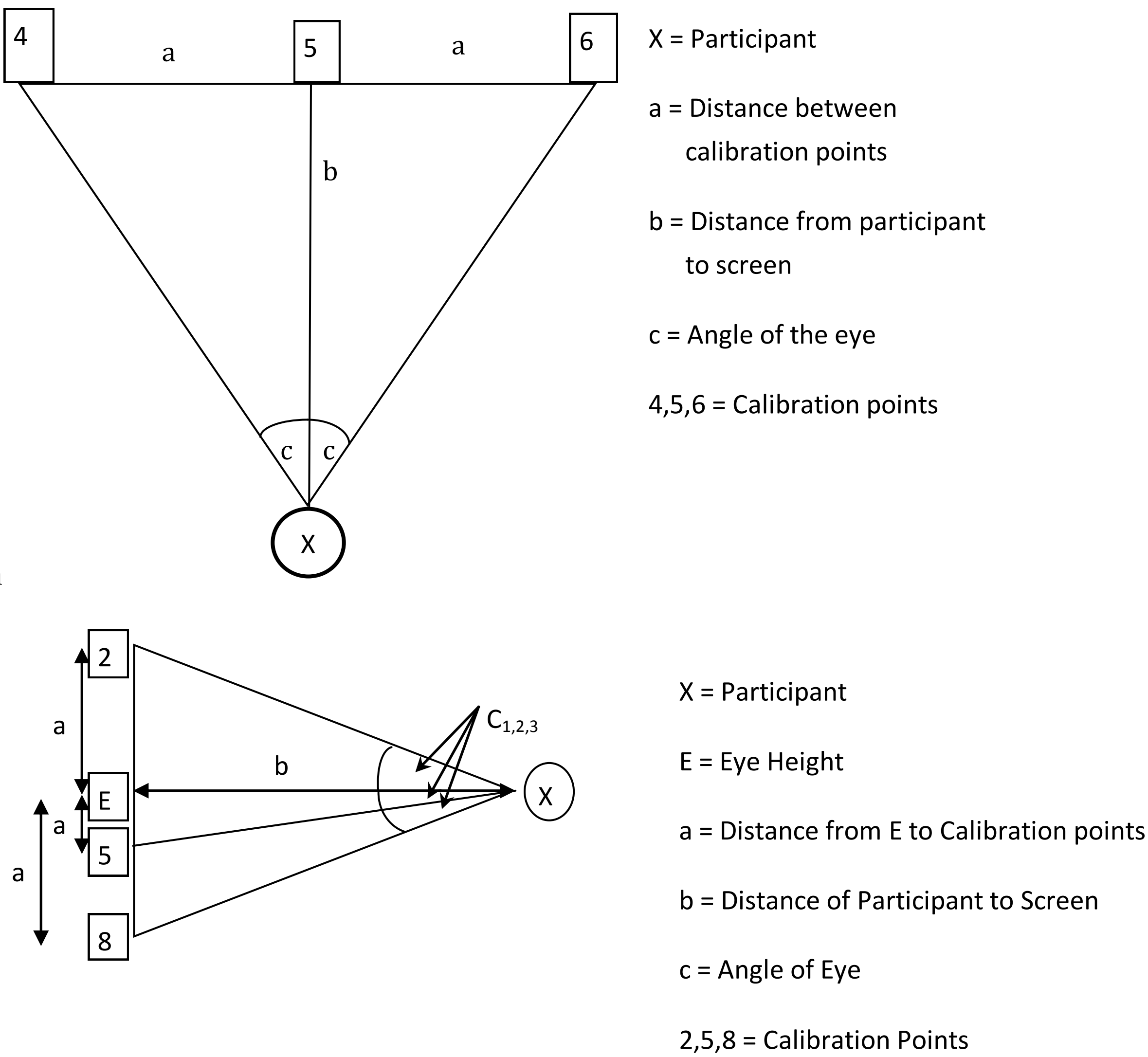
A nine point calibration was carried out by presenting dots in rows and columns of three to the participant. Initially the participant was asked to fixate on each dot in turn to ensure the pupil and corneal reflection remained stable on the eye monitor. The target points were set by asking the participant to remain still and look straight ahead. In the scene monitor there was a black crosshair which could be moved over each of the calibration dots in turn starting with dot one. After the target points had been defined the participant was asked to remain still and to fixate on each dot in turn as the mouse was clicked. Calibration was then checked to ensure that as the participant fixated on each dot the crosshair shown on the scene monitor moved to the location of expected fixation, calibration was then recorded for future reference.

2.3: Calculation of horizontal and vertical angle of the eye

To calculate the angle of the eye for the frequency graphs the participant was positioned in line with dots 2, 5 and 8 and their distance from the screen and the height of their eyes was measured. The distance between each of the dots in the 3x3 calibration grid was also measured. The vertical and horizontal position of the eye when looking at each of the dots was retrieved from the output produced by the eye tracker. To calculate the angles for the horizontal and vertical plane the following formula was used:

$$c = tan^{-1}\, a/b$$

c refers to the angle of the eye, a is the distance between the eye and the calibration points and b is the distance from the participant to the screen as illustrated by figure 2-1a for the horizontal angles and 2-1b for the vertical angles.



a

b

Figure 2-1. Calculation of the horizontal (a) and vertical angles (b)

Once the angles had been calculated they were plotted against the vertical and horizontal coordinates of the eye for each of the 9 calibration points taken from the eye tracker. The equation for the line, ($y = mx \pm d$) were m determines the gradient for the line and d is the point where the line crosses the y-axis, was then used to convert the horizontal and vertical coordinates of the eye tracker for each trial into angles.

2.4: Filming of scenes

The videos of the local area were filmed using a Sony Handy cam (DCR-H30) which was placed on top of a "poor man's steady cam" (Lee, 2002) to help reduce unsteadiness produced during the filming process. The steady cam consisted of an upright metal pole (52cm) with a screw on the top to attach the camera and a 1kg weight on the bottom which acted as a counter weight. A metal pole (27cm) was attached at right angles to the upright pole at the half way point. The steady cam was held by the vertical pole just below the camera and by the horizontal pole during filming.

Chapter 3

A comparison of real-world eye movement behaviour during walking to scene viewing

3.1: **Introduction for experiments 1, 2 and 3**

Vision is crucial for human locomotion as it is the only sense which provides information about the future travel path necessary for safe and efficient travel through our cluttered environment (Land et al., 1999). Recent advances in technology have allowed vision researchers to accurately measure where individuals look as they walk, providing hitherto missing insight into the nature of the visual information that is sampled from our visually rich environment. Hollands *et al* (1995) were the first to document eye movement behaviour during human walking while participants walked multiple times on specified footfall targets. The authors showed a close temporal relationship between looking and stepping to a target indicative of eye-stepping coordinative processing within the central nervous system. Subsequent eye tracking studies have confirmed that looking at features of our environment (e.g. safe places to step) at appropriate times is crucial for balance and safe walking (Di Fabio et al., 2003; Chapman & Hollands, 2006b; Di Fabio et al., 2001) and that problems generating accurate eye movements may contribute towards walking deficits in certain populations e.g. patients with degenerative brain disease (Crowdy, Hollands, Ferguson, & Marple-Horvat, 2000). In particular, there is a growing body of evidence that older adults display different gaze behaviour to younger adults during everyday walking tasks, such as standing and walking from a seated position (Di Fabio et al., 2001), stepping over obstacles (Di Fabio et al., 2003), stepping onto targets (Chapman & Hollands, 2006b), and negotiating stairs (Zietz & Hollands, 2009). It has also been demonstrated that older adults categorized as having a high risk of falling exhibit different gaze and stepping behaviour than those with a low risk of falling (Chapman & Hollands, 2006b; Di Fabio et al., 2001). It has been shown that those at a high risk of falling adopt suboptimal visual sampling strategies which are causally linked to impairments in their stepping performance (Chapman & Hollands, 2007). These differences in gaze behaviour could not simply be explained by general age-related decline in visual ability (eyesight), which was broadly similar across groups. Instead, findings support the proposal that the increased likelihood of trips and falls in older adults is due, in part, to less effective visual sampling with the consequence that regulation of movement by the central nervous system is guided by suboptimal sensory information. Young and Hollands (2010) have recently provided direct evidence for this model by showing that training older adults to adopt gaze behaviour similar to that displayed by younger adults significantly reduces stepping inaccuracies. These studies highlight how studying the gaze behaviour of frail individuals during walking can be a useful strategy for understanding the changes to visual and visuomotor processing that may contribute to increased falls risk.

Although eye tracking systems that allow recording of participant gaze behaviour during relatively unrestricted movement are commercially available, these systems are either limited in their technical capabilities (i.e. they have low temporal and spatial resolution), or require the participants to carry equipment which is heavy and cumbersome. Because of these limitations, most previous studies of gaze characteristics during walking have been conducted in the laboratory using repetitive walking tasks with questionable ecological validity. However, laboratory-based studies are not ideal for investigating mechanisms underlying falls since it is logistically difficult to simulate naturalistic scenarios in which falls are commonplace. Alternatively, placing frail individuals in a vulnerable position in uncontrolled naturalistic environments would place them at an unethically high-risk of injury.

Another limitation of studying real-world behaviour is that for any given walking situation the visual experience of each participant will differ depending on transient environmental factors e.g. pedestrians, traffic, lighting conditions etc. These differences would have a confounding influence on between-participant analysis of behaviour.

One possible solution for avoiding the logistical problems associated with recording real-world behaviour is to study participant behaviour in a virtual environment which allows the researcher to carefully control all elements of the participant's visual experience. Reed-Jones *et al.* (2009) explored the steering behaviour of participants who walked on the spot in front of a large screen displaying a computer-generated video. The scene was displayed from a first person perspective and depicted a visual simulation of walking along a corridor and turning a corner at the end. Participants displayed similar steering behaviour to that normally observed when people turn in the real-world; characterised by a distinct pattern of postural alignment initiated by a rotation of the eyes, followed by head, trunk, body and finally the feet (Reed-Jones et al., 2009). Schoch *et al.* (2005) investigated the similarities between gaze behaviour measured from participants walking along a corridor in the real-world and gaze behaviour measured from the same participants navigating a computer simulation of the same corridor using a joystick. They found no significant differences between the number of times objects were fixated in the real-world and virtual conditions. Cristino and Baddeley (2009) explored the gaze behaviour of participants whilst they watched a first person perspective video of someone walking along a street. They found that, despite using different filters which emphasised either spatial or temporal characteristics of the video scene, participants consistently made fixations to objects relevant for safe locomotion through the environment. For example, participants were observed to fixate kerbs and people's feet but did not look at a flock of seagulls; a salient but irrelevant visual event.

These findings indicate that viewing a moving scene can elicit the same visual and postural behaviour as produced whilst walking around a real environment and raises the possibility of using virtual visual environments as a substitute for real-world experiences in probing gaze behaviour during walking tasks. However, there are currently only a limited number of published studies which directly and quantitatively compare gaze behaviour measured from participants passively viewing video scenes designed to emulate a visual walking experience with gaze behaviour measured during real walking. 't Hart *et al* (2009) compared gaze behaviour collected while a single participant walked around the real-world with that measured from two groups of participants during scene viewing under continuous replay and during random presentation of a single video frame at a frequency of 1Hz. The authors found that the gaze behaviour during continuous replay was a better predictor of where participants looked during the real-world compared to the 1s frame replay condition. However, the experimenters compared data from different groups of participants in the laboratory conditions to data from a single "observer" in the real walking condition. In addition the experimenters did not explicitly analyse fixations due to confounding factors introduced by their use of a between-groups statistical design. Droll and Eckstein (2009) studied gaze behaviour during walking in a real-world environment; however, their primary research question and corresponding analyses was aimed at characterizing participants' ability to recall objects within the travel path and how the knowledge that they would be given a memory test at the end of the study affected their gaze behaviour. Foulsham, Walker and Kingstone (2011) compared the eye movement behaviour of participants walking around a real environment compared to scene viewing in the laboratory. They reported that the fixation behaviour of the participants was significantly similar between the two conditions. The study has similarities to the current studies; however there are a number of differences to the method. Their participants did not view their own videos but were matched to another participant for the scene viewing part of the experiment and the scene viewing condition was presented on a small screen. They did not apply their method to a group of participants who only completed the scene viewing part of the experiment. The participant's head was constrained within a chin rest during the scene viewing condition preventing the participant from been able to make head movements. There was an additional task where participants viewed clips from their own walk and other participants' walks. Participants were instructed to imagine they were walking through the scene during the scene viewing condition which meant they were not passively viewing the video. Participants did not walk the same route as they were instructed to walk to a predefined location but not along a predefined route.

3.2: Real-world versus Scene Viewing - Experiment 1

Aims:

1. To quantitatively describe the gaze behaviour of participants walking around and interacting with a real environment.
2. To assess the extent of similarities between gaze behaviour measured while participants walked a predefined route around a building and gaze behaviour measured while participants passively viewed a video recording of the same visual scene they previously experienced while walking.

We hypothesised there would be a high level of congruence between the spatial and temporal characteristics of gaze behaviour recorded during real and virtual walking conditions indicating that the same neural processes determining gaze behaviour are in operation.

3.3: Method

3.3.1: Participants

10 participants (6 male) were recruited from the postgraduate community of the School of Sport and Exercise Sciences, University of Birmingham. Mean participant age was 24.7 (range 23-29). All participants either had normal or corrected vision (contact lenses). Ethical permission was gained from the college ethics board, and informed consent was gained from each participant before the experiment began. Participants were told that they could withdraw at any time without giving a reason. Participants who wore glasses were excluded from participation due to the logistical difficulties associated with calibrating the eye tracker, as were participants with a history of musculo-skeletal problems that could be exacerbated by wearing the required backpack containing the eye tracking equipment.

3.3.2: Apparatus and Experimental Set up

An ASL500 mobile eye tracker (weight 480g), which had a sampling rate of 30Hz, was used to track participants' eye movements. Participants carried technical equipment for the eye tracker in a backpack weighing 4.1kg. An Acer projector (S1200) and screen (height 148cm, width 290cm) was used to project calibration points, and to display the video used in the scene viewing condition. The average video length for the real-world condition was 104.3 seconds (range 75secs-129secs), and for the scene viewing condition was 101.3 seconds (range 85secs-128secs).

In the real-world condition, the route through which the participants walked necessitated the following everyday activities: stair ascent and descent, door opening, corridor walking and circumnavigating obstacles (tables) in a laboratory.

During the scene viewing condition participants sat 116cm away from the screen on a stool which was 70cm in height, and the projected image was 62cm above the floor. The resolution of the projected image was 1280 x 1024 pixels, the refresh speed was 60Hz, and the ratio of the real-world to the scene viewing condition was 1:0.8. During the scene viewing condition, the projected image was the only source of light in the otherwise darkened room. Participants completed the real-world and scene viewing condition once.

3.3.3: Design and Procedure

On entering the laboratory participants were asked to read an information sheet detailing the study and to sign a consent form. Before the study began participants were asked if they had any questions about the procedure.

Initially participants walked through the route accompanied by the researcher. Once the participant was familiar with the route they returned to the laboratory and were equipped with the eye tracker, after which they returned to the start of the route. The eye tracker was used to record a first person perspective video as the participant walked the route. This video was subsequently used in the scene viewing condition, to ensure that the visual stimuli participants experienced in that condition was similar to that experienced during their walk. Participants then returned to the laboratory where the video was downloaded ready for use in the second condition. The eye tracker was calibrated using points projected onto the screen. Participants then returned to the start of the route, where calibration was checked and recorded again. Participants then walked through the route, while their gaze behaviour was recorded (Figure 3-1a).

In order for the start of the walk to be ascertained from the videos participants were instructed to start walking once they had seen a flashing light which was discernible from the video recording. Upon completion of the second walk participants returned to the laboratory where calibration was checked and repeated if necessary. Calibration was recorded again and participants were asked to watch the first person perspective video while their eye movement was recorded (Figure 3-1b).

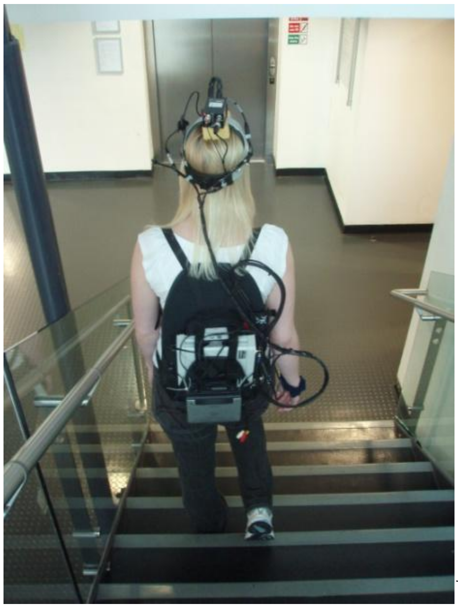
a)  b) 

Figure 3-1. a) Real-world walking condition. b) Scene viewing condition

3.3.4: Analysis

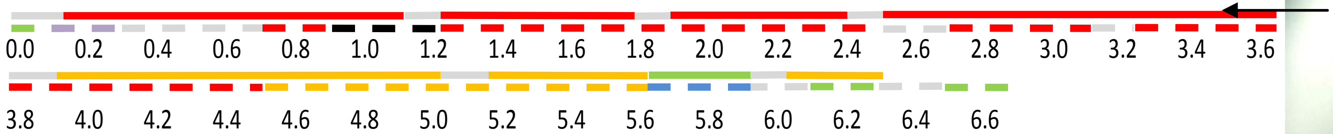
Video data was analysed, frame by frame, using an AVI splitter and the location of the fixation cross was recorded for each frame. A fixation was recorded if the participant looked at an environmental feature within the travel path (e.g. stair edge, door, table etc) for the duration of 3 or more video frames (Patla & Vickers, 1997). A number of environmental features commonly fixated by multiple participants were identified and used as descriptors of behaviour for quantitative analysis. The total time spent fixating each environmental feature and the frequency with which participants fixated each environmental feature were calculated as main outcome variables. Pearson product-moment correlation was performed to test the strength of relationship between the two main outcome variables measured under the real-world and scene viewing conditions, for each participant. The data for each participant was also pooled to give grand averages for fixation duration of each of the environmental features for both the real-world and scene viewing condition. Pearson product-moment correlation was then performed to assess the extent of similarity between grand averaged data obtained in the two experimental conditions.

Pearson product-moment correlation assesses the strength and direction of a relationship between two continuous variables. Pearson product-moment correlation was used because the aims of the study were to assess the similarity between the duration of fixations and number of fixations made to different environmental features between the two conditions and the strength of the similarity.

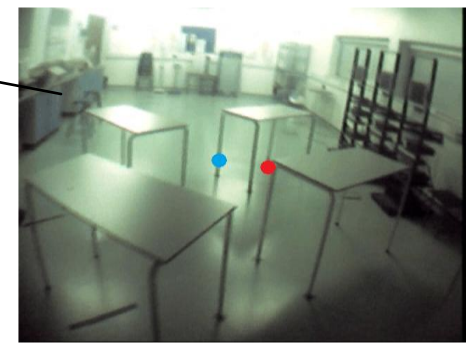
3.4: Results

Figure 3-2 shows a typical example of the temporal gaze fixation patterns measured from one participant during the real-world and scene viewing conditions. The data is presented as a time series of fixation locations with the numbers representing time in seconds. Data from each condition were temporally synchronized to the start of each subtask identified from the video image. Each coloured bar represents a different environmental feature, fixated by the participant. The solid lines represent fixation during the real-world condition and the dashed lines represent fixation duration during the scene-viewing condition. Figure 3-2a demonstrates that participants fixated the doors during the majority of the approach and fixated the lock and handles whilst interacting with them. Figure 3-2b shows that the participant adopted a pattern of alternating fixation between tables and the floor when actively circumnavigating the tables set up as obstacles in a laboratory (figure 3-2b).

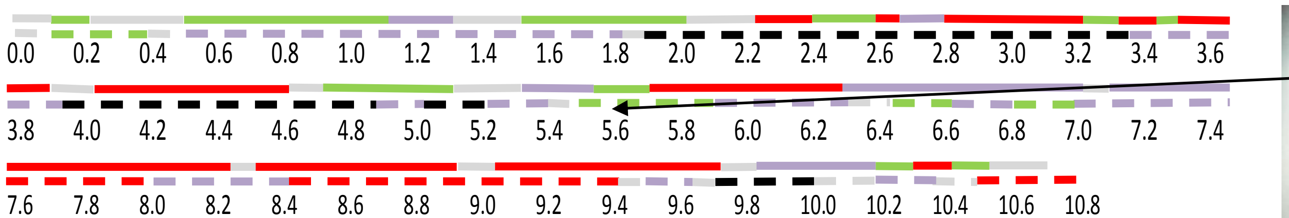
Figures 3-2c and 3-2d show data describing gaze behaviour during corridor walking and stair ascent. A broadly similar spatiotemporal fixation pattern is observable between the real-world and scene-viewing conditions in each of the walking subtasks i.e. approximate timing, duration and frequency of fixations on the various environmental features.

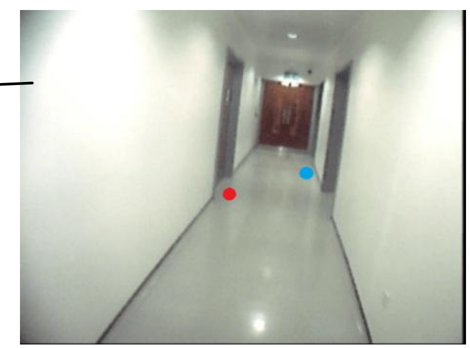


a) Example of participants gaze behaviour as they approach a door in both conditions.

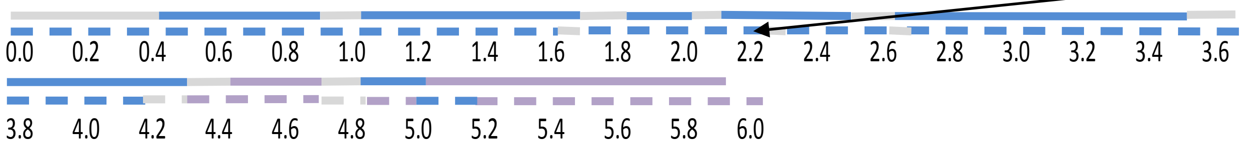


b) Example of gaze behaviour whilst participant negotiates walking around tables.





c) Example from a section of corridor walking.



d) Example from a section of stair ascent

Behaviour of Eyes	Real World	Scene Viewing
Door approach	—	- - - -
Door interaction	—	- - - -
Floor	—	- - - -
Wall/Ceiling	—	- - - -
Table	—	- - - -
Stairs	—	- - - -
Non-relevant object	—	- - - -
Off screen	—	- - - -
Eye in motion	—	- - - -

Condition	Point of fixation
Real-world	●
Scene Viewing	●

Figure 3-2. Sections taken from one participant's walk comparing real-world and scene viewing conditions to demonstrate the similarities in gaze fixation (seconds). The screen shots indicate where the participant is fixating in each condition at a given point in time.

Figure 3-3 illustrates the distribution of gaze behaviour across all participants expressed as a percentage of the total time spent walking or viewing the scene. The time participants spent looking at each environmental feature was generally very similar in both conditions. Further analysis demonstrates that in both conditions the majority of the trial time was spent fixating environmental features that are pertinent to successful completion of the walking task e.g. doors, stairs, or the floor ahead (real-world 65%, scene viewing 73%) with much of the remaining time spent either moving the eyes (real-world 12%, scene viewing 12%) or directing gaze beyond the range of the eye tracker (real-world 19%, scene-viewing 10%). Participants spent the shortest percentage of time fixating items not relevant for locomotion (real-world 5%, scene viewing 5%).

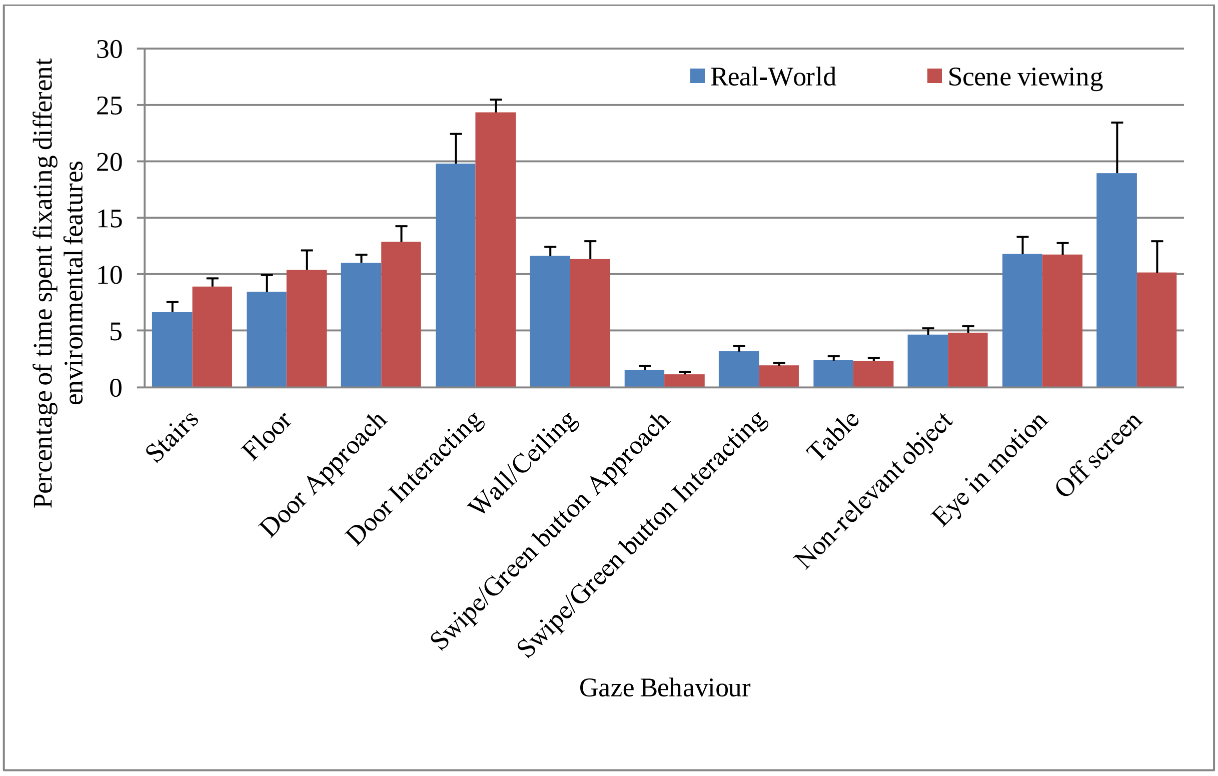


Figure 3-3. Distribution of gaze behaviour across all participants for the total time spent real-world walking, or scene viewing.

A significant positive correlation was found between the total average fixation time on environmental features measured during real-world and scene viewing conditions r(8)= 0.96, p<.0001. The statistical power was 0.80 indicating that the analysis had power (figure 3-4a).

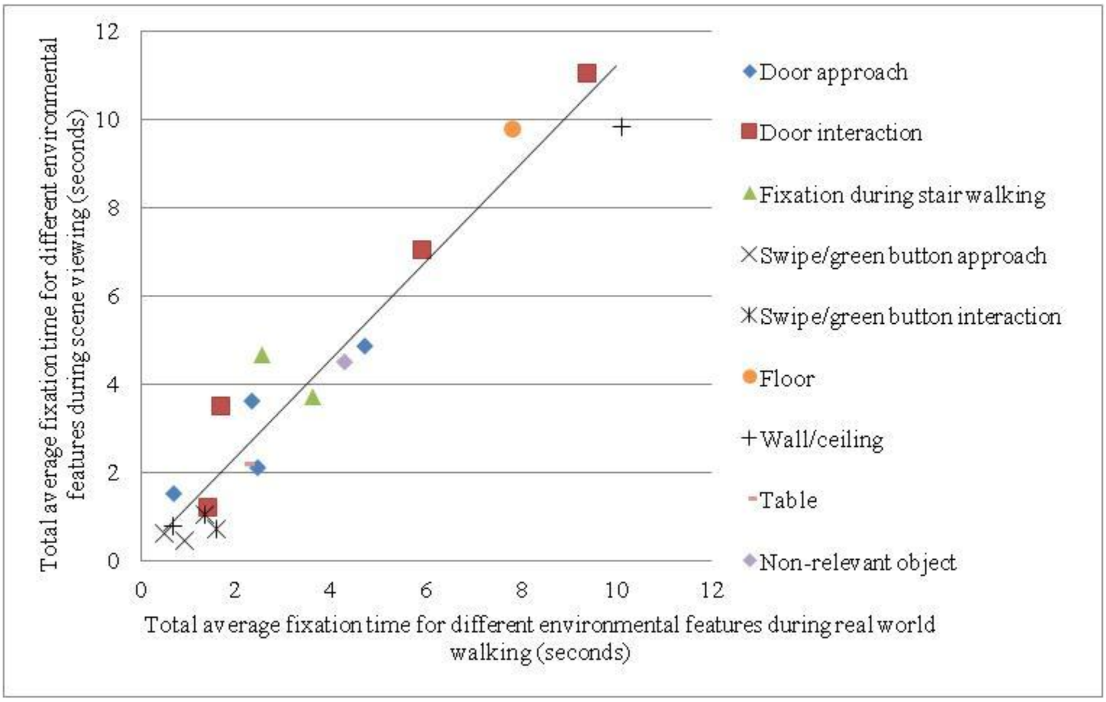


Figure 3-4a. A significant positive correlation for the mean duration of time that participants spent fixating on environmental features between the real-world and scene viewing conditions

There was also a significant positive correlation between the number of times participants looked at each environmental feature during the real-world and scene viewing conditions r(8)=0.97, p<.0001 (figure 3-4b). The statistical power was 0.83 indicating that the analysis had power

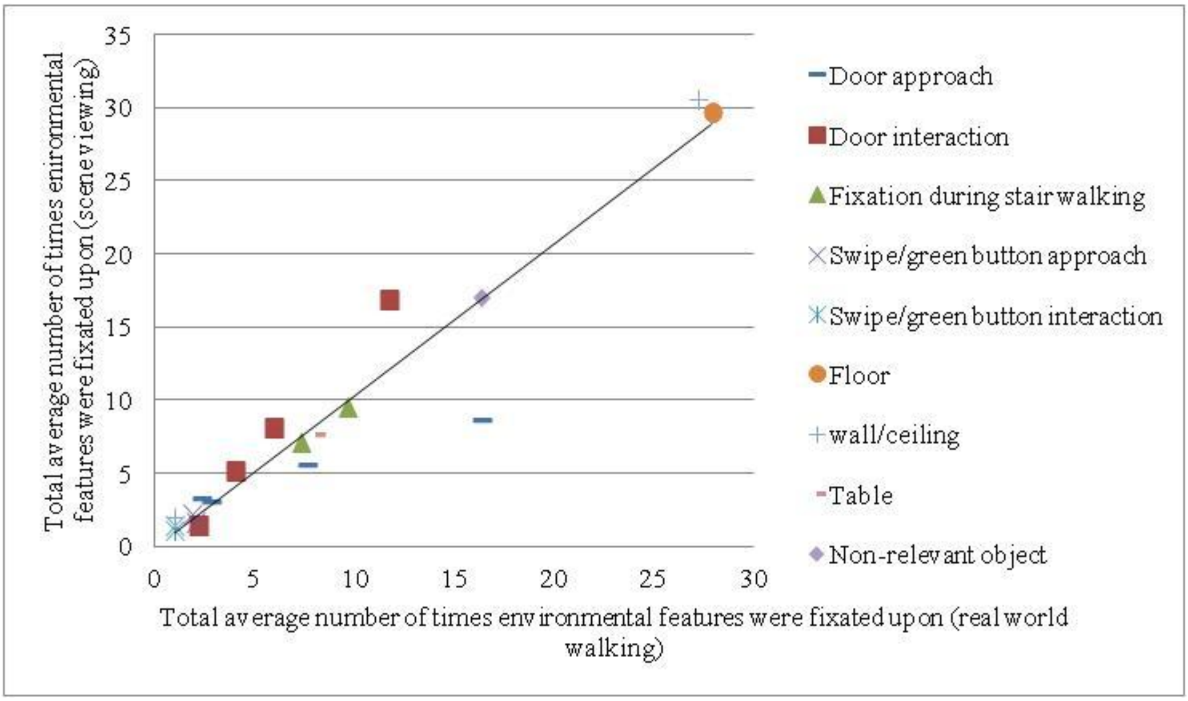


Figure 3-4b. A significant positive correlation between the average number of times participants looked at environmental features during the real-world and scene viewing conditions.

Table 3-1 demonstrates the individual correlations for each participant. For the number of times each environmental feature is fixated upon the results are significant for all participants. For the duration of time each environmental feature is fixated the results are significant for all participants except participant 3.

Table 3-1. Individual correlations for each participant, exploring the significance of fixation duration and number of times environmental features are looked at.

Participant	Fixation Duration	Frequency of Fixation
1	.828*	.980*
2	.687*	.987*
3	.409	.743*
4	.869*	.851*
5	.871*	.826*
6	.745*	.799*
7	.686*	.703*
8	.695*	.828*
9	.856*	.907*
10	.821*	.856*
* Significant p<.0001		R values

3.5: Real-world versus Sitting only - Experiment 2

This experiment was conducted to address a potential confound caused by the design of experiment 1. Due to the nature of the design participants completed the scene viewing condition straight after completing the real-world condition which might have influenced their gaze behaviour.

Experiment 2 aimed to compare the gaze behaviour of participants who only completed the scene viewing condition to those who completed the real-world walk and scene viewing conditions.

We hypothesised that there would be a high level of congruence between participants who only completed the scene viewing condition to those who completed the scene viewing and real-world conditions.

3.6: Method

3.6.1: Participants

16 participants (7 female) were recruited from the postgraduate community of the School of Sport and Exercise Sciences, University of Birmingham. Mean participant age was 24.3 (range 22-29). Ten participants were allocated to the real-world walking and scene viewing conditions and six participants were allocated to the scene viewing only condition. All participants either had normal or corrected vision (contact lenses). Ethical permission was gained from the college ethics board, and informed consent was gained from each participant before the experiment began. Participants were told that they could withdraw at any time without giving a reason. Participants who wore glasses were excluded from participation due to the logistical difficulties associated with calibrating the eye tracker, as were participants with a history of musculo-skeletal problems that could be exacerbated by wearing the required backpack containing the eye tracking equipment.

3.6.2: Apparatus and Experimental Set up

The experimental set up and apparatus for experiment two was the same as experiment 1 with a number of differences. The video length for the scene viewing only condition was 90secs. In the scene viewing only condition the video image size was 111cm high and 154cm wide. The resolution of the projected image was 1024x768 pixels, the refresh speed was 60Hz and the ratio of the real-world to scene viewing condition was 1:0.54. Participants completed the scene viewing only condition once.

3.6.3: Design and Procedure

The procedure for the real-world walk and scene viewing was the same as that detailed in experiment one.

In the scene viewing only condition participants were given an information sheet to read detailing the study and a consent form to sign. Before the study began participants were asked if they had any questions about the procedure.

Participants were set up with the eye tracking equipment, the eye tracker was calibrated and calibration was recorded. Participants were then asked to watch one of the first person perspective videos which had been recorded during experiment 1.

3.6.4: Analysis

Analysis of the videos was conducted in the same way as experiment 1.

3.7: Results

Figure 3-5 illustrates the distribution of gaze behaviour across all participants expressed as a percentage of the total time spent real-world walking, scene viewing and scene viewing only. Across the three conditions it is clear that participants spent a similar amount of time fixating the same environmental features. Further analysis indicated that for the majority of the trial participants fixated environmental features important for successful completion of the walking task e.g. doors, stairs, or the floor ahead (real-world 65%, scene viewing 73%, scene viewing only 70%). With the majority of the rest of the trial time spent with eyes in motion (real-world 12%, scene viewing 12%, scene viewing only 17%) or gaze directed beyond the range of the eye tracker (real-world 19%, scene viewing 10%, scene viewing only 7%). The shortest percentage of time was spent fixating environmental features not important for locomotion (real-world 5%, scene viewing 5%, scene viewing only 7%).

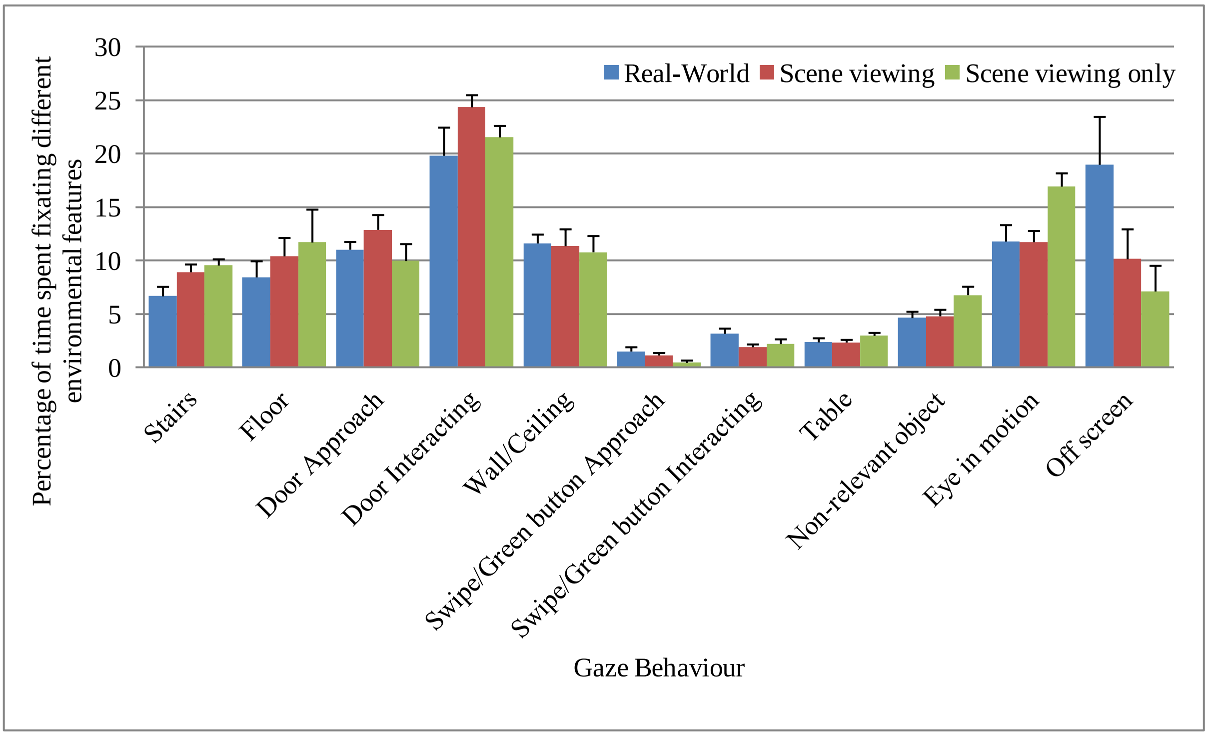


Figure 3-5. Distribution of gaze behaviour across all participants for the total time spent real-world, scene viewing, or scene viewing only.

Table 3-2 shows correlations for the six participants who completed the scene viewing only compared to the ten participants who completed both real-world and scene viewing conditions. The results show significant correlations comparing the real-world condition to the scene viewing only condition and the scene viewing condition to the scene viewing only condition.

Table 3-2. Significant positive correlations, comparing participants who completed the real-world and scene viewing conditions to those who completed the scene viewing only condition.

Condition	Fixation Duration	Power	Frequency of Fixation	Power
Real-world/Scene viewing only	.992*	0.97	.931*	0.95
Scene viewing/Scene viewing only	.955*	0.96	.955*	0.96
* Significant p<.0001			r value	

The power analysis indicated that the analysis had statistical power.

3.8: Real-world versus Scene viewing: A spatial comparison - Experiment 3

The aims of experiment 3 were to compare the spatial distribution of eye movement behaviour between real-world and scene viewing and to establish if the results from experiment 1 could be reproduced in a different environment. In experiment 1, participants were required to negotiate stairs and corridors but in this experiment participants walked around the atrium in the School of Sport and Exercise Sciences, University of Birmingham which resembles a cafe with tables, chairs and people to negotiate.

We hypothesised that there would be a high level of similarity between the spatial spread of eye movement behaviour between the real-world and scene viewing conditions. We also hypothesised that there would be a high level of congruence between the gaze behaviour of participants completing the real-world and scene viewing conditions.

3.9: Method

3.9.1: Participants

Six participants (3 females) were recruited from the undergraduate community of the School of Sport and Exercise Sciences, University of Birmingham. Participants were given one and a half research hours in exchange for their participation, which is a requirement of their course. Participants had a mean age of 19.1 (range 18-20). Ethical permission was gained from the college ethics board and participants gave informed consent before the experiment began. Participants were told that they could withdraw at any time without giving a reason.

All participants had normal or corrected vision (contact lenses). Participants who wore glasses were excluded from the study due to logistical issues associated with calibrating the eye tracker. Participants with a history of musculo-skeletal problems were also excluded as the weight of the backpack might have exacerbated their condition.

3.9.2: Apparatus and Experimental Set up

An ASL500 mobile eye tracker (470g) with a sampling rate of 60Hz was used to record the vertical and horizontal position of the participants' eye. The eye tracker also recorded a video image, at a sampling rate of 30Hz, of which environmental features the participant fixated on during the two conditions. An Acer projector (S1200) and screen (height 148cm, width 290cm) was used to project calibration points and the video in the scene viewing condition.

During the scene viewing condition participants sat on a chair which was 70cm high and the videos were presented on a screen with a resolution of 1024 x 768 with a refresh speed of 60Hz. Participants were positioned 118cm from the screen and the screen started 62cm above the floor. The ratio of the real-world to scene viewing condition was 1:0.78.

In the real-world condition, participants carried essential equipment for the running of the eye tracker in a rucksack (6.77kg). Along with the video filmed by the eye tracker a Sony Handy cam (DCR-H30) was used to film a video of the walk for the final condition. The video feed from the eye tracker was split during the real-world condition so that the two videos could be filmed at the same time. During the real-world condition participants had to navigate through a route in the School of Sport and Exercise Sciences Atrium. The route required participants to negotiate tables, chairs, sofas, and a door and was chosen because it reflects a real world situation similar to walking through a cafe.

3.9.3: Design and Procedure

On entering the laboratory participants were given an information sheet to read and a consent form to sign. Before the experiment began they were asked if they had any questions about the experimental procedure.

Participants were walked through the route once by the researcher. They then returned to the laboratory where they were equipped with the eye tracker. The eye tracker was calibrated and the calibration was checked and recorded. Measurements of the participants eye height whilst positioned in front of the calibration points and the distance of their eyes from the screen were taken for use in the analysis.

Participants returned to the start of the route and the eye tracker, laptop, and handy cam were set up to record. Before the walk began, participants were asked to fixate on the researcher's finger whilst they rotated their head from left to right. Participants were required to do this so that the video and laptop data could be temporally matched up during analysis. Participants were signalled to walk by the presentation of a flashing light; this allowed the video of the walk to be temporally aligned between the 2 conditions. Once the walk had been completed participants returned to the laboratory.

The video which, had been recorded on the handy cam, was downloaded in preparation for the scene viewing condition. Participants were seated in front of the screen and calibration was checked and recorded. Before the experiment began the eye tracker and laptop was set up to record and participants were asked to fixate on the researcher's finger whilst they rotated their head from left to right. The video which had been previously recorded was started and the instructions given to the participant was to simply sit and watch the video. During scene viewing the laboratory lights were set to dim. At the end of the experiment participants were fully debriefed and thanked for their time.

3.9.4: Analysis

The video analysis for experiment 3 was the same as experiment 1.

The horizontal and vertical eye position data for five of the six participants was converted into angles by using the height of the eye relative to the position of the 9 calibration points and the distance of the participant's eye to the screen. One participant was not included in this analysis because of missing data. The raw horizontal data for each participant was plotted to locate the position in the data where the participant had fixated the researcher's finger whilst rotating their head, this was also located on the videos. The time between the participant fixating the researcher's finger and the flashing light on the video was then timed and this information was used to establish when in the horizontal and vertical angle data the start of the experiment was. The data was then processed to remove all the points where the eye was out of range of the eye tracker and angles which were beyond 90° or -90° in the horizontal and vertical plane were removed as outliers. A matrix was used to calculate the frequency with which different points were fixated by participants and the average across participants was calculated to produce frequency plots.

3.10: Results

Figure 3-6 is an illustration of the temporal gaze behaviour observed in one participant during the real-world and scene viewing conditions. Different environmental features which were fixated by the participant are colour coded and the time is presented in seconds. The real-world condition is represented by the solid line, and the scene viewing condition is the dashed line. The screen shots indicate where in the scene the participant is fixating at a given point in time for the two conditions. Figure 3-6 demonstrates that the participant spent the majority of the clip fixating the floor (green), the walls (pink) and along the route (brown). During the remainder of the clip the participant fixated people (blue) and obstacles (purple).

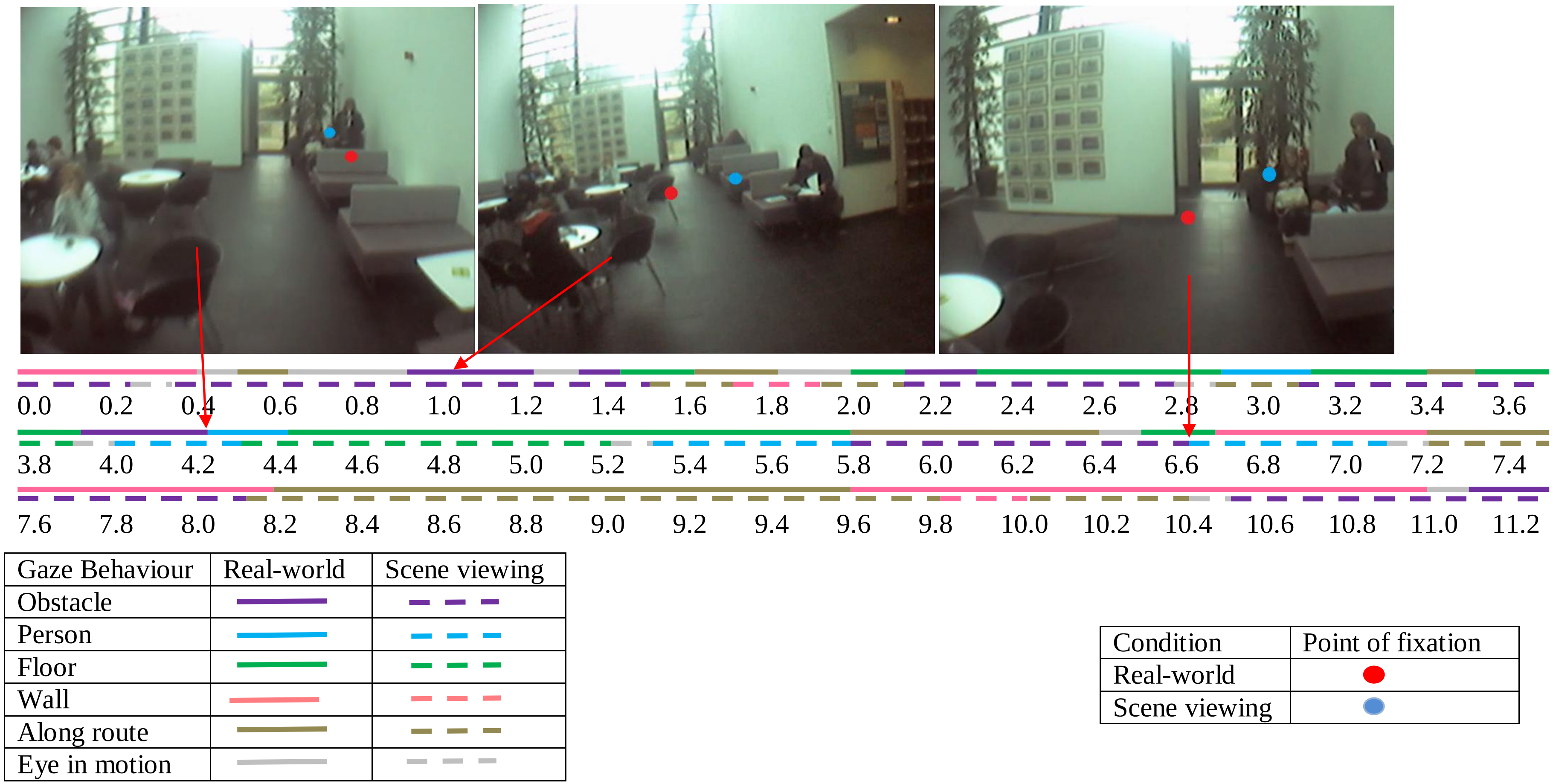
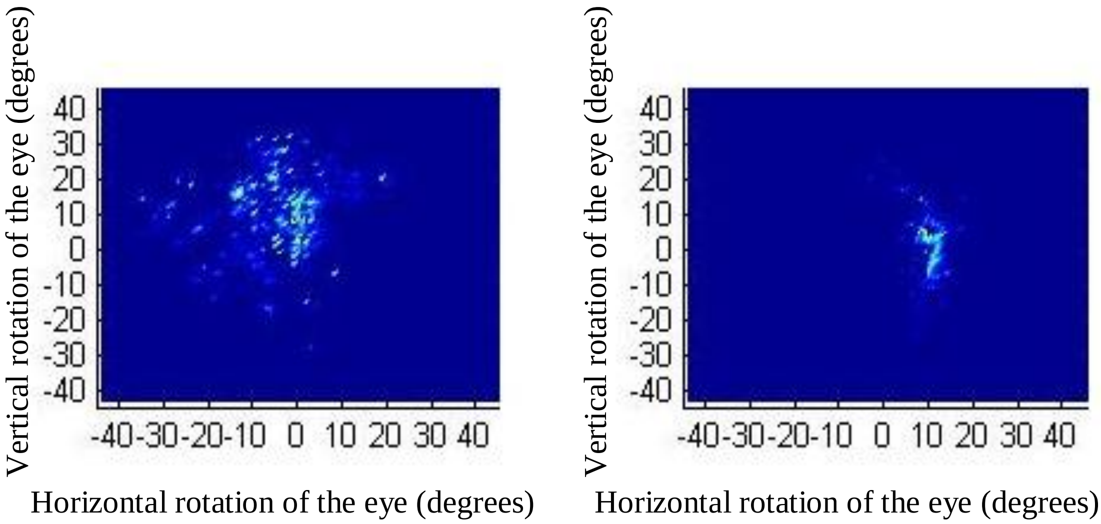


Figure 3-6. An example of 11 seconds of gaze behaviour for the real-world, and scene viewing conditions for one participant. The screen shots indicate where the participant is fixating in each condition at a given point in time.

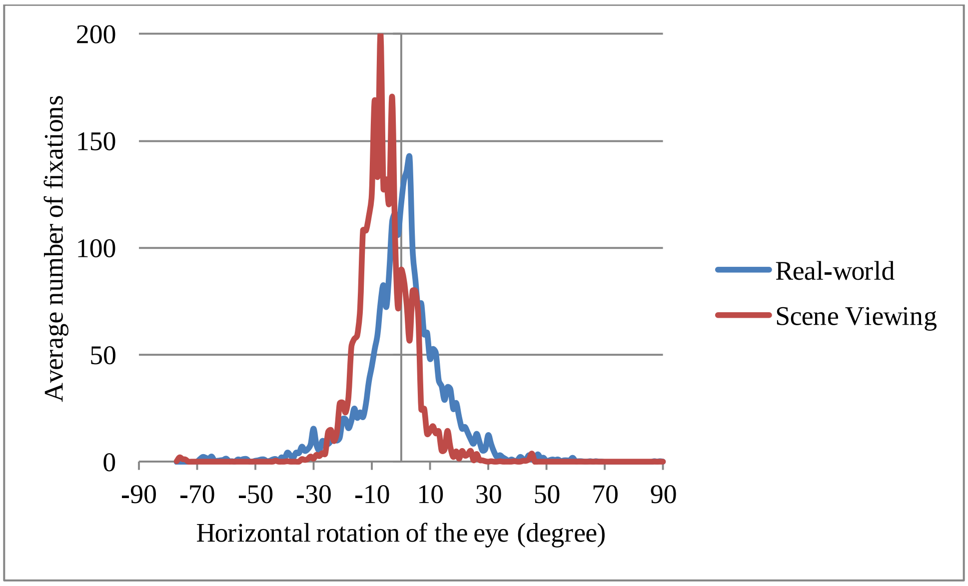
Figure 3-7 shows the spatial gaze distribution for the length of the experiment for five of the participants. The scale of the scene viewing condition has been adjusted so the angles are comparable to the real-world. The brighter colours indicate the areas where participants fixated the most. The gaze distribution indicates differences between the real-world and scene viewing conditions. Overall the participants fixated in the centre of the visual display; however, they made a greater spread of fixations in the real-world condition compared to the scene viewing condition, where the fixations were much more localised.



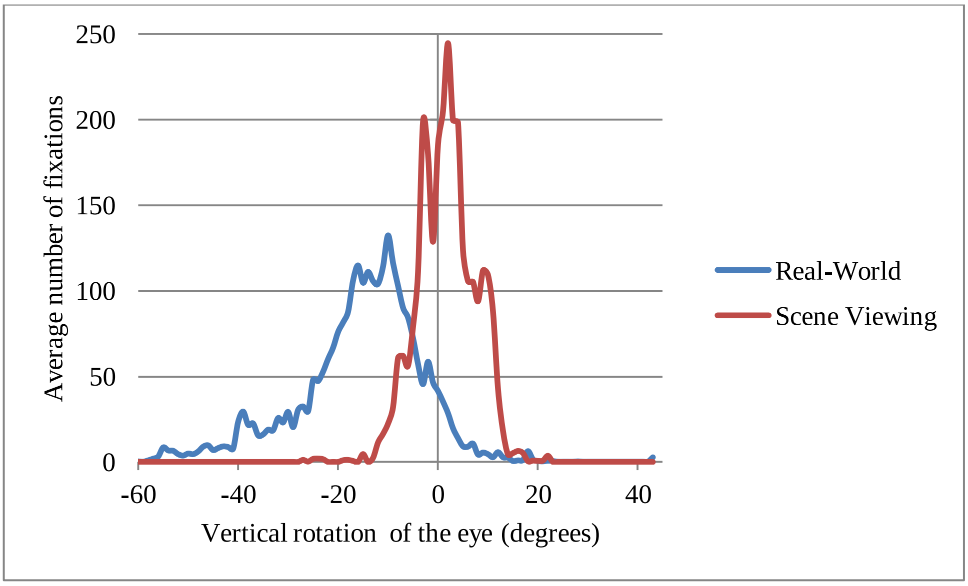
a) Real-world condition b) Scene viewing condition

Figure 3-7. Spatial gaze distribution for the two conditions for five of the participants.

Figure 3-8 shows the average number of fixations participants made at different eye angles during the real-world and scene viewing conditions for 5 of the participants. The graphs show that participant's fixation patterns were similar in the horizontal plane (a). In the vertical plane (b) participants are observed to make more fixations to the lower part of the visual scene in the real-world condition compared to the scene viewing condition.



a)



b)

Figure 3-8. Demonstrates the average number of fixations made in the real-world and scene viewing conditions by 5 of the participants in the Horizontal (a) and Vertical (b) plane expressed as the angle of the eye.

Figure 3-9 illustrates that participants spent the majority of the time fixating environmental features which are important for locomotion such as the floor, doors, and obstacles (real-world 71%, scene viewing 86%). For the remaining time participants eyes were in motion (real-world 13%, scene viewing 10%) or were directed outside of the range of the eye tracker (real-world 14%, scene viewing 3%). The shortest amount of time was spent fixating items not relevant for locomotion (real-world 2%, scene viewing 2%).

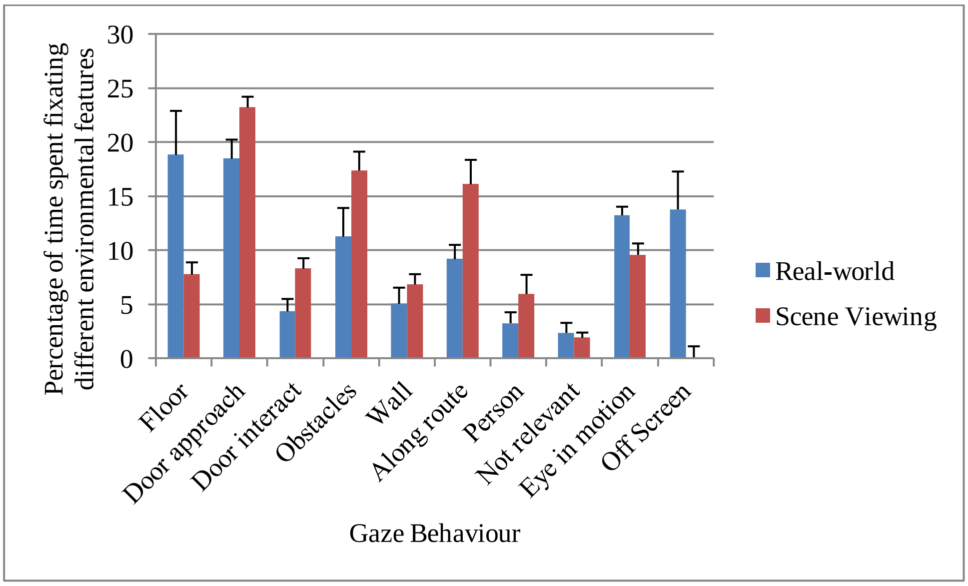


Figure 3-9. Distribution of gaze behaviour expressed as a percentage for the real-world, and scene viewing conditions

Positive significant correlations were found for the total average fixation time on environmental features measured during the real-world and scene viewing conditions r (4)= 0.81, p<.0001. The statistical power was 0.44 indicating that the analysis did not have desired statistical power (figure 3-10).

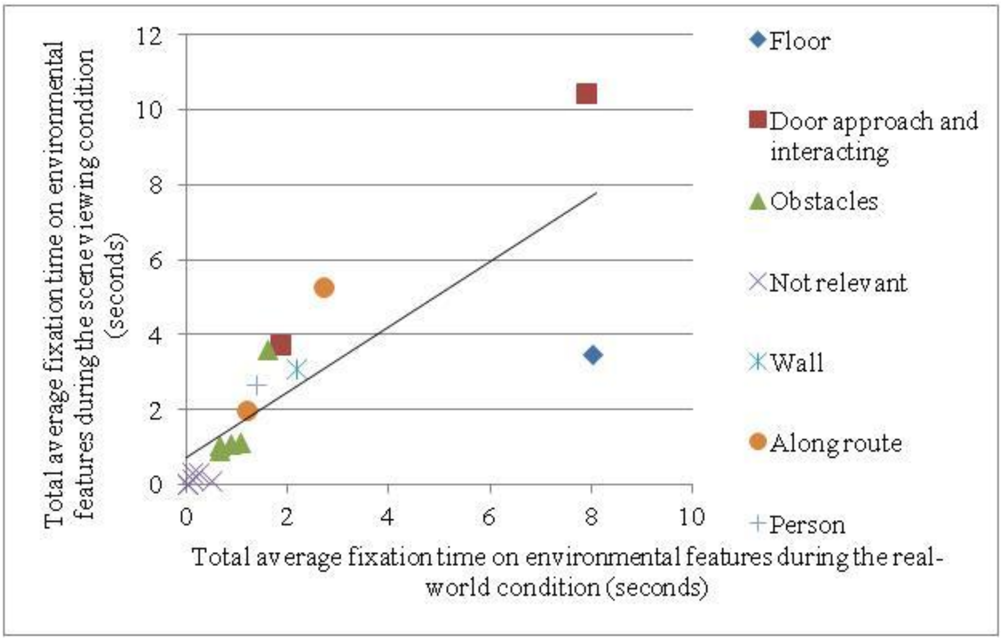


Figure 3-10. A significant positive correlation for the mean duration of time that participants spent fixating environmental features during the real-world and scene viewing conditions

Positive significant correlations were found for the total average number of times different environmental features were fixated upon during the real-world and scene viewing conditions $r(4) = 0.80$, $p<.0001$. The statistical power was 0.40 indicating that the analysis did not have desired statistical power (figure 3-11).

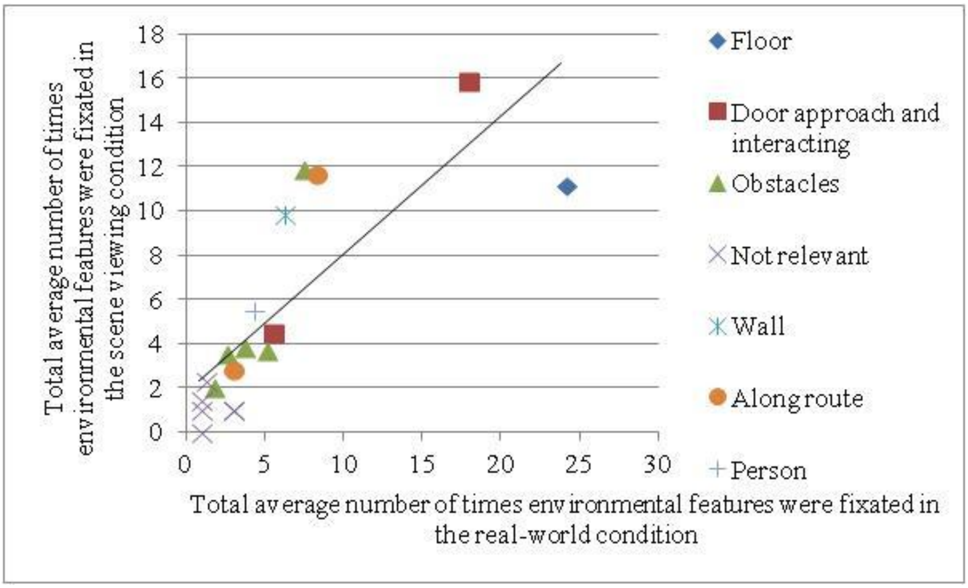


Figure 3-11. A significant positive correlation for the average number of times different environmental features were fixated during the real-world and scene viewing conditions.

Individual correlations were conducted for each participant to ascertain if the positive correlations were accurate and had not resulted from the process of averaging the fixation durations and number of fixations across participants (table 3-3). The individual correlations show that all comparisons are significant at $p<.05$ with the exception of participant 4 for the duration of fixation.

Table 3-3. Individual correlations for each participant, exploring the significance of fixation duration and number of times environmental features were fixated during the real-world, and scene viewing conditions.

Participant	Fixation Duration	Frequency of Fixations
1	.707*	.829**
2	.766**	.509*
3	.910**	.815**
4	.382	.538*
5	.780**	.825**
6	.881**	.905**
** Significant p<.000	* Significant p<.05	R values

3.11: Discussion for experiments 1, 2 and 3.

These are some of the first studies to quantitatively describe the gaze behaviour of participants walking around and interacting with a real environment. It is supportive of the findings from ‘t Hart *et al*, (2009) who concluded that continuous scene viewing is a good predictor of where people look when they are walking around the real-world. It also supports the findings of Foulsham, Walker and Kingstone (2011) who concluded that scene viewing produces similar gaze behaviour as walking around a similar environment. The present studies address some of the limitations of Foulsham *et al*’s study (2011) in the following ways: all participants walked the same route and watched a first person perceptive video of themselves walking to enable direct comparisons to be made. This was then counterbalanced by comparing the gaze behaviour of participants who only completed the scene viewing condition to those who completed both scene viewing and real-world conditions, to establish if the similarities in gaze behaviour were not a confound caused by the participants having just walked the route they were watching in the video. In addition, during the scene viewing condition the videos in the current studies were presented on a large screen and the participants head was not constrained allowing for greater freedom of movement and a more immersive environment. Finally participants in the current study were not given any instruction as to how they should view the videos meaning their gaze behaviour during the scene viewing condition was not influenced by the researcher.

Past research has been restricted to observing gaze behaviour in a laboratory setting with participants performing multiple walks along the same path, or staircase making them low in ecological validity (Zietz & Hollands, 2009; Chapman & Hollands, 2006b; Patla & Vickers, 1997; Hollands, Patla, & Vickers, 2002; Chapman & Hollands, 2006b; Chapman & Hollands, 2006a; Chapman & Hollands, 2007). Using a scene viewing paradigm would allow for participants to be exposed to scenes which reflect situations that they encounter in the real-world enabling richer data about where we look when we walk to be collected.

3.11.1: Gaze behaviour during real-world walking

The current studies support the findings from previous laboratory studies that relevant visual cues are sampled in a feed-forward manner (Zietz & Hollands, 2009; Patla, 1998; Patla & Vickers, 1997; Hollands & Marple-Horvat, 2001; Hollands, Sorensen, & Patla, 2001) during adaptive locomotion. The studies report that participants make eye movements to fixate objects before a motor action relating to that object is carried out (Hayhoe & Ballard, 2005; Land et al., 1999; Land & Furneaux, 1997) and is presumably used in the planning of the movement. This pattern of eye movements is observed in the current studies. For example, participants were observed to fixate on a door during the approach phase when walking down a corridor or fixate several steps ahead when ascending stairs (Land et al., 1999; Hayhoe & Ballard, 2005) (figure 3-2a, 3-2c). Interestingly, none of our participants demonstrated the gaze behaviour observed by Patla and Vickers (1997) who reported that participants spent 40% of the time during locomotion "travel fixating" whereby participants eyes remain fixed with respect to the head and gaze was passively carried along by the body. All participants in the current studies were found to continually fixate environmental features: either points of interest within the immediate travel path or more distant goals. This suggests that visual information describing task-relevant environmental goals and obstacles is primarily important for guiding successful navigation through a complex real-world environment rather than non-specific visual information describing self-motion e.g. optic flow. Land and Hayhoe (2001) reported that, when performing sandwich making and tea making tasks, fixation of irrelevant objects accounted for less than 5% of participants' eye movements. In the present studies participants fixated on irrelevant objects for 5% of the total time in the real-world condition, 5% in the scene viewing condition in experiment 1 (figure 3-3) and 7% in the scene viewing only condition in experiment 2 (Figure 3-5). In experiment 3 the total percentage of time spent fixating irrelevant objects in the real-world condition was 2%, and in the scene viewing condition was 2% (figure 3-8). Although, tea and sandwich preparation and walking through a building are very different tasks, in each case, the majority of eye movements made by participants were to fixate environmental features relevant for successful completion of the task. These findings can potentially be explained by the previous proposal that optimal gaze behaviours are learnt as a result of a reward system (Land & Hayhoe, 2001). The notion of reward based gaze behaviour is an example of a top-down model (Rothkopf, Ballard, & Hayhoe, 2007) which proposes that participants use short-term and long-term knowledge of scenes when directing their gaze and that gaze is not simply directed to the most salient aspects of a scene (Henderson, 2003). Areas of the cortex which are associated with the direction and generation of saccades (e.g. lateral intraparietal area, frontal eye field, supplementary eye field and dorsolateral prefrontal cortex) project to the basal ganglia, which is associated with reward and the basal ganglia then projects back to the cortex (Hikosaka, Nakamura, & Nakahara, 2006; Jovancevic-Misic & Hayhoe, 2009). Previous studies have shown that monkeys trained to look at certain environmental features to gain rewards make significantly faster saccades when a bigger reward is expected (Hikosaka et al., 2006). These studies are supported by the findings of single neuron studies in primates, which showed a greater firing rate from the caudate neuron when the expected reward was large. The greater firing rate correlated with the primates making faster saccades to locations where the expected reward was larger. If a saccade was made to an area of expected reward but the reward was not received then the firing rate reduced. The caudate neuron is associated with learning and memory and its increased firing to expected reward and decreased firing rate when rewards are not received indicates that it could be important in the learning of where to make eye movements when interacting with the environment (Hikosaka et al., 2006).

Even though the environment we encounter is constantly changing during locomotion, it is conceivable that a reward system also influences eye movements during walking. From the moment humans enter the world they start interacting with it and learning from their experiences. Humans may learn that whilst walking around their gaze should be aimed in the direction of the travel path (Cristino & Baddeley, 2009), to stationary or moving obstacles which might be hazardous or affect future progress (Jovancevic-Misic & Hayhoe, 2009). This hypothesis is supported by the findings of the current studies which showed that the majority of fixations were to environmental features which are required for safe locomotion through the environment (experiment 1 real-world 65%, and scene viewing 73%; experiment 2 scene viewing only 69%; experiment 3 real-world 71%, and scene viewing 86%).

3.11.2: Walking versus scene viewing

These are some of the first studies to compare gaze behaviour collected during real-world walking with that collected during passive scene viewing. The results demonstrate a significant positive correlation between the duration and the frequency that participants fixate task-related environmental features for both scene viewing, scene viewing only and real-world walking suggesting that similar neural processes are responsible for gaze behaviour in the different experimental conditions. However there are sustainable differences in the spatial spread of eye movements observed in experiment 3 (figure 3-7). In the real-world condition participants made a greater spread of fixations compared to the scene viewing condition were fixations were much more localised. In addition, participants made more fixations to the lower extremities of the vertical plane in the real-world condition than the scene viewing condition (figure 3-8b). This could be caused by a confound of the present study because the video image, in the scene viewing condition, did not start at the floor but started at a height of 62cm so participants did not have to rotate their eye as far in the scene viewing condition in order to fixate the floor. An alternative explanation for the difference in eye movement behaviour, in the vertical plane, could be that during scene viewing fixating the immediate travel path is not as important compared to really walking in the environment. Patla and Vickers (1997) found that when required to step over an obstacle in the travel path participants' fixation behaviour altered depending on the height of the obstacle, with participants fixating bigger obstacles for longer compared to smaller obstacles. In addition, tea (Land et al., 1999) and sandwich making (Hayhoe et al., 2003) studies have shown that the task demand alters the fixation behaviour of the participants. The observation that task demand alters fixation behaviour supports the idea that the differences in spatial distribution results from participants not needing to fixate the immediate travel path during scene viewing.

Neurophysiological studies of primates have shown that “mirror neurons” in the ventral pre-motor cortex of monkeys are similarly active when the monkeys are producing a goal-directed action as when they observe another performing the same action (Buccino, Binkofski, & Riggio, 2004). It is conceivable that mirror neurones in the brain areas which are activated during walking are also activated whilst watching the scene, in a similar way to that observed in the aforementioned primate studies. Brain areas that are likely to be activated are those areas associated with the dorsal and ventral streams, along with areas associated with the generation and direction of saccades including the basal ganglia (Hikosaka et al., 2006; Jovancevic-Misic & Hayhoe, 2009). Regardless of the neural processes responsible for the similarity between gaze behaviour observed under the different conditions in the current experiments, the findings clearly indicate that measuring gaze patterns of participants' passively viewing movies of walking, shown from a first-person perspective, is likely to provide reliable insight into the gaze patterns they would normally produce during real walking.

3.11.3: Active versus passive perception

In recent years it has been highlighted that using video simulation to study differences in fixation behaviour between expert and novice sports people might not be the best way to explore differences in their gaze behaviour (Mann, Williams, Ward, & Janelle, 2007). Dicks, Button and Davids (2010) compared the fixation behaviour of goalkeepers whilst preparing to save a penalty kick under five different conditions. In two of the conditions the goalkeeper viewed a video simulation of a penalty kick and either made a verbal response or a simplified movement in response to where they thought the ball would go. In the other three conditions a natural experimental set up was used and the goal keeper responded by either making a verbal response, a simplified movement or an unrestricted movement where they attempted to save the goal. Dicks, Button and Davids (2010) found that the goal keeper fixated the ball sooner and for longer in the condition where they were allowed to make an unrestricted movement to save the goal. It has been suggested that the reason for the differences in gaze behaviour when experts make a natural, unrestricted movement to a stimulus compared to making a verbal response or a simplified movement is because of the area of the brain processing the information. There are two distinct areas of the brain which process different aspects of visual information. The dorsal stream, which provides spatial information about a objects location so an accurate body movement can be made to interact with the object and the ventral stream which enables recognition of shapes, objects, people and routes (Deubel, Schneider, & Paprotta, 1998). It has been proposed that the differences in eye movement between unrestricted movement conditions compared to verbal and simplified movement conditions are caused because by not performing a naturalist action the dorsal stream is not activated and only the ventral stream is activated (Dicks, Button, & Davids, 2010). The proposal that passively viewing a video of an action does not activate the action pathway (dorsal) has implications for the findings presented in the current study as it implies that the same areas of the brain which would be activated during walking are not been activated during scene viewing suggesting that there might be differences in the gaze behaviour of participants in the different conditions. However, the findings from the current study found the eye movements to be similar. To establish if there are differences future research should concentrate on the timings of fixations to different environmental features to ascertain if this is influenced by passively viewing the scene (scene viewing) compared to walking around the scene.

3.12: Conclusion

These studies demonstrate that scene viewing evokes significantly similar gaze behaviour to that evoked when a participant walks around the same environment when the duration and number of fixations are compared. This suggests that similar neural processes are responsible for gaze behaviour in the different conditions. However there are sustainable differences in the spatial distribution of fixations when the real-world is compared to the scene viewing condition.

We propose eye tracking during virtual walking may be useful as a novel research and diagnostic tool for the identification of the eye movement and visual problems that may contribute towards increased falls risk in frail individuals. To explore this proposal, in the future the scene viewing element of the experiment will be applied to older adults.

Chapter 4

A novel paradigm to study the mechanisms underlying age- and falls risk- related differences in gaze behaviour during walking.

Vision is crucial for safe human locomotion as it is the only sensory modality that provides information about the future travel path. The development of mobile eye trackers has allowed researchers to explore how humans visually sample the world when walking. Hollands *et al* (1995) were one of the first to explore the importance of eye movements for controlling locomotion. They found that when participants walked along a predefined, stepping stone route, saccades to the next stepping stone were most commonly made during the late stance phase of the targeting foot, and the remainder were completed during the early swing phase. These findings indicate that visual information is usually sampled at predictable times during the step cycle. Subsequent studies have also shown a strong temporal link between visual sampling behaviour and execution of locomotive activities. For example, during obstacle interaction participants fixate an obstacle in the travel path prior to stepping over the obstacle but not whilst stepping over the obstacle (Patla & Vickers, 1997; Di Fabio et al., 2003). During direction change participants make a coordinated eye and head movement to the new direction of travel before reorienting their body (Hollands et al., 2002) and whilst stair walking participants fixate about three steps ahead (Zietz & Hollands, 2009). In combination, the findings from these studies suggest that vision is used in a feed-forward manner to control stepping and that the ability to make accurate eye movements at appropriate times during the action sequence is important for safe locomotion.

As with young adults, older adults consistently look at features of the future travel path before initiating the step to the fixated location. However, older adults fixate obstacles and targets in the travel path for significantly longer than young adults (Di Fabio et al., 2003;

Chapman & Hollands, 2006b). This suggests that older adults require longer to process visual information about the future travel path needed for safe locomotion (Di Fabio et al., 2003). Chapman and Hollands (2006b) found that unlike lower risk older adults (LROA) and younger adults, higher risk older adults (HROA) tended to transfer their gaze away from targets they were stepping towards before completing the on-going step and that the extent of early gaze transfer correlated with foot placement errors. This finding further supports the notion that the normally observed close temporal link between gaze behaviour and locomotor events is important for maintenance of balance and safe locomotion. However, the mechanisms underlying altered gaze behaviour in HROA have yet to be fully clarified. One possibility is that decline in cognitive functioning in HROA may contribute towards the aforementioned altered gaze patterns.

A number of studies have indicated that decline in executive functions associated with the natural ageing process are associated with increased risk of falling. For example, Ble *et al.* (2005) used the Trail Making Task (TMT) and Mini Mental State Examination (MMSE) to assess executive function decline and walking speed in 900 healthy older adults aged 65 and over on an obstacle course. TMT provides an assessment of a participants visuomotor functioning and assesses ability to visually scan and cognitive flexibility (Yogev-Seligmann et al., 2008). Ble *et al* (2005) found that participants with lower scores on these tests were slower at performing the walking task indicating that decline in visual scanning and cognitive flexibility might have a negative impact on a person’s ability to safely navigate through their environment. Holtzer *et al* (2006) showed that the self-selected walking speeds of healthy older adult participants correlated with their scores on executive function tests (visual memory, attention, speed, etc). Dual task experiments with healthy older adults showed that those classified as fallers presented with greater gait variability and walking instability whilst performing an additional task during walking (Springer et al., 2006). Gérin-Lajoie, Richards and McFadyen (2006) explored the effects of having older participants listen to announcements, resembling those they might hear in a department store, whilst walking in trials with either no obstacle, a stationary obstacle, or a moving obstacle. They found older adults at a higher risk of falling walked slower and maintained a larger personal space between themselves and the obstacles. These dual task experiments suggest that healthy older adults at a higher risk of falling have reduced ability to divide attention which potentially increases their likelihood of falling.

From past research it is clear that changes in eye movement behaviour, as a result of normal ageing, might have an impact on falling risk in healthy older adults (Chapman & Hollands, 2006b; Chapman & Hollands, 2007). However, these studies were conducted in a laboratory setting and required the participant to repeat the same task a number of times. Laboratory studies do not reflect real-life situations making them low in ecological validity. An obvious way to avoid this limitation is to explore eye movement changes in older adults whilst they are walking around the real-world; however, there are a number of problems with this proposal. Although eye tracking systems that allow recording of participant gaze behaviour to be recorded during relatively unrestricted movement are commercially available, these systems are either limited in their technical capabilities (i.e. they have low temporal and spatial resolution), or require the participant to carry heavy equipment which may alter behaviour.

Another limitation of studying real-world behaviour is that for any given walking situation the visual experience of each participant will differ depending on transient environmental factors such as, pedestrians, traffic, lighting conditions etc. These differences would have a confounding influence on between-participant analysis of behaviour.

One possible solution for avoiding the logistical problems associated with recording real-world behaviour is to study participant behaviour in a virtual environment which allows the researcher to carefully control all elements of the participant's visual experience. Reed-Jones *et al.* (2009) explored the steering behaviour of participants as they walked on the spot in front of a large screen displaying a movie of a walk along a corridor with a turn at the end. Participants displayed similar steering behaviour to that normally observed when people turn in the real-world (Reed-Jones et al., 2009). Schoch *et al.* (2005) investigated the similarities between gaze behaviour measured from participants walking along a corridor in the real-world and gaze behaviour measured from the same participants navigating a computer simulation of the same corridor using a joystick. They found no significant differences between the number of times objects were fixated in the two conditions. Cristino and Baddeley (2009) explored the gaze behaviour of participants watching movies of someone walking along a street. They found that participants consistently made fixations to objects relevant for safe locomotion. These findings indicate that viewing a moving scene can elicit the same visual and postural behaviour observed whilst walking around a real environment and raises the possibility of using virtual environments as a substitute for real-world experiences in probing gaze behaviour during walking tasks.

There are three studies which directly and quantitatively compare gaze behaviour measured from participants viewing movies designed to emulate a visual walking experience with gaze behaviour measured during real walking. 't Hart *et al* (2009) compared gaze behaviour collected while a single participant walked around the real-world with that measured from a group of participants during movie viewing under continuous replay. Stanley and Hollands (2010) and Foulsham, Walker and Kingstone (2011) compared eye movement behaviour of participants walking around a real environment to movie viewing in the laboratory. They reported that fixation behaviour of participants was significantly similar between the two conditions. Studies comparing real-world and scene viewing gaze behaviour during walking ('t Hart et al., 2009; Foulsham et al., 2011; Stanley & Hollands, 2010) provide encouraging evidence that similar eye movement behaviour is produced; therefore, studying the eye movement of older adults during virtual walking is likely to be a viable alternative to lab-based and real-world walking studies for exploring age-related differences in visual sampling behaviour during locomotion.

The current study aimed to quantitatively assess differences in gaze behaviour between young and older adult groups, with higher and lower risk of falling, during a virtual walking paradigm. We hypothesised that there would be differences in where and when the different groups made fixations to environmental features whilst watching the first person perspective videos. In addition we predicted that healthy older adults at a higher risk of falling would have significantly lower scores on visual, motor and cognitive function tasks than the healthy older adults at a lower risk of falling and the young adults. We also predicted that we would find significant correlations between scores on visual, motor and cognitive function tests and travel path fixation duration, with participants who achieve lower scores on these tests fixating the travel path for longer and more frequently.

4.1: Method

4.1.1: Participants

Nine young adult participants with a mean age of 24.3 years (22-30) were recruited from the postgraduate community of the School of Sport and Exercise Sciences at the University of Birmingham. Fourteen community-dwelling older adults were recruited from the local community through advertisement in the local media. The older adults were ranked according to their scores on each of the following screening measures: Berg Balance Scale, Activities Balance Confidence Scale (ABC), and number of falls in the past year. The ranked scores from each measure were then summed and used to divide the older adults into two groups, representing participants with a relatively higher (HROA) and lower (LROA) risk of falling respectively. Seven of the older adults were allocated to the HROA (6 females, 1 male) with a mean age of 73.14 (67-82) and seven were allocated to the LROA (5 female, 2 male) with a mean age of 69.14 (65-80) (see table 4-1). All participants had normal to corrected (glasses or contact lenses) visual acuity score of 20/40 or better.

Ethical permission was gained from the College Ethics board and participants gave informed consent before the experiment began. Participants were told that they could withdraw from the experiment at any time without having to give a reason.

Table 4-1. Demographics for the young adults, HROA and LROA.

	Young	HROA	LROA
Age	22-30 (24.3)	67-82 (73.1)	65-80 (69.1)
Gender	6 female 3 male	6 female 1 male	5 female 2 male
Height (cm)	157.5-185.5 (171.7)	156.5-182 (165.29)	158-175 (167.07)
Weight (kg)	49.7-92.1 (65)	58-82.1 (74.09)	65.1-113 (79.43)
Berg (max 56)	56	45-56 (53.71)	54-56 (55.57)
MMSE (max 30)	29-30 (29.78)	26-29 (28.29) *	28-30 (28.71) *
Vision acuity (Snellen)	All 20/15	20/15-20/40	20/15-20/25
Pelli-Robson Contrast Sensitivity (max 2.1)	1.95-2.1 (1.97)	1.65-1.95 (1.91)	1.65-1.95 (1.86)
TMT (seconds)			
A	15-26 (20.1)	33-59 (40.89) *	25-51 (35.96) *
B	26-130 (40.9)	62.14-211 (102.06) *	44-93 (63.07)
ABC (%)	78-100 (95)	38-90 (69) *	88-98 (93)**
General Health Questionnaire (max 21)			
Somatic Symptoms	1-10 (4.2)	2-12 (6.43)	2-5 (3.57)
Anxiety/Insomnia	0-16 (5)	1-8 (5.43)	0-11 (3.43)
Social Function	4-13 (7.1)	5-18 (9.14)	6-8 (7.14)
Depression	0-11 (1.3)	0-1 (0.29)	0-1 (0.43)
Falls			
Average number of falls	0.2	2.43	0.71
% of participants fallen in past year	22	71	43

* Significantly different to young ** Significantly different to higher risk

4.1.2: Apparatus and Experimental set up

A head-mounted ASL 500 mobile eye tracker (470g) with a video sampling rate of 30Hz was used to record which environmental features participants fixated and when whilst they viewed five movies. An Acer projector (S1200) and screen (height 148cm, width 290cm) was used to project calibration points and the movies (video image size: height 111cm, width 154cm). Participants sat on a chair at a height of 70cm, at a distance of 118cm from the screen. The movies were presented on a screen with a resolution of 1024 x 768 and a refresh speed of 60Hz. The screen started 62cm above the floor and the ratio of real-life to the video image was 1:0.54.

Participants watched five first-person perspective movies representing the viewpoint of a pedestrian walking through various environments. The movies depicted the following walking scenarios; a local canal towpath (2 locations), a local high street in Birmingham (2 locations) and the final movie showed a route through our department. The four movies of the local area were filmed using a Sony Handycam (DCR-H30). The movie of the department had been filmed using the mobile eye tracker during a previous experiment. An additional movie was included at the start of the experiment, which was not analysed, to allow familiarization of participants with the experimental paradigm.

Participants also completed a number of cognitive tests which were displayed on the same screen as the movies, at a screen size of 148cm high and 154cm wide. The screen resolution was 1024 x 768 and the refresh speed was 60Hz. The tests were presented using the software DMDX and comprised a reaction time, congruent and incongruent Stroop tasks (Stroop, 1935) and four different visual search tasks. Participants responded to the cognitive tests by pressing colour coded keys on a laptop. The reaction time test required participants to respond as quickly as possible to the presentation of a red N. Participants completed 9 practice trials and 40 experimental trials. The congruent and incongruent Stroop tasks were presented separately and the stimuli were presented in a randomised order. Participants completed 8 practice trials and 50 experimental trials for both the congruent and incongruent conditions. The congruent condition was presented first and the stimuli were coloured words. The visual search tests comprised five practice trials and 50 experimental trials each and the stimuli were presented in a randomised order. In 25 of the trials the red target N was present and in 25 the red N was not present. In the trials where the N was present its position within the display was randomised between trials. The visual search tasks were split into two different types of search (pop out and conjunction search) with different numbers of stimuli presented on the screen (16 and 30). The pop out search had a red N as the target and blue Hs as distracters. In the conjunction search the distracters were red Hs and blue Ns and the participant responded to the presentation of a red N.

4.1.3: Procedure

On entering the laboratory participants were given an information sheet to read which detailed the experimental procedure and they were asked to sign a consent form. They were told that they had the right to withdraw at any time.

Participants then completed the screening measures which are outlined in table 1 and a falls history was taken. Participants were instrumented with the ASL mobile eye tracker and a nine point calibration was carried out. The calibration was recorded and the video clips were started. The movies played consecutively and were always presented in the same order. The instructions given to the participants' was to simply watch the movies. After watching the movies participants completed the cognitive tests. On completion of the experiment participants were thanked for their time and fully debriefed as to the purpose of the experiment.

4.1.4: Analyses

The eye movement video data was analysed frame by frame and a fixation was recorded if the point of gaze crosshair stabilised on an environmental feature for three frames or more (Patla & Vickers, 1997). A number of environmental features were identified which were fixated by all of the participants and these were classified into the following three categories: "travel path" (pavement, path or looking in the direction of travel), "potential hazard" (people in the travel path, canal, tables, lock gates etc) and "other" (cars, shops, looking away from the direction of travel).

The total percentage of time that each participant fixated the travel path, potential hazards and other features was averaged for data collected from four of the five movie viewing tasks since these movies evoked broadly similar gaze behaviour. Data collected during viewing of the remaining movie was not analysed because it evoked very different gaze behaviour to the other movies, probably due to the presence of a highly salient visual event which dominated the movie; a turning car. The percentage of time that the three groups (young adult, LROA, and HROA) fixated the travel path, potential hazards and other features were compared in a one way between-groups ANOVA. The percentage of time that the participants' eye was in motion or not in range of the eye tracker was taken into account and included in the analysis. The number of fixations made to the travel path, potential hazards and other, by each participant, was totalled for the movies and entered into one way between group ANOVAs. The data for three of the young participants was removed for this analysis as they did not watch one of the movies and the process of totalling the fixations across the movies caused the results to become skewed.

One way between group ANOVAs allow for differences between one independent variable with three or more levels to be investigated when there is one continuous dependent variable. One way between group ANOVAs were selected to assess for differences between the percentage of time spent fixating and number of times different environmental features were fixated by the three groups because the study had one independent variable (group) with three levels (HROA, LROA and young) and one continuous dependent variable (either percentage of time or number of times).

Incorrect responses and outliers (3SD above or below the mean) were removed from the results of cognitive tests for each participant. The filtered responses were then analysed in the following ways. One way between group ANOVAs were run on the reaction time task and visual search tasks to compare group differences to speed of response. One way between group ANOVAs were selected for the reaction time and visual search tasks because the reaction time and visual search had one independent variable with three levels (HROA, LROA and young) with one continuous dependent variable (speed of response). A MANOVA was run on the congruent and incongruent Stroop tasks to compare group differences to speed of response. Data for one of the higher risk older adults for the congruent Stroop task was not included due to technical issues during data collection.

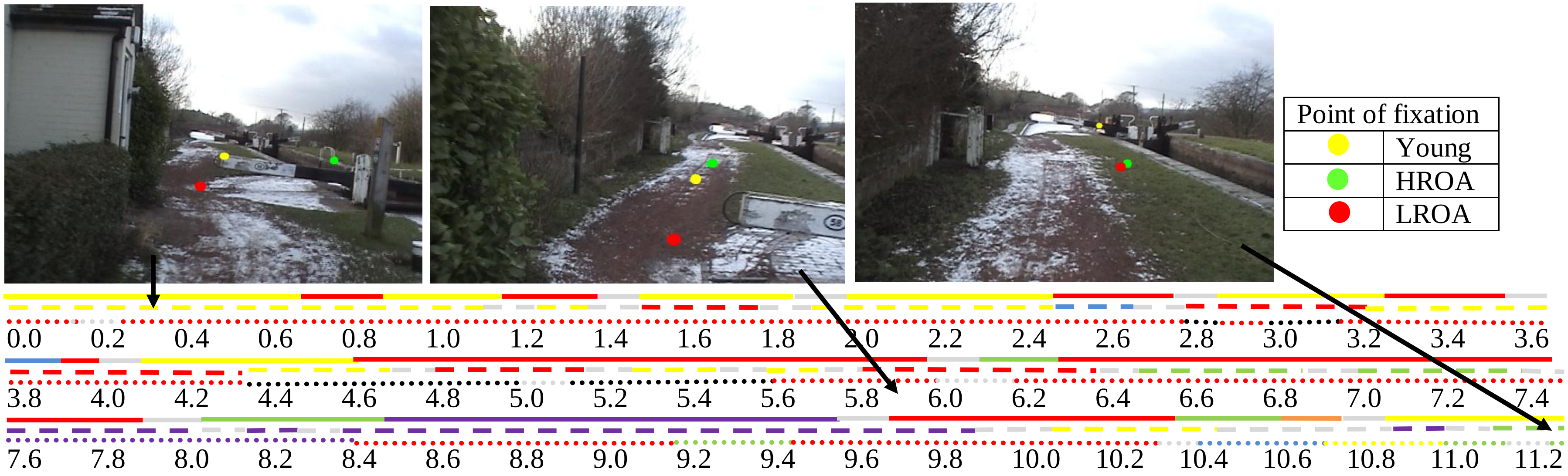
MANOVA was selected because it allows for differences to be explored when there is one independent variable with more than one level and more than one continuous dependent variable to be analysed in the same test. In the Stroop test there was one independent variable with three levels (HROA, LROA and young) and there were two continuous variables (congruent and incongruent).

4.2: Results

4.2.1: Demographics

All participants completed a number of screening measures to assess their falling risk (table 4-1). One way between group ANOVAs demonstrated a number of significant differences. There was a significant effect of group on the scores from the MMSE at $p<.05$, $f(2,20) = 7.72$, $p=.003$ (power = 0.55, effect size = 0.43). Post hoc analysis using LSD found that the HROA and LROA achieved significantly lower scores than younger adults. There was a significant effect of group on the speed at which participants completed the TMT part A, $f(2,20) = 18.82$, $p=.0001$ (power = 0.90, effect size = 0.65), with post hoc analysis showing the HROA and LROA were significantly slower than younger adults. In addition there was a significant effect of group on the speed at which participants completed the TMT part B, $f(2,20) = 5.65$, $p=.011$ (power = 0.40, effect size = 0.36), with post hoc analysis showing that the HROA were significantly slower than the young adults. There was a significant main effect of group on the ABC, $f(2,20) = 11.34$, $p= .001$ (power = 0.74, effect size = 0.53). Post hoc comparison showed that the HROA reported significantly lower confidence levels when completing different tasks relating to balance than LROA and young adults.

Figure 4-1 shows an example of gaze behaviour from a short segment of video taken from one of the towpath movies, for a young adult (solid line), HROA (dotted line) and LROA (dashed line). Each of the coloured bars indicates a different environmental feature fixated by the participants. The three photos depict 3 frames extracted from the movie at the times indicated by the black arrows. The gaze location of the three individuals is indicated by the coloured circles superimposed on the movie still. The figure shows that participants spent the majority of the movie clip fixating environmental features relevant to safe locomotion such as the travel path (red) and potential hazards such as the lock (yellow).



Gaze Behaviour	Young	HROA	LROA
Path			
Hedge/Wall/House			
Grass			
Lock			
Far distance			
Canal			
Off screen			
Eye in motion			

Figure 4-1. An example of 11 seconds of gaze behaviour for a young adult, a HROA and a LROA taken from one of the movies. The screen shots show where each participant is fixating at a given point in time.

4.2.2: Fixation Duration Analysis

The one way between group ANOVAs indicated that the movies evoked significantly different gaze behaviour between groups for the amount of time the travel path was fixated f(2,20)= 3.79, p=.040 (power = 0.24, effect size = 0.27). Post hoc analysis using LSD showed that the HROA fixated the travel path for a significantly greater percentage of time than the LROA and the young adults (figure 4-2). There were no significant differences between groups for the amount of time potential hazards f(2,20)= 0.444, p=.647 (power = 0.05, effect size = 0.04), and other f(2,20)= 1.235, p=.312 were fixated. In addition there were no significant differences for the amount of time participant's eyes were in motion f(2,20)=.533, p=.595 (power = 0.08, effect size = 0.05) or their eyes were out of the range of the eye tracker f(2,20)=1.813, p=.189 (power = 0.10, effect size = 0.15) between groups.

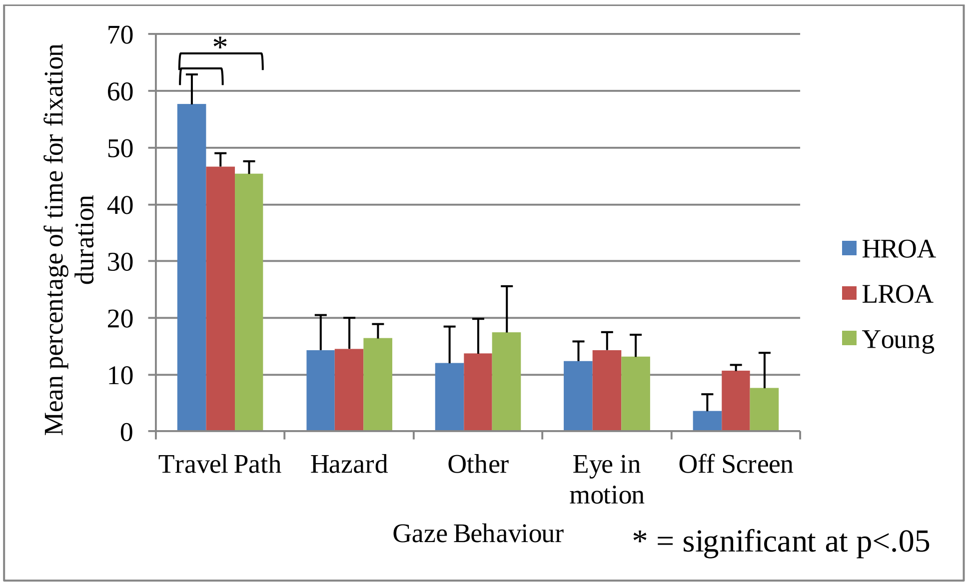


Figure 4-2. Gaze behaviour as a percentage of time comparing the HROA, LROA and young adults.

4.2.3: Number of times features fixated

One way between group ANOVAs for the number of times participants fixated the travel path, potential hazards and other features did not show a significant difference between groups (table 4-2).

Table 4-2. ANOVA results for the number of times the HROA, LROA and young adults fixated different environmental features.

	HROA		LROA		Young					
	M	SD	M	SD	M	SD	f (2,17)	p<.05	Power	Effect
Travel Path	266.6	34.8	240.6	37.5	252	24.6	1.08	0.362	0.08	0.11
Potential Hazard	83.7	28.6	87.1	33.3	94.5	24.7	0.23	0.801	0.05	0.03
Other	76.4	37.7	87.1	26.3	85.7	24.9	0.25	0.782	0.05	0.03

4.2.4: Cognitive Tests

A one way between groups ANOVA indicated a significant effect of group on reaction time, $f(2,20)=4.23$, $p = 0.029$ (power = 0.29, effect size = 0.30). Post hoc comparison using LSD found that the HROA were significantly slower when responding to the reaction time task than the young adults by around 60ms (figure 4-3).

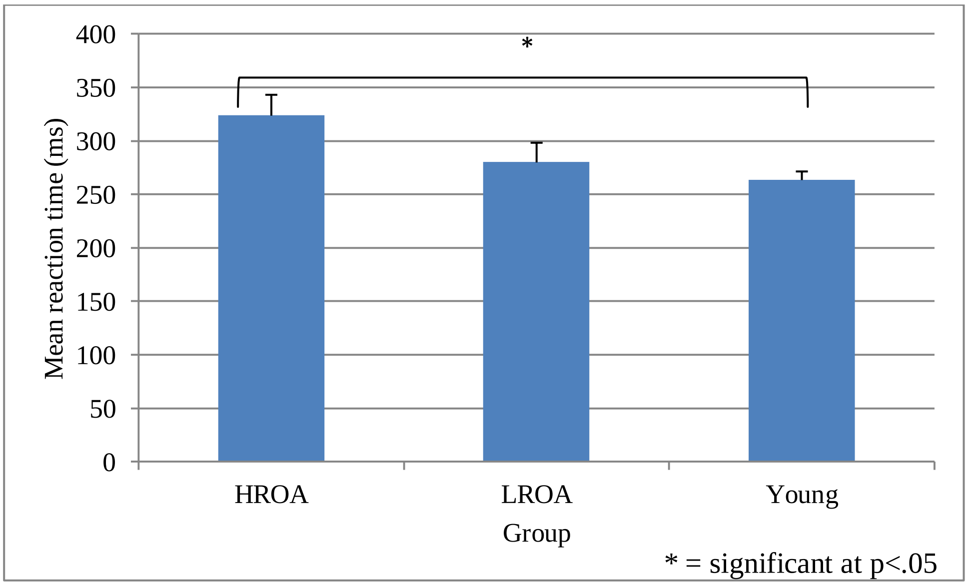


Figure 4-3. Mean reaction time for the HROA, LROA and young adults.

Separate one way between-group ANOVAs were carried out to compare the four different visual search tasks to group differences in performance (figure 4-4). A significant mean effect for group was found for the hard conjunction condition $f(2,20) = 4.90$, $p= .019$ (power = 0.35, effect size = 0.33). Post hoc comparison using LSD found that the HROA and LROA were significantly slower at responding than the young adults. A significant main effect of group was found in the easy conjunction condition $f(2,20) = 3.68$, $p= .043$ (power = 0.24, effect size = 0.27). Post hoc comparison using LSD found that the HROA were significantly slower at responding than the young adults. A significant main effect of group performance was found for the easy pop out condition $f(2,20) = 5.23$, $p= .015$ (power = 0.36, effect size = 0.34). Post hoc comparison using LSD found that the HROA and LROA were significantly slower at responding than the young adults.

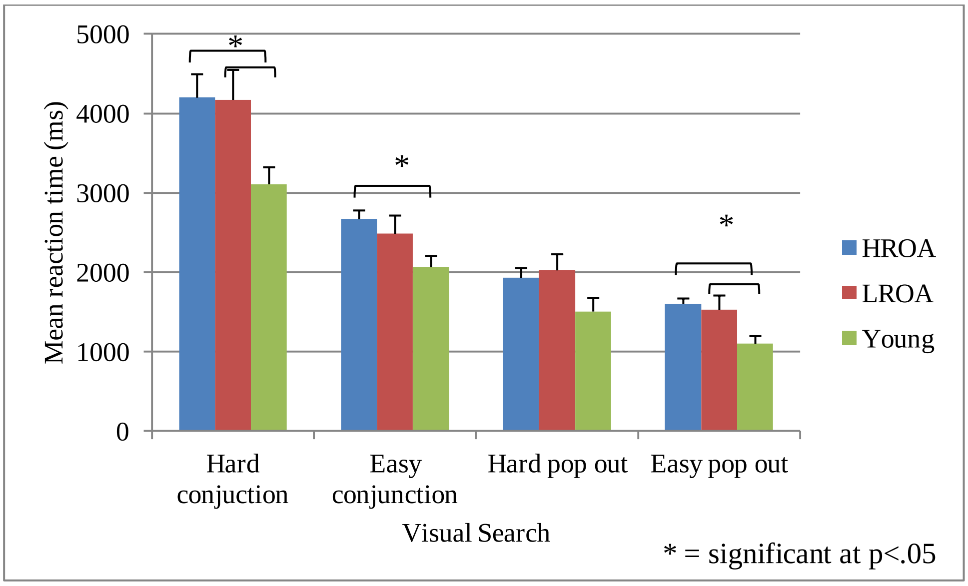


Figure 4-4. Mean reaction time for the four visual search tasks across the three groups.

A MANOVA was conducted to ascertain if there was a significant difference between the reaction time on the Stroop task for the congruent and incongruent conditions and if there was an effect of group. Using Wilk's Lamda a significant effect of group was found f(3,36)= 7.17, p<.0001 (power = 0.17, effect size = 0.22). Post hoc comparison using LSD found that the HROA and LROA were significantly slower when responding to the congruent conditions than the young adults. In the incongruent condition the HROA were significantly slower than the LROA and the young adults (figure 4-5).

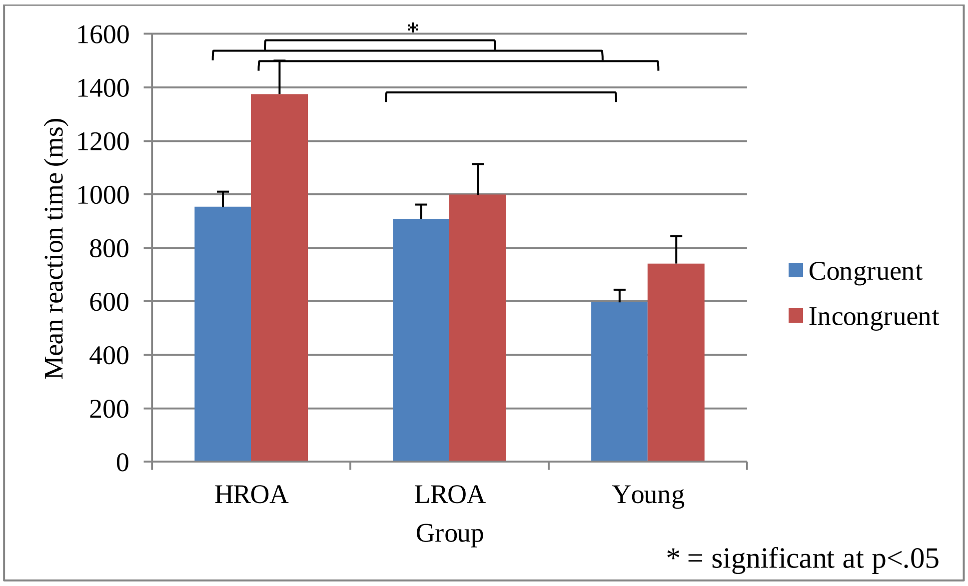


Figure 4-5. Mean reaction time for the Stroop task comparing group differences in congruent and incongruent responses.

4.2.5: Correlations

Correlations were conducted to assess the extent to which variability in the visual, motor and cognitive function tests explained variability in the duration of fixation to the travel path. The R values are presented in table 4-3, and the only comparison to show a significant result was between the incongruent Stroop task and the duration of fixation to the travel path. This result showed a positive correlation with participants who spent longer fixating the travel path taking longer to respond in the incongruent Stroop task $r(21) = .436$, $p=.037$.

Table 4-3. Correlations between the duration of time spent fixating the travel path and scores on visual, motor and cognitive function tests.

Visual, motor and cognitive test	R Value
Berg Balance Scale	.132
Mini Mental Status Examination	-.048
Trail Making Test A	.108
Trail Making Test B	-.032
Activities Balance Confidence Scale	-.017
Congruent Stroop task	.344
Incongruent Stroop task	.436*
Easy Pop Out Search	.080
Hard Pop Out Search	-.051
Easy Conjunction Search	.065
Hard Conjunction Search	.123
Reaction Time	.140

* = Significant at p<.05

4.3: Discussion

This is the first study to quantitatively describe age-related differences in gaze behaviour evoked by watching first person perspective movies of another person walking around the real-world and to relate these differences to performance on tests of visual, motor and cognition function.

We hypothesised that there would be differences in when and where the different groups made fixations to environmental features whilst watching the first person perspective videos. In addition we predicted that the healthy older adults at a higher risk of falling would have significantly lower scores on visual, motor and cognitive function tasks than the healthy older adults at a lower risk of falling and the young adults and these differences would correlate with travel path fixation duration.

In line with our hypotheses, the results showed that the first person perspective movies did evoke different eye movement behaviour between groups with the HROA fixating the travel path for significantly longer than the LROA and young participants. Findings from the cognitive tests also supported our hypothesis with HROA responding significantly slower than LROA and young adults on the incongruent Stroop task. HROA were significantly slower when performing the reaction time task and the easy conjunction visual search than the young adults. The older adults were slower when responding to the hard conjunction visual search, easy pop out visual search and the congruent Stroop task than the younger adults. In the test of visuomotor function (TMT) the older adults were significantly slower than the young in part A and the HROA were significantly slower than the young in part B. There was a significant correlation between the incongruent Stroop task scores and travel path fixation duration, with participants who were slower when responding to the incongruent Stroop task, fixating the travel path for a greater percentage of time.

4.3.1: Similarities to real-world studies and laboratory studies

Participants spent the majority of the time fixating task-specific cues i.e. aspects of the environment that are important for locomotion (higher 72%, lower 61%, and young 59%) and less time fixating aspects of the movie not relevant for locomotion (higher 12%, lower 14% and young 19%). This finding is consistent with real-world studies, which explored gaze behaviour during sandwich and tea making. For the majority of the time participants fixated environmental features (such as the kettle) which were important for the task they were completing and only fixated non-relevant items for 5% of the time (Land & Hayhoe, 2001).

Laboratory studies have demonstrated that healthy older adults make fixations to the targets in the travel path for longer than young adults (Di Fabio et al., 2003; Chapman & Hollands, 2006b; Chapman & Hollands, 2007). The present study supports these findings as the HROA were shown to spend significantly more time fixating the travel path than the other groups. These findings provide encouraging evidence that movie viewing produces similar eye movement behaviour to that observed in laboratory studies of eye movement behaviour in older and younger adults during locomotion. However, there has previously been little attempt to investigate the mechanisms responsible for this altered gaze behaviour.

4.3.2: Mechanisms underlying differences in gaze behaviour

As part of normal healthy ageing decline is reported in cognitive function (Yogev-Seligmann et al., 2008). This decline affects areas of the brain associated with attention, planning, visual perception and speed of processing (Yogev-Seligmann et al., 2008). Correlations comparing duration of fixation to the travel path with measures of visual, motor and cognitive function showed a positive correlation only with the incongruent Stroop task. This finding suggests that the cognitive processes which are required for a quick response in the incongruent Stroop task are related to the changes in travel path fixation duration observed in older adults at a higher risk of falling. The incongruent Stroop task measures a sub-domain of executive functions which relates to a person's ability to deliberately inhibit a dominant response in order to complete the required task (Stroop, 1935; Miyake et al., 2000). In the virtual walking task the dominant response could be to fixate the travel path and the higher risk older adults are unable to inhibit this response in order to scan the environment for potential hazards, increasing their risk of falling. Rapport *et al.* (1998) assessed the falling risk of older adults admitted to a rehabilitation hospital, following a fall, and executive function. They found that participants at a higher risk of falling presented with significant levels of cognitive decline and response inhibition was a greater predictor of falling risk than other measures of executive function (working memory and cognitive fluency). The finding from Rapport *et al.* (1998) support the conclusion that reduced ability to inhibit a response could be a mechanism which increases falling risk in older adults. The findings from the current study provide a possible explanation as to why problems with response inhibition lead to an increased risk of falling. Chapman and Hollands (2007) demonstrated that higher risk older adults consistently looked away prematurely from stepping targets to fixate future obstacles and that the extent of early gaze transfer correlated with stepping inaccuracies. This maladaptive behaviour may result from a reduced ability for higher risk older adults to inhibit gaze transfer to a future target until after the on-going step has been completed.

4.4: Conclusion

We found measurable age- and falls risk-related differences in eye movements evoked by watching first person perspective movies of walking behaviour. We have also provided evidence that decline in cognitive processes relating to response inhibition may be responsible for the observed changes in gaze behaviour.

We propose that this experimental technique will prove useful in further clarifying the mechanisms underlying falls in frail individuals. We also suggest that this technique could be used as a novel diagnostic tool to identify individuals who are at a higher risk of falling, as a result of cognitive decline, in an environment which does not pose a risk to their safety and that reflects real-world walking to a greater degree than traditional laboratory studies.

Chapter 5

A novel paradigm to investigate stroke-and falls-related changes in eye movements during walking

In the UK it is estimated that there are 100,000 new stroke cases each year (Truelsen et al., 2006; Poole et al., 2002; O'Mahony, Thomson, Dobson, Rodgers, & James, 1999) and the risk of stroke increases with age (Truelsen et al., 2006; Poole et al., 2002; O'Mahony et al., 1999).

In recent years mortality rates as a result of stroke have reduced but milder strokes, which cause some degree of deficit have increased (Corriveau et al., 2004). Survivors of stroke are at high risk of suffering a fall, and are at the greatest risk six months following stroke (Foster & Young, 1995). Hyndman, Ashburn and Stack (2002) found that 50% of stroke patients reported falling and 80% reported a near fall. Most falls did not result in injury, but fallers were more likely to suffer from depression and be less socially active than non-fallers (Hyndman et al., 2002). The majority of falls occurred in the home during walking, turning and rising from sitting to standing and patients reported their reasons for falling to be misjudgement, lack of concentration and loss of balance (Hyndman et al., 2002). However, the reasons for falling reported by stroke patients might not be the underlying cause of falls. For example, amongst stroke patients there is a high prevalence of oculomotor dysfunction (Ciuffreda et al., 2007; Ciuffreda et al., 2008) and visual disorders, which include low vision, visual abnormalities and visual perception difficulties (Rowe et al., 2009). The severity and manifestation of visual deficits experienced by stroke patients vary widely, and include problems with visual field loss; most commonly resulting in a hemianopia which occurs from lesions in the occipital lobe (MacIntosh, 2003). Damage to the parietal lobes, especially in the right hemisphere, often resulting in neglect with patients failing to report, respond to or orient to stimuli which are presented on the contralateral side of the body to the brain lesion (Bonato, 2012). In the chronic phase patients often appear recovered from the neglect but present with extinction where they fail to report stimuli presented to the neglected side if it is presented at the same time as a stimulus to the non-neglected side (Bonato, 2012). As patients are unaware that they have neglect they do not make compensatory adjustments, so have an increased risk of bumping into things on the neglected side resulting in an increased risk of trips and falls (MacIntosh, 2003). The implications of these findings are that visual disorders following stroke might contribute to the high prevalence of falls.

In recent years a number of studies involving older adults, have explored changes to oculomotor and locomotive coordination, and demonstrate that older adults at a higher risk of falling show altered eye movement behaviour and greater instability when walking (Chapman & Hollands, 2006b; Chapman & Hollands, 2007; Young & Hollands, 2010). Alterations in coordination during locomotion are also observed following stroke. Stroke patients are reported to make slower head movements when tracking external cues, during standing and walking (Lamontagne et al., 2003), have altered coordination patterns of the head, thorax and pelvis and significant head instability whilst walking (Lamontagne et al., 2005). Stroke survivors also present with alterations during pre-planned turns in the orientation and sequencing of gaze and body movements (Lamontagne et al., 2007); however, Hollands *et al.* (2010) only reported this alteration in basal ganglia patients when initiating turns to the non-paretic side and found, in general, stroke patients who were 6 months post-stroke were able to reorient in a similar way to healthy participants.

The implication for the visual deficits and changes in coordination during standing and walking observed in stroke patients are that these changes might have negative consequences for their ability to safely negotiate the environment and increase their risk of falling. To date no studies have directly investigated changes in gaze behaviour during walking following stroke. To explore changes in eye movements, following stroke, eye movements could be recorded as patients walk around different environments and be compared to healthy age and sex matched controls. However, it would be hard to standardise the experience between participants and the environments which participants can be exposed to, are restricted by the constraints of the mobile eye tracking technology.

In recent years a number of studies have compared the eye movement behaviour of young adults as they interact with real environments to eye movements which are evoked whilst watching first person perceptive videos of the same scene. These studies show that participants spend a similar amount of time fixating the same environmental features in the scene and make a similar number of fixations to the same environmental features when scene viewing is compared to real-world walking (Stanley & Hollands, 2010; Schoch, Gillner, & Mallot, 2005; 't Hart et al., 2009; Foulsham et al., 2011). These findings suggest that scene viewing could offer a safe alternative to walking around a real environment and still produce useful information about the effect a stroke has had on an individual's ability to use vision to accurately sample their environment.

5.1: Parietal Stroke - Experiment 5

The stroke patients were split according to lesion location and the largest group of stroke patients were those with lesions in the parietal lobe. The number of parietal stroke patients allowed for statistical analysis to be conducted and so the parietal patients were presented separately to the patients with lesions in the occipital and frontal-temporal lobe.

Aims:

1. To ascertain if measurable differences in gaze behaviour would be observed in a group of parietal stroke patients compared to a group of age and sex matched controls, whilst scene viewing.
2. To understand the consequences of stroke-related visual deficits on gaze behaviour during walking.
3. To establish if differences in gaze behaviour are related to neurological problems which arise from lesions in the parietal lobe.

We hypothesised that there would be significant differences in the gaze behaviour of parietal stroke patients, whilst watching the first person perspective videos compared to the age and sex matched controls, and that the gaze behaviour differences would relate to falling risk and lesion location.

5.2: Method

5.2.1: Participants

Seven participants (6 males) with a mean age of 69.4 (57-79) who had suffered a stroke in the parietal lobe (table 5-1) were recruited from the School of Psychology's participant panel. Seven age (mean 69.9, 59-81) and sex matched controls were recruited from the local community.

Ethical permission was gained from the National Research Ethics Service for the stroke patients and the University of Birmingham's ethics board for the healthy controls. Participants gave informed consent before the experiment began. Participants were told that they could withdraw at anytime without having to give a reason.

Table 5-1. Lesion location and neurological deficit.

Participant	Lesion location	Neglect	Visual Field Loss	Extinction
SP1	Left parietal	No	No	Right
SP2	Bilateral parietal (worse right)	No	No	Left
SP5	Left temporal-parietal	Object based	No	Right
SP7	Right parietal	No	No	Left
SP8	Bilateral parietal (worse right)	No	No	Left
SP9	Right parietal	Left	No	No
SP10	Right Parietal	Left	Possible left visual field	No

5.2.2: Apparatus and Experimental Set up

A head-mounted ASL 500 mobile eye tracker (470g) with a video sampling rate of 30Hz was used to record which environmental features participants fixated and when, whilst they viewed six movies. The eye tracker also recorded the horizontal and vertical position of the eye at a sampling rate of 60Hz. An Acer projector (S1200) and screen (height 148cm, width 290cm) was used to project calibration points and the movies (video image: 111cm high, 154cm wide). Participants sat on a swivel chair at a height of 70cm, at a distance of 100cm from the scene. The movies were presented on a screen with a resolution of 1024 x 768 and a refresh speed of 60Hz. The screen started 62cm above the floor and the ratio of the real-world to the size of the video image was 1:0.69.

Participants watched six first-person perspective movies representing the viewpoint of a pedestrian walking through various environments. The movies depicted the following walking scenarios; a local canal tow path (2 locations), a local high street in Birmingham (2 locations), and the final two movies were of the School of Sport and Exercise Sciences, University of Birmingham. The four movies of the local area were filmed using a Sony Handy cam (DCR-H30). The movies of the department had been filmed using the mobile eye tracker during a previous experiment. An additional movie was included at the start of the experiment, which was not analysed, to allow familiarisation of the participants with the experimental paradigm.

5.2.3: Design and Procedure

On entering the laboratory participants were given an information sheet to read which detailed the experimental procedure and they were asked to sign a consent form. They were informed that they had the right to withdraw at any time.

Participants were instrumented with the ASL mobile eye tracker and a nine point calibration was carried out. The distance of the participant to the screen and their eye height was measured along with the distance between the dots presented on the calibration grid.

The laptop which recorded the signal from the eye tracker and the video recorder were set up to record. The calibration of the eye tracker was recorded and the participant was asked to fixate on the central calibration dot whilst the researcher rotated the swivel chair from left to right, this produced a recognisable eye movement signal which allowed for the recorded output to be synchronised. The videos were then started and the participant was instructed to sit and watch them. Participants then completed a number of screening measures to access their falling risk, cognitive function, general wellbeing and visuomotor function which are outlined in table 5-2 and a falls history was taken. On completion of the experiment participants were thanked for their time and fully debriefed.

5.2.4: Analyses

The eye movement video data was analysed frame by frame and a fixation was recorded if the cross hair stabilised on an environmental feature for three frames or more (Patla & Vickers, 1997). The researcher identified a number of environmental features which were fixated upon by all of the participants and these were classified into the following three categories: travel path (pavement, door, looking in the direction of travel), potential hazard (people in the travel path, canal, tables) and other (cars, shops, looking away from the direction of travel).

The total percentage of time that each participant fixated the travel path, potential hazards and other features was averaged for data collected from the six movies. The percentage of time the parietal stroke patients and the age and sex matched controls fixated the travel path, potential hazards and other features was compared in independent t-tests. The percentage of time that the participants' eye was in motion or not in range of the eye tracker was taken into account and included in the analysis. The number of fixations made to the travel path, potential hazards and other, by each participant, was expressed as a percentage for the movies and entered into independent t-tests.

Independent t-tests allow for the mean scores of two different groups to be compared to establish if there are differences between the two groups. Independent t-tests were selected because the aim of the study was to establish if there were differences between the two groups (parietal stroke patients and the age and sex matched controls) in the amount of time they spent fixating and number of times they fixated different environmental features, whilst scene viewing.

The horizontal and vertical output from the ASL eye tracker for five of the parietal patients and five of the controls was converted into angles by using the height of the eye relative to the position of the 9 calibration points and the distance of the participant's eye to the screen. Two of the stroke patients were unable to perform the task which synchronised the equipment because they had limited mobility on one side of their body and found the motion of the chair rotating disorientating so their data along with their age and sex matched control was not included. The raw horizontal data for each participant was plotted to locate the point in the data where the eye movement occurred which was produced by rotating the chair, this eye movement was then located on the videos. The time between the eye movement occurring in the video data and the start of the movies was established and this information was used to ascertain when in the horizontal and vertical angle data the start of the movies was. The data was then processed to remove all the points where the eye was out of range of the eye tracker and angles which were beyond 90° or -90° in the horizontal and vertical plane were removed as outliers. A matrix was used to calculate the number of times different points in the visual scene were fixated by participants and the average across participants was calculated to produce the frequency plots (figure 5-2 and 5-3).

5.3: Results

Figure 5-1 is an illustration of the temporal gaze behaviour observed in a parietal patient and a control whilst they watched one of the canal scenes. The different environmental features which were fixated by the participants are colour coded and the time is presented in seconds. The parietal patient is represented by the solid line, and the control is the dashed line. The screen shots indicate where in the scene each of the participants is fixating at a given point in time. The figure shows that participants spent the majority of the video clip fixating the path (blue) and in the direction of travel (yellow) and potential hazards such as the lock (purple) and the canal (brown). For the remainder of the clip participants' eyes are in motion (grey), or fixating environmental features which are not important for locomotion, such as the hedge or grass (green).

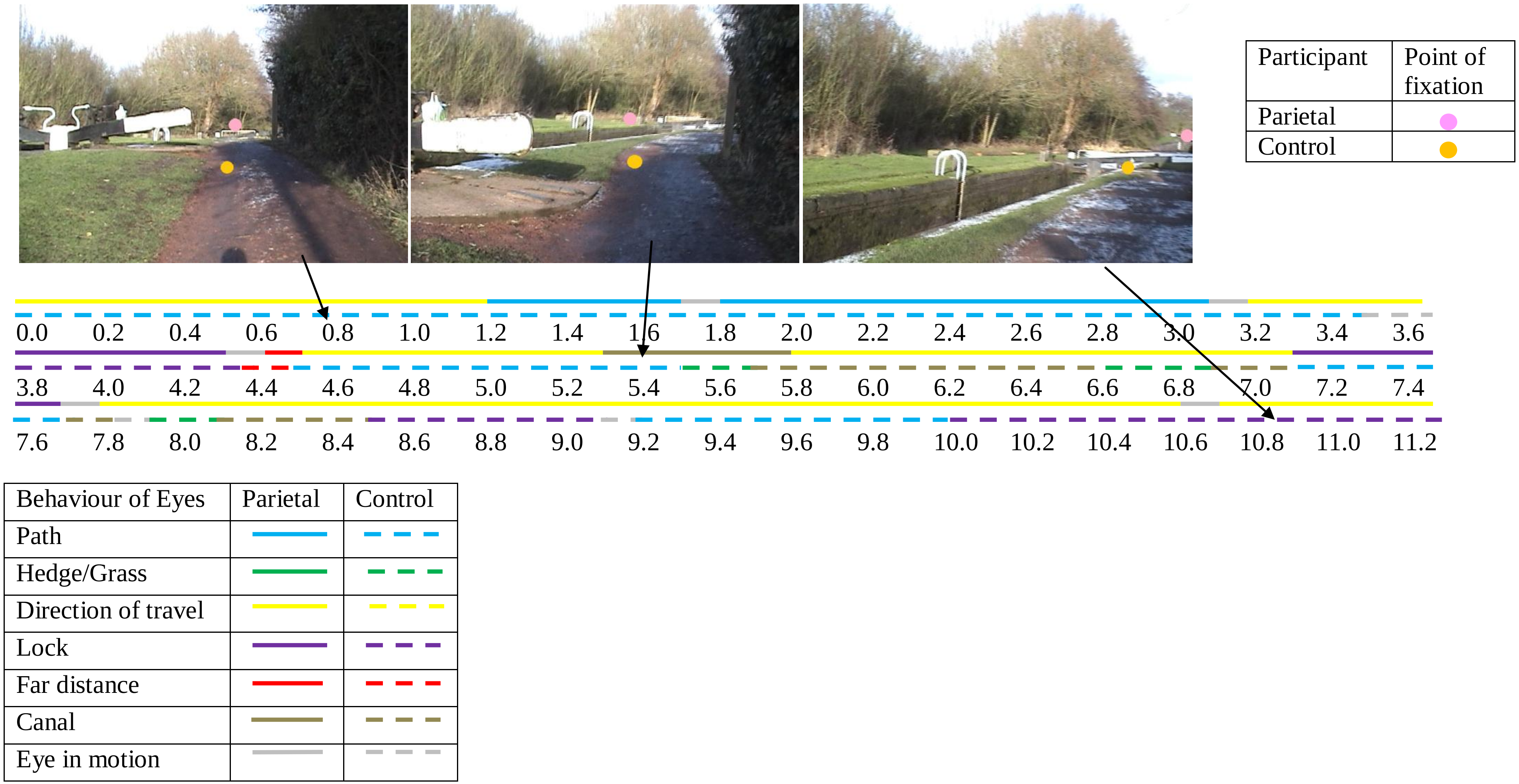


Figure 5-1. An example of 11 seconds of gaze behaviour for a parietal patient and a control participant. The screen shots show the image in front of a participant at a given point in time and indicate where each of the participants is fixating.

5.3.1: Demographics

Table 5-2. Demographics for the parietal patients and control group.

	Parietal Stroke	Control
Age	65.77 (38-79)	69.86 (59-81)
Height (cm)	168.79 (161-178)	175.64 (157-187)
Weight (kg)	80.28 (69.77-106)	82.14 (63.5-95.8)
Berg (max 56)	46.86 (27-55)	55.86 (55-56)
Mini Mental Status Examination (MMSE) (max 30)	20.43 (13-27)*	(28.71) 28-30
Time up and go (TUG) (seconds)	21.59 (9.87-44.68)	9.65 (7.18-15.18)
Visual acuity (Snellen)	20/15-20/50	20/15-20/30
Pelli-Robson Contrast Sensitivity (max 2.1)	1.78 (1.65-1.95)	1.86 (1.65-1.95)
Trail Making Task (TMT) (seconds)		
A	102.80 (64-139)	33.10 (22.28-53.72)
B	277.50 (224-349)*	61.75 (46.47-74)
Activities Balance Confidence Scale (ABC) (%)	75 (54-97)	92 (80-99)
General Health Questionnaire (max 21)		
Somatic Function	1.57 (0-5)	5.29 (1-8)
Social Function	7.29 (4-10)	8.14 (7-11)
Anxiety/Insomnia	1.43 (0-5)	4.14 (1-9)
Depression	0.29 (0-2)	1.00 (0-6)
Falls (Total in past year)	3	3
* = performed significantly worse than matched group at p<.005		

Independent sampled t-tests were conducted and after Bonferroni correction a number of significant differences between groups at $p<.005$ were observed. In the TMT part B three of the stroke patients were unable to complete the task. The stroke patients (mean = 277.50s) who were able to complete were significantly slower than the controls (mean = 61.75s) $t(9) = 7.62$, $p= .004$ (power = 1, effect size = 0.87). The stroke patients (mean = 20.43) showed significant levels of cognitive impairment on the MMSE than the controls (mean = 28.71) $t(12) = -4.23$, $p= .005$ (power = 0.92, effect size = 0.60).

5.3.2: Spatial Distribution

Figure 5-2 shows the mean spatial gaze distribution, for the duration of the movies, for five of the parietal stroke patients and five age and sex matched controls. The brighter colours indicate the areas where participants fixated the most. The distribution for the control participants indicate that fixations were centrally localised shown by the bright red, where as the stroke patients presented with a greater spread of fixations.

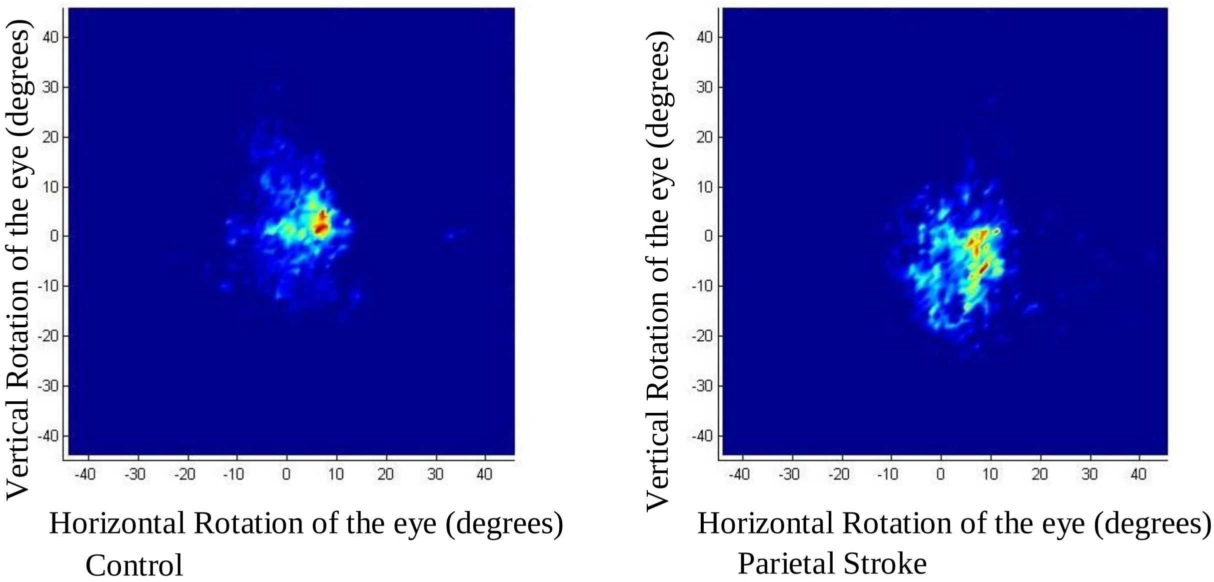
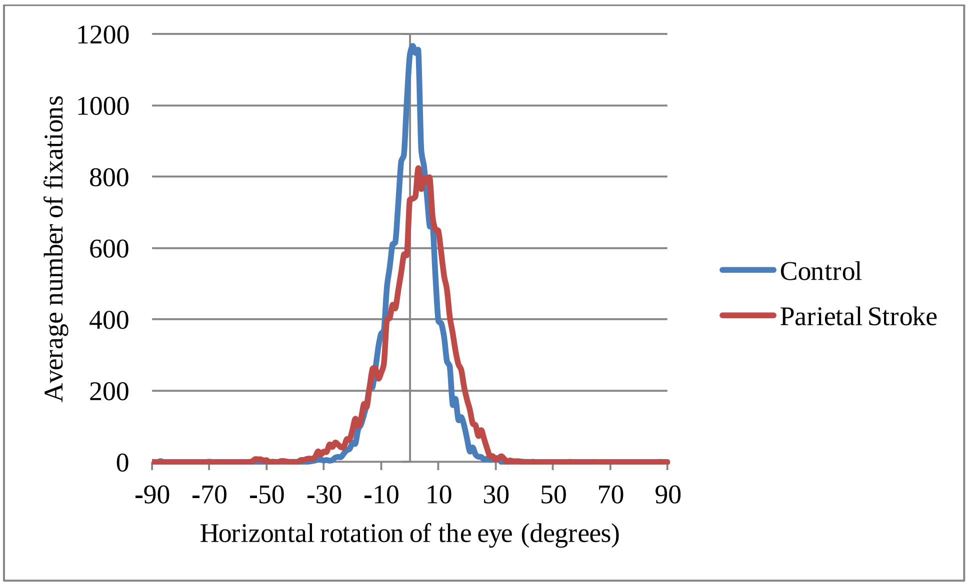


Figure 5-2. Spatial gaze distribution for the parietal patients and the age and sex matched controls.

Figure 5-3 shows a frequency distribution histogram for the average number of fixations made by participants at different eye angles for the duration of the movies comparing the parietal stroke patients to the age and sex matched controls in the horizontal (figure 5-3a) and vertical (figure 5-3b) planes. A Mann-Whitney test compared the distribution of fixations between the parietal stroke patients and controls in the horizontal and vertical planes. There was no significant difference between the distribution of horizontal eye movements made by the parietal stroke patients (Mdn = 41) and control participants (Mdn = 27), U=4868, p=0.84, r=0.06. A Mann-Whitney test indicated that there was a significant difference between the distribution of vertical eye movements made by the parietal stroke patients (*Mdn* = 16) and control participants (*Mdn* = 57), U=2073, p=0.05, r=0.61.



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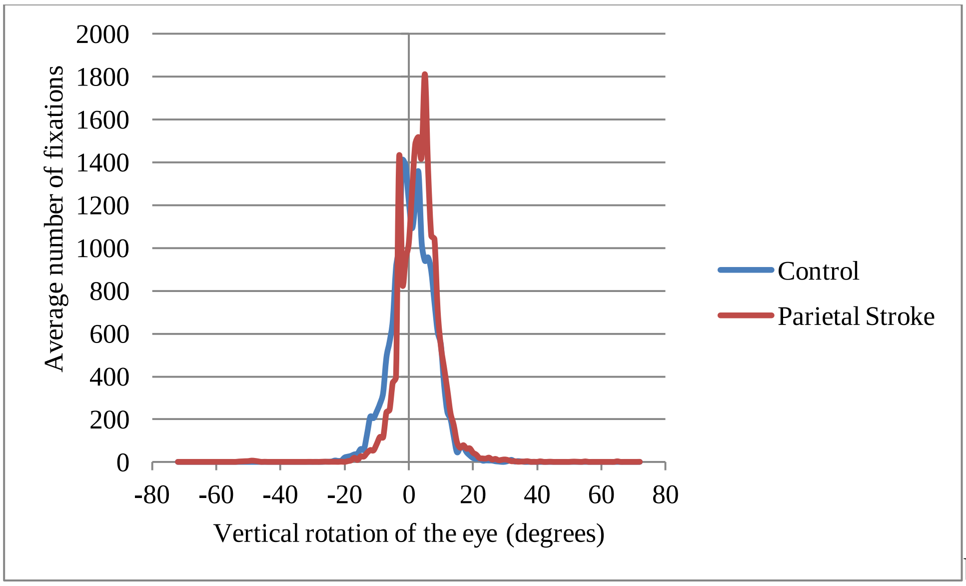


b

Figure 5-3. Shows the average number of fixations made by the parietal patients compared to the controls in the Horizontal (a) and Vertical (b) plane expressed as the angle of the eye.

5.3.3: Fixation Duration

Figure 5-4 shows the significant results after Bonferroni correction at p<.01 for the percentage of time the parietal stroke patients and the controls spent fixating different aspects of the scene. The results indicate that the parietal patients spent significantly less time making eye movements than the controls t(12) = -6.92, p = .0001 (power = 1, effect size = 0.80).

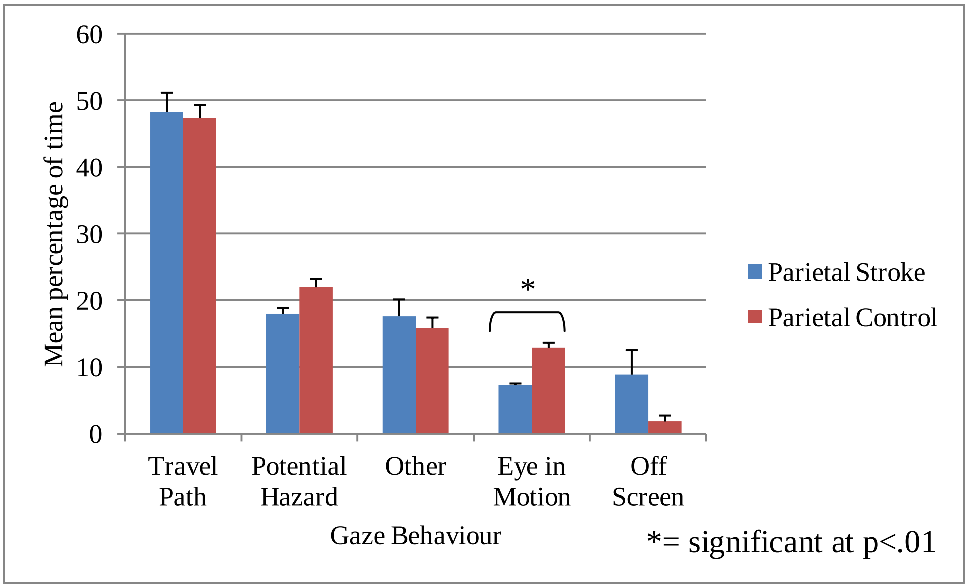


Figure 5-4. Amount of time the parietal patients spent fixating different aspects of the scene compared to the controls.

5.3.4: Number of fixations

Figure 5-5 shows the number of times expressed as a percentage that the parietal patients fixated different aspects of the scene compared to the controls. After Bonferroni correction none of the results were significant at p.<02.

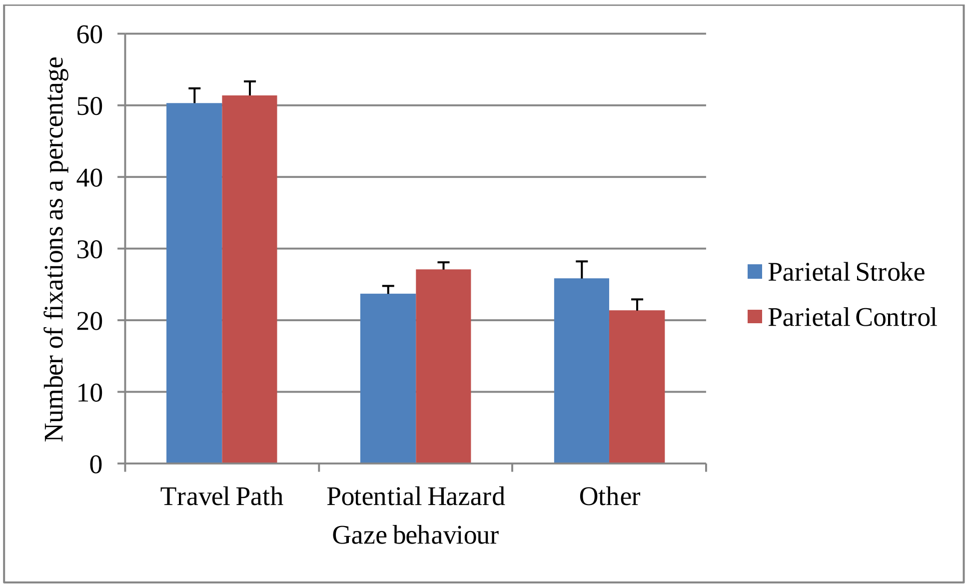


Figure 5-5. Number of times the parietal patients and controls fixated different aspects of the six scenes, expressed as a percentage.

5.4: Occipital and Frontal-Temporal Stroke Patients - Experiment 6

Aims:

1. To explore differences in eye movements made by occipital and frontal-temporal stroke patients to healthy age and sex matched controls whilst scene viewing.
2. To ascertain if eye movement differences are related to falling risk and neurological deficits which occur as a result of the lesion location.

We hypothesised that differences would be observed in the gaze behaviour of the occipital stroke patients compared to the age and sex matched controls which relate to visual field deficits in the stroke patients. We hypothesised that there would be differences in the gaze behaviour of the frontal-temporal patients compared to the age and sex matched controls and these differences would relate to falling risk.

5.5: Method

5.5.1: Participants

Six participants who had experienced a stroke were recruited from the School of Psychology's participant panel. Four, with a mean age of 63.5 (54-79) (3 males), had lesions located in the occipital lobe and two males, with a mean age of 57.5 (38-77), had a lesion located in the frontal-temporal lobe (table 5-3). Six age (mean 62.33, 40-78) and sex matched controls were recruited from the local community.

Ethical permission was gained from the National Research Ethics Service for the stroke patients and from the University of Birmingham's ethics committee for the controls. Participants gave informed consent before the experiment began and were told that they could withdraw at anytime without having to give a reason.

Table 5-3. Lesion location and neurological deficits

Participant	Lesion location	Neglect	Visual Field Loss	Extinction
		Occipital		
SP11	Left occipital temporal	No	Right	No
SP12	Bilateral occipital	No	Right	No
SP15	Left occipital temporal	No	Right	Right
SP16	Right occipital	No	Left	No
		Frontal-Temporal		
SP3	Left inferior temporal	No	No	No
SP4	Left temporal and inferior frontal	No	No	Right

5.5.2: Apparatus and Experimental Set up

Refer to experiment 5

5.5.3: Design and Procedure

Refer to experiment 5

5.5.4: Analysis

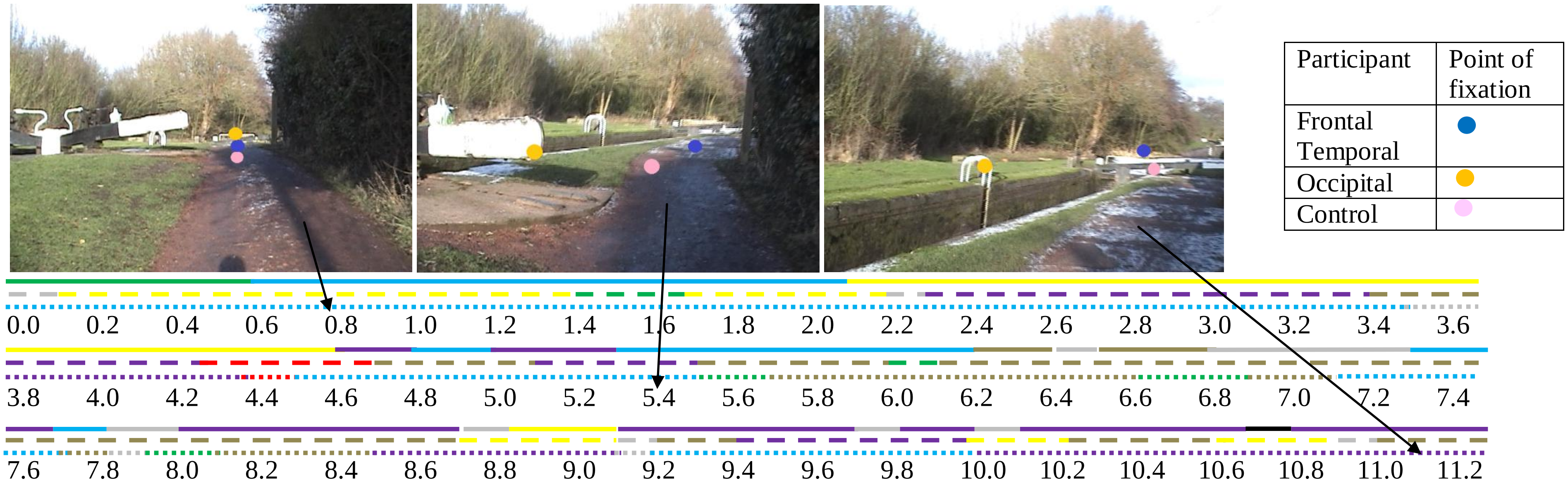
The eye movement video data was analysed frame by frame and a fixation was recorded if the cross hair stabilised on an environmental feature for three frames or more (Patla & Vickers, 1997). The researcher identified a number of environmental features which were fixated upon by all of the participants and these were classified into the following three categories: travel path (pavement, door, looking in the direction of travel), potential hazard (people in the travel path, canal, tables) and other (cars, shops, looking away from the direction of travel).

The total percentage of time that each participant fixated the travel path, potential hazards and other features was averaged for data collected from the six movies. The percentage of time the occipital and frontal-temporal patients and the age and sex matched controls fixated the travel path, potential hazards and other features was compared to ascertain if trends were observed. The percentage of time that the participants' eye was in motion or not in range of the eye tracker was taken into account and included in the comparison. The number of fixations made to the travel path, potential hazards and other, by each participant, was totalled for the movies and compared to ascertain if trends were observed.

The horizontal and vertical output from the ASL eye tracker for three of the occipital patients and the two frontal-temporal patients and five of the controls was converted into angles which indicated the rotation of the eye relative to the screen. This was done by using the height of the eye relative to the position of the 9 calibration points and the distance of the participant's eye to the screen. One of the occipital patients was unable to perform the task which produced the eye movement trace needed to synchronise the equipment because they found the chair rotating disorientating so their data along with the age and sex matched control was not included. The raw horizontal data for each participant was plotted to locate the point in the data where the eye movement produced by rotating the chair occurred, this eye movement was then located on the videos. The point between the eye movement occurring in the video data and the start of the movies was timed and this information was used to establish when in the horizontal and vertical angle data the start of the movies was. The data was then processed to remove all the points where the eye was out of range of the eye tracker and angles which were beyond 90° or -90° in the horizontal and vertical plane were removed as outliers. A matrix was used to calculate the frequency each point was fixated by participants and the average across participants was calculated to produce the frequency plots (figure 5-7 and 5-8).

5.6: Results

Figure 5-6 is an illustration of the temporal gaze behaviour observed in a frontal-temporal patient, an occipital patient and a control whilst they watched one of the canal scenes. The different environmental features which were fixated by the participants are colour coded and the time is presented in seconds. The frontal-temporal patient is represented by the solid line, the occipital patient by the dashed line and the control by the dotted line. The screen shots indicate where in the scene each of the participants is fixating at a given point in time. The figure shows that participants spent the majority of the video clip fixating the path (blue) and in the direction of travel (yellow) and potential hazards such as the lock (purple) and the canal (brown). For the remainder of the clip participants eyes are in motion (grey), out of range of the eye tracker (black) or fixating environmental features which are not important for locomotion, such as the hedge or grass (green).



Behaviour of Eyes	Frontal Temporal	Occipital	Control
Path			
Hedge/Grass			
Direction of travel			
Lock			
Far distance			
Canal			
Off screen			
Eye in motion			

Figure 5-6. An example of 11 seconds of gaze behaviour for a frontal-temporal, occipital and control participant. The screen shots show the image in front of a participant at a given point in time and indicate where each of the participants is fixating.

5.6.1: Demographics

Table 5-4. Demographics for the stroke and control groups.

	Occipital	Control	Frontal-Temporal	Control
Age	63.5 (54-79)	64 (54-78)	57.5 (38-77)	59 (40-78)
Gender	1 female 3 male	1 female 3 male	2 male	2 male
Height (cm)	173.38 (160-185)	177.18 (172-180)	177.65 (173-182)	173.75 (162-186)
Weight (kg)	93.3 (51.47-93.58)	82.83 (77.5-91.8)	82.72 (73.41-92.03)	72.65 (69.1-76.2)
Berg (max 56)	54.5 (51-56)	55.75 (55-56)	53 (50-56)	55.5 (55-56)
MMSE (max 30)	24.75 (17.28)	27.75 (26-30)	24 (22-26)	29
TUG (seconds)	9.38 (6.13-12.16)	8.73 (7.66-9.65)	14.85 (11.5-18.19)	8.10 (6.28-10.31)
Vision acuity (Snellen)	20/15-20/30	20/15-20/40	20/30	20/15-20/30
Pelli-Robson Contrast Sensitivity (max 2.1)	1.95	1.88 (1.8-1.95)	1.95	1.8 (1.65-1.95)
TMT (seconds)				
A	57.75 (40-91)	33.62 (27-38.12)	87.5 (60-155)	34.55 (15.37-53.72)
B	166.25 (96-337)	101.63 (51.5-125)	245 (232-258)	61.46 (35.91-87)
ABC (%)	81 (64-97)	90 (78-98)	94(91-93)	91 (83-100)
General Health Questionnaire (max 21)				
Somatic Symptoms	3.75 (1-10)	3.75 (0-10)	1	2
Social Function	3 (0-12)	7	2.5 (2-3)	7
Anxiety/Insomnia	7.25 (6-9)	3.5 (1-6)	0	2.5 (2-3)
Depression	0.75 (0-3)	1 (0-2)	0	0
Falls in past year	0	2	0	0

A number of trends are observed in the demographic data when the stroke patients are compared to the controls (table 5-4). The occipital (*M* = 24.75) and frontal-temporal (*M* = 24) patients demonstrated a greater degree of cognitive impairment in the MMSE than the occipital controls (*M* = 27.75) and the frontal-temporal controls (*M* = 29). The frontal-temporal patients (14.85s) were slower at completing the TUG than the frontal-temporal controls (8.10s). The occipital patients (A: *M* = 55.75s, B: *M* = 166.25s) and frontal-temporal patients (A: *M* = 87.5s, B: *M* = 245s) were slower at completing the TMT part A and B than the occipital controls (A: *M* = 33.62s, B: *M* = 101.63s) and the frontal-temporal controls (A: *M* = 34.55s, B: *M* = 61.46s).

5.6.2: Spatial Distribution

Figure 5-7 shows the spatial gaze distribution for the duration of the movies for the occipital patients and controls (figure 5-7a) and the frontal-temporal patients and controls (figure 5-7b). The brighter colours indicate where participants fixated the most. The gaze distribution for the occipital patients and the controls (figure 5-7a) indicates that the patients made more fixations to peripheral areas of the scene than the controls. The distribution of fixations made by the frontal temporal patients indicates a narrow spread of fixations in the horizontal plane with more fixations being made in the vertical plane compared to the controls where fixations were located in the centre (figure 5-7b).

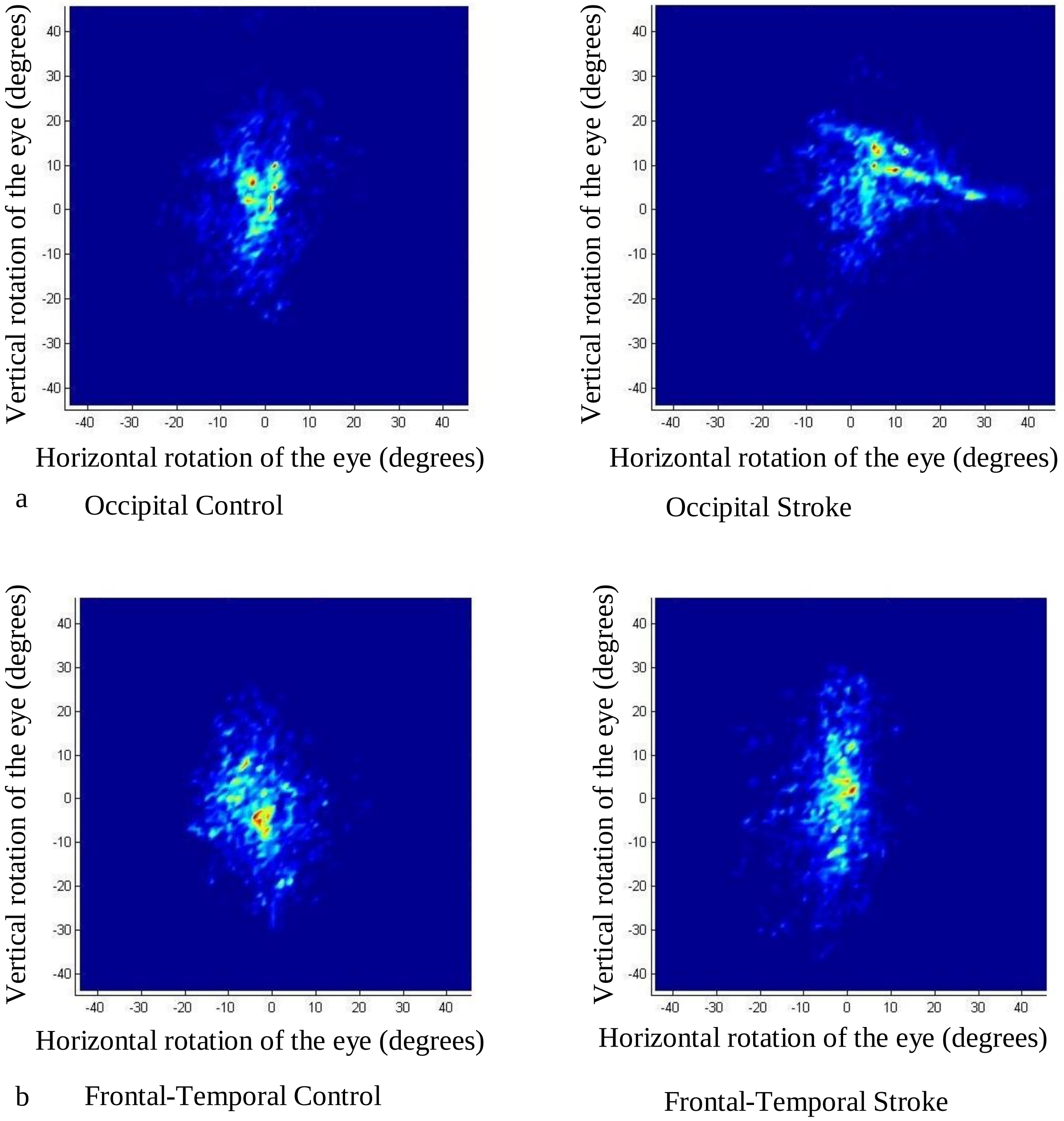
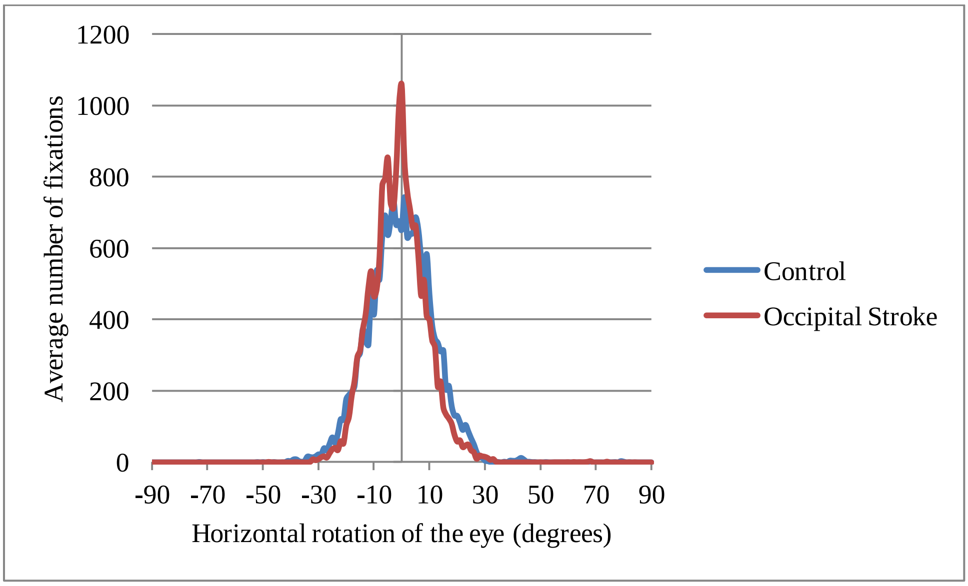
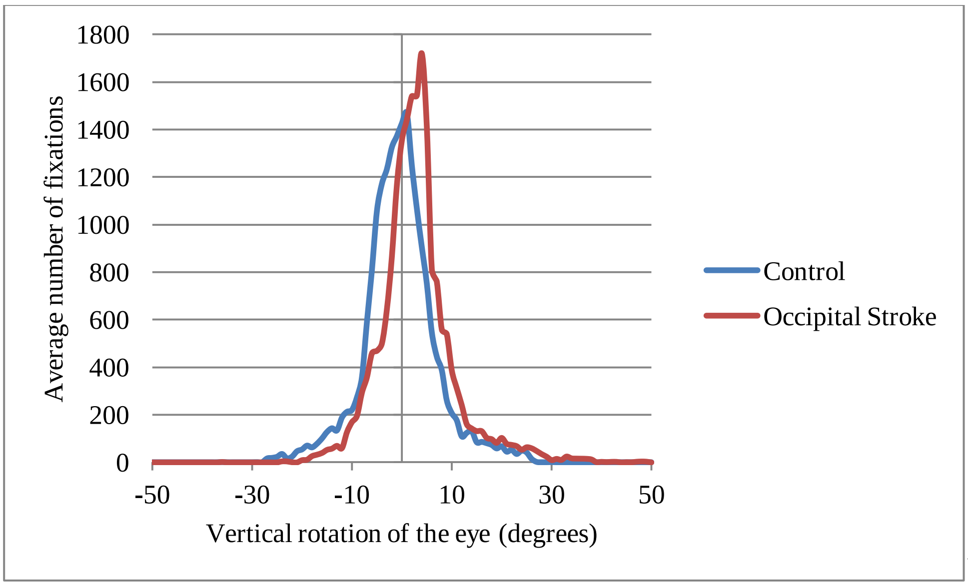


Figure 5-7. Spatial gaze distribution for the occipital patients and controls (a) and the frontal-temporal patients and controls (b).

Figure 5-8 shows the average number of fixations expressed as the angle of rotation of the eye for the duration of the movies comparing the occipital patients in the horizontal (figure 5-8a) and vertical (figure 5-8b) plane to the controls and the frontal-temporal patients in the horizontal (figure 5-8c) and vertical (figure 5-8d) plane to the controls. There are no major differences in the distribution of fixations in the horizontal (figure 5-8a) and vertical (figure 5-8b) plane when the average number of fixations, at each angle, made by the occipital patients and the controls are compared. There are no major differences in the distribution of fixations in the horizontal plane (figure 5-8c) when the average number of fixations, at each angle, made by the frontal-temporal patients and the controls are compared. Differences are observed in the average distribution of fixations made at each angle when the frontal-temporal patients are compared to the controls in the vertical (figure 5-8d) plane.



a



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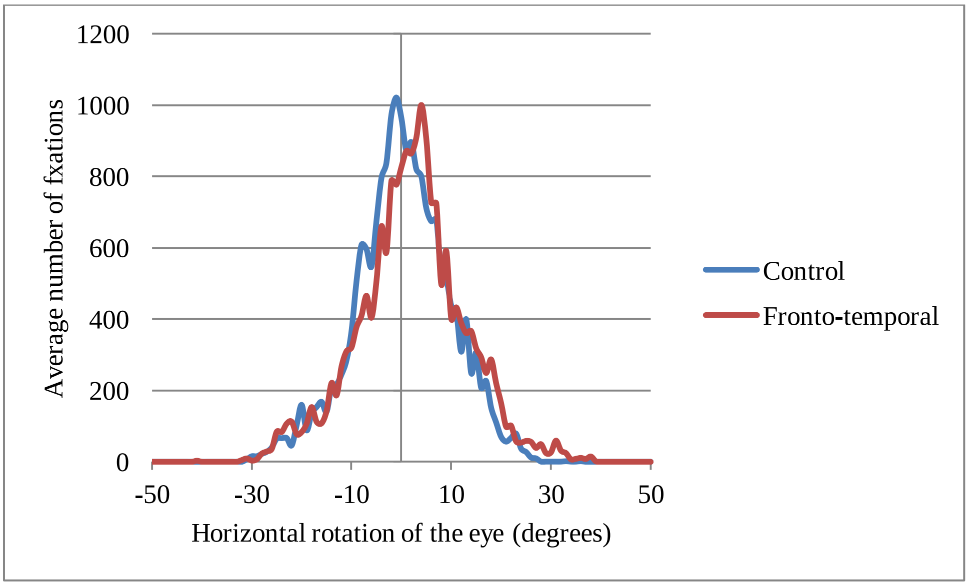

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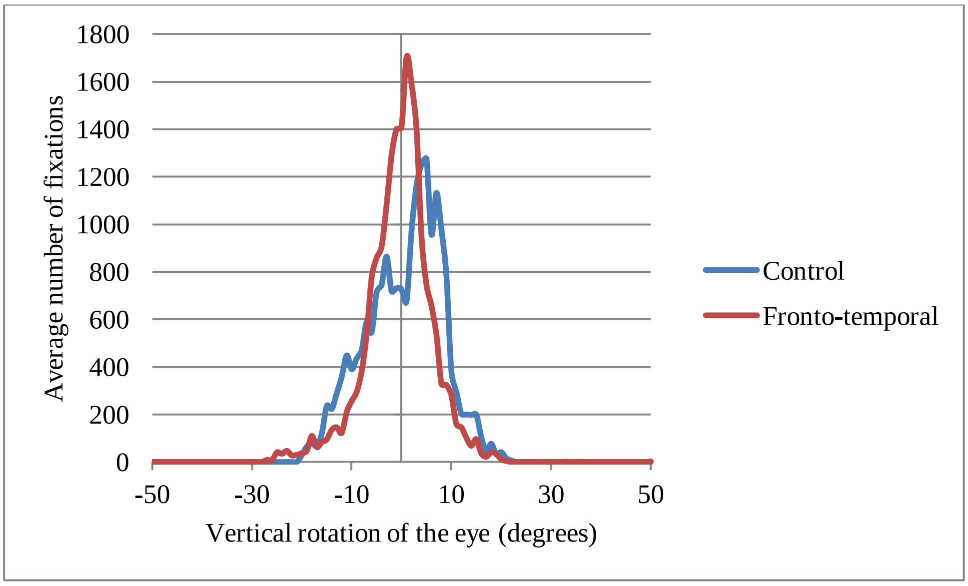

d

Figure 5-8. Average number of fixations made by the occipital patients and controls in the horizontal (a) and vertical (b) plane and the frontal temporal patients and controls in the horizontal (c) and vertical (d) plane expressed as the angle of the eye.

5.6.3: Fixation Duration

Figure 5-9 shows the percentage of time the occipital patients spent fixating different aspects of the movies compared to the controls. There are no observable differences when the patients are compared to the controls.

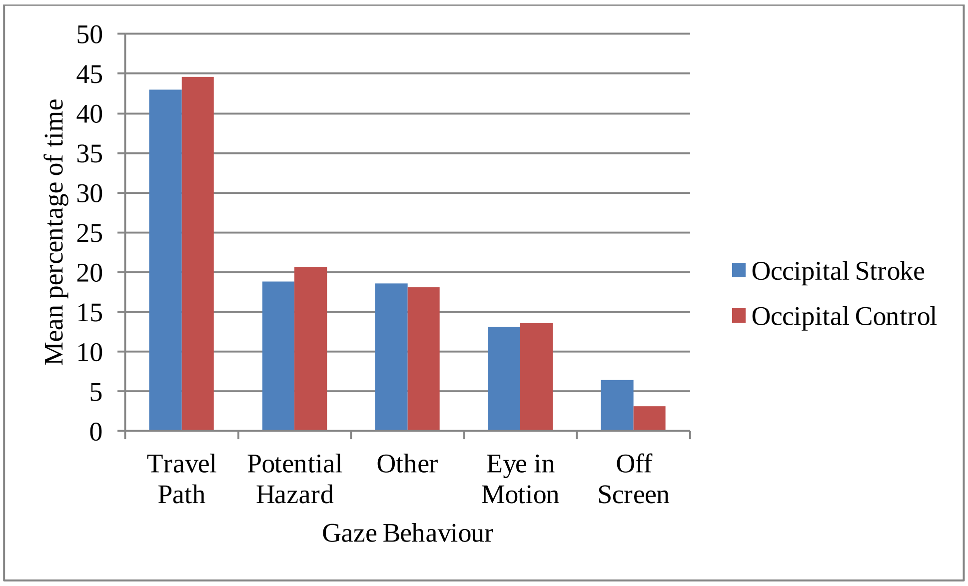

Figure 5-9. Percentage of time the occipital patients spent fixating different aspects of the movies compared to the controls.

Figure 5-10 shows the percentage of time the frontal-temporal patients and the controls spent fixating different aspects of the movies. There is a trend for the frontal-temporal patients to spend less time fixating the travel path than the controls. The patients showed a trend to fixate potential hazards for longer than the controls and the patients made fewer eye movements than the controls.

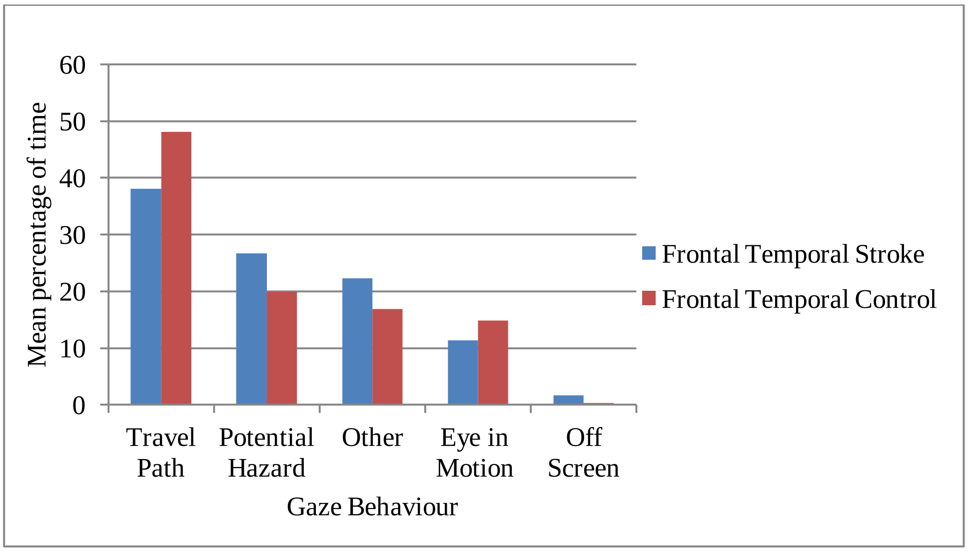

Figure 5-10. Percentage of time the frontal-temporal patients spent fixating different aspects of the movies compared to the controls.

5.6.4: Number of fixations

Figure 5-11 shows the number of times the occipital patients fixated different aspects of the movies compared to the controls; no general trends were indicated.

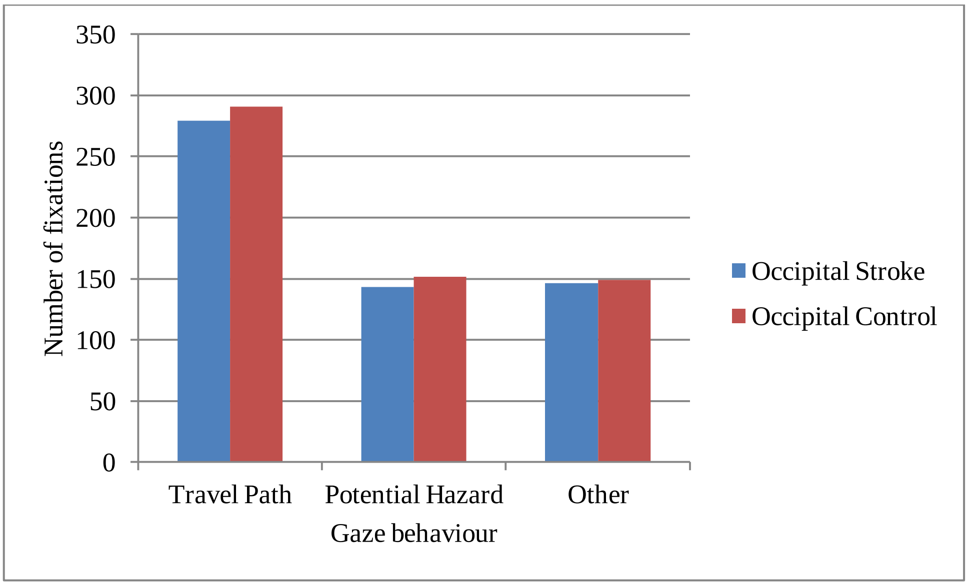

Figure 5-11. Total number of times different aspects of the movies were fixated by the occipital patients and the controls.

Figure 5-12 shows the number of times different aspects of the movies were fixated by the frontal-temporal patients compared to the controls. There is a trend for the frontal-temporal patients to make fewer fixations to the travel path than the controls and to make more fixations to other features than the controls.

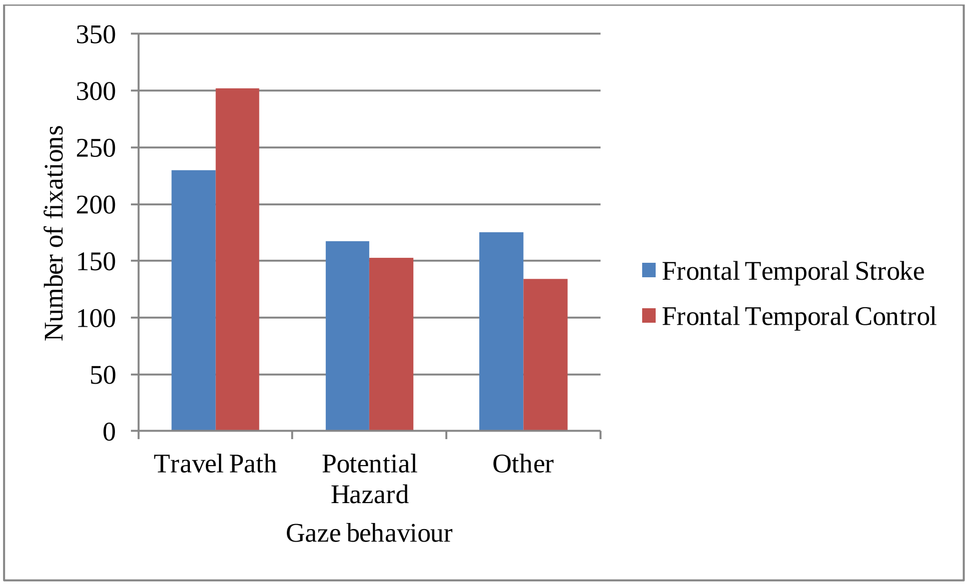

Figure 5-12. Total number of times different aspects of the movies were fixated by the frontal-temporal patients and the controls.

5.7: Discussion for experiments 5 and 6

This is the first study to quantitatively describe the gaze behaviour evoked when stroke patients and age and sex matched controls watch first person perspective movies of a person walking around a number of real-world environments.

We hypothesised that there would be significant differences in the gaze behaviour of parietal patients whilst watching the first person perspective movies compared to the age and sex matched controls and these differences would relate to falling risk and lesion location. In addition we hypothesised that there would be differences in the gaze behaviour of the occipital patients which would relate to visual field deficits and differences in the eye movement behaviour of the frontal-temporal patients compared to the controls which would relate to falling risk.

In line with our hypothesis there were measurable differences between the parietal patients and the age and sex matched controls. Analysis of the spatial distribution of fixations showed that the parietal patients presented with a greater spread of fixations; whereas, the controls presented with a centralised pattern of fixations (figure 5-2). Differences were observed in the spatial spread of fixations made by the occipital patients who made a wider spread of fixations than the controls (figure 5-7a). This is consist with the findings of Crabb *et al.* (2010) who compared the eye movement behaviour of glaucoma patients with visual field loss to matched controls whilst watching videos from the UK driving hazard perception test. They reported that the glaucoma patients made more eye movements compared to the controls suggesting that the patients were scanning the scene more to compensate for the deficits caused by the visual field loss. The greater spread of fixations observed in the occipital patients could also be a result of a conscious or unconscious response to compensate for the visual field loss so that important information about the scene is not missed.

The parietal patients made significantly fewer eye movements than the controls. The implication of making fewer eye movements is that they are not scanning the scene as much as the controls and might be missing elements of the scene which are important for safe locomotion. A number of trends where observed for the amount of time the frontal-temporal patients spent fixating different environmental features than the controls. The frontal-temporal patients spent less time fixating the travel path and with their eyes in motion than the controls, and spent longer fixating potential hazards within the scenes than the controls. Trends were observed in the number of times different environmental features were fixated. The frontal-temporal patients made fewer fixations to the travel path and made more fixations to other than the controls.

Screening measures, which assessed visual, motor and cognitive function (table 5-2), indicated that the parietal patients performed significantly worse on the MMSE, and the TMT part B. On average the parietal patients scored 20.43 on the MMSE which demonstrates significant cognitive impairment amongst the parietal patients (Folstein et al., 1975), and cognitive impairment has been shown to indicate increased falling risk (Yogev-Seligmann et al., 2008). The TMT has been shown to predict decreased gait speed which indicates an increased risk of falling (Ble et al., 2005). The significantly worse performance of the parietal patients on the MMSE and TMT are in line with our hypothesis as the findings suggest that the parietal patients are at a greater risk of falling than the age and sex matched controls and have a significant level of cognitive impairment. The screening measures demonstrated a number of trends when the occipital patients and the frontal-temporal patients were compared to the age and sex matched controls (table 5-4). The occipital and frontal-temporal patients showed a greater degree of cognitive impairment on the MMSE than the occipital controls and the frontal-temporal controls. The frontal-temporal patients were slower at completing the

TUG than the frontal-temporal controls and on average took longer than 14 seconds which indicates a high risk of falling (Podsiadlo & Richardson, 1991). The occipital patients and frontal-temporal patients were slower at completing the TMT part A and B than the occipital controls and the frontal-temporal controls. The findings from the occipital and frontal-temporal screening measures support our hypothesis because they demonstrate that the patients scored worse on the TMT and MMSE indicating a greater degree of cognitive impairment compared to the controls. The TUG findings also showed that the frontal-temporal patients where at a greater risk of falling than the controls which supports our hypothesis.

5.7.1: Similarities to real-world studies

The stroke patients and the age and sex matched controls spent the majority of the experiment fixating environmental features which are important for safe locomotion (parietal patients = 66%, occipital patients = 62%, frontal-temporal patients = 65% and control = 68%), this is consist with studies of tea and sandwich making which showed that participants spend the majority of the task fixating features important for the completion of the ongoing task (Land & Hayhoe, 2001). Less time was spent fixating environmental features not important for locomotion (parietal patients = 18%, occipital patients = 19%, frontal-temporal patients = 22% and control = 17%) which is also consist with tea and sandwich making studies which showed items not relevant to the task where fixated for 5% of the time (Land & Hayhoe, 2001). The remainder of the trial was spent with participants eyes in motion (parietal patients = 7%, occipital patients = 13%, frontal-temporal patients = 11% and control = 14%) or out of the range of the eye tracker (parietal patients = 9%, occipital patients = 6%, frontal-temporal patients = 2% and control = 2%). The finding that the stroke patients and controls fixated environmental features which are important for safe locomotion for the majority of the trial indicates that our paradigm evoked gaze behaviour similar to that which would be observed if the participants were really walking around the environment.

5.7.2: Visual function of parietal lobes and scene viewing

In order to effectively negotiate our environment it is crucial to be able to disengage attention from the current focus, move our attention to a new target and then actively attend to that target (Posner, Walker, Friedrich, & Rafal, 1984). Patients who present with a unilateral lesion in the inferior parietal lobe have problems with attending and orienting to stimuli which are presented on the contralateral side of the body, demonstrating that they have neglect (Driver & Mattingley, 1998). The deficits shown by patients with lesions in the parietal lobe show that the parietal lobes are involved in the orienting of visual attention to stimuli in our cluttered environments (Driver & Mattingley, 1998; Kanwisher & Wojciulik, 2000). In the current study five of the parietal patients had extinction and two had neglect (table 5-1). The findings from the current study indicate that the parietal patients made significantly fewer eye movements than the age and sex matched controls. The reduced number of eye movements could occur because the patients were unable to disengage their visual attention from the current target to a new target (Posner et al., 1984). The inability to disengage attention could have adverse consequences for parietal patients when walking around the environment because they would be unable to attend to potentially dangerous targets in the environment which could result in a trip or fall.

5.7.3: Visual function of the occipital lobes and scene viewing

In order to safely negotiate the environment it is important to be able to accurately visualise the world. Patients with damage to the occipital lobes often have some degree of visual field loss which creates areas in the visual field where participants are unable to see targets or hazards (MacIntosh, 2003). All four of the occipital patients in the current study had some degree of visual field loss (table 5-3). This means that when interacting with the environment targets which are initially observable in areas of the visual field where they had a deficit would not be seen and potentially could result in a trip or fall.

5.7.4: Implications for rehabilitation of stroke patients

The findings from our study clearly show that the stroke patients have altered gaze behaviour when watching first person perceptive movies and the differences they present with are altered by the area of the brain affected by the stroke. This finding adds support to Rowe *et al* (2009) who demonstrated that visual deficits are common amongst stroke patients but are often not detected which potentially has negative implications for rehabilitation in stroke patients, where the ability to accurately sample the environment is crucial for effective treatment. Walking studies with older adults at a high risk of falling demonstrate that they present with changes in visual sampling behaviour that has been casually linked to greater step-width variability and sway which is believed to increase falling risk (Chapman & Hollands, 2006b; Chapman & Hollands, 2007). This study shows that parietal patients also have altered gaze behaviour which could be a factor in the increased risk of falling reported amongst stroke patients (Jorgensen et al., 2002; Hyndman et al., 2002). For rehabilitation to be effective in stroke patients it is important not to focus solely on speech therapy and limb function but to also assess visual deficits and ensure that they are treated so as to achieve the best outcome for the patient.

5.8: Conclusion

The implications from the current study are that first person perspective videos produce gaze behaviour which is similar to that observed in real-life situations and measurable differences between stroke patients and healthy age and sex matched controls are evoked. The scene viewing technique could be used to better inform our understanding of the changes in gaze behaviour which occur following stroke and provide a safe environment in which to test vulnerable participants. It also demonstrates the importance of assessing visual function in stroke patients early in the treatment process and the importance of including visual rehabilitation in care plans

Chapter 6

General Discussion

The first aim of the studies presented in this thesis was to establish if similar gaze behaviour would be evoked during scene viewing compared to the eye movements produced whilst walking around the same environment. The second aim was to explore if measurable differences in gaze behaviour are evoked during scene viewing between older adults at a high risk of falling compared to older adults at a low risk of falling and young adults and establish if these differences are related to increased falls risk. The third aim was to compare the eye movement behaviour evoked, whilst scene viewing, in a group of chronic stroke patients to a group of age and sex matched controls and ascertain if measurable differences are observed which relate to falling risk. The final aim was to explore the cognitive mechanisms which underlie changes in gaze behaviour in older adults and stroke patients.

It was hypothesised that the gaze behaviour in the scene viewing condition would be similar to that observed during walking around the same scene. It was also hypothesised that the scene viewing condition would evoke measurable differences in the gaze behaviour of higher risk older adults (HROA) compared to lower risk older adults (LROA) and young adults and the differences in eye movements would relate to falling risk and age related cognitive decline. In addition it was hypothesised that there would be measurable differences in the eye movement behaviour of the stroke patients compared to the age and sex matched controls which would relate to lesion location and falling risk.

6.1: Real-world versus scene viewing

The first collection of experiments in this thesis explored the theory that viewing a first person perspective scene of a person walking around an environment would evoke the same eye movement behaviour as walking around the same environment. Experiments 1 and

3 showed strong correlations for the duration of time and number of times participants fixated the different environmental features when interacting with the environment compared to watching a video of the same environment. In addition, experiment 2 showed strong correlations for the duration of time and number of times participants who only completed the scene viewing part of the experiment made fixations to different environmental features compared to a group whose eye movements were recorded as they walked around the same environment. Experiment 3 compared the spatial distribution of eye movements made by participants comparing scene viewing to real-world walking. The distribution of fixations showed substantial differences between the scene viewing and real-world conditions, with participants making more fixations to the lower part of the vertical scene (figure 3-8b) in the real-world condition compared to the scene viewing condition. This difference could result from an artefact of the screen in the scene viewing condition not starting on the floor so the participants' eye did not have to rotate as far in order to fixate the floor compared to the real-world condition. Another possible explanation for the difference observed in the spatial distribution of eye movements in the vertical plane could be that whilst scene viewing fixating the immediate travel path is not as important to the participants as when they are walking in the environment. Patla and Vickers (1997) found that the fixation behaviour of participants altered depending on the height of the obstacle in the travel path, with participants fixating bigger obstacles for longer compared to smaller obstacles. In addition tea (Land et al., 1999) and sandwich making (Hayhoe et al., 2003) studies demonstrated that the demands of the task alters the fixation behaviour of participants. The observation that task demand alters the fixation behaviour of participants supports the idea that the differences in spatial distribution results from participants not needing to fixate the immediate travel path during scene viewing.

The findings from these studies provided encouraging evidence that similar gaze behaviour would be evoked when participants are watching a video image of a scene compared to walking around the same environment. These findings are supported by Foulsham, Walker and Kingstone (2011) and 't Hart *et al.* (2009) who also demonstrated that the gaze behaviour evoked during scene viewing is similar to that observed when participants walk around the real-world. The scene viewing versus real-world walking studies demonstrate that scene viewing could offer a safe, more ecologically valid alternative to exploring changes in gaze behaviour than previous laboratory studies.

6.2: Older adults and virtual walking

Experiment 4 aimed to establish if measurable difference between the eye movements of HROA and LROA and young adults would be observed during scene viewing. In addition experiment 4 aimed to establish if eye movement differences would be associated with age-related decline in cognitive processes which have been implicated in an increased risk of falling. The HROA spent significantly longer fixating aspects of the travel path than the LROA and young adults. This was an encouraging finding as it indicated that recording gaze behaviour during scene viewing produced measurable differences in the behaviour of HROA compared to LROA and young adults. In addition a relationship was found between participants who fixated the travel path for longer and participants who were slower at responding to the incongruent Stroop. The finding that HROA were slower at responding to the incongruent Stroop suggests that the cognitive processes which relate to performance on the incongruent Stroop might explain the increase in falling risk observed in some older adults.

The findings from experiment 4 demonstrates that scene viewing does evoke measureable differences in the eye movement behaviour of HROA compared to LROA and young adults. The study also provided evidence that decline in cognitive processes relating to response inhibition may be responsible for the observed changes in gaze behaviour in HROA. The observed differences in eye movement behaviour suggests that the scene viewing technique could be used as a novel diagnostic tool to identify individuals who are at a higher risk of falling, as a result of cognitive decline, in an environment which does not pose a risk to their safety and that reflects real-world walking to a greater degree than traditional laboratory studies.

6.3: Chronic stroke patients and virtual walking

Experiments 5 and 6 aimed to explore if measureable differences would be evoked in the eye movement behaviour of a group of parietal, occipital and frontal-temporal stroke patients compared to age and sex matched controls whilst watching first person perspective movies of a person walking around different environments and if these differences would relate to lesion location and falling risk. The findings indicated that the parietal patients spent significantly less time with their eyes in motion than the controls. The parietal lobes have been shown to be involved in directing attention and patients with damage to the parietal lobes have problems with attending to and orienting towards stimuli presented to the contralateral side of the body to the lesion (Driver & Mattingley, 1998). The reduced number of eye movements made by the parietal patients could result from attentional deficits caused by damage to the parietal lobes. The parietal patients scores on the Mini Mental State Examination (MMSE) indicated significant cognitive impairment (Folstein et al., 1975), which has been linked to increased falling risk (Yogev-Seligmann et al., 2008). In addition, the parietal patients performed significantly worse on the Trial Making Task (TMT) indicating that they were at a greater risk of falling than the controls (Ble et al., 2005).

There were also observable differences in the spatial distribution of fixations made by the occipital patients than the controls. These differences suggested that the occipital patients were making compensatory eye movements to overcome the visual deficits caused by their visual field loss (Crabb et al., 2010). The occipital and frontal-temporal patients showed a greater degree of cognitive impairment on the MMSE than the age and sex matched controls. The frontal-temporal patients were slower at completing the Time Up and Go (TUG) than the controls and on average took longer than 14 seconds to complete the TUG which indicates a high risk of falling (Podsiadlo & Richardson, 1991). The occipital patients and frontal-temporal patients were slower at completing both parts of the TMT than the age and sex matched controls. The lower scores of the occipital and frontal-temporal patients on the TMT and MMSE indicated a degree of cognitive impairment and an increased risk of falling. The worse score of the frontal-temporal patients on the TUG indicated a greater risk of falling than the controls. The findings that the stroke patients performed worse on the MMSE and the TMT indicated that the stroke patients had decreased levels of cognitive function and an increased risk of falling compared to the controls.

Experiments 5 and 6 are the first studies to explore the effect of stroke on the eye movements participants make whilst viewing movies of a person walking around different environments. Chapman and Hollands (2006b; 2007) demonstrated that older adults at a higher risk of falling present with altered gaze behaviour compared to lower risk of falling older adults and young adults, the changes in gaze behaviour observed in the stroke patients could also account for their increased falling risk.

6.4: Limitations and Future Direction

There are a number of limitations to the studies presented in this thesis. As previously discussed, there appears to be artefact in the spatial analysis of experiment 3, potentially caused by the video image not starting from the floor in the scene viewing condition. In addition the size of the image in the scene viewing conditions was not the same size as the real-world making the findings from the experiments not completely comparable to walking in the real-world. To overcome this future use of the scene viewing technique should use a full length scene which is the same scale as the real-world. It is not believed that the size of the video image and the image not starting from the floor adversely affected the result in these experiments but making these changes in future experiments will make the experience more immersive for the participants and better reflect real-life walking. Using a full length screen would also address whether the difference in vertical fixations between the real-world and scene viewing condition are caused by the screen size or by participants eye movement been altered by the demands of the task.

In order to analysis the fixation data collected throughout this thesis each video had to be analysed manually frame by frame which was an extremely time consuming process. Recent advances in eye tracking technology allow for analysis to be automated, speeding up data analysis; in addition using a standardised battery of videos would also speed up the analysis. For the purposes of the experiments presented in this thesis enough participants were tested; however, speeding up the analysis would allow for a greater number of participants and patients to be tested and enable the scene viewing technique to be used to better understand the eye movement changes which occur in frail populations during walking. A further limitation of the analysis of the gaze behaviour of participant's whilst they were viewing the videos used in this thesis is that only one observer scored the gaze behaviour of the participants, and this observer was aware of the aim of the experiment. This means that the experiments are low in intra and inter reliability and the gaze behaviour which has been reported might have been affected by experimenter bias. To reduce this in the future the videos should be analysed by two observers, who are unaware of the purpose of the experiment. The experiments presented in this thesis also lack test-retest reliability as each participant watched the videos only once. To increase the test-retest reliability in the future participants should watch the videos on more than one occasion to establish if there are differences in their gaze behaviour between trials.

In the future it would be interesting to record the brain activity of participants as they watch the first person perspective movies in addition to recording the eye movement behaviour of participants. This would help to better inform us of the role different areas of the brain play when we are walking around and interacting with the environment. It would also help us to understand the changes which occur in the brain as a result of ageing in high risk of falling older adults and patients with neurological disorders such as stroke and Parkinson's disease which result in an increased risk of falling. Understanding the changes in the brain which occur in groups who are at an increased risk of falling would help us to better understand the mechanisms which lead to an increased risk of falling amongst certain groups. The findings from experiment 4 demonstrated that changes in eye movement behaviour in HROA were related to decline in response inhibition. Milham *et al.* (2002) compared the brain activation of older adults to young adults as they completed the Stroop task. They found that the older adults had reduced activation in dorsolateral prefrontal cortices and the parietal cortices, which have been implicated in attentional control compared to the young adults. They also observed increased activation in the ventral visual processing regions and anterior inferior prefrontal cortices in the older adults which has been implicated in a reduced ability to inhibit an irrelevant response (Milham et al., 2002). It is hypothesised that recording the brain activity of HROA, whilst scene viewing, would show decreased activation in the dorsolateral prefrontal cortices and the parietal cortices and increased activation in the ventral visual processing regions and anterior inferior prefrontal cortices compared to the LROA and young adults.

A further possibility for future research would be to use the scene viewing paradigm as an intervention to reduce falling risk amongst populations who are at a high risk of falling. Young and Hollands (2010) demonstrated that encouraging older adults who are at a higher risk of falling to adopt a pattern of gaze behaviour which is similar to that observed in younger adults and older adults at a lower risk of falling reduced the instability observed in the higher risk older adults. A possible intervention for the scene viewing paradigm would be to encourage older adults who are at a high risk of falling to reduce the time spent fixating the travel path and scan the scene to locate potential hazards.

6.5: Conclusion

The studies presented in this thesis demonstrate that scene viewing does evoke similar eye movement behaviour as walking around in the real-world, showing that scene viewing could be used as a novel way to explore changes in eye movements, during walking, in frail populations. It was also demonstrated that scene viewing evoked measurable differences between the eye movements of HROA compared to LROA and young adults and the differences were related to decline in response inhibition. When the scene viewing paradigm was applied to groups of stroke patients with lesions in either the parietal, occipital or frontal-temporal lobes differences in eye movements were observed compared to the age and sex matched controls. The findings from these studies demonstrate that scene viewing could offer a standardised, more ecologically valid alternative to laboratory studies and recording eye movements as participants walk around the real-world.

Using this technique to study changes in eye movement behaviour in frail populations such as HROA and stroke patients would enable us to better understand the cognitive mechanisms which led to an increased risk of falling and potentially develop rehabilitation techniques to reduce falling risk.

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