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Mobility changes in older age: Neuropsychological, neurophysiological and cognitive predictors of successful adaptation in real world scenarios.

A thesis submitted for the degree of

Doctor of Philosophy

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General Abstract

The aims of this thesis were to investigate the neuropsychological, neurophysiological, and cognitive contributors to mobility changes with increasing age. In a series of studies with adults aged 45-88 years, unsafe pedestrian behaviour and falls were investigated in relation to i) cognitive functions (including response time variability, executive function, and visual attention tests), ii) mobility assessments (including gait and balance and using motion capture cameras), iii) motor initiation and pedestrian road crossing behavior (using a simulated pedestrian road scene), iv) neuronal and functional brain changes (using a computer based crossing task with magnetoencephalography), and v) quality of life questionnaires (including fear of falling and restricted range of travel).

Older adults are more likely to be fatally injured at the far-side of the road compared to the near-side of the road, however, the underlying mobility and cognitive processes related to lane-specific (i.e. near-side or far-side) pedestrian crossing errors in older adults is currently unknown. The first study explored cognitive, motor initiation, and mobility predictors of unsafe pedestrian crossing behaviours. The purpose of the first study (Chapter 2) was to determine whether collisions at the near-side and far-side would be differentially predicted by mobility indices (such as walking speed and postural sway), motor initiation, and cognitive function (including spatial planning, visual attention, and within participant variability) with increasing age. The results suggest that near-side unsafe pedestrian crossing errors are related to processing speed, whereas far-side errors are related to spatial planning difficulties. Both near-side and far-side crossing errors were related to walking speed and motor initiation measures (specifically motor initiation variability).

The salient mobility predictors of unsafe pedestrian crossings determined in the above study were examined in Chapter 3 in conjunction with the presence of a history of falls. The purpose of this study was to determine the extent to which walking speed (indicated as a salient predictor of unsafe crossings and start-up delay in Chapter 2), and previous falls can be predicted and explained by age-related changes in mobility and cognitive function changes (specifically within participant variability and spatial ability). 53.2% of walking speed variance was found to be predicted by self-rated mobility score, sit-to-stand time, motor initiation, and within participant variability. Although a significant model was not found to predict fall history variance, postural sway and attentional set shifting ability was found to be strongly related to the occurrence of falls within the last year.

Next in Chapter 4, unsafe pedestrian crossing behaviour and pedestrian predictors (both mobility and cognitive measures) from Chapter 2 were explored in terms of increasing hemispheric laterality of attentional functions and inter-hemispheric oscillatory beta power changes associated with increasing age. Elevated beta (15-35 Hz) power in the motor cortex prior to movement, and reduced beta power post-movement has been linked to age-related changes in mobility. In addition, increasing recruitment of both hemispheres has been shown to occur and be beneficial to perform similarly to younger adults in cognitive tasks (Cabeza, Anderson, Locantore, & McIntosh, 2002). It has been hypothesised that changes in hemispheric neural beta power may explain the presence of more pedestrian errors at the far-side of the road in older adults. The purpose of the study was to determine whether changes in age-related cortical oscillatory beta power and hemispheric laterality are linked to unsafe pedestrian behaviour in older adults. Results indicated that pedestrian errors at the near-side are linked to hemispheric bilateralisation, and neural overcompensation post-movement,

whereas far-side unsafe errors are linked to not employing neural compensation methods (hemispheric bilateralisation).

Finally, in Chapter 5, fear of falling, life space mobility, and quality of life in old age were examined to determine their relationships with cognition, mobility (including fall history and pedestrian behaviour), and motor initiation. In addition to death and injury, mobility decline (such as pedestrian errors in Chapter 2, and falls in Chapter 3) and cognition can negatively affect quality of life and result in activity avoidance. Further, number of falls in Chapter 3 was not significantly linked to mobility and cognition alone, and may be further explained by a fear of falling. The objective of the above study (Study 2, Chapter 3) was to determine the role of mobility and cognition on fear of falling and life space mobility, and the impact on quality of life measures. Results indicated that missing safe pedestrian crossing gaps (potentially indicating crossing anxiety) and mobility decline were consistent predictors of fear of falling, reduced life space mobility, and quality of life variance. Social community (total number of close family and friends) was also linked to life space mobility and quality of life. Lower cognitive functions (particularly processing speed and reaction time) were found to predict variance in fear of falling and quality of life in old age.

Overall, the findings indicated that mobility decline (particularly walking speed or walking difficulty), processing speed, and intra-individual variability in attention (including motor initiation variability) are salient predictors of participant safety (mainly pedestrian crossing errors) and wellbeing with increasing age. More research is required to produce a significant model to explain the number of falls.

Keywords: ageing, mobility, frailty, pedestrian crossings, falls, cognition, magnetoencephalography, beta power, hemispheric lateralisation, fear of falling, life space mobility, quality of life

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1 Mobility changes in older age: Neuropsychological, neurophysiological and cognitive predictors of successful adaptation in real world scenarios.

This thesis investigated neuropsychological, neurophysiological, and cognitive contributors to mobility changes with increasing age. Four different kinds of evidence were examined with the objective to draw these together and give an overview of important indicators and implications of mobility change in old age. First the thesis explored cognitive, motor initiation, and mobility predictors of unsafe pedestrian crossing behaviours. Second, the salient mobility predictors of unsafe pedestrian crossing found from the above study were examined to uncover underlying precursors. In addition, these same predictors were examined to determine if they also predicted another potential real world outcome of mobility changes, the occurrence of falls. Thirdly, unsafe pedestrian crossing behaviour and pedestrian predictors (both mobility and cognitive measures) were explored in terms of neuronal and functional brain changes associated with increasing age. The fourth area of interest was how these changes in cognitive, mobility (including fall history and pedestrian behaviour), and motor initiation impacted on and predicted fear of falling, life space, and quality of life in old age.

1.1 Introduction: The Prevalence and Impact of Mobility Difficulties, Pedestrian Incidents and Falls with Age

Global average life expectancy has improved from 65.3 years in 1990 to 71.5 years in 2013 (Murray, Barber, Foreman, et al., 2015). Worldwide populations are predicted to continue ageing with reduced fertility rates and increased life expectancy figures (Lanzieri, 2011). Although healthy life expectancy (HLE; life lived without a life limiting health issue) has increased from 56.9 years to 62.3 years between 1990 and 2013, HLE is still 9.2 years less

than actual life expectancy (Murray, et al., 2015). Many older adults will spend these extra years with a restricted life space due to disability and/or reduced mobility (Portegijs, Rantakokko, Mikkola, Viljanen, & Rantanen, 2014), or living in care homes (Census Analysis, 2014). Reduced mobility, that is, high levels of sitting and standing compared to walking and various vigorous activities, (Salguero, Martínez-García, Molinero, & Márquez, 2011) and care home admittance can and does have a real detrimental impact on quality of life, such as social engagement (Netten, Trukeschitz, Beadle-Brown, et al., 2012).

Two major facets of mobility are balance and having the capacity to successfully navigate a readily changing environment, for example roads. One must have adequate control of one's limbs and body, along with the ability to filter and process relevant information to successfully arrive at the intended destination (Yogev-Seligmann, Hausdorff, & Giladi, 2008). For a motor act to occur, a number of steps must take place. An individual must first compose a plan of movement, continue the plan until the movement is performed, be flexible in such instances as an environment change, and to successfully complete the action (Stelmach, Goggin, & Amrhein, 1988). Successful mobility depends upon being able to navigate from a starting position to the target destination, independently and without harm. It encompasses activities ranging from standing up from a chair, walking, keeping balance to negotiating a complex environment (Shumway-Cook & Woollacott, 2011)

A reduction in mobility function is one of the main causes of disability in older adults (Mottram, Peat, Thomas, Wilkie, & Croft, 2008). Further, the pervasiveness of mobility difficulties, including slowed walking speed, chair rises, and reduced performance balance tests, have been found to occur more frequently in women than in men with increasing age

(Kim, Yabushita, & Tanaka, 2012; Butler, Menant, Tiedemann, & Lord, 2009). Up to 50% of older adults (aged 65 years and over) have reported difficulties walking and using the stairs (Webber, Porter, & Menec, 2010). Mobility difficulties, such as slower walking speed, can predict disability up to six years post study even if they had previously reported no disability (Guralnik, Ferrucci, Pieper, et al., 2000). The ease and speed in performing five uninterrupted chair rises in a test commonly named the 'sit-to-stand' test has previously been described as a test of lower extremity muscle strength (Lord, Murray, Chapman, Munro, & Tiedmann, 2002; Bohannon, 1995). Slower chair rises, slower waking speed, and reduced grip strength, amongst other variables such as sudden weight loss and exhaustion, have previously been described as frailty phenotypes (Veld, van Rossum, Kempen, et al., 2015; Fried, Tangen, Walston, et al., 2001). These frailty measures (walking speed, balance, chair rising ability, and grip strength) have been found to be highly predictive of needing nursing home care, having a fracture, and general decline a year onwards in older adults (Giuliani, Gruber-Baldini, Park, et al., 2008). Further, frailty can predict mortality (Chang, & Lin, 2015 review; Bandeen-Roche, Xue, Ferrucci, et al., 2006), and walking speed alone can predict death up to five years later (Studenski, Perera, Patel, et al., 2011).

Age-related changes in mobility that may occur include slowed chair rises (Bohannon, 2015), reduced walking speed, stride time, step length, step frequency, and irregular gait movement (Lamoth, van Deudekom, van Campen, et al., 2011; Manckoundia, Pfitzenmeyer, d'Athis, et al., 2006; Sheridan, Solomont, Kowall, & Hausdorff, 2003). Bohannon (2015) conducted a meta-analysis of literature into chair rising speed in older adults to provide normative data. It was found that in older adults 60-69 years, taking 11.4 seconds to make five consecutive chair rises was reasoned to be below average performance for their age group. This changed in the 70-79 years cohort whereby 12.6 seconds was considered below average speed; and

above 80 years 14.8 seconds was considered to be below average (Bohannon, 2015). Younger adults walk at an average speed of 1.43 m/s (Bohannon & Andrews, 2011), however, after the age of 65 years walking speed reduces and is on average 0.9m/s in men and 0.8m/s in women (Asher, Aresu, Falaschetti, & Mindell, 2012). Further, older adults tend to have a delay between the time they say they will begin walking and when they actually begin to walk, i.e. start-up delay, and walking speed is often slower than their younger counterparts (Holland & Hill, 2010).

Reduced walking speed and a delay in beginning movement once a gap is identified may be problematic when road pedestrian crossings typically allow a walking speed of approximately 1.2m/s (Bohannon & Andrews, 2011). Older adults are more likely to be involved in a fatal or severe pedestrian incident crossing the road per trip compared to younger age groups (Rolinson, Hewson, Hellier, & Husband, 2012). This may be partially as a result of frailty associated with older age (Rubenstein, 2006). Sex has also been found to be a factor with older women being involved in more pedestrian incidents than men (Santamariña-Rubio, Pérez, Olabarria, & Novoa, 2014). This may be as a result of driving experience, as suggested in Holland & Hill (2010)'s research. Holland & Hill found that a relationship was found between increased years of driving experience in women and reduced number of unsafe crossing decisions made, but this relationship was not found for men. Understanding unsafe pedestrian crossing behaviour and active life space may inform potential interventions that will reduce mortality and loneliness, and increase quality of life. Chapter 2 directly investigated the predictive link between age-related changes and unsafe pedestrian behaviour.

Age-related mobility changes such as lower extremity strength, slower walking speed, postural instability whilst walking, and difficulties in balance have also been linked to fall occurrence (Ambrose, Paul, & Hausdorff, 2013). One in three people over the age of 65 years' experience at least one fall each year (WRVS, 2012; Masud & Morris, 2001). Falls are one of the leading causes of death in older adults, exceeded only by cardiovascular disease, cancer, stroke, and pulmonary disease (Rubenstein, 2006). Although other group populations, such as children, have higher rates of falling, there are more dangers associated with falls in older adults; for example, older adults are more likely to have additional diseases and age-related changes that may exacerbate injuries acquired during a fall and increase recovery time (Rubenstein, 2006). Older adults also possess reduced upper extremity strength to absorb falling energy by up to 50% compared to younger adults (Sran, Stotz, Normandin, & Robinovitch, 2009), suggesting that the impact from breaking a fall would be more severe in older adults. This reduced strength, in combination with other common age-related ailments such as osteoporosis (Rubenstein) could further aggravate the impact of a fall. In addition to age, falls have also been linked to gender with women being found to be more likely to fall than men (O'Halloran, Pénard, Galli, et al., 2011) and are more likely to seek treatment after a fall (Stevens, Ballesteros, Mack, et al., 2012). Chapter 3 examined the extent to which falls can be predicted by mobility changes with age.

1.2 Aging Mobility: Functional and Cognitive Changes

Originally, walking was considered to be an automatic process which was a rhythmic and habitual act, similar to other automatic motor acts such as finger tapping (Hausdorff, Yogev et al., 2005). Some support for this notion includes the seeming walking action that newborn babies make when supported (Lamb & Yang, 2000) and also the ease with which adults can conduct an additional, but taxing task whilst walking (Hausdorff, et al., 2005). However,

mobility changes, such as a slowing walking speed, can occur in older adults without an obvious physical cause (Alexander, 1996). More recent research has found evidence suggesting that walking may instead be a complex task. Hausdorff, et al., (2005) explored whether walking was more like the automatic finger tapping or rather a more complex motor tasks. They found that walking was in fact more similar to the complex motor tasks, thus suggesting that it is not merely an automatic task. Such difficulty with gait may be as a result of a global slowing and reduced attentional resources with age. Some theorists, such as Salthouse (1996), believe that the central nervous system globally deteriorates with increasing age and this could lead to a global slowing of processing. This is due to what they refer to as the 'limited time mechanism' whereby mental processes that are complex, require a lot of time and/or neural components to be dedicated to them. These mental processes will suffer as this limited time and attentional resource will be dedicated to the earlier components and so there will be fewer resources available for the later components (Park & Schwarz, 2000).

Another theory which describes the prioritisation and reorganisation of attentional resources as a result of global slowing is the selection, optimisation & compensation theory by Baltes and colleagues. Baltes and colleagues argue that attentional resources are prioritised and shared to compensate for this global slowing (Baltes & Carstensen, 1996; Baltes, 1997). This theory explains that these three processes (selection, optimisation, and compensation) are prioritised dependent on the key goals of the specific task (loss-based selection), and is more commonplace with increasing age (Li, Lindenberger, Freund, & Baltes, 2001). This selection, optimisation, and compensation theory can be demonstrated in mobility tasks in older adults whilst performing another attention demanding task, that is, a dual task paradigm. The dual task (DT) paradigm is a method whereby a participant could be taking part in one task, such

as walking speed task, whilst simultaneously performing a cognitive task. The cognitive task is designed or selected to challenge attentional resources and cognitive reserve (Hawkes, Siu, Silsupadol, & Woollacott, 2012). Li, Lindenberger et al., (2001) conducted a study investigating the loss-based selection and compensation from the above theory. Using a memory task as the cognitive task and walking along a narrow track as a sensorimotor task, they looked at age-related changes and compensation aids (a walking aid or a memory aid) in single task and dual task conditions. Participants were trained separately in both the single walking and the memory task prior to the dual task and results showed that increased age had a larger impact on memory scores than walking. This and the preference for hand rails rather than memory aids as compensatory aids suggested that the older adults optimised walking. The opposite was found for their younger counterparts who prioritised memory scores. This study supports the notion that attentional and cognitive processes are recruited to aid balance while walking; also that with increasing age individuals prioritise and compensate for reduced walking ability. This thesis investigated the extent to which specific reduced cognitive and attentional resources can explain aspects of mobility issues such as walking speed and falls.

Dual tasking has also been found to have a large negative impact on balance in the form of increased trunk instability as well as slowed walking speed (Van Iersel, Kessels, Bloem, Verbeek, & Rikkert, 2008), especially in older adults when the rules of the cognitive task changed (attention switching) (Hawkes, et al., 2012). Age alone did not have an effect on dual task ability (Hawkes, et al., 2012), however, from childhood through to older adulthood, there appears an inverted-U shape of performance in the ability to dual-task whilst walking, which occurs around the time that brain functions are changing (Krampe, Schaefer, Lindenberger, & Baltes, 2011). In addition, falls have also been found to be indirectly related

to dual task costs with those who had fallen within the previous 12 months demonstrating an increased gait variability whilst completing a dual task (walking whilst subtracting in threes) compared to those who had not fallen within that time period (Herman, Mirelman, Giladi, Schweiger, & Hausforff, 2010). In support of these findings, Springer, Giladi, Peretz, et al., (2006) found that swing time variability was increased in fallers compared to younger adults and non-fallers in a dual task condition, and that executive function is significantly correlated with this variability. These results suggest that reduced attentional resources were present in older fallers. However, these studies did not directly measure attention performance, rather the extent to which a cognitive task impacts on walking was used. This thesis directly examined the role of reduced attentional capacity on recent fall history.

Age-related dual-task costs have also been found in pedestrian behaviour. Nagamatsu, Voss, Neider, et al., (2011) used a real world simulation of walking (on a treadmill) across a virtual street while listening to music, holding a conversation on a phone or with no distractions. Participants were divided into two groups, people at risk of falls and not at risk of falls, using the Physiological Profile Assessment. The two groups were also found to have significant differences in mobility measured by the Timed up and Go (TUG), and chair rise (Sit-to-Stand task, STS) tasks. Participants who were deemed at risk of falling were found to make more 'collisions' with moving cars, particularly at the near-side of the road, and took longer to 'cross the road' than those not at risk of falls in the phone condition and listening to music condition. As those at risk of falling demonstrated reduced attention sharing capacity and balance, it could be inferred that attention and balance may contribute towards near-side unsafe crossing errors. Chapter 2 of this thesis examined the extent to which specific mobility (such as balance and walking speed) and cognitive measures (such as reduced attention) could predict near-side crossing errors.

Further support for the role of cognitive factors in relation to pedestrian safety can be found by Neider, Gasper, McCarley, et al., (2011). They investigated the dual task effect of crossing behaviours (simulated crossing whilst performing cognitive task) in older adults with the same conditions as the Nagamatsu study above (while undistracted, listening to music or talking on the phone), only this time the groups were younger (18-26 year olds) and older adults (59-81 years). Older adults were found to take longer to 'cross' once identifying a gap and less likely to attempt crossing when the task difficulty increased compared to younger adults. Older adults were more likely to make more unsafe crossing choices (leave smaller crossing gaps) when dual tasking but there was little differences between the two dual conditions. These studies suggest that distractions whilst crossing, particularly in older adults with reduced attentional resources, can increase the likelihood of making a judgement error whilst crossing the road. This could indicate that reduced attentional resources are available in those with increased start-up delay, and in older pedestrians making unsafe crossing decisions. With this in mind, Chapter 2 of this thesis investigated the extent to which attentional resources and cognition can predict unsafe crossing errors in older adults, and whether differences can be found for near-side and far-side unsafe crossings.

Contrary to the above findings, dual-tasking studies have found that both walking speed on its own and walking speed under dual task conditions are equally able to predict fall history (Menant, Schoene, Sarofim, & Lord, 2014). These results, in addition to gait and balance previously being linked to falls and being negatively impacted by dual tasks, suggest that a combination of general mobility and cognition may be important in predicting falls, rather than just mobility on its own. Chapter 3 examined the extent to which mobility and cognitive changes with age can predict and explain the presence of falls in older adults.

The next few sub-sections cover the specific attention and cognitive functions that were examined in this thesis and the potential impacts they may have on age-related mobility and road safety measures. First, section 1.2.1 covers what is currently known and not known about the role of processing speed and visual attention on unsafe crossing decisions and specific mobility difficulties. Next 1.2.2 introduces an emerging area of research into within participant variability and the potential to contribute to and predict unsafe crossing decisions and mobility issues. Finally 1.2.3 discusses the role of specific cognitive and executive functions and how they may relate to specific pedestrian lane crossing errors and mobility difficulties.

1.2.1 Visual Attention/Useful Field of View

In addition to having an impact on dual task performance when attentional resources are shared, attention can also have an impact on how able we are to perceive and respond to the environment. The Useful Field of View (UFoV; Ball, Owsley, 1992) determines the visual field range in which an observer can process and extract information in a given moment, particularly when the target is presented alongside a second peripheral target and with distractors. This divided and selective attention becomes more difficult with increasing age (Sekuler, Bennet, & Marnelak, 2000; Sekuler & Ball, 1986).

Reduced UFOV ability has previously been linked to reduced driving ability (Clay, Wadley, Edwards, et al., 2005) and has been found to predict car crashes in older adults aged 70 years and above (Hennessy, 1995), suggesting that visual attention is required for successful road navigation. However, little is known about how UFoV predicts unsafe crossing behaviour. Studies that have investigated pedestrian crossing behaviour and UFOV (Dommes, Cavallo, & Oxley, 2013; Dommes & Cavallo, 2011) did so without differentiating between specific

lane errors despite evidence to suggest that older adults are involved in differing numbers of near-side and far-side unsafe pedestrian crossings in fatality statistics. Further, Nagamatsu, et al's (2011) finding that older adults at risk of falling (partially categorised by postural sway) made more near-side crossing errors, it could be implied that visual attention may be linked to near-side crossing errors. Chapter 2 directly tested whether distinct useful field of view patterns have a differential relationship with near-side or far-side unsafe crossing errors.

In addition to pedestrian errors, composite UFoV scores have previously been found to be related to self-reported mobility difficulties, particularly in balance and gait, along with composite mobility scores (score of balance, gait, and sit-to-stand activities) (Owsley & McGwin, 2004). When UFOV subtests were separated, divided attention was found to be related to the composite mobility score. Further, UFOV divided attention performance has been related to balance (Reed-Jones, Dorgo, Hitchings, & Badar, 2012), and the ability to avoid obstacles when walking (Broman, West, Muñoz, et al., 2004). This could indicate that different visual attention elements are important for different aspects of mobility. However, despite these relationships with composite mobility including gait, and walking to avoid obstacles, currently limited research has been conducted into whether visual attention could predict walking speed performance. As both gait and balance have previously been linked to falls (Ambrose, Paul, & Hausdorff, 2013) visual attention may also be a factor in the onset of falls. Chapter 3 investigated the extent to which different elements of UFOV could predict and explain changes in mobility measures (walking speed) and also a recent history of falls.

1.2.3 Within Participant Variability

In addition to visual attention, variability in attention may also contribute towards mobility changes with age. Recent research has identified that within participant variability, e.g. occasional very long response times in reaction times across trials, is negatively related to perceptual speed, working memory, episodic memory, and crystallised abilities (vocabulary and world knowledge). It has also been found to be a strong predictor of cognitive performance with advancing age (Hultsch, MacDonald, & Dixon, 2002). Within participant variability has previously been linked to performance during simulated driving, particularly making errors in the immediate lane (Bunce, Young, Blane, & Khugputh, 2012). Despite this evidence that attention variability and road safety, there is no research into attention variability and pedestrian behaviour. Chapter 2 investigated whether within participant variability can influence pedestrian road safety errors, particularly at the near-side of the road.

As cognition has been found to affect mobility and falls (1.2), it could be inferred that within participant variability could also impact on mobility performance and falls. In support of this, fallers have been found to be exhibit larger within participant variability (see review by Graveson, Bauermeister, McKeown, & Bunce (2015). The relationship between within participant variability and walking speed, on the other hand, has been less consistent in the literature which may be as a result of small sample sizes and inconsistencies in calculating within participant variability (i.e. raw standard deviation or a more sophisticated coefficient of variance) (Graveson, et al., 2015). Chapter 3 aimed to uncover whether within participant variability (measured using a coefficient of variance) could indeed predict previous falls along with mobility ability in measures including walking speed, chair rises, and postural sway.

1.2.3 Links to Executive Function

Executive function (EF) consists of an array of higher order cognitive processes which manage and regulate lower order cognitive functions and attention (Alvarez & Emory, 2006) and include functions such as task-switching, planning, and the executive function sub-process, working memory (Elliot, 2003). EFs are adversely affected by deficits in the frontal lobe but they are not dependent on the frontal lobes alone (Alvarez & Emory, 2006) as anterior and posterior regions may also be recruited (Yogev-Seligmann, Hausdorff, & Giladi, 2007). De Luca, Wood, Anderson, et al. (2003) found that executive function performance (measured using the Cambridge Neuropsychological Test Automated Battery, CANTAB), such as spatial planning/ problem solving, spatial working memory, and attentional set shifting has previously been found to decline with increasing age after 50 years of age. Relationships between EF and gait are well supported (Yogev-Seligmann, et al., 2007) with links to the frontal lobe, particularly the dorsolateral prefrontal cortex. Yogev-Seligmann, et al., (2007) stressed the importance of executive function and attention in gait, claiming that gait can no longer be considered an automatic process as there has been evidence of cognitive factors linked to a disruption in gait even in healthy younger adults. Walking speed has been found to be significantly related to global executive function and memory performance in older adults (Watson, Rosano, Boudreau, et al., 2010).

Although previous research has attributed falls to physical factors such as poor vision (Black, Wood, & Lovie-Kitchin, 2011; Rossat, Fantino, Nitenberg, et al., 2010), muscle strength, motor function, and postural control (AGS, 2001; Kannus, Sievanen, Palvanen, Jarvinen, & Parkkari, 2005), more recent studies have also recognised the importance of cognitive and executive function on fall occurrence and risk. Holtzer, Friedman, Lipton, et al. (2007) investigated various cognitive traits in healthy older adults and their effect on fall risk. The

trait that was noted as the most important was speed/executive attention (measured using the Digit Symbol task and Block Design subtests of the Wechsler Adult Intelligence Scale—Revised, and the Trail Making Test- a measure of set shifting). The results showed that in their sample, an increase of one standard deviation in speed/executive attention performance could predict a 50% reduction in fall risk. However, speed/executive attention could only predict the occurrence of single falls. To explain recurrent falls, verbal IQ (measured using Vocabulary, Digit Span, Information subtests of the Wechsler Adult Intelligence Scales—Revised, Boston Naming Test, and Executive Function Letter Fluency test) and the presence of other diseases were a better predictor. Stern (2002) suggests that verbal IQ represents cognitive reserve in individuals and so, this study would indicate that reduced cognitive reserve is also associated with fall risk (Holtzer, et al., 2007).

Executive function may also contribute towards unsafe pedestrian road crossings. One of the findings by Holland & Hill (2010) was that along with mobility measures and start-up delay (slowed motor initiation), crossing skills such as walking time estimation and looking behaviour were linked to successful crossings in a simulated road environment. The authors found that those who failed to look left one more time before crossing were more likely to have had an unsuccessful crossing attempt (which was commonly observed in older participants). The looking behaviour findings suggest that some of the unsafe crossing decisions may be as a result of participants only observing the immediate threat but not planning effectively for the next lane of traffic and so, not taking into account both sides of the road when crossing. This could indicate that planning ability or a reduced ability to shift attention at least partially accounts for unsafe pedestrian crossings. A self-reported limitation with the Holland & Hill (2010) paper is that the role of cognitive function such as visual attention and executive function was not explored in relation to unsafe crossing judgements.

Chapter 2 directly assessed the control of attention and executive function, such as planning for the occurrence of unsafe crossing errors in older adults.

One aspect of executive function is set shifting. Set shifting decline has previously been found to be related to age-related walking speed decline (Soumaré, Tavernier, Alpérovitch, et al., 2009), reduced balance performance (Brauer, Woollacott, Shumway-Cook, 2001, 2002), along with unsafe pedestrian crossings (Dommes, Cavallo, & Oxley, 2013). Further, previous research by Li, Roudaia, Lussier, et al. (2010) found that cognitive training using various executive function tests measuring set shifting and executive control/speed improved standing balance performance in older adults. There has also been evidence for the role of response inhibition in unsafe pedestrian crossing decisions (Dommes & Cavallo, 2011). The authors argued that the ability to inhibit responses may be important for ignoring irrelevant information and redirecting attention to the relevant information in a rapidly changing environment. However, currently attentional set shifting ability has not been investigated in terms of specific pedestrian lane crossing errors. Such ability could be necessary in order to change focus from the near-side of the road to the far-side of the road, or even from attending to the road to beginning walking. Chapter 2 directly assessed the potential role of attentional set shifting in near-side and far-side unsafe crossings, along with start-up delay.

Inhibition has also been linked to successful mobility performance. This was supported by Redfern, Müller, Jennings, & Furman (2009) who found that difficulties in perceptual and motor inhibition could impact on participants' postural stability and balance. Balance is not the only mobility aspect found to have links to response inhibition. Participants with a recent history of falls performed more poorly than non-fallers on measures of Stroop and Go-No Go

tests, both of which are measures of response inhibition (Hausdorff, Doniger, Springer, et al., 2006; Springer, Giladi, Peretz, et al., 2006). In addition, deficits in these measures were related to walking swing time variability. This was exacerbated in a dual task scenario (Springer, et al. 2006). However, these studies did not determine whether these executive functions had a differential relationship with specific lane crossing errors. Chapter 2 investigated whether set shifting and inhibition were more influential than mobility and motor initiation for lane specific unsafe pedestrian crossings in older adults. Chapter 3 then investigated whether set shifting and inhibition could impact on significant mobility pedestrian predictors from Chapter 2, including mobility measures such as chair rises.

In a review by Yogev-Seligmann, et al. (2007) it was suggested that updating (or response monitoring) could be an important factor in navigating everyday environments as without it, and without it interacting with other areas/functions, one would not be able to stop if needed, turn, or modify speed with the presence of an oncoming obstacle. Despite this, limited research has been conducted into a relationship between updating ability with pedestrian crossing judgements. Chapter 2 directly measures this potential relationship. Poor updating ability has previously been found to interfere with walking tasks (Theill, Martin, Schumacher, et al., 2011) and is associated with slower walking speed (Holtzer, Verghese, Xue, & Lipton, 2006). Kawagoe & Sekiyama (2014) conducted a series of N-back tests (a measure of working memory and updating) with a timed-up and go test (measure of mobility status and a test of manual dexterity (peg board test). All three N-back tests were related to timed-up and go, but not manual dexterity. These findings demonstrate that updating ability are related to gross mobility tasks but not necessarily fine motor tasks. Chapter 3 investigated the effects of updating ability on other gross mobility tasks including walking speed. Also, updating was explored in terms of a predictive relationship with previous falls.

Planning ability, such as that measured by the Tower of London task (Shallice, 1982) is another executive function that may impact on mobility, falls, and unsafe crossing behaviour. Freezing of gait in older adults with Parkinson's disease has been previously been linked to spatial planning ability (Ferrari, Lagravinese, Pelosin et al., 2015), thus suggesting that spatial planning is required for successful walking. However, little is known about spatial planning in healthy ageing for walking ability, and other mobility abilities such as balance. This is despite evidence of other spatial abilities being related to mobility such as evidence of a visuo-spatial switching task link to walking speed (Hawkes, Siu, Silsupadol, & Woollacott 2012), and spatial mental rotation ability previously linked to balance ability (Jansen & Kaltner, 2014). Chapter 3 investigated the relationship between spatial planning and spatial working memory with falls and various mobility abilities including postural sway, chair rises, and walking speed. In addition, as older adults tend to make more pedestrian errors at the far-side of the road (section 1.1), and are more influenced by the distance of the car rather than the speed (Lobjois & Cavallo, 2007), it could be inferred that spatial planning, and possibly the sub-measure spatial working memory may impact on far-side unsafe pedestrian crossing decisions. Chapter 2 directly tested this link between far-side unsafe crossings with spatial planning and spatial working memory.

1.3 Aging Mobility: Neuronal and Anatomical Changes

As age increases, the amount of grey matter in the brain, particularly in the frontal lobe decreases (this includes the motor cortex), resulting in an increase in the size of the ventricles and cortical sulci (Van Petten, Plante, Davidson, et al., 2004). Age-related changes in the prefrontal cortex have been found to be associated with deficits in memory, and high level cognitive processes, such as executive function (Spreng, Wojtowicz, & Grady, 2010). As indicated above, executive function includes items such as updating, set shifting, spatial

planning, and inhibition (section 1.2). Too great a decline in the volume of prefrontal and medial temporal lobes has been associated with dementia (Maillet & Rajah, 2013). As it is evident that the brain undergoes changes in structure with increasing age, and also the ability to perform motor functions, such as normal mobility and pedestrian behaviour alters with age (section 1.1), one may expect a relationship between motor difficulties and pedestrian behaviour with brain structure in older adults.

Neuroimaging studies have attributed mobility changes with age to regional brain atrophy (Rosano, Aizenstein, Brach, et al., 2008; Rosano, Bennett, Newman, et al., 2012; Rosano Studenski, Aizenstein, et al., 2012). Rosano, et al., (2008) found that gait step length and width were related to gray matter loss in areas associated with motor ability (motor, sensorimotor and supplementary areas, basal ganglia, cerebellum), areas relating to visuo-spatial function (inferior and superior posterior parietal lobules) and 'cognitive processing/executive control function' areas (dorsolateral prefrontal cortex). Further to this, wider stepping could be explained by gray matter loss in right dorsolateral prefrontal cortex along with the bilateral pallidum & inferior lobules once age, and gender had been controlled for (Rosano, et al., 2008). These findings indicate that gait decline is at least partially as a result of a gray matter decline in the structural integrity of specific areas of the brain, and also that there is a relationship with cognitive processes. In support of these findings, Rosano, Studenski et al., (2012) found that smaller grey matter volume in the prefrontal cortex with older age was significantly related to walking speed and to information processing speed (mainly the Digit Symbol Substitution test), but not measures of visuo-spatial & perceptual attention, global functioning or memory. Also grey matter atrophy was linked to sit-to-stand times, postural stability (recovery when balance perturbed), posture (stooping and leaning)

and gait (speed, arm swing, abnormality) (Rosano, Bennett et al, 2012).These studies implicate the role of the frontal lobe gray matter in mobility measures such as gait.

In addition to changes to grey matter volume, changes to white matter in the brain can also have an impact on mobility functioning. Reduced connective white matter organisation (or white matter hyperintensity) has previously been linked to difficulties in postural sway (Novak, Haertle et al., 2009). Also, reduced structural white matter atrophy in the corpus callosum, which allows communication between hemispheres, and periventricular areas were found to predict mobility performance in areas such as balance, chair rising ability, walking speed, and ease at taking the stairs and could predict decline in set shifting, inhibition, and cognitive processing speed (Wakefield, Moscufo, Guttmann, et al., 2010). Further, in a longitudinal study by Ryberg, Rostrup, Paulson, et al., (2011), it was found that structural white matter atrophy in the corpus callosum could predict walking speed, standing balance and chair rising ability, along with cognitive (Mini Mental State Examination; MMSE) impairment three years later. Overall, this indicates that structural changes in white matter can influence and even predict mobility (balance, walking speed, chair rises, and stair climbing) and specific executive functions (set shifting, inhibition) and processing speed in older adults, and that hemispheric communication is important in order to conduct such activities in older adults.

Age-related changes in the motor cortex have also been linked to neuronal changes. Continual beta (15-30 Hz) oscillations are produced within the primary motor cortex, mainly in the contralateral (to the dominant hand) hemisphere (Baker, Olivier, & Lemon, 1997). In healthy younger adults this beta power reduces before movement initiation (event related beta desynchronisation) and then strongly increases after the movement has been completed (post

movement beta rebound) (Gaetz, MacDonald, Cheyne, & Snead, 2010). With increasing age, beta power prior to movement has been found to increase and post-movement beta power has been found to decrease (Labyt, Szurhaj, Bourriez, et al., 2003) and similar beta power patterns has been linked to maladaptive movement disorders such as Parkinson's disease (Hall, Prokic, McAllister, et al., 2014). Parkinson's disease has previously been linked to unsafe pedestrian crossings (Lin, Ou, Wu, & Liu, 2013). This could suggest that increasing age and age-related oscillatory beta power changes may be contributing towards unsafe pedestrian crossings in older adults. Chapter 4 determined whether age-related beta power changes pre-and post-movement are related to unsafe pedestrian crossing errors (computer based crossing task and Chapter 2 pedestrian performance).

Foerch & Steinmetz (2009) theorised that age-related structural changes, mainly in the right hemisphere, may negatively impact on processing of the left side of their environment. Therefore, this may contribute towards pedestrian crossing errors particularly on the far-side of the road (i.e. the UK far-side of the road where traffic arrives from the left field of view). However, research has not been conducted into the potential link between unsafe pedestrian crossings and hemispheric neural activation. However, in a review by Greenwood (2007), it was found that the areas that displayed the greatest decline, such as the prefrontal and posterior parietal cortices, also demonstrated the greatest activation. Further, the review stated that increasing use of the contralateral hemisphere (contralateral to the dominant hand/hemisphere) occurs with increasing age. The author claimed that this increased activation and hemispheric neuronal recruitment may be a form of compensation or plasticity, particularly considering evidence regarding stroke patients increasingly using both hemispheres after training. Chapter 4 examined whether reduced neuronal activation in the

contralateral hemisphere or whether hemispheric bilaterality may be linked to unsafe pedestrian crossings.

To summarise, there has been no research conducted into pedestrian behaviour and changes in neural power changes with age. As pedestrian behaviour has previously been linked with cognition and mobility, and mobility and cognition have been linked to neural beta power changes, one may hypothesise that a relationship may be found between neural beta power and effective pedestrian crossings. Chapter 4 assessed whether there was a relationship between maladaptive neural activation prior to movement and during post movement recovery with pedestrian behaviour (including cognitive and mobility pedestrian predictor results from Chapter 2). In addition, Chapter 4 examined the impact of such structural changes, in terms of maladaptive neural beta power, on unsafe pedestrian crossing judgements with increasing age.

1.4 Fear of falling and Life Space Mobility

In addition to mobility and cognitive measures, fear of falling has also been found to be a risk factor for falls (de Vries, Peeters, Lips, & Deeg, 2013; Delbaere, Close, Heim, et al., 2010) and frailty (Lach, 2005; Tennstedt, Howland, Lachman, et al., 1998).Although a fear of falling is a common consequence of having had a fall (Niino, Tsuzuku, Ando, & Shimokata, 2000; Howland, Lachman, Peterson, et al., 1998), a fear of falling can also occur in the absence of falls (Myers, Powell, Maki, et al., 1996). This fear of falling can lead to a restriction of activities (Painter, Allison, Dhingra, et al., 2012), mobility avoidance such as being fearful of leaving the house (WRVS, 2012), a reduced quality of life (Li, Fisher, Harmer, McAuley, & Wilson, 2003), and increased social isolation (Rantakokko, Iwarsson, Vahaluoto, et al., 2014). Fear of falling has been thought to contribute towards increased and

perhaps undue disability in older adults (Lach, 2005; Tennstedt, Howland, Lachman, et al., 1998).This avoidance of activity could lead to additional frailty due to increased muscle weakness (Rubenstein, 2006). Frailty in older adults has also been found to be highly predictive of the timing and presence of future falls (de Vries, Peeters, Lips, & Deeg, 2013; Delbaere, Close, Heim, et al., 2010).

Older pedestrians are also likely to be anxious and/or overwhelmed due to sensory overloads, poor signage, and perceived barriers such as physical and social factors in unfamiliar areas or due to changes within the person such as reduced eyesight or cognitive impairments making the area seem unfamiliar. These anxieties may be exaggerated if mobility and cognitive impairments are also present (Phillips, Walford, Hockley, Foreman, & Lewis, 2013). Perceived barriers in one's environment can lead to feelings of loneliness (Rantakokko, Iwarsson, Vahaluto, et al., 2014), and reduced physical activity (Portegjis, Tsai, Rantanen, & Rantakokko, 2015).

To date, no significant body of work has combined behavioural methods with relevant neuropsychological features such as motor initiation, quality of life, life space mobility, and fear of falling measures. Understanding fear of falling and life space limiting factors may provide a chance of preventing future falls, frailty & disability, mortality, and increase the quality of life of older adults. Chapter 5 examined the impact of mobility and cognition on fear of falling and life space, and how these measures impacted on quality of life in older adults.

1.5 Chapter Summary and Thesis Rationale

To summarise, it is uncertain whether pedestrian crossing errors in older adults are as a result of mobility changes and changes in motor initiation, or as a result of cognitive impairments or a combination. Further, little is known about why older adults are likely to make more unsafe crossings in the far-side of the road than the near-side of the road. Limited research has been conducted into the role of spatial ability (i.e. spatial planning and spatial working memory) in relation to mobility, particularly pedestrian behaviour. This is despite older adults statistically being involved in more fatal far-side road collisions, and indirect relationships between spatial judgements and simulated pedestrian studies (car distance judgements, Lobjois & Cavallo, 2007). Also, it may be inferred that judgments at the near-side of the road may be as a result of balance issues, visual attention or attentional within participant variability. Chapter 2 directly examined the impact of mobility and cognition on lane specific road crossing errors.

Within participant variability has also been linked to cognition, but little research has been conducted between within participant variability with mobility & pedestrian behaviour despite emerging evidence for a link with cognition and falls. In addition, it is unclear whether age-related mobility difficulties and falls are a result of mobility and motor initiation, or as a result of cognition, or a combination, and there have been inconsistencies in the literature regarding the executive functions identified as important in mobility decline. This may be as a result of the possibility that different combinations of executive functions are required for differing aspects of mobility. Chapter 3, guided by the mobility predictors from Chapter 2, examined the predictive components of mobility and falls in older adults.

Some of the changes in safe crossing behaviour may be as a result of age-related changes in the brain; these changes are both structural and functional, such as gray matter decline causing a slowing of processing and an increased dependence on both hemispheres. To date, this link between pedestrian behaviour and maladaptive neural beta power has not been directly measures. Chapter 4 investigated the relationship between neural changes and pedestrian behaviour with increasing age.

In investigating the impact of each cognitive process in relation to mobility (including pedestrian behaviour and falls), this may provide a greater understanding into how to develop a suitable treatment and prevention. In addition, these measures may be imperative in quality of life, fear of falling, and life space mobility in older adults. A series of studies using an extensive neuropsychological battery of assessments were employed to delineate predictors of impaired function, along with adaption/compensation, by combining behavioural methods with relevant neurophysiological features.

2 Examining links between cognitive markers, movement initiation & change, and pedestrian safety in older adults

Objective

The purpose of this study was to determine the extent to which mobility indices, motor initiation, and cognitive function, within participant variability, differentially predicted pedestrian traffic collisions in the near and far sides of the road with increasing age.

Methods

Adults aged over 45 years participated in cognitive tests measuring executive function and visual attention (using Useful Field of View; UFoV®), mobility assessments (walking speed, sit-to-stand, self-reported mobility, and postural sway assessed using motion capture cameras), and gave road crossing choices in a two-way filmed real traffic pedestrian simulation.

Results

A stepwise regression model of walking speed, start-up delay variability, and processing speed) explained 49.4% of the variance in near-side crossing errors. Walking speed, start-up delay measures (average & variability), and spatial planning explained 54.8% of the variance in far-side unsafe crossing errors. Start-up delay was predicted by walking speed only (explained 30.5%).

Conclusion

Walking speed and start-up delay measures were consistent predictors of unsafe crossing behaviours. Cognitive measures, however, differentially predicted near-side errors (processing speed), and far-side errors (spatial planning). These findings offer potential contributions for identifying and rehabilitating at-risk older pedestrians.

2.1 Introduction: Pedestrian Incidents and Fatalities

Chapter 1 highlighted that unsafe pedestrian crossings are influenced by age-related changes in cognition (particularly executive functions), motor initiation, and mobility measures. However, previous research has not studied lane specific errors separately. This is despite previous research and pedestrian fatality statistics suggesting that there may be different processes in near-side and far-side crossing errors. This chapter aimed to explore the predictive relationships between cognitive (such as spatial planning and within participant variability), motor initiation, and mobility measures identified in Chapter 1, and unsafe crossing choices in the near- and far-sides of the road using a simulation paradigm.

Adults over the age of 65 years represent 17.4% of the UK population, a rise of 17.3% since 2003 (UK National Statistics, 2014), and this figure is expected to rise (UK National Statistics, 2012). Rolinson, Hewson, Hellier, & Husband (2012) compared the number of pedestrian traffic collisions between 1989 and 2009 with the UK National Travel Survey of estimated trips. They found that the estimated risk of pedestrian fatal injury in the age group 70 years and above was 5.19 times greater per trip compared to pedestrians aged 21-29 years. The high number of fatalities in older adults may be partially due to increased physical frailty, for example, caused by additional diseases, such as osteoporosis (Rubenstein, 2006), which could make a collision more likely to result in serious injury or death. However, this lack of resilience to physical collision does not explain why so many over the age of 60 years are being involved in such an incident in the first place (21.82% killed or severely injured, 14.68% of all injury severities; DFT, 2010). Determining the person based risk markers for the occurrence of pedestrian collisions in older adults is necessary if prevention strategies are to be developed.

2.1.1 Near-side and Far-Side Fatalities in Older Adults

A first question is whether there are salient differences in the type of incidents older pedestrians have as compared to younger adults or other high risk groups such as children. Police reports, such as that of Fontaine & Gourlet (1997) in France found that older pedestrians over the age of 65 were more likely to be fatally injured in the middle or far-side of the road than the first half of the road (near-side, nearest to the pedestrian start point). Additionally, Oxley, Fildes, Ihsen, Charlton, & Day (1997) in Melborne found larger numbers of older pedestrian collisions (where obstacles were not present) were made when traffic was coming from the far-side of the road compared to near-side collisions. In contrast, for younger adults, there was little difference between near-side and far-side collisions. Similar results were found using a simulated road environment (Dommes, Langevin, Cavallo, Oxley, & Vienne, 2011) whereby more unsafe crossing decisions were made when the closest vehicle was on the far-side of the road with increasing age (from 20-84 years). Later, Dommes, Cavallo, Dubuisson, Tournier, & Vienne (2014) also discovered that both younger old (62-71 years) and older old (72-85 years) had a tendency to cross more slowly, and leave enough of a safety margin to cross the near-side gap but not enough time to successfully cross the far-side gap in traffic. Various authors have suggested that this data implies that older pedestrians are mainly attending to the immediate threat and either misjudging or not acknowledging the next lane of traffic.

In a meta-analysis of pedestrian collisions and the types of roads in which they occurred, Dunbar (2012) found that the numbers of near-side compared to far-side pedestrian casualties declined across the lifespan from the ages of 10-15 years until the ages of 85 years and above. This suggests that there may be an increasing failure to attend to the far-side of the road as age increases. This pattern, however, reversed after 85 years of age, which although not

significant, an increase in the number of near-side errors may also demonstrate a lack of general attentional control in very old age. The current study examined the potential different roles of attention and spatial abilities in far-side and near-side traffic errors in order to attempt to clarify the predictors of errors relevant to each direction and any age-related change in this.

2.1.2 Crossing Decisions, Motor Control & Mobility

Normal gait becomes increasingly more difficult, and slower with increasing age. Walking speed in older adults is on average 0.9m/s in men and 0.8m/s in women over the age of 65 years (Asher, Aresu, Falaschetti, & Mindell, 2012), whereas younger adults walk at an average speed of 1.43 m/s (Bohannon & Andrews, 2011). This is problematic when road pedestrian crossings typically allow a walking speed of approximately 1.2m/s (Bohannon & Andrews, 2011). In addition to the data above on near versus far-side collisions, older adults have also been found to be more likely to be involved in a pedestrian incident on wider roads (Zegeer, Stutts, Huang, Zhou, Rodgman, 1996; Zegeer, Stutts, Huang, & Zhou, 1993), suggesting that frailty may be a factor in reaching the second half of the road safely. Walking speed has been previously found to be important in predicting unsafe crossing errors in simulated environments (Dommes, Cavallo, & Oxley, 2013; Holland & Hill, 2010).

Older adults also display a delay in starting to walk once they have decided to do so (Holland & Hill, 2010). This delay (i.e. motor initiation, or start-up delay), along with changing mobility and crossing skill, may influence crossing error. Using a two-way simulated road environment, Holland & Hill (2010) found that older adults (particularly older men) demonstrated significantly more total unsafe crossing decisions, and unsafe crossing

behaviour (smaller safety margins, fewer or wrong direction head turns) compared to their younger counterparts. Road crossing skill (e.g. walking time estimation, looking behaviours, and safety margins) as well as mobility indicators (mobility assessment, start-up delay, walking speed) were major determinants of crossing errors. Start-up delay alone predicted 21% of unsafe crossing variance. Delay in beginning to cross would be likely to result in a safe crossing gap no longer being safe once the person began to move. After controlling for age, safety margin left when 'crossing' was negatively associated with the following mobility measures: walking time, timed sit-to-stand measure, and self-reported mobility difficulties. This implied that mobility and motor initiation are major components of unsafe crossings, but also suggested differing effects between genders. Dommes, Cavallo, & Oxley (2013) found that walking speed, rather than cognition, was the most predictive of total unsafe simulated crossing errors (supporting Dommes & Cavallo, 2011, and Holland & Hill, 2010, but contradicting findings in the meta-analysis by Dunbar, 2012).

Further to this, Holland & Hill (2010) found unsafe crossing choices in older men were significantly predicted by reduced mobility, but in women, unsafe crossings were significantly affected by driving experience (years) (driving performance has previously been linked to visual attention; Clay, Wadley, Edwards, et al, 2005) and age. This may suggest that there is both a mobility and cognitive component, such as perhaps visual attention, which may be involved with crossing error. As pedestrian fatality statistics show more far-side than near-side errors, the inconsistency in predictive factors of total unsafe crossings across genders may be due to differences in the type of lane error made. This study therefore explored potential differences in mobility and cognition for varying lane errors with gender and increasing age.

The role of start-up delay seems central to the investigation, and potential remediation, since not only does it seem to be one of the most salient predictors of unsafe crossings, it is also possible that it is amenable to training, with Thomson, Tolmie, Foot, Whelan, Sarvary, & Morrison, (2005) demonstrating that motor initiation improved with perceptual training in children, which may generalise to adults. In support of a start-up delay component, Neider, Gaspar, McCarley, Crowell, Kaczmarski, & Kramer (2011) found that older adults (59-81 years) had longer initiation times to begin to cross once a crossing gap was chosen (pedestrian simulation using virtual reality CAVE and a treadmill) than younger adults (18-26 years) whilst undistracted. Older adults also took longer to cross once movement was initiated, left smaller crossing gaps, and missed more available gaps compared to younger adults. An interaction was found, whereby older adults were more affected by increased attentional demand for each of these measures than younger whilst performing a secondary task (listening to music or talking on the phone), suggesting an attentional resource component to motor control and unsafe crossing. In addition, attention accuracy, reaction time, and vehicle distance were also positively correlated with more virtual 'collisions', suggesting but only indirectly testing the presence of cognition and spatial planning in pedestrian behaviour and motor initiation. As start-up delay appears to be a reliable strong predictor of unsafe crossing behaviours in older adults, this chapter directly assessed the extent to which cognition or mobility contributes towards start-up initiation time (delay), as well as further exploring the role of start-up delay on unsafe crossing errors by comparing its contribution to near and far side errors.

Besides walking speed and sit-to stand measures, balance may also be a factor in unsafe crossing decisions. Nagamatsu, et al (2011), in a pedestrian simulator (CAVE virtual environment) study, found that those at risk of falling (assessed using the Physiological

Profile Assessment, including postural sway), were found to make more 'collisions' with virtual moving cars, and took longer to 'cross the road' (slower walking speed) than those not at risk whilst completing an 'active' secondary attention-based task (talking on the phone), but not with 'passive' distraction (listening to music) and no distraction. 'At risk' older adults were also involved in more 'collisions' (in the divided attention condition) in the near-side. As the 'at risk' group showed issues of postural sway, this study implied that balance may be an additional contributor to pedestrian behaviour.

2.1.3 Crossing Decisions and Cognition

One reason for the overrepresentation of older adults in pedestrian fatalities, particularly in the far-side of the road, may be as a result of incorrect crossing judgments. Oxley, Ihsen, Fildes, Charlton, & Day (2005), in a two-way simulated roadside environment, and Lobjois & Cavallo (2007) in a one-way simulation, found that both younger and older adults' decisions to cross were influenced more by the distance of the car than by the speed, suggesting difficulties in integrating and processing two sources of spatial information whilst deciding on whether to cross. Also, as this appears to be present in both a one-way and two-way crossing environment, this spatial planning may be a factor in both near-side and far-side unsafe crossings, although not measured directly in the above studies. In support of a role of spatial planning ability in negotiating a rapidly changing environment, navigational planning (measured using a zoo mapping test) has previously been found to be related to a reduced ability to successfully navigate a virtual reality shopping environment in older adults (Sangani, Koenig, Kizony, & Weiss, 2013). Spatial planning ability, such as that measured by the Tower of London task (Shallice, 1982) is commonly used as a measure of executive function, along with measuring working memory load for older adults (Phillips, Gilhooly, Logie et al., 2003). Moreover, planning ability measured by the Tower of London has been

shown to be related to a sudden termination of gait in Parkinson's disease (Ferrari, Lagravinese, Pelosin et al., 2015). In addition to motor initiation and the physical ability to begin to cross once a safe crossing gap has been chosen, pedestrian decisions may involve mentally assessing internal capabilities and environmental spatial cues, and judging the consequences of crossing at a given point, that is the essence of planning. In this study, a touch screen version of the Tower of London, the Stockings of Cambridge task (CANTAB) was used to assess spatial planning.

Further, both long and short term spatial memory deficits (i.e. working memory capacity for spatial cues, measured using a block tapping test) have been indicated with increasing age (Piccardi, Iaria, Bianchini, Zompanti, & Guariglia, 2011). Working memory, measured using backwards digit span and visual (spatial) working memory were found to be related to visual attention (Useful Field of View, see below for details), and driving hazard observation measures (Anstey, Horswill, Wood, & Hatherly, 2012), indicating that spatial working memory may also be necessary in successfully navigating a roadside environment. This chapter therefore directly measures the relationship between spatial working memory with near and far side crossing indicators.

Useful Field of View (UFoV^{R}; Ball, Owsley, 1992), measures processing speed (optimal inspection time for central vision), divided attention (optimal inspection time to recognise central and concurrent secondary target), and selective attention (optimal inspection time to identify central and secondary target in the presence of distractors). A measure of visual attention performance, it can be worsened by the presence of distractors, especially if similar in appearance, and shown for a shorter stimulus exposure period. Poorer UFoV performance

has been found to be consistently linked to poor driving outcomes (including retrospective recorded driving incidents, and driving simulator studies), as shown by a meta-analysis by Clay, Wadley, Edwards, et al, (2005) in older adults. These findings suggest that UFoV may be involved in attending to, and processing salient items on the road. In addition, lower UFoV inspection times have been related to physical mobility indices, for example, higher balance levels achieved in older adults (Reed-Jones, Dorgo, Hitchings, & Bader, 2012). As balance has been implied in relation to unsafe crossings (Nagamatsu, et al, 2011), and as pedestrian fatality statistics imply a role of inattention, it could be hypothesised that UFoV may relate to unsafe pedestrian behaviour. Combined with Nagamatsu, et al's (2011) finding that older adults at risk of falling (partially categorised by postural sway) made more near-side crossing errors, this previous research implies that visual attention may be linked to near-side crossing errors. In support of a link between UFoV and pedestrian crossing error, Dommes, Cavallo, & Oxley (2013), and Dommes & Cavallo (2011) found that the reduced processing speed (measured using the UFoV), was an important predictor of total unsafe crossing errors in one and two lane simulated traffic. These authors, however, did not explore whether there was a differential effect of UFoV on near-side and far-side unsafe crossings, despite reported differences in number in pedestrian fatality statistics.

Further executive functions, such as set shifting and inhibition, may also contribute towards unsafe crossing errors. Dommes, Cavallo, & Oxley (2013) found that vehicle time-to-arrival estimates and attention shifting were highly predictive of total unsafe crossing errors. This suggests that perceptual speed and cognition are important, even after including mobility, in predicting total unsafe crossing errors. Dommes & Cavallo, (2011) also found inhibitory executive control (measured using the Go No-Go and Stroop task) to be significantly predictive of unsafe crossings with increasing age, adding an additional 4.1% once UFoV,

/ehicle time to arrival, and walking speed were accounted for. As indicated above, these uthors did not explore whether these different aspects of cognition and mobility contribute lifferentially towards predicting near-side and far-side crossing error.

2.1.4 Within Participant Variability

Age has also been related to increased intra-individual variability in reaction times across trials (i.e. reaction time changeability) (Bunce, MacDonald, & Hultsch, 2004). This variability in cognitive performance is especially apparent when tasks are cognitively demanding (Strauss, Bielak, Bunce, Hunter, & Hultsch, 2007), due to competing attentional processes carrying out the task (Kelly, Uddin, Biswal, Castellanos, & Milham, 2008). Recent research has identified that intra-individual variability in reaction times is negatively related to other cognitive functions such as perceptual speed, working memory, and episodic memory (Bunce, MacDonald, & Hultsch, 2004) and inhibition control (Bellgrove, Hester, Garavan, 2004).

Currently there is a limited amount of research exploring the link between within participant variability in everyday activities (Bunce, Young, Blane, & Khugputh, 2012). Bunce, et al (2012) examined effects of within participant variability (task standard deviation) on simulated driving performance. Inhibition, reaction time, and within participant variability were related to more unsafe distances and variable gaps between themselves and the car in front, along with more deviation in lane position. This variability in cognitive and driver performance increased with age. Given this link between within participant variability and driver road safety margins, and as executive functions previously linked to pedestrian safety also relate to within participant variability, variability may at least partially contribute towards pedestrian crossing errors. As attentional variability in Bunce et al's (2012) study

was related to immediate lane position and safety margin in driving, this suggests that it could be extended to immediate lane (or near-side) crossing decisions. The current study therefore hypothesised that within participant variability may affect crossing accuracy, particularly near-side errors, as a result of potential gaps in vigilance caused by variability.

In summary, it is unclear whether crossing errors are due to issues with mobility and motor control, or to aspects of cognitive function, or a combination. Some of the inconsistencies in previous literature may be due to different mobility and cognitive abilities relating to differing lane error types, given that previous studies examining pedestrian behaviour either use one lane of traffic, or do not separate lane errors in two lane traffic simulations when attempting to investigate risk factors. Although it is clear that there are more far-side crossing errors than near-side with increasing age, near-side errors still occur in this population and so the possibility of differential predictors needs investigation. In addition, little is known about the link between certain aspects of cognitive function such as spatial planning and spatial working memory, with start-up delay, and crossing error. Previous studies have generally focused on fall risk and walking speed, but not on other aspects of physical ability that could affect crossing safety, despite evidence that suggest other mobility abilities may impact on pedestrian success. Further to this, as start-up delay appears to be strong predictor of unsafe crossing behaviours in older adults, and has potential training possibilities, this chapter directly assessed the extent to which cognition or mobility contributes towards start-up initiation time.

With this in mind, a battery of executive function and visual attention and processing speed tests was employed. Additionally, physical capabilities such as postural sway were added.

The purpose of this study was to elucidate the role of specific cognitive functions, visual attention, and motor function markers on components of unsafe crossing, including start-up delay in older age, specifically comparing cognitive with motor predictors of potential collisions in the near- and far-sides of the road using a simulation paradigm.

The hypotheses that were tested were:

1a) There will be a significant covariance between age and the difference in the number of crossing errors in the near- and far- side conditions

1b) There will be significant positive correlations between unsafe crossing behaviours (i.e. near- and far- side errors, and start-up delay) and age and gender (0=male, 1=female)

2a) Better performance in mobility (such as postural sway), start-up delay, and cognitive function (specifically visual attention and within participant variability) will be correlated with reduced near-side unsafe crossing errors.

2b) Better performance in mobility (such as walking speed), start-up delay, and cognitive function (specifically executive functions such as spatial planning) will be correlated with reduced far-side unsafe crossing errors.

3a) Visual attention, within participant variability, mobility and start-up delay will have a strong linear relationship with near-side unsafe crossing errors

3b) Executive functions (specifically spatial planning), mobility and start-up delay will have a strong linear relationship with far-side unsafe crossing errors

4) Cognition, as well as mobility, will have strong linear relationships with start-up delay

2.2 Method

2.2.1 Design

The study uses an experimental design to examine relationships between assessments of cognition and mobility, and road crossing performance in a simulated pedestrian situation. Age is treated as a continuous variable, starting from 45 years and onwards. This age range was chosen as changes in road fatality statistics begin at the age of 60 years (Department for Transport, 2011), and then fatalities increase further after 70 years (Rolinson, Hewson, Hellier, & Husband, 2012).

2.2.2 Plan of Analyses

To measure Hypothesis 1a (There will be a significant covariance between age and the difference in the number of crossing errors in the near- and far- side conditions), a one-way within participants ANOVA and a one-way within participants ANCOVA, in which age was controlled for (to see if controlling for age would remove any differences between lane crossing errors, proportion of near- and far-side errors as the directional factors) were used. Hypothesis 1b (There will be significant positive correlations between unsafe crossing behaviours and age and gender) was measured using correlational analyses. A partial correlation matrix was conducted, controlling for age and gender, to measure Hypothesis 2 a & b (Better performance in mobility (such as postural sway), start-up delay, and cognitive function (specifically visual attention and within participant variability) will be correlated with reduced near- and far- side unsafe crossing errors.). A series of stepwise regressions were employed to test Hypothesis 3a (Visual attention, within participant variability, mobility and start-up delay will have a strong linear relationship with near-side unsafe crossing errors), 3b (Executive functions (specifically spatial planning), mobility and start-up delay will have a strong linear relationship with far-side unsafe crossing errors) and Hypothesis 4 (Cognition,

as well as mobility, will have strong linear relationships with start-up delay). The following variables were entered into the regressions: age, gender, walking speed, self-rated mobility score, sit-to-stand times, perturbation average (transformed), perturbation coefficient of variance (transformed), start-up delay average and start-up delay coefficient of variance (except for the start-up delay regression), processing speed (transformed), divided attention (transformed), selective attention, updating, spatial planning, spatial working memory, inhibition, set-shifting (transformed), reaction time (transformed), and cognitive within participant variability (transformed). Prior to the regressions being performed, checks were made for normality. Variables that did not meet this criterion were transformed using logarithmic transformation. Checks were also made to ensure that the predictors selected did not correlate highly with each other, and that they would not violate the sample-predictor ratio.

2.2.3 Procedure

Participants took part in one assessment session which took approximately two and a half hours. Participants were offered breaks at regular intervals between tasks to avoid fatigue. First, participants filled in a consent form (Appendix 1) and any queries were addressed before continuing. Following the consent form, a self-report demographic mobility questionnaire (Appendix 2) was completed. The Useful Field of View® task was then executed, followed then by the mobility assessments. Next participants completed specific cognitive assessments using the Cambridge Neuropsychological Test Automated Battery (CANTAB®) (tests listed below), and the Pedestrian simulation task. Once the assessment finished, the participant was then debriefed (Appendix 1) about the nature of the study.

2.2.4 Participant Sample

The research sample was obtained from community volunteers, the university volunteer panel, and volunteers from a university optometry clinic. Further community volunteers were contacted through a local University of the Third Age (U3A) group (a trust for retired and semi-retired adults to socialise and share knowledge). Participants received an advertisement, or viewed a poster version (Appendix 1) around the university with instructions about how to opt in to the study.

104 participants were recruited; however, 1 participant was excluded from the analysis as they were unable to complete the pedestrian simulator task, leaving a total of 103 participants in the sample. The sample consisted of participants aged 45-88 years (see Figure 1 for the participant age range and distribution). There were 65 female participants (63.1%). Participant travel expenses were reimbursed for taking part. A power analysis indicated a need to recruit and retain a minimum of 103 participants to enable multiple regression analysis using 7 step predictors at 80% power to detect a moderate effect size (Soper, 2006).

Inclusion criteria for participants included people capable of going out and crossing roads independently; any visual impairment that could be corrected (i.e. using spectacles or contact lenses); reporting no recent head trauma, and not displaying significant cognitive impairment in the cognitive tests.

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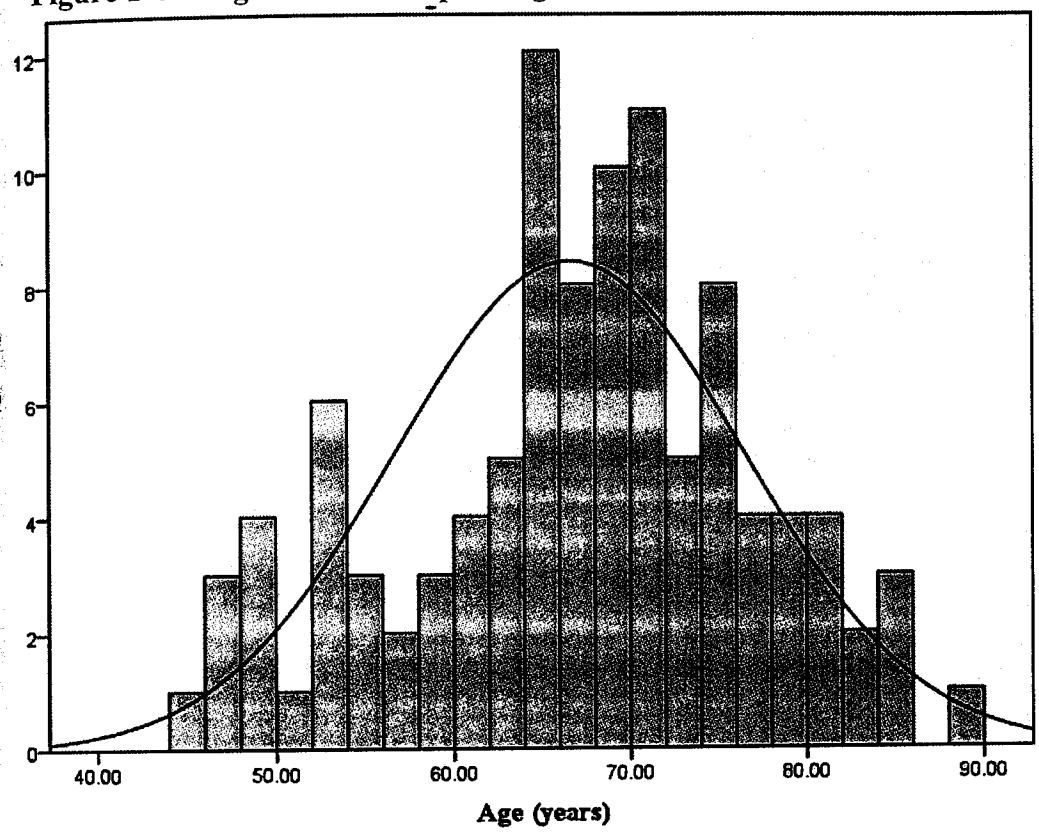
Figure 1- Histogram of Participant Age Distribution



Mean= 66.5 years
Std. Dev. = 9.89
Skewness= -.290
Kurtosis= -.460

2.2.5 Location

The study took place within the University psychology laboratories. The research environment was checked by the Health and Safety Officer for the psychology laboratories before the experiment commenced. Risk assessments for the tasks within this environment were also conducted.

2.2.6 Materials and Test Assessments

2.2.6.1 General Mobility Score & Walking Speed

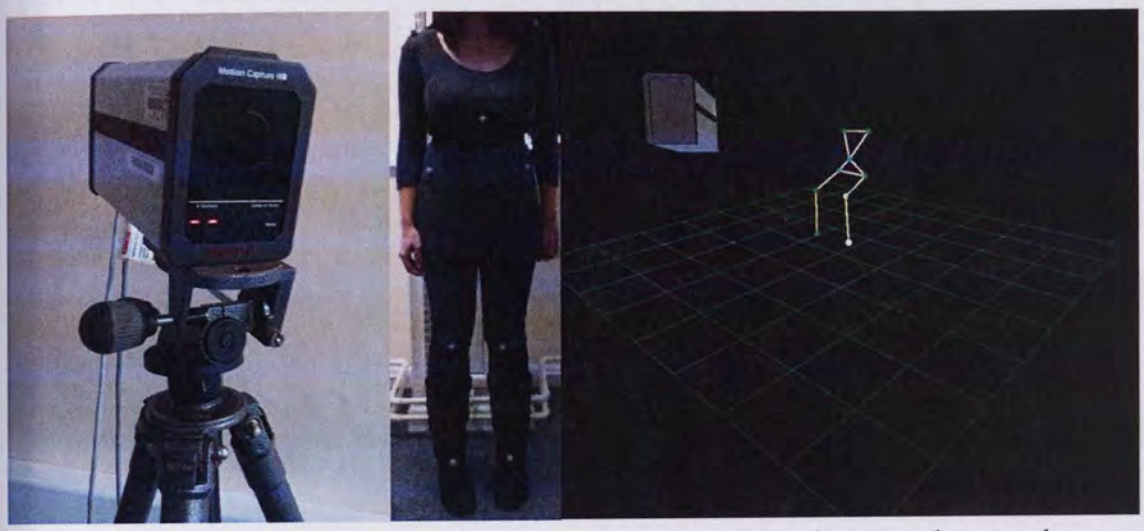
A self-report, paper based mobility questionnaire based on the questionnaire by Holland & Hill (2010) was used to achieve a score for general participant mobility (Appendix 2). This contained questions regarding independence indices including: the ability to walk a quarter of a mile; manage the stairs easily; and information about any illness or injury that may have an impact on their walking. The walking speed task (as used by Holland & Hill, 2010) used a 7 metre walk way to match the width of the road in the simulator task. The use of walking aids was allowed if required. Walking time was measured from the time the participant crossed the starting line using a digital stopwatch. Participants were asked to complete this twice at their normal walking speed and an average of the two measurements was used. The outcome measure was walking speed in metres per second.

2.2.6.2 Sit-to-Stand & Postural Sway

Sit-to-stand time and postural sway were measured by three motion capture cameras using the Qualisys Systems ProReflex Motion Capture Unit (MCU) (Figure 2). This MCU records 120 frames per second (120 Hz). Nine 19 mm non-invasive, passive retro-reflective markers were attached to the left and right shoulder (acromion), the xiphoid process (lower part of the sternum), hips, knees and feet (Figure 2). The perturbation task, (Rochelle, Witton, & Talcott, 2009), was used to measure postural sway and instability. A belt was secured around the participant's waist; attached to the belt were a pulley and a counterweight (5% of participants' body weight). Perturbation was achieved by releasing the weight unexpectedly. The outcome measures were the average anterior-posterior movement from the time of the weight release to resting point, and the individual variability across four trials. The sit-to-stand task is a measure of lower extremity strength and general motor ability (Lord et al,

2002). The outcome measure was the time taken to complete five sit-to-stands from a seated position, without use of hands to push up.

Figure 2- Qualisys Systems ProReflex Motion Capture Unit (MCU).



Left: Image of one of the Qualisys motion capture cameras used to record postural sway and sit-to-stand mobility tasks. Centre: Model showing the positions of the retro-reflective markers. Right: Illustration of a participant sitting during the sit-to-stand task (complete with "bones") using the motion capture cameras.

2.2.6.3 Visual Attention & Executive Function

Visual attention was measured using the Useful Field of View (UFoV; Ball, & Owsley, 1992). The test measures the optimal exposure time in milliseconds to process the stimuli presented and get responses reliably correct. There are three parts to the UFoV test; central vision and processing speed, divided attention, and selective attention. In the first part, the participants were presented briefly with one of two stimuli. The stimulus presented would either be a car or a truck and participants then had to identify which of the two stimuli they had seen. The divided attention task is an extension to this task, where in addition to identifying the central target stimuli (car or truck), the participant must also recall the location of a simultaneously presented peripheral stimulus (a car). The selective attention task is similar to Part two, only there are many distractors (triangles) accompanying the target

stimuli in the periphery of the screen. Three outcome measures were provided: processing speed, divided attention, and selective attention.

To test cognitive function, tests from the Cambridge Neuropsychological Automated Testing Battery (CANTAB®) battery were used (see Figure 3 for an illustration). The CANTAB tests have high test-retest reliability (Cambridge Cognition, 2008). The Stockings of Cambridge (SOC) is a spatial planning test based on the Tower of London (Shallice, 1982) which required participants to manipulate an arrangement of coloured balls to match a target pattern within a limited number of moves, therefore requiring mental planning (see Figure 3 for an illustration). The outcome measure was the difficulty level reached. The Spatial Span (SSP) task was used to test spatial working memory and required participants to remember the order in which squares changed colour. The outcome measure take was the maximum level reached. The Affective Go No-Go Task (AGN) was used as an executive function set shifting task. 'Rules' changed from responding to 'positive' words and ignoring 'negative' words and then the rules reversed. These words were presented briefly on the screen which meant that participants had to process the stimuli and respond quickly. The number of commission errors made (responding to the previous category after a switch) was taken as a measure of difficulty shifting between the sets of target words. The Stop Signal Task (SST) was used to assess executive function inhibition ability. Participants were required to respond whenever they saw an arrow unless a 'beep' was heard immediately before the arrow was presented in which case they had to inhibit their response. The outcome measure for inhibition was the proportion of successful stops was employed to measure response inhibition. The Intra-Extra Dimensional Set Shift (IED) was used to assess updating ability. Updating has previously been used as a measure of executive function (Miyake & Friedman, 2012). This test required participants to figure out which of the patterns on the screen were

the current 'rule' using on screen feedback. As this rule would change without notice, participants needed to remember and update their tactics in order to do well. The outcome measure for updating was the number of extradimensional errors (i.e. revising the rule when the previous rule was no longer correct) was used to measure updating ability when new information has been produced. The Choice Reaction Time (CRT) test required participants to press the left button if they saw a left arrow, and a right button if they saw a right arrow. Participants were encouraged to respond as quickly and as accurately as they could. The outcome measures from the CRT test were the average time taken to respond in milliseconds which provided the reaction time measure and CRT coefficient of variance (CRT standard deviation divided by CRT mean) which provided the within participant variability measure.

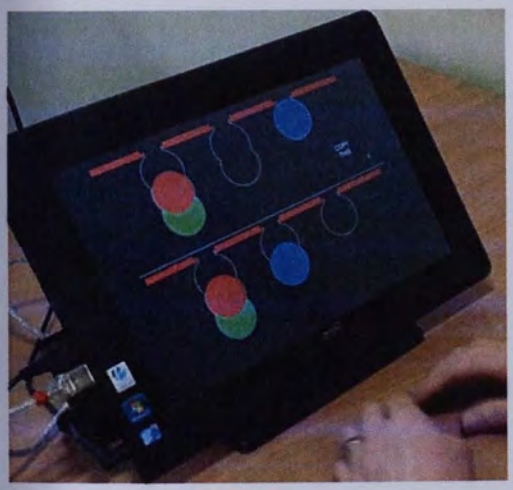


Figure 3- Cambridge Neuropsychological Automated Testing Battery (CANTAB®) battery

Illustration of participant completing the CANTAB Stockings of Cambridge task

2.2.6.4 Pedestrian Behaviour

A pedestrian simulation was employed to measure pedestrian behaviour, as used in the study by Holland & Hill (2010). This consisted of a naturalistic road scene in a city location with two-way traffic in a thirty mile per hour zone. The road location did not have a central reservation or place to stop between the lanes of traffic. The video had been filmed with three angled cameras, and was then shown on three angled screens so as to encourage head turning. Vehicles in the near lane arrived from the right field of visionand vehicles in the far lane arrived from the left. Participants were instructed to notify the experimenter when they felt it was safe to cross the road (i.e. to cross both lanes of traffic) at their normal walking speed by saying "now" and then take a step forward. Each participant was shown the same pedestrian environment, which was 9 minutes long.

The total number of possible crossing gaps for each individual varied according to each person's assessed walking time. The traffic stream was continuous giving all participants the opportunity to choose unsafe gaps. The maximum possible number of safe crossing gaps that could be safely achieved by this sample was 39 and the minimum which could be achieved by even the slowest of walkers was 9. An unsafe crossing was a gap chosen (i.e. when they began to take a step) that could not be crossed at the participant's normal walking speed. To account for the variable number of available crossings between individuals (i.e. between 9 and 39), proportions of unsafe crossings were used as the dependent variable. The proportion of near-side unsafe crossings was calculated as the number of near-side unsafe crossings ('collisions' in the near lane) divided by the total number of crossings made by that person (number of safe crossings and unsafe crossings made). The proportion of far-side unsafe crossings was calculated as the number of far-side unsafe crossings ('collisions' in the far

lane) divided by total crossings made. In addition, start-up delay time (the time taken from a safe gap appearing and the participant starting to cross) was also taken.

Figure 4- Pedestrian Simulator Set-up

Model performing pedestrian simulation task and waiting for a safe gap in which to "cross"

2.2.7 Ethical Considerations

This study was reviewed and approved by Aston University Research Ethics Committee (Appendix 1). Participants that were having difficulty in completing any of the mobility tasks were offered the option of either completing a shortened version of the task or choose to miss it out entirely. Data use and storage complied by the standards of the Data Protection Act (1998).

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2.3 Results

2.3.1 Missing Data

Out of the 103 participants who completed the pedestrian simulator, 5 participants did not complete the perturbation task due to lumbar or back problems, and/or were unable to support themselves independently. 2 of these 5 participants were also unable to complete the sudden stop and the sudden turn due to a concern over stability. Out of the 98 participants who completed all the mobility tasks, 1 participant did not complete the UFoV test, and another participant did not complete the selective attention subtest within the UFoV. In addition, 2 participants did not complete the Affective Go/No-Go, 2 did not complete the Spatial Span, and 1 did not complete the Stop Signal Task. The missing values within the multiple regression analysis were replaced with mean values (Rubin, 2004).

2.3.2 Pedestrian Crossings Overview

The minimum available safe crossing gaps for this participant sample was 9 and the maximum available was 39 (Table 1). Table 1 suggests that some participants in the sample either did not always take advantage of all the safe crossing gaps available, or they may have begun crossing too late meaning that that these gaps were no longer safe to cross in. In addition, all participants in this sample made at least 1 but no more than 12 unsafe crossing errors.

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Table 1- Means, Standard Deviations and Proportions of Available Pedestrian Crossings and Unsafe Crossing Behaviours

(N=103)		Available Safe Crossings	Crossings Made	Unsafe Crossings Made	Near-Side Unsafe Crossings	Far-Side Unsafe Crossings
Total	Minimum	9	10	1	0	0
	Maximum	39	27	12	6	9
	Mean (SD)	32.62 (5.64)	19.12 (3.75)	2.53 (2.35)	1.17 (1.55)	1.37 (1.31)
Proportion	Minimum			.04	.00	.00
	Maximum			.63	.26	.38
	Mean (SD)			.13 (.11)	.06 (.07)	.07 (.06)

SD= Standard Deviation

2.3.3 Hypothesis 1a: There will be a significant covariance between age and the difference in the number of crossing errors in the near- and far- side conditions

When the proportion of near-side and far-side lane crossing errors were compared without controlling for age, a significantly higher proportion of far-side unsafe crossing errors were found (mean proportion= .073, SD=0.06) compared to near-side errors (mean proportion= .057, SD=0.07) ; F (1, 102) = 4.574, p<.05. When age was entered as a covariate, this difference between near and far-side unsafe crossings was no longer found (F (1, 101) = 0.276, p>.05).

These results suggest that age is a significant covariant for this difference in lane crossing errors. However, lane error and age were found to be independent of each other (interaction effect of age x direction is not significant; F (1, 101) = 0.717, p>.05). As age did not interact with lane direction, and error proportion differences wee removed once age has been controlled for, these results support the above hypothesis that there is an age effect on unsafe crossings direction.

2.3.4 Hypothesis 1b: There will be significant positive correlations between unsafe crossing behaviours (i.e. near- and far- side errors, and start-up delay) and age and gender (0=male, 1=female)

Correlation analyses showed that gender (0=men, 1=women) was significantly positively related to proportion of near-side unsafe errors and total unsafe errors; in both conditions women made more crossing errors than men. Gender was not significantly correlated with far-side errors or start-up delay. Age on the other hand was positively correlated to more far-side and total unsafe errors but not to more near side errors (see Table 2 for the Age, Gender, & Pedestrian Behaviour matrix). Age but not gender was correlated with longer start-up delays. To conclude, gender (specifically women) and increasing age were found to be correlated with different aspects of unsafe crossing behaviours.

Table 2- Correlation Matrix Age and Gender with Pedestrian Behaviour Measures

Variables (N=103)	Age	Gender
Start-up Delay	.233*	.053
Prop. Unsafe Crossings	.219*	.234*
Prop. Near-Side Unsafe	.126	.224*
Prop. Far-Side Unsafe	.228**	.102

*= Significant at .05 level **=Significant at .01 level

2.3.5 Hypothesis 2a: Better performance in mobility (such as postural sway), start-up delay, and cognitive function (specifically visual attention and within participant variability) will be correlated with reduced near-side unsafe crossing errors.

Correlation analyses, controlling for age and gender to partial out effects found in Hypothesis 1, are shown in Table 3. Near-side and total errors were found to be significantly related to start-up delay variability, perturbation variability and also a non-significant trend was found with inhibition ($p = .075$). Worsened walking speed performance was related to larger proportions of near-side unsafe crossings only. Visual attention and within participant

variability, however, were not found to be related to near-side unsafe crossing errors. These results partially support the above hypothesis as although postural sway, start-up delay and within participant variability were not found to be directly significant, a significant relationship with within participant variability in postural sway and within participant variability in start-up delay were found instead. Worsened mobility in terms of slower walking speed, within participant variability in certain tasks and a possible link with slower inhibition reaction times suggest that mobility and cognition may be important in the occurrence of near-side unsafe crossing errors.

2.3.6 Hypothesis 2b: Better performance in mobility (such as walking speed), start-up delay, and cognitive function (specifically executive functions such as spatial planning) will be correlated with reduced far-side unsafe crossing errors.

Correlation analyses, controlling for age and gender to partial out effects found in Hypothesis 1, are also shown in Table 3. Slower walking speed, slower sit-to-stand times and higher perceived mobility difficulty were found to be significantly correlated with a higher proportion of total, and far-side unsafe crossing errors. Total and far-side errors were also related to start-up delay average. Far-side errors only showed a trend (p=.066) with selective attention. Executive functions including spatial planning, however, were not found to be related to far-side unsafe crossing errors. Start-up delay, on the other hand, was negatively related to walking speed, and positively related to mobility score, sit-to-stand times and reaction time, indicating both mobility and cognitive elements to a delay in initiating movement. These results support the above hypothesis in that better performance in mobility, start-up delay and cognitive function may be related to a lower proportion of far-side unsafe crossing behaviours. Start-up delay, however, was linked to reduced mobility and reaction time.

Table 3- Partial correlation Matrix of Mobility, Start-up Delay, and Cognitive Function, with Pedestrian Behaviour Measures, controlling for Age and Gender

Variables (N=103)	Start-up Delay	Start-up Delay COV	Walking Speed	Mobility Score	Sit to Stand	Pert Ave	Pert COV	PS	DA	SA	Spatial Span	SWM	In	Up	Set Shift	RT	WPV
Start-up Delay			-.524**	.351**	.324**	.158	.054	.138	.131	.162	.015	-.130	.079	.156	.056	.245*	-.082
Prop. Unsafe Crossings	.253*	.506**	-.438**	.243*	.182m	.085	.264**	.055	-.001	.138	.108	-.007	.216*	.075	.017	.060	.087
Prop. Near-Side Unsafe	.058	.583**	-.233*	.137	.062	.015	.247*	.103	-.011	.082	-.001	.057	.198m	.029	.017	-.026	-.003
Prop. Far-Side Unsafe	.552**	.053	-.614**	.351**	.405**	.134	.123	-.054	.005	.190m	.172	-.038	.069	.171	.098	.172	.133

*= Significant at .05 level **=Significant at .01 level m=marginally significant (p=.051-.075)

Ave= Average, COV= Coefficient of Variance, Pert= Perturbation, PS= Processing Speed, DA= Divided Attention, SA= Selective Attention, Spatial Span= Spatial Planning, SWM= Spatial Working Memory, In= Inhibition, Up= Updating, SetS= Set Shifting Commissions, RT= Reaction Time, WPV= RT Within Participant Variability

2.3.7 Hypothesis 3a: Visual attention, within participant variability, mobility and start-up delay will have a strong linear relationship with near-side unsafe crossing errors

A stepwise regression was conducted to determine the predictors of near-side unsafe crossing behaviour. The following variables were entered into the model: age, gender, walking speed, self-rated mobility score, sit-to-stand times, perturbation average (transformed), perturbation coefficient of variance (transformed), start-up delay average, start-up delay coefficient of variance, processing speed (transformed), divided attention (transformed), selective attention, updating, spatial planning, spatial working memory, inhibition, set-shifting (transformed), reaction time (transformed), and cognitive within participant variability (transformed). The steps and order of entry produced by the stepwise regression for near-side crossing can be seen in Table 4. The overall model for near-side crossing errors was significant (F (3, 97) = 31.506, p <.001), and explained 49.4% of near-side crossing variance (see Table 4). All three steps were significant step changes: Model 1 start-up delay (F (1, 99) =61.208, p<.001); Model 2 mobility (F (1, 98) =14.107, p <.001); Model 3 visual attention (F (1, 97) =6.455, p=.013). Model 1 alone contributed 38.2% of the variance in near-side unsafe crossings, whereas walking speed and processing speed contributed an additional 7.8% and 3.4% respectively.

Table 4- Predictive Contribution of each Step in explaining Total Proportion of Near-Side Unsafe crossing variance

Model Steps	Variable	R^2	^ R^2	Beta	Sig.
1 Start-up Delay	Start-up Delay COV	.382**	.382**	.618**	<.001
2 Mobility	Start-up Delay COV	.460**	.078**	.631**	<.001
	Walking Speed			-.279**	<.001
3 Visual Attention	Start-up Delay COV	.494**	.034*	.647**	<.001
	Walking Speed			-.242**	.001
	Processing Speed			.188*	.013

*= Significant at .05 level **=Significant at .01 level ^ R^2= R^2 change COV= Coefficient of Variance

COV= Coefficient of Variance

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2.3.8 Hypothesis 3b: Executive functions (specifically spatial planning), mobility and start-up delay will have a strong linear relationship with far-side unsafe crossing errors

Another stepwise regression was conducted to measure predictors of far-side unsafe crossings. The same variables were entered as the near-side crossing regression. For this regression the steps and order of entry produced by the stepwise regression can be seen in Table 5. The total model for predicting the proportion of far side crossings was significant (F (4, 91) = 27.528, p<.001), and accounted for 54.8% of the variance (see Table 5). All four steps were significant step contributors: Model 1 mobility (F (1, 94) =66.482, p<.001); Model 2 start-up delay average (F (1, 93) =12.824, p=.001); Model 3 start-up delay coefficient of variance (F(1, 92) =8.103, p=.045); Model 4 cognition (F (1, 91) =4.143, p=.045). Model 1 alone contributed 41.4%. Start-up delay Steps 1 and 2 contributed an additional 7.1% and 4.2% respectively. Spatial planning explained and additional 2.1% once mobility and start-up delay steps had been accounted for.

Table 5- Predictive Contribution of each Step in explaining Total Proportion of Far-Side Unsafe crossing variance

Model Steps	Variable	R^2	^ R^2	Beta	Sig.
1 *Mobility*	Walking Speed	.414**	.414**	-.644**	<.001
2 *Start-up Delay 1*	Walking Speed	.485**	.071**	-.467**	<.001
	Start-up Delay Ave			.319**	.001
3 *Start-up Delay 2*	Walking Speed	.527**	.042**	-.426**	<.001
	Start-up Delay Ave			.412**	<.001
	Start-up Delay COV			.218**	.005
4 Cognition	Walking Speed	.548**	.021*	-.425**	<.001
	Start-up Delay Ave			.424**	<.001
	Start-up Delay COV			.223**	.004
	Spatial Planning			.144*	.045

*= Significant at .05 level **=Significant at .01 level ^ R^2= R^2 change RT= Reaction Time

COV= Coefficient of Variance Ave= Average

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In summary hypothesis 3 was supported in that visual attention (processing speed), within participant variability in start-up delay and mobility (walking speed) predicted near-side unsafe crossing error variance (Table 4). In addition, far-side unsafe crossing variance was predicted by spatial planning, start-up delay performance, and mobility (walking speed) (Table 5). These results suggest some commonality in the mobility measures predicting unsafe crossing variance, but also differences in the important cognitive predictors for lane-specific unsafe crossings.

2.3.9 Hypothesis 4: Cognition, as well as mobility, will have strong linear relationships with start-up delay

As both the literature and the above regressions suggest that start-up delay is highly predictive of crossing errors, a stepwise regression was used to determine the extent to which mobility and/or cognition predict start-up delay. Stepwise regression only selected walking speed as a step predictor. Walking speed produced a significant model ($F(1, 100) = 43.810$, $p < .001$) and predicted 30.5% of start-up delay variance (see Table 6). In summary the hypothesis was only partially supported as mobility, but not cognition, was predictive of start-up delay.

Table 6- Predictive Contribution of each Step in explaining Total Proportion of Start-up Delay variance

Model Steps	Variable	R^2	Beta	Sig.
Mobility	Walking Speed	.305**	-.552**	<.001

*= Significant at .05 level **=Significant at .01 level Ave= Average

2.4 Discussion

The purpose of the study was to examine the contributions of cognitive and mobility functions on pedestrian crossing errors, specifically differentiating those which would have resulted in a collision in the near or far side of the road. In addition, the contributions of these indices as predictors of start-up delay were explored.

In line with pedestrian fatality statistics, a higher proportion of far-side errors were made than near-side errors in this sample. Once age was controlled for, this difference was no longer found, suggesting that this effect is at least partially related to age. In addition, age was positively correlated with proportion of far-side unsafe errors only, showing that older age is related to more far-side than near-side crossing errors (Oxley, et al, 1997; Dommes & Cavallo, et al, 2014), and more crossing errors in general (Holland & Hill, 2010; Dommes, Cavallo & Oxley, 2014). Gender was also found to be important, supporting Holland & Hill (2010)'s findings, although this was only found for near-side crossing errors and not far-side errors. This suggests that older women are liable to more near-side errors than men, but they are equally likely to make far-side crossing errors. This may be as a result of driving experience, as suggested in Holland & Hill's research, whereby a relationship was found between increased years of driving experience in women and reduced number of unsafe crossing decisions made. In this previous research, as driving experience was not found to make a significant impact on unsafe crossing decisions for men.

A salient finding of this study was that walking speed was a significant predictor in all unsafe crossing behaviours (near-side, far-side, and start-up delay) replicating findings by Holland & Hill (2010), and Dommes, Cavallo, & Oxley (2013). Walking speed remained a constant

predictor throughout for proportion of far-side errors, near-side errors, and start-up delay. Self-rated mobility score was also found to be related to all unsafe crossing behaviours (near-side, far-side, and start-up delay), and sit-to-stand time was found to be related to all but near-side unsafe crossing errors. Near-side unsafe crossing errors also differed in that a non-significant trend was found with perturbation variability suggesting that balance ability is also an important predictor for near-side unsafe crossings. These results support findings reported by Nagamatsu et al. (2001) whereby a relationship was found between unsafe crossings and balance. This may suggest that physical frailty may be an important predictor, not just of fatality in any given collision, but also of the likelihood of those collisions to begin with. These findings are consistent with the hypothesis that mobility difficulties contribute towards unsafe crossings decisions and behaviour.

Another important finding was that motor control components had strong and differential predictive power for specific lane crossing errors. Start-up delay was found to be a significant predictor for far-side errors, but not for near-side errors. This supports previous findings that start-up delay is a significant contributor in unsafe crossings (Holland & Hill, 2010; Dommes & Cavallo, 2012; Tomson et al, 2005). Start-up delay variance (start-up delay coefficient of variance), and not start-up delay average predicted both far-side and near-side errors. This suggests that variability in start-up delay has a negative impact on crossing errors. These differential patterns may be useful in predicting and treating at risk pedestrians for specific lane risk. Although cognitive within participant variability was not related to or predictive of near-side or far-side errors, within participant variability in start-up delay was found to be predictive for both crossing error types. These results partially support the notion that within participant variability can impact on safety on roads (Bunce, et al., 2012), but here this is related to motor initiation variability.

However, other measures of cognition played a significant and differential role in specific lane crossing errors. UFoV (specifically processing speed) was predictive of near-side unsafe crossing behaviour, even though a correlational relationship was not found. This confirms findings by Dommes, Cavallo, & Oxley (2013) for the role of visual attention (UFOV) in total crossing error, but specifies this into an effect on near-side errors, supporting predictions that visual attention has a differential relationship with specific lane crossing errors.

A significant relationship was also found between inhibition and total unsafe crossings, and a trend was found between inhibition and near-side unsafe crossing errors, but not for far-side unsafe crossing errors. These results partially support and extend findings by Dommes & Cavallo (2011) who found predictive relationships between inhibition and total unsafe crossings (using the Stroop measure of inhibition). The stop signal task used to measure inhibition was assumed to be directly analogous to refraining from stepping out on the near side of the road when near traffic is perceived and the differentiation of the relationship between directions of traffic supports this.

Spatial planning, but not spatial working memory, was predictive of far-side crossing errors only. This confirms that the component of spatial information processing that is involved in making road crossing decisions is executive planning function. Although previous research has indicated that spatial planning is related to a freezing of gait in patients with Parkinson's Disease, (Ferrari, Lagravinese, Pelosin et al., 2015), planning ahead was not associated with start-up delay in this study with a healthy population.

In summary, mobility (specifically walking speed), and motor control measures (start-up delay average and/or coefficient of variance) were important and consistent predictors for unsafe crossing errors (total, near-, and far-side). Visual attention (UFOV, specifically processing speed) and spatial planning were also differential contributors to specific lane crossing errors, with visual attention being linked to near-side errors, and spatial planning being linked to far-side errors. Motor control also appears to be strongly affected by walking speed. These results have implications for prediction and training purposes for pedestrian safety with increasing age, with different patterns emerging for men and women.

2.4.1 Limitations

Despite frequent breaks being offered to participants, as the session lasted 2.5 hours, fatigue effects may have been present, and thus on occasion full concentration may not have been paid to the pedestrian, cognitive and mobility tests. Although the laboratory simulated roadside environment allowed for better control over the variables, and enabled the testing of cognitive and mobility abilities, participants may have behaved differently in a real-world environment (i.e. when not knowingly being observed, and when a real risk is present). Some of the older adults sampled mentioned that they were not a supporter of "jaywalking" and much preferred using the designated crossings available, even if they felt it was safe to cross. For these older adults, they may be inexperienced or over-cautious in judging the road in the task as a result. However, this study provides a more realistic road-side setting than some other current research as it uses a two-way crossing simulation as opposed to one, plus it uses both visual and auditory cues coming from three directions rather than one. Some of the crossings deemed to be unsafe here in this simulated environment may not necessarily have resulted in collisions in a real-life as the vehicle or the pedestrian may have taken evasive action. Driving experience data, however, was not collected nor accounted for. Older adults

with longer driving experience may be more familiar with road planning judgements. Holland & Hill (2010) found that increased years of driving reduced the number of simulated unsafe crossing errors made in older women. Future research may benefit from determining if this variable can predict more unsafe crossing variance than mobility and cognitive factors.

2.4.2 Conclusion and Future Directions

To conclude, age was only found to be a minor factor in unsafe crossing behaviour (lane errors). Rather, walking speed, motor initiation and variability, planning and aspects of attention were significant. Practical implications for this are that these elements cane be measured and trained or rehabilitated. Walking speed was identified as an important predictor of unsafe crossing behaviour and start-up delay suggesting that it may be worth exploring the predictive components of walking speed separately. This was investigated in Chapter 3. Future research may wish to use a longer video simulation/road exposure technique, closer to the time of an average trip travelled by older adults, to see if any of the cognitive and visual attention factors become significantly predictive. Separate sessions may also be useful to reduce fatigue effects. Alternatively, another factor that has not been explained or accounted for, that cannot be linked to age, may be present in this group (e.g. modal mode of transport and driving history) which could be explored.

3 Identifying predictors of walking speed and fall prevalence in older adults

Objective

The purpose of this study was to determine the extent to which walking speed (indicated as a salient predictor of unsafe crossings and start-up delay in Chapter 2), and previous falls can be predicted and explained by age-related changes in motor initiation, mobility and cognitive function changes (specifically within participant variability and spatial ability).

Methods

This study used participant data collected in Study 1 (Chapter 2) to determine predictors of walking speed and previous falls. The dependent measures included were mobility (self-rated mobility, sit-to-stand and postural sway), start-up delay, and cognitive tests measuring executive function, visual processing & attention (UFoV®).

Results

A stepwise regression model determined that mobility (self-rated mobility score and sit-to-stand times), start-up delay, and within participant variability produced a significant model which accounted for 53.2% of walking speed variance. A stepwise logistic regression conducted for falls did not produce a significant model. However, set shifting and postural sway (perturbation average) were identified as significant independent and step predictors of previous falls, and together explained 9-13.9% of fall variance.

Conclusion

Both walking speed and falls have mobility and cognitive components, suggesting that these measures are more complex than just a result of physical decline. This could have implications for treatment for pedestrian errors, falls, and the onset of frailty in older adults.

3.1 Introduction

Results from Chapter 2 indicated that walking speed was consistently shown to be predictive of, and related to pedestrian errors, and the sole predictor of start-up delay. In addition to pedestrian fatalities, walking speed has also previously been linked to reduced independence, frailty, disability, and nursing home admittance (1.1). Another major cause of death and disability in older adults are falls (1.1) and can lead to further frailty due to activity avoidance (1.4). These findings suggests that walking speed and falls are important factors of disability, death, and well-being with increasing age and worthy of being investigated further.

It is unclear whether walking speed and falls are due to mobility decline (i.e. physical frailty) and reduced motor initiation, or as a result of cognitive impairments, or a combination of all three. Currently, tenuous research has been conducted into the potential role of spatial planning and spatial working memory in relation to mobility (including falls), despite previous evidence of other spatial abilities being linked to walking speed such as visuo-spatial switching (Hawkes, Siu, Silsupadol, & Woollacott, 2012), and spatial mental rotation ability being linked to balance (Jansen & Kaltner). Also, emerging research has linked attentional within participant variability with falls, although currently relationships with walking speed have been inconsistent. This chapter examined the predictive contributions of mobility, motor control, and cognitive function (especially within participant variability, spatial planning and spatial working memory) with walking speed and fall prevalence.

3.1.1 Mobility Difficulties, Motor Control and Falls in Older Adults

Human gait consists of a complex combination of stance and swing phases. Gait requires the following three components: progression, postural control, and adaptability for successful locomotion. Whilst in the support phase, one must be able to progress in a horizontal direction, and withstand gravitational forces (postural control). With an ever changing environment, one must be able to make alterations to movement if necessary (adaptation). During the swing phase, one must first progress forward with the leg swing, then relocate the leg ready for the rest of the trunk weight (postural control). The individual must also be able to adapt the leg swing to avoid potential obstacles (Shumway-Cook & Woolacott, 2011).

Lower extremity muscle strength has previously been found to negatively affect on walking speed in disabled older adults (Cuoco, Callahan, Sayers, et al., 2004; Bean, Kiely, Herman, et al., 2002). A combination of both reduced lower extremity strength and poor standing balance was found to predict reduced walking speed 3 years later in women, even when age, height, weight, and race was accounted for (Rantanen, Guralnik, Ferrucci, et al., 2001). In a review by Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo (2012) they found that a combination of strength, endurance, and balance training was successful in improving both walking speed and balance, and in reducing fall numbers in frail older adults. These results suggest that mobility, particularly balance and lower extremity strength, is important in maintaining a healthy walking speed. In addition to general mobility decline, increased start-up delay has been related to a reduction in mobility measures, such as walking speed in older adults (Holland & Hill, 2010).

Falls frequently occur in older adults while walking as a result of external factors, such as slipping, tripping, obstacles, and losing footing on a staircase (Niino, Tsuzuku, Ando, & Shimokata, 2000), or as result of reduced postural control (Ambrose, Paul, & Hausdorff, 2013). Reduced walking speed, and stride variability has been found to predict falls in older adults (mean age= 80.5 years, SD= 5.4), even when controlling for cognitive impairment and reported disability (Verghese, Holtzer, Lipton, & Wang, 2009). Further, poorer gait such as slower speed and increased variability was found to predict recurrent falls (Callisaya, Buzzard, Schmidt, et al, 2011). This indicates that mobility, including walking speed, is an important risk factor in the onset and recurrence of falls.

Previous research has uncovered relationships between a delay in beginning movement (start-up delay) and unsafe pedestrian crossing errors, an everyday application of mobility (see Chapter 2 for a review). A slowing of motor initiation may also contribute towards other types of mobility difficulties presented within older adults. Walking time, sit-to-stand, and self-reported mobility difficulties have been found to be negatively associated with start-up delay (Holland & Hill, 2010). With relationships being found between falls and walking speed (Ambrose, et al., 2013), start-up delay could also be relevant in predicting the likelihood of falls. In summary, walking speed and falls are at least partially explained by a reduction in mobility, although the relationship between start-up delay and falls is as yet unclear. This chapter examined the predictive contributions of mobility and start-up delay for walking speed and falls once cognition has been accounted for.

3.1.2 Attentional Resources linked to Walking Speed and Falls in Older Adults

In addition to increasing age-related mobility difficulties, cognition has also been found to play an important part in effective mobility. As indicated in section 1.2, there is a global deterioration and slowing in the brain with age (Salthouse, 1996), and thus there are fewer attentional resources available to perform complex tasks (Park & Schwarz, 2000). Baltes and colleagues posited the life span theory of selection, optimization, and compensation (SOC), whereby they suggested that older adults specifically recruit cognitive and attentional resources in order to compensate for these age-specific areas of decline, and optimise a given task, thereby reducing losses and increasing gains (Baltes & Carstensen, 1996; Baltes, 1997). If mobility function such as walking were automatic as previously speculated (Hausdorff, Yogev, Springer, et al., 2005), then a simultaneous cognitive task (otherwise known as dual tasking, see Chapter 1, section 1.2 for more information) would not impact on mobility performance.

However, dual tasking studies have indeed demonstrated that additional cognitive tasks do impact on mobility performance. Li, Lindenberger, Freund, & Baltes (2001) tested this theory of selectively optimising and compensating in relation to dual task ability. Participants (younger: 20-30 years, and older: 60-75 years) were required to walk along a narrow track whilst completing a secondary cognitive task (memorising a list of words). Results showed dual-task costs in older adults to the memorising task whilst simultaneously walking compared to their performance in the single-task memorising condition. Further, when given the option between having a walking aid or a memory aid for during a second attempt, older adults prioritised walking by accepting a walking aid rather than accepting a memory aid. Younger adults in comparison chose memory aids. These findings suggest that there is an underlying cognitive process that is present when walking (Srygley, Mirelman, Herman, et

al., 2009) and that older adults require additional attentional resources for walking with advanced age.

In addition to cognitive task performance suffering due to dual-task interference, walking speed has been found to reduce whilst performing a cognitive task (Theill, Martin, Schumacher, Bridenbaugh, & Kressig, 2011), along with stride length and individual step speed variability becoming even more pronounced (de Bruin & Schmidt, 2010). Dual tasking has also been found to have a large negative impact on falls (Ambrose, et al, 2013), along with balance (systematic review by Ruffieux, Keller, Lauber, & Taube, 2015; Van Iersel, Kessels, Bloem, et al., 2008), especially when the cognitive task rules changed (attention switching) (Hawkes, Siu, Silsupadol, & Woollacot, 2012).

Hawkes, et al. (2012) conducted a dual-task paradigm with two difficulty levels: auditory stroop with no rule change, and auditory stroop with a rule change. These results were then compared to age, balance ability, and performance on an executive function visuo-spatial set shifting task. Dual task difficulties, i.e. the slowing of reaction times in the cognitive task, were found to be poorer when the rules were changed in the cognitive task whilst walking, especially in those with poorer balance. In addition, dual-task difficulty was related to slower set shifting reaction times, increasing age, poorer balance and slower timed-up and go times. The authors suggest that these findings are as a result of slower attentional switching between cognitive and mobility tasks with increasing age, especially when mobility is impaired. In addition to reduced attentional resources, these results indicate that executive function (set shifting) is involved in reduced balance and gait.

These studies support the notion that attentional reserve is related to gait, balance, and falls. However, they also implicate a role of executive functions, such as set shifting in the trail making test and spatial visualisation in the block design test, and alternate attentional capabilities, such as attentional set shifting and attentional speed. This study investigated the extent to which cognition and attention could explain walking speed and falls in older adults. The attentional measures examined in this study were visual attention (section 3.1.2.1) and within participant variability (section 3.1.2.2).

3.1.2.1 Visual Attention

In addition to a difficulty with divided attention (evident in dual tasking studies, see 3.1.2.1), an ever increasing global slowing of processing speed is also found with increasing age as a result of reduced attentional resources and, as a result, increased demand for such resources (Salthouse, 1996). Prioritisation and reorganisation of these attentional resources occur in order to provide the same level of performance (Lindenberger, Marsiske, & Baltes, 2000; Greenwood, 2007).

The useful field of view test (UFoV; Ball, Owsley, 1992), a measure of visual attention measures optimal central vision/ processing speed, divided attention, and selective attention inspection times (see Chapter 2 for more details). Age-related visual attention change has also been linked to certain aspects of mobility decline. Owsley & McGwin (2004) examined the role of visual attention (using a composite score of all three subtests: processing speed, divided attention, and selective attention) on mobility. UFOV (composite score) was found to be significantly related to self-reported mobility difficulties (particularly in balance and gait), composite mobility scores (Performance Oriented Mobility Assessment, POMA composite mean rated performance score of balance, gait, and sit-to-stand activities), and fear of falling

(Falls efficacy score). When adjusted for age, gender, race, education, medical and visual conditions, cognitive status, and depressive symptoms, only the POMA mobility composite scores remained significantly predicted by UFOV. This composite mobility performance score suggests that visual attention may be important in separate balance, gait, and chair rise performance times. When the UFOV subtests were tested separately, a significant relationship was found between divided attention and POMA mobility composite score only.

When balance was measured separately (using the Nintendo WiiFit Balance test) in a study by Reed-Jones, Dorgo, Hitchings, & Badar (2012) divided attention was not found to be related to the balance level achieved and time taken to reach each level, rather reduced balance ability was related to the UFOV processing speed subtest only. This could indicate that different visual attention elements are important for different aspects of mobility. These findings into visual attention imply that reduced performance on visual attention subtests, particularly processing speed and divided attention, are associated with increased mobility difficulties and navigation of surroundings. This chapter directly assessed postural perturbations, walking speed, chair rises, and falls in relation to visual attention to determine if visual attention differentially related to different measures of mobility.

3.1.2.2 Cognitive Within Participant Variability

In addition to visual attention, increased within participant variability in reaction times across trials, i.e. reaction time changeability, (Bunce, MacDonald, & Hultsch, 2004) found with age may also be related to mobility difficulties and falls. In a study by Bunce, Anstey, Christensen, Dear, Wen, & Sachdev (2007) 469 older adults aged 60-64 years took part in a variety of cognitive tests including a simple reaction time, choice reaction time, backward digit span, memory (California verbal learning test and a delayed recall trial), word knowledge (spot the word test), and global cognition (Mini Mental State Examination) and measured white matter hyperintensities by measuring white matter lesions using magnetic resonance imaging (MRI).

Within participant variability was derived from the average deviations of the simple and choice reaction time tests. White matter hyperintensities were associated with increased reaction time within participant variability in older adults, but not the other measures of cognitive function. As white matter hyperintensities have previously been linked to mobility (Novak, Haertle, Zhao, et al., 2009), it could be suggested that within participant variability could also be associated with mobility difficulties with increasing age.

In support of this notion, increased within participant variability has also been found in older fallers compared with older non-fallers. Hausdorff, Doniger, Springer, et al. (2006) found similarities between fallers and participants with Parkinson's disease across cognitive tasks (Neurotrax Mindstreams cognitive battery), however, fallers were found to be more erratic in their reaction times (i.e. more variable within participant variability). The authors suppose that these erratic reaction times may be due to a unique cognitive processing deficit (Hausdorff, et al., 2006). Bunce, Barrowclough, & Morris (1996) believes that changeable reaction times are due to these older adults having larger vigilance/monitoring gaps and unusually slow reaction times.

As falls were linked to within participant vigilance variability, and falls have been linked to mobility difficulties (see 3.1.1) it could also be supposed that within participant variability affects mobility. In a systematic review by Graveson, Bauermeister, McKeown, & Bunce (2015), it was found that out of all the papers sampled, falls in older adults were related to within participant variability every time without fail. The relationship between within participant variability and walking speed, on the other hand, demonstrated a significant predictive relationship in only two out of the total of four relevant papers sampled. However, the authors speculate that the inconsistencies in studies could be as a result of differing

sample sizes, and also as a result of the way that within participant variability was calculated. The papers that did not yield significant results used a raw standard deviation score as opposed to a more sophisticated coefficient of variance score (removing the confounding influence of the mean from the standard deviation). What is evident in this review is that limited published research has been conducted into within participant variability and mobility. This study determined the extent to which within participant variability can contribute to walking speed and falls using the more sophisticated coefficient of variance score method.

3.1.3 Executive Functions linked to Mobility Difficulties and Falls in Older Adults

Executive functions (EFs) decrease with increasing age (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010) and there has been evidence linking EFs with changes in mobility function. In a review by Yogev-Seligmann, Hausdorff, & Giladi (2007) it is suggested that updating (or response monitoring) could be an important factor in navigating everyday environments as without it, and without it interacting with other areas/functions, one would not be able to stop if needed, turn, or modify speed with the presence of an oncoming obstacle. Updating (in this case, working memory) has previously been linked to slower walking speed and worsened dual-task performance (Theill, Martin, Schumacher, Bridenbaugh, & Kressig, 2011). In addition, Yogev-Seligmann et al. (2007) speculate that updating could also be linked to increased fall risk. However, little research has been conducted into the role of updating in relation to falls. This study directly assessed the predictive relationship between falls and updating, and he extent to which updating can explain walking speed once other mobility and cognitive measures have been accounted for.

There has also been evidence for the role of response inhibition and set shifting (changing focus) in successful mobility performance (Liu-Ambrose, Katarynych, Ashe, et al., 2009).

Liu-Ambrose, et al. (2009) uncovered a relationship between set shifting (Plus-minus task), response inhibition (Stroop test), and poor balance performance in both single and dual task walking tests. Set shifting ability (measured using trail making task) was also related to a slowing of walking speed in older adults (Soumare, Tavernier, Alpérovitch, et al., 2009). Participants with a recent history of falls performed more poorly than non-fallers on measures of Stroop and Go-No Go tests (both measures of response inhibition). In addition, deficits in these measures were related to walking swing time variability. This was exacerbated in a dual task scenario (Springer, Giladi, Peretz, et al., 2006). However, it is unclear how much of walking speed and falls can be explained by set shifting and inhibition once attentional measures, mobility, and start-up delay have been accounted for. This chapter examined the extent to which executive functions such as inhibition and set shifting cam predict walking speed changes and falls in older adults.

Planning ability, such as that measured by the Tower of London task (Shallice, 1982) is another executive function that may affect mobility, falls, and unsafe crossing behaviour. However, as identified in Chapter 1, there has been little research into the role of spatial ability (i.e., spatial planning and spatial working memory) in relation to mobility, such as walking speed and falls. This is despite previous research uncovering relationships between spatial planning sub-processes such as visuo-spatial set shifting with walking speed (Hawkes, Siu, Silsupadol, & Woollacott 2011), and spatial mental rotation ability with balance ability (Jansen & Kaltner, 2014).In addition, freezing of gait in Parkinson's disease has been found to be related to spatial planning ability (Ferrari, Lagravinese, Pelosin et al., 2015). Further, with both long and short term spatial memory deficits (working memory capacity for working cues) being found with increasing age (Piccardi, Iaria, Bianchini, Zompanti, & Guariglia, 2011), and other measures linked to mobility such as visual attention (Anstey, Horswill,

Wood, & Hatherly, 2012), it could be inferred that spatial working memory may also have an impact on successful mobility. This chapter directly assessed the role of spatial planning and spatial working memory on walking speed and falls.

The hypotheses that were tested were:

1) Better performance in mobility, start-up delay, and cognitive function will be correlated with faster walking speed and fewer previous falls

2) Cognitive function (specifically executive functions and within participant variability), mobility and start-up delay will have a strong linear relationship with walking speed

3) Cognitive function (specifically executive functions and within participant variability), mobility and start-up delay will have a strong linear relationship with previous falls

3.2 Method

3.2.1 Participant Sample

Participant data collected in Study 1 (Chapter 2) was used. Further analysis was conducted using this data in order to determine predictors of walking speed and previous falls. The participant that was excluded from Chapter 2 due being unable to complete the pedestrian simulator task was included in this study. The participant sample therefore consisted of 104 participants aged 45-88 years, and 63.8% of those sampled were female. Out of this sample 21.9% of participants had experienced a fall within the previous 12 months. Of those who did have falls within this time frame, 11.4% had 1 fall, and 9.7% had between 2-6 falls. 5 people did not complete the perturbation task due to spinal problems and/or were unable to stand independently of a walking aid, and 1 did not complete the pedestrian simulator task. 1 participant did not take part in the visual attention tests, 1 participant did not complete the spatial working memory task (spatial span test), and a further participant did not complete set shifting (affective go-no go test). Missing values within the stepwise regression analysis were replaced with mean values (Rubin, 2004).

3.2.2 Tasks and Variables

The numbers of previous falls within the previous year were taken from the demographic questionnaire (see 2.2.6.1). Those who had fallen were classed as fallers, whereas those who had not fallen were classed as non-fallers. Mobility measures were used as both dependent and predictive variables within this chapter. To test the pedestrian mobility correlates from Chapter 2, the following mobility measures were used: walking speed (7 metre walkway measured m/s, see 2.2.6.1), self-rated mobility score (including presence of physical problems that could affect walking, ability to use stairs, walk quarter mile, see 2.2.6.1 and Appendix 1 for details), sit-to-stand times (5 timed chair rises, see 2.2.6.2), and perturbation

average and coefficient of variance (postural sway task measuring recovery when balance perturbed, see 2.2.6.2). In addition to mobility, visual attention and cognition were used as predictive variables within this chapter. Visual attention (processing speed, divided attention inspection time, and selective attention inspection time) using the Useful Field of View (see 2.2.6.3), and executive function measures using Cambridge Neuropsychological Automated Testing Battery (CANTAB®) battery (spatial planning, spatial working memory, inhibition, updating, set-shifting, choice reaction time, and choice reaction time coefficient of variance) (see 2.2.6.3) were also used to examine the impact of cognition and visual attention on Chapter 2 pedestrian mobility correlates.

3.2.3 Plan of Analyses

To examine Hypothesis 1 (Better performance in mobility, start-up delay, and cognitive function will be correlated with faster walking speed and fewer previous falls), partial correlations were conducted, controlling for age and gender. Age and gender was controlled for as previous research have found a relationship between age and gender with mobility such as walking speed, chair rising speed, balance, and taking the stairs (Butler, Menant, Tiedemann, & Lord, 2009) and falls (O'Halloran, Pénard, Galli, et al. (2011).

A stepwise regression was conducted to test Hypothesis 2 (Cognitive, mobility and start-up delay will have a strong linear relationship with walking speed), and a stepwise logistic regression was used to test Hypothesis 3 (Cognitive function, mobility and start-up delay will have a strong linear relationship with previous falls). The following variables were entered into the stepwise regressions: age, gender, walking speed, self-rated mobility score, sit-to-stand times, perturbation average (transformed), perturbation coefficient of variance

(transformed), start-up delay average, start-up delay coefficient of variance, processing speed (transformed), divided attention (transformed), selective attention, updating, spatial planning, spatial working memory, inhibition, set-shifting (transformed), reaction time (transformed) and cognitive within participant variability (transformed).

3.3 Results

3.3.1 Hypothesis 1- Better performance in mobility, start-up delay, and cognitive function will be correlated with faster walking speed and fewer previous falls

Age ($r = -.347$, $p<.001$) but not gender ($r = -.090$, $p>.05$) was found to be related to walking speed, with increasing age being linked to a slowing of walking speed. Previous falls was not significantly related to either age or gender: $r = .053$, $p>.05$ and $r = .092$, $p>.05$ respectively. As age was found to be related to walking speed, a partial correlation was conducted controlling for age to examine the above hypothesis. As illustrated in Table 7, reduced walking speed was negatively correlated with increased self-rated mobility score, slower sit-to-stand times, and increased perturbation average, indicating a role of frailty and balance. In addition to mobility, reduced walking speed was also related to visual attention (selective attention), longer reaction time, and increased start-up delay. A within participant variability was also marginally related to walking speed ($p=.068$) (Table 7). Similarly to walking speed, a significant positive relationship was also found between previous falls and sit-to-stand times (Table 7), and a marginal relationship with perturbation average ($p=.065$). Further, previous falls were also related to reduced walking speed (Table 7). However, start-up delay was not significant. These results partially support the above hypothesis as mobility and cognition was related to walking speed, but only mobility was related to previous falls once age was accounted for. Only walking speed was related to start-up delay.

Table 7- Correlation Matrix Mobility and Falls with Pedestrian Mobility and Start-up Delay Predictors, controlling for Age

Variables (N=103)	Walking Speed	Mobility Score	Sit to Stand	Pert Ave	Pert COV	PS	DA	SA	SP	SWM	In	Up	Set Shift	RT	WPV	Start-up Delay	Start-up Delay COV
Walking Speed		-.521**	-.476**	-.219*	-.154	-.079	-.164	-.251**	-.062	.069	-.005	129	-.103	-.307**	-.181m	-.516**	.042
Previous Falls	-.242*	.077	.239*	.183m	.029	.176	.126	.157	-.003	-.022	.051	16	.165	.126	.146	.156	-.043

*= Significant at .05 level **=Significant at .01 level m=marginal effect

Ave= average, COV=coefficient of variance, PS= Processing Speed, DA= Divided Attention, SA= Selective Attention, SP= Spatial Planning, SWM= Spatial Working Memory, In= Inhibition, Up= Updating, Set Shift= Set Shifting Commissions, RT= Reaction Time, WPV= RT Within Participant Variability

3.3.2 Hypothesis 2- Cognitive function (specifically executive functions and within participant variability), mobility and start-up delay will have a strong linear relationship with walking speed

A stepwise regression was conducted to predict walking speed (Chapter 2 pedestrian predictor). The steps and order of entry produced by the stepwise regression can be seen in Table 8. The whole model consisting of mobility, start-up delay, and cognition was found to be significant (F (4, 97) =27.535, p<.001) and predicted 53.2% (Table 8) of walking speed variance. All four steps were significant step changes: Model 1 mobility 1 (F (1, 100) =46.888, p<.001); Model 2 start-up delay (F (1, 99) =23.845, p <.001); Model 3 mobility 2 (F (1, 98) =10.422, p=.002); Model 4 cognition (F (1, 97) =5.722, p =.019). Model 1 alone contributed 31.9% of the variance in walking speed, whereas start up delay, sit-to-stand, and within participant variability contributed an additional 13.2%, 5.3% and 2.8% respectively. In summary, walking speed is strongly predicted by mobility (particularly mobility score and sit-to-stand), start-up delay, and cognition (within participant variability).

Table 8- Predictive Contribution of each Step in explaining Walking Speed variance

Model	Variable	R^2	^ R^2	Beta	Sig.
1 Mobility 1	Mobility Score	.319**	.319**	-.565**	<.001
2 Start-up Delay	Mobility Score	.451**	.132**	-.415**	<.001
	Start-up Delay Ave.			-.393**	<.001
3 Mobility 2	Mobility Score	.504**	.053**	-.324**	<.001
	Start-up Delay Ave.			-.335**	<.001
	Sit-to-Stand			-.261**	.002
4 Cognition	Mobility Score	.532**	.028*	-.298**	<.001
	Start-up Delay Ave.			-.356**	<.001
	Sit-to-Stand			-.239**	.003
	Within Participant Variability			-.170*	.019

*= Significant at .05 level **=Significant at .01 level Ave= average ^ R^2= R^2 change

3.3.3 Hypothesis 3- Cognitive function (specifically executive functions and within participant variability), mobility and start-up delay will have a strong linear relationship with previous falls

A stepwise logistic regression was performed to assess the impact of mobility and cognition on the likelihood that participants would report a fall. The stepwise regression produced can be found in Table 9. The full model containing the two predictors (set shifting and perturbation average) was not significant (χ^2 (8) =4.494, p=.810) in distinguishing between fallers and non-fallers. The model as a whole explained between 9.0% (Cox & Snell R square) and 13.9% (Nagelkerke R square) of fall variance (Table 9), and correctly classified 78.4% of cases (both fallers and non-fallers). As shown in Table 9 set shifting was a consistent independent predictor even when perturbation average was entered to the model. Perturbation average was also found to marginally significant predictor of fall history. The odds ratio for set shifting was 7.161 (Table 9) (with a 95% confidence range of 1.637-88.805), indicating that for every increase in set shifting commissions, participants were 7.161 times more likely to fall. In addition, with every increase in perturbation average, participants were 12.058 times more likely to fall (95% confidence range of .952-53.878). These results partially support the above hypothesis as although the model was not found to be significant, cognition (set shifting) and mobility (perturbation) were found to be important in explaining fall variance.

Table 9- Predictive Contribution of each Step in explaining Fall variance

	Variable	R^2	Wald	Sig.	Exp (B)
0 Baseline			28.758	<.001	.275
1 Cognition	Set Shifting	.056-.087	5.219	.022	9.916
2 Mobility	Set Shifting	.090-.139	3.656	.056	7.161
	Perturbation Average		5.973	.015	12.058

*= Significant at .05 level **=Significant at .01 level Ave= Average

3.4 Discussion

The purpose of this study was to compare the impact of cognitive ability, mobility function, and start-up delay on walking speed (pedestrian predictor in Chapter 2) and falls.

In support of the chapter predictions, walking speed was found to be significantly predicted by mobility decline (self-reported mobility score and sit-to-stand times), start-up delay, and cognition (within participant variability). These results are in line with previous research linking walking speed to differing mobility abilities (Vasunilashorn, Coppin, Patel, et al., 2009), and start-up delay (Holland & Hill, 2010). In addition, as walking speed was predicted by self-reported mobility score, it may mean that older adults are aware of physical changes, and thus could be useful in reaching the target population. The review by Graveson, Bauermeister, McKeown, & Bunce (2015) suggested that some of the inconsistent relationships between walking speed and within participant variability may have been as a result of some studies using crude raw standard deviation scores, whereas others used a more sophisticated coefficient of variance method. This study used the coefficient of variance method and produced both a significant correlated relationship and a predictive relationship between walking speed and within participant variability.

However, start-up delay was found to predict walking speed in Chapter 2, and these results indicate that walking speed is also predicted by start-up delay. These circular findings raise the question of which occurs first, slowed walking speed or start-up delay. Future research may benefit from examining whether it may be possible that people have a slowed/changed initiation prior to a change in walking speed as this could have an impact on walking speed prediction and rehabilitation.

On the other hand, a significant predictive model for falls was not found. Within the model, however, set shifting and perturbation were found to be significant independent predictors. These independent predictors are consistent with previous research linking set shifting (Soumare, Tavernier, Alpérovitch, et al., 2009) and balance (Ambrose, Paul, & Hausdorff, 2013) with falls. However, in contrast with the review by Graveson, Bauermeister, McKeown, & Bunce (2015), falls was not found to be correlated with or predicted by within participant variability. This may suggest that set shifting ability is a more salient factor in the occurrence of falls, or that an additional demographic variable within the participant sample has not been identified and controlled for. These results suggest that with increasing age, it is difficult to remove attention from one task to a more pressing second task, such as regaining one's balance, and that this may result in a fall. However, as previous falls were not significantly predicted by mobility and cognition it could be suggested that there are more factors at play in fall predictions that have not been considered. These may be due to population factors that were not accredited or accounted for, or simply that in line with population statistics only a third of the cohort had experienced a fall within the previous year. Future research could sample participants in relation to their falling status and record more demographic information in addition to walking speed and cognitive changes to see if this does indeed increase the model predictive value.

Visual attention was not found to be predictive of either walking speed or falls history in contrast with Owsley & McGwin (2004). However, a significant correlation was found between walking speed and selective attention, rather than divided attention formerly found by Owsley & McGwin (2004) with composite mobility scores. Also, spatial ability (spatial planning and spatial working memory) was not found to be correlated with or predictive of

either walking speed or falls, suggesting that spatial planning and working memory is not necessary in maintaining walking speed or preventing falls.

In summary, walking speed was linked to increasing frailty (mobility difficulties and sit-to-stand times), motor initiation, and within participant variability, whereas falls were partially predicted by balance and attentional set shifting ability. Future research could benefit from investigating additional demographic variables in conjunction with postural sway and set shifting ability in an attempt to produce a predictive model of falls risk. In addition, the effectiveness of training interventions for walking speed in relation to increased lower extremity strength, motor initiation, and within participant variability. To date it has been found that lower extremity strength/resistance training alone can have limited effect on improving walking speed, rather a combination of resistance training with other types of interventions such as coordination training can have a better chances of improvement (review by Hortobágyi, Lesinski, Gäbler et al., 2015). It has been found to be possible to train start-up delay in children using a computer-simulated traffic environment (Thomson, Tolmie, Foot, et al., 2005) and so may be possible to implement in older adults. To the best of the authors knowledge, interventions for within participant variability has not been yet been published. However, as within participant variability has previously been linked to changes in perceptual speed, working memory, episodic memory, and crystallised abilities (vocabulary and world knowledge). It has also been found to be a strong predictor of cognitive performance with advancing age (Hultsch, MacDonald, & Dixon, 2002), it could be theorised that training in these measures may improve within participant variability and thus walking speed.

4 Does Beta Power Change Influence Motor Initiation and Crossing Ability with Age?

Objective

This chapter examined whether changes in age-related cortical oscillatory neural beta (15-35 Hz) power is linked to mobility in real world scenarios, i.e. unsafe pedestrian behaviour in older adults.

Methods

11 participants aged 46-84 years were recruited from Study 1 (Chapter 2). A computerised road crossing game "frogger" was completed within a Magnetoencephalography scanner. Motor cortex beta power pre-, and post-movement in both hemispheres were examined in relation to 'frogger' and Chapter 2 pedestrian performance, and Chapter 2 pedestrian predictors: start-up delay, walking speed, spatial planning, and processing speed.

Results and Conclusion

Elevated post-movement beta power and hemispheric bilaterality was found in participants who made 'frogger crossing' errors. Hemispheric bilaterality was also found in older adults, and participants with slower processing speed. On the other hand, hemispheric laterality was found for those making more far-side unsafe crossing errors, slower walkers, and more variable start-up delays. These preliminary findings suggest that age-related beta power and hemispheric changes may underlie unsafe crossings, and that different beta power patterns are present for near-side crossing errors and related predictor processing speed compared with far-side crossing errors and Chapter 2 predictors walking speed and start-up delay variability.

4.1 Introduction

The brain's structure changes with increasing age. Such changes include reduced grey matter volume in areas such as the temporal and frontal lobes (including the motor cortex) shrink (Greenwood, 2007). In addition, changes occur in terms of increased ventricle and cortical sulci size in the frontal lobes (which includes the motor cortex), and cerebrum (Van Petten, Plante, Davidson, et al., 2004). These areas of the brain are involved in various aspects of mobility such as gait, and executive function such as visuospatial attention and processing speed (Rosano, Aizenstein, Brach, et al., 2008). In addition, increasing white matter hyperintensities with increased age impacts on various aspects of cognition (Perry, McDonald, Hagler, et al., 2009), executive functions (Van Petten, et al, 2004), and mobility, such as gait and balance (Novak, Haertle, Zhao, et al., 2009). See Chapter 1 for a review on changes in brain structure and function with increased age. This chapter specifically focused on motor cortex activity.

Age-related changes have been previously associated with various aspects of mobility including slower walking speeds, and increased start-up delay, along with real-life applications such as pedestrian behaviour (Holland & Hill, 2010). Age-related movement changes have also been observed in the motor cortex, with increased beta power oscillations (15-30 Hz; Baker, Olivier, & Lemon, 1997) and hemispheric beta asymmetry being observed whilst performing movement, such as hand and finger movements (Hall, Stanford, Yamawaki, et al, 2011) and in pathological disorders, such as Parkinson's disease (Hall, Prokic, Mc Allister, et al, 2014; Heinrichs-Graham, Wilson, Santamaria, et al., 2013).

Chapter 2 was able to explain 49.4% of near-side, and 54.8% of far-side unsafe crossing decisions. Although significant models were produced, this still leaves approximately half of unsafe crossing error variance unexplained. It has been hypothesised that unsafe crossing errors at the far-side of the road (traffic arriving from the left visual field) in older adults may be partially as a result of hemispheric lateralisation (attentional resource sharing) with increasing age (Foerch & Steinmetz, 2009). Also, as maladaptive changes in beta power has been linked to Parkinson's disease (Hall, et al, 2014; Heinrichs-Graham, et al., 2013) and Parkinson's disease has previously been linked to unsafe crossing decisions (Lin, Ou, Wu, & Liu, 2013), age-related oscillatory beta power changes may also be related to unsafe pedestrian crossings in older adults. However, currently research has not yet been conducted to examine the potential presence of such biological indicators in older individuals at risk of unsafe pedestrian crossing behaviour.

Previous literature has recorded changes in beta power pre-movement (i.e. higher resting beta power) and post-movement (i.e. lower rebound beta power) in activities such as mobility (section 4.1.1), and cognition (section 4.1.3). As walking speed, start-up delay, spatial planning and processing speed were all found to be highly predictive of unsafe pedestrian behaviour in Chapter 2, this chapter predicted that unsafe crossing behaviour may produce similar beta power and hemispheric patterns (i.e. using both hemispheres) to individuals with movement and cognitive pathologies. This chapter used the mobility and cognitive pedestrian predictors outlined in Chapter 2 (walking speed, start-up delay, start-up delay coefficient of variance, processing speed and spatial planning), and simulated pedestrian behaviour (far-side unsafe crossing errors from Chapter 2, and a computerised one-lane crossing 'Frogger task' (see 4.5.7.2).

4.1.1 Healthy beta power and brain oscillations with movement

The primary motor cortex produces continual neuronal oscillations in the beta (15-30Hz) range at rest (Baker, Olivier, & Lemon, 1997). In healthy young to middle aged adults, beta, and mu (8-14 Hz) power bilaterally reduces prior to a movement being made (Gaetz, MacDonald, Cheyne, & Snead, 2010), referred to as event related desynchronisation (ERD) (Pfurtscheller & Berghold, 1989). After the movement has been completed, there is an increase in beta power whereby beta power exceeds pre-movement resting beta power levels, otherwise known as a post movement beta rebound (PMBR) (Jurkiewicz, Gaetz, Bostan, & Cheyne, 2006). The opposite pattern occurs for gamma oscillations whereby the gamma power increases prior to movement initiation and decreases post movement (Gaetz et al, 2010). Gamma activity has been found to reduce in power for subsequent movements compared to the initial movement (Muthukumaraswamy, 2010; Muthukumaraswamy, 2011). Some between participant variability can be found in the time and power patterns presented during movement initiation and termination, however, within participant performance in healthy younger adults (adults aged 21-47 years) is relatively consistent (Cheyne, Bells, Ferrari, Gaetz, & Bostan, 2008).

The planning ERD stage of movement healthy younger adults starts approximately 2 seconds before movement execution. The ERD and the accompanying PMBR mainly takes place contralaterally (to the dominant hemisphere), whereas the beta power activity prior to movement occurs bilaterally in the brain. This pattern can be found in both internally and externally paced finger, and wrist movements (Pfurtscheller, Stancák, & Neuper, 1996; Pfurtscheller, Stancák, & Edlinger, 1997). In both brisk and slow finger tapping, the dominant hand showed greater PMBR contralaterally, whereas the less dominant hand recruits a slightly more bilateral approach. Beta ERD prior to movement remained fairly

similar in both those using their dominant and non-dominant hand (Stancák, & Pfurtscheller, 1996).

A different pattern to the above beta power patterns in motor initiation is found PMBR when forcibly, as opposed to voluntarily, terminating movement. Using EEG, younger adults (26-34 year olds) completed a variation of the Go No-Go task (inhibition task whereby a specific stimulus, in this case an audible tone, indicates when to stop a given action). Participants were required to write their signature at the sound of the first tone, if a second tone occurred (50% probability) they had to cease writing. The results showed that in the go condition, ERD lasted until the movement had naturally finished. ERD was followed by an earlier and increased PMBR power compared to the No-Go condition. When the movement was forcibly stopped (the No-Go stimulus was presented), there was a significantly reduced PMBR compared to if they were allowed to finish writing their signature. The authors suggest that beta rebound post movement is a separate process independent of ERD. In addition, PMBR depends on how a movement concludes (Alegre, Alvarez-Gerriko, Valencia, Iriarte, & Articda, 2008).

With increasing age, in addition to structural changes (1.6, Chapter1), differences in oscillatory patterns in the brain can also be found in healthy older adults. Oscillatory changes, such as higher resting beta power and high ERD, have been found to be a result of maladaptive GABAergic inhibition (Hall, et al, 2011). Changes such as higher contralateral resting beta power and higher ipsilateral ERD may contribute towards difficulty and neuroplastic variability in movement in older age (Rossiter, Davis, Clark, Boudrias, & Ward, 2014).

4.1.2 Age effects on beta power and brain oscillations with movement

Age differences in sensorimotor oscillations can be found during motor initiation. Rossiter, et al. (2014) explored beta power activity (using MEG) during rest and movement using a force grip task in 22-82 year olds. The maximum force was first recorded and then several force levels were produced from this. Participants were then to match the same amount of grip strength with a visually cued force 'thermometer' on the screen. Although age differences were not found in grip strength or the offline behavioural motor tasks such as the Nine Hole Peg test (fine motor task measuring speed taken to position nine pegs into slots into a wooden block), and the Box and Blocks test (measure of gross motor movement), that is motor score were variable throughout the sample, differences were found for beta power. Imaging results for grip response showed that at rest, a significant positive correlation was found between beta resting power (but not beta frequency) and age in both contralateral and ipsilateral hemispheres (i.e. increased age produced increased beta resting power). When movement was initiated using the force thermometer, age was significantly positively correlated with increased beta power during desynchronisation, and reduced frequency of beta power. Activation in the ipsilateral hemisphere increased with increasing age, demonstrating more hemispheric symmetry with increasing age (Rossiter, et al., 2014). The authors suggest that this increased hemispheric symmetry may be a biological marker of plasticity in older adults. Alternatively, this change in distinct hemispheric beta power activity may be as a result of the development of additional neural connections over the lifespan, otherwise known as scaffolding, in order to compensate and maintain cognitive function (Park & Reuter-Lorenz, 2009). Similarly to Rossiter, et al. (2014), this chapter used a grip strength force transducer as a method of specifically testing beta power changes in the motor cortex. This method was able to identify subtle oscillatory changes that had not yet translated into behavioural motor tasks (Rossiter, et al., 2014).

Age-related changes are also present when movement is halted, either voluntarily or suddenly. In a study by Labyt, Szurhaj, Bourriez, et al., (2004), it was found that when performing brisk finger extensions within an electroencephalography machine (EEG), older adults demonstrated a higher contralateral beta desynchronisation prior to movement and a decreased post-movement beta rebound power once movement had been terminated compared to younger adults. Further, older adults displayed increased pre-and post-movement beta power in the ipsilateral hemisphere compared to younger adults, suggesting that there may be increasing hemispheric bilaterality with increasing age to perform similarly in the task and compensate for age-related structural changes.

In support of increasing hemispheric bilaterality and compensation, Berchicci, Lucci, Pesce, Spinelli, & Russo (2012) found that in both simple finger tapping reaction speed tasks, and in a more complex discrimination response task (or a selective inhibition task), older adults showed a prefrontal hyperactivity (recorded as an EEG event-related potential) during motor planning (motor response generation prior to stimulus) rather than the stimulus processing stage (stimulus response generation). Older adults also tended to slow their response times to maintain inhibition task accuracy. Interestingly, middle aged (mean age=49 years) participants displayed similar reaction speeds to the younger adults (mean age=23.4 years), but the prefrontal hyperactivity of the older adults (mean age=70 years), suggesting neural compensation starting from middle age.

Further, bilateral employment with increasing age was found by Zimmerman, Heise, Gerloff, Cohen, & Hummel (2014) who found that when older adults (aged 58-85 years) received electrical interference to the ipsilateral motor cortex during their motor practicing of a

unimanual finger tapping sequence, they were more affected by this than their younger counterparts (aged 22-35 years). Previous theorists, such as Cabeza (2002), claim that increasing hemispheric symmetry with increasing age is needed in order to perform similarly to younger adults in the same task. Changes in hemispheric bilaterality during movement (in this case, unilateral and bilateral finger abductions) can be seen as early as middle age (mean aged 50 years) compared to younger adults (mean age 24 years) (Heetkamp, Hortobágyi, & Zijdewind, 2014).

Parkinson's disease has previously been linked to elevated beta desynchronisation, reduced post-movement beta rebound, and increased used of the ipsilateral hemisphere compared to healthy age matched controls. Use of medication such as Zolpidem has been found reduce Parkinson's symptoms, reduce pre-movement beta desynchronisation and increase hemispheric bilaterality (Hall, et al, 2014). These results suggest that too high a beta desynchronisation, too low a beta rebound power may be indicative of increasing mobility difficulty, and increasing hemispheric bilaterality may ease the symptoms..

To summarise, starting from middle age, healthy adults with little movement difficulty begin to demonstrate increased resting and desynchronised beta power prior to movement, and lower beta rebound post movement compared to younger adults, but not as pronounced as adults with Parkinson's disease and similar movement pathologies. In addition, older adults with worse performance in pedestrian judgments, mobility, and cognition would recruit increased resources from the ipsilateral hemisphere (evident with increased beta asymmetry) which would indicate that these movement problems are centrally based as opposed to peripheral muscle weakness or other non central nervous system based frailty issues. It could

be hypothesised that these patterns could be found in older adults demonstrating difficulties in real world mobility, i.e. making pedestrian crossing errors, particularly as Chapter 2 determined that pedestrian behaviour can be predicted by walking speed (gross mobility) and difficulties in motor initiation (start-up delay). This chapter determined whether these differences in movement-related beta power with increasing age could be found in real world mobility, i.e. pedestrian crossing.

4.1.3 Links to Cognition and Crossing Ability

In support of the potential role of maladaptive beta power activity in pedestrian safety, a study by Lin, Ou, Wu, & Liu (2013) compared participants with controlled Parkinson's disease (controlled by medication) with age matched healthy controls in a series of cognitive measures and a seated pedestrian simulated crossing task. Those with Parkinson's disease, albeit with controlled symptoms, demonstrated higher numbers of pedestrian errors compared to healthy controls. Road crossing performance with participants with Parkinson's disease could be predicted by visual-spatial function (clock drawing test), and visual form discrimination abilities but not executive function (trail making test). Visual attention (Useful Field of View; UFOV) was also found to increase risk of reduced road crossing performance in individuals with Parkinson's disease but not the healthy matched controls. In addition, car speed, car distance, and time of day also affected participants with Parkinson's disease more so than healthy controls. This study implies that increased neurological differences presented in Parkinson's disease, even when physical difficulties have been moderated, are linked to spatial perception (car speed and distance judgements), visual attention, and unsafe crossing behaviour. As Parkinson's disease has previously been linked to maladaptive pre- and post-movement beta power activity (Hall, et al, 2014), and Chapter 2 found that processing speed

and spatial planning abilities are predictive of unsafe pedestrian crossings, it could be inferred that beta power activity could have an impact on pedestrian safety.

Previous literature has found increased hemispheric symmetry (mainly measured using Positron Emission Tomography; PET, and Magnetic Resonance Imaging; MRI scanners) in older adults when taking part in cognitive tasks such as episodic and semantic memory, working memory, inhibition (go/no-go task), and visual perception. In contrast, younger adults do not recruit both hemispheres in order to complete such tasks (see Cabeza, 2002 for full review). This suggests that similarly to motor initiation and termination, older adults require additional attentional resources in order to produce similar cognitive results to younger adults. Chapter 2 found that along with mobility and start-up delay, cognitive functions (namely processing speed and spatial planning) were predictive of unsafe crossing decisions in older adults. These results could indicate that individuals that are making more unsafe pedestrian errors may have reduced attentional resources available and may recruit both hemispheres in order to perform cognitively demanding tasks such as crossing the road.

Foerch & Steinmetz (2009) hypothesised that age-related neuronal and functional change, particularly in the right hemisphere, may affect the processing of the left half of their environment. In line with literature regarding increased attentional compensation and neuronal recruitment with increasing age (see Greenwood, 2007), it may be speculated that this hemispheric lateralisation found with increasing age equates to difficulties in attending to the left hand side of the road (i.e. the UK far-side of the road), thus contributing to explaining the high number of far-side pedestrian and driver incidents. The author recommends further research into lane specific pedestrian incidents and hemispheric laterality in older adults.

This chapter examined whether, increased hemispheric bilaterality, elevated beta pre-movement and reduced post-movement beta rebound could present a biological indicator for unsafe pedestrian crossings. As gross movements, particularly road crossings, cannot easily be conducted within imaging studies, a modified computer based version of "Frogger" crossing task was used (using Presentation software) to investigate the underlying neural processes taking place whilst 'crossing' the road. Frogger, a game which aims to aid a frog safely across one or more lanes of 'traffic', has been successfully utilised in age-related computer training research, as mentioned in reviews by Zelinski & Reyes (2009), & Kueider, Parisi, Gross, & Rebok (2012). A simplified version of this game was used with one-lane of 'traffic' for the frog to 'cross' in order to reduce confounding variables and provide a sufficient time window to collect pre-and post-movement beta power activity.

'Virtual electrode' beamformer spectrograms were used so as to measure beta power specifically within the motor cortex, and recorded beta power activity at three time points: during resting state, during movement initiation, and post movement (Hall, et al, 2014; McAllister, Rönnqvist, Stanford, Woodhall, Furlong, & Hall, 2013). An opportunity sample was recruited from the Chapter 2 study and the age range started from middle age as this has been found to be when age-related beta power and hemispheric recruitment changes are likely to begin (Heetkamp, Hortobágyi, & Zijdewind, 2014).

The hypotheses that were tested were:

1) There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in older adults compared to younger adults;

2) There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people making more pedestrian judgement errors than those making fewer

3) There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower mean start-up delay

4) There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower walking speed

5) There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower processing speed and lower spatial planning performance

4.2 Methods

4.2.1 Aim

To explore predictive relationships between age-related changes in cortical oscillatory neural beta power activity and mobility skills in older adults.

4.2.2 Design

A between participant design was used whereby the predictive variables used were age, unsafe pedestrian behaviour (far-side unsafe crossing error data collected in Study 1 Chapter 2, and a computerised one-lane crossing 'Frogger task' (see 4.2.6.1) and pedestrian predictor data collected in Study 1 Chapter 2 (walking speed, start-up delay, start-up delay coefficient of variance, processing speed, and spatial planning, see 4.2.6.2).The outcome measures were the difference ratios between mean rest and pre- movement desynchronisation (pre-movement), and between mean desynchronisation and post- movement motor rebound (post-movement). These variables were measured in the motor cortex, both contralaterally and ipsilaterally.

4.2.3 Participant Recruitment and Demographics

The participants for the brain imaging study were volunteers from Study 1. Participants from the Study 1 sample were contacted via post, or email so as to include all the information (about the study, the equipment, and the health and safety guidelines; Appendix 3) to allow for an informed decision. Originally participants were going to be sampled based on the best and worst mobility performers from Chapter 2. However, due to a low response, an opportunity sampling method was used instead. Participants were reimbursed for travel

expenses. Out of the 17 participants who responded, only 11 met the health and safety guidelines for brain imaging studies to be included (Appendix 3). The exclusion guidelines included: the presence of pacemakers, valve or cochlear implants, surgical clips, stents, implanted metal, hearing aids, non-approved metal dental work, exposure to metal debris (through work, recreation, or injury), pregnant, history of epilepsy, heart disease, diabetes, or thermoregulatory problems, tattoos near the head and shoulders, and permanent eye makeup (Appendix 3). Participants were aged 46-84 years (mean=63.64 years) and 54.5% of the study sample were men. All but 1 participant was right handed. Only 1 out of the sample had experienced a fall within the previous 12 months, and one individual had self reported mobility difficulties. All had very low risk or low risk Useful Field of View scores (assessed in the previous visit, see Chapter 2), indicating good visual attention abilities. 1 participant completed all the tests but due to a technical difficulty only the psychometric data for the MEG test was available. For this participant a sensible mean value was used which took into account similar aged participants, and similar cognitive & mobility abilities.

4.2.4 Group Divisions and Demographics

The following group divisions were made in order to compare mean beta power levels between groups: age, Frogger performance details of criteria), proportion of far-side unsafe pedestrian crossing error performance, average start-up delay performance, start-up delay coefficient of variance performance, processing speed performance, and spatial planning performance. Frogger performance groups were simply divided into proportion of those who did not make an error, and the proportion of those who did make errors. To analyse the differences in unsafe crossing performance, the cut offs for the proportion of far-side unsafe crossing error groups, start-up delay average groups, start-up delay coefficient of variance

groups, processing speed, and spatial planning groups were divided using semi-automated median splits (Table 10).

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Despite mean age differences between groups for walking speed, processing speed, and spatial planning (Table 10), these differences were not found to be significant: t (9) = -1.724, p=.119; t (8) = 1.294, p=.232; and t (8) =1.073, p=.314 respectively. There was a significant age difference, however, between start-up delay average performance groups (t (9) = -.2633, p=.027) with older adults demonstrating slower start-up delay (Table 10).

Table 10- MEG Study Participant Demographics

	Younger Group		**Older Group**	
Variable	**Age (SD)**	**Divide**	**Age (SD)**	**Divide**
Age	56.5 (7.61)	<65	72.2 (6.72)	>68
	High Performers		**Low Performers**	
	Age (SD)	**Divide**	**Age (SD)**	**Divide**
Frogger Performance	62 (9.61)	0 errors	65.6 (12.7)	≥0.1
Proportion Far-side Errors	63 (15.43)	≤.05	64.17 (6.11)	≥.06
Walking Speed	59 (9.3)	≥1.31	69.2 (10.33)	≤ 1.29
Start-up Delay Average	57.5 (9.05)	≤ 2.5	71 (7.68)	>2.66
Start-up Delay Variability	63.78 (7.86)	<1.5	63.83 (13.38)	>1.6
Processing Speed	63.86 (7.34)	<17	56.33 (11.06)	>18
Spatial Planning	64 (9.23)	≥ 7	58 (7.62)	≤ 6

4.2.5 Ethical Considerations

The study was reviewed and approved by the Aston University Ethics Committee (Appendix 3). Participants were required to meet the health and safety guidelines for brain imaging studies in order to be included in the study (see 4.2.3 for exclusion criteria and Appendix 3). Participants were regularly screened (paper based questions, and a request to check pockets) for any metal objects on or in their person, skin patches, contact lenses, and conditions (such as pregnancy and disease) that may make it unsafe to continue (Appendix 3). Data use and storage complied by the standards of the Data Protection Act (1998). All responses remained anonymous, confidential and each participant used the identification code previously given in Study 1. Participants were given up to two weeks after completion to withdraw from the study should they wish to, without risk of penalty.

4.2.6 Materials and Assessments

Five fiducial coils were attached to each participant. Out of these five coils, three of them were attached to the participants forehead, and the remaining two were attached to the left and right pre-auricular in order to enable the Magenetoencephalographic (MEG) scanner to detect head position during recordings, monitor movements, and to provide co-registration with the MRI (see 4.2.7) (McAllister, Rönnqvist, Stanford, et al., 2013). Prior to entering the MEG scanner, these five coils, plus the participant's nose, scalp, and forehead were digitally recorded by using a digitiser pen which was linked to the MEG recording system. The experimenter digitally 'traced' the participants head by holding down a button on the pen and digitally marking the points of interest (scalp, nose, and coils) in three dimensions. The digitised head shape made prior to the MEG recording was later coregistered (see 4.2.7) to the individual's MRI anatomical scan using the Polhemus Isotrak System (Kaiser Aerospace Inc.) (McAllister, Rönnqvist, Stanford, et al., 2013).

Electromyography (EMG) activity was recorded using bipolar surface silver 10x1mm EMG electrodes (DE-2.1; Delsys). One electrode was attached to the first dorsal interosseous (FDI) muscle, and another was spaced 10mm apart on the ulnar process as a reference grounding electrode on the dominant hand. These were later used to accurately measure participant responses (McAllister, et al., 2013).

The study took place with the participant in a seated position within the MEG scanner (see Figure 5 for an illustration). The MEG system was an Elekta Triux (Elekta Corp, Helsinki) 306 channel device comprising 106 magnetometers and 200 planar gradiometers. This was located in a shielded room comprising an aluminium Faraday cage and an active low frequency noise cancellation system. The shielded room contained an intercom system so that communication could be maintained once in the room. In addition, a surveillance camera was used inside the shielded room as a safety precaution, and also to discourage movement once the task had begun.

Figure 5- Illustration of the Elekta Triux Magnetoencephalography scanner

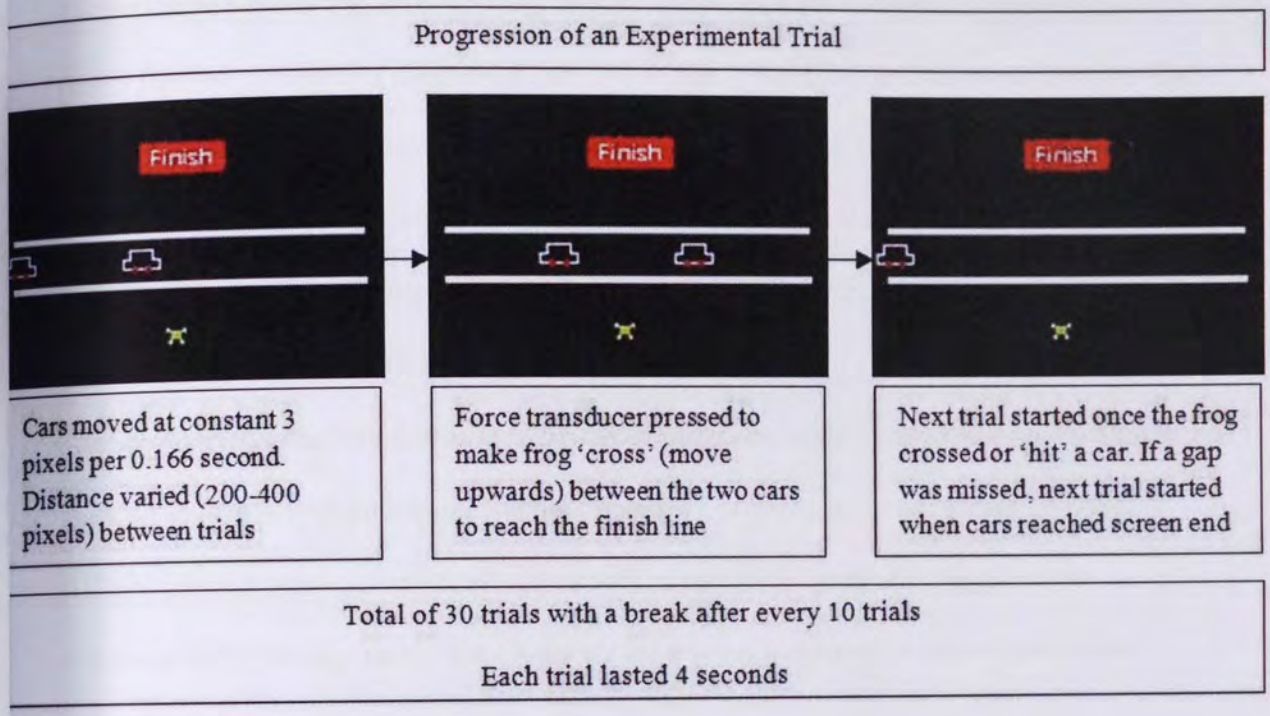
The experimental task (Frogger task, details in 4.2.6.1) required the use of a projector and screen (approximately 1.5 metres away from the seated participant) within MEG shielded room, and a force transducer for participant responses. Frogger was created and delivered using Presentation® software (www.neurobs.com), as it provides temporal accuracy and is compatible with neuroimaging studies. The task used a MEG compatible force transducer (a device in which participants squeeze in order to respond to the task specifications) to indicate movement initiation. The force transducer has previously been found to be a good localiser of motor cortex activity (Rosssiter, Davis, Clark, et al., 2014). The Elekta Neuromag Data Analysis (DANA) software was used for recording and analysing the data (see 4.2.7 for details on analysis). The MRI used was a 3 Tesla Trio Magnetum MRI scanner (Siemens, Erlagen, Germany) in a magnetically shielded room inside a controlled MRI facility. The shielded room also had an intercom system and a surveillance camera for communication and safety purposes.

4.2.6.1 Frogger Task

The Frogger task was based on a Sega arcade game and was used to measure motor initiation/spatial planning. Previously, Frogger has been successfully used in computer training studies in older adults (see Zelinski & Reyes, 2009; Kueider, Parisi, Gross, & Rebok, 2012 for a review). Frogger requires participants to facilitate an animated 'frog' to travel across one or more lanes of 'traffic' to get to safety; this 'traffic' may be cars on the road or turtles in a river, in which they must avoid or they will lose a 'life' (Shaw, Grayson, & Lewis, 2005). The participant must be able to quickly assess the varying environment, then plan and respond quickly in order to do well in the task (Bellack, Dickinson, Morris, & Tenhula, 2005).

As this was a proof of concept study, only one lane of 'traffic' was used. Firstly, instructions were presented on the screen regarding the nature of the task, and participants were required to squeeze the force transducer with their dominant hand when ready to begin to cross. A practice trial was then shown to familiarise participants to the task and the force transducer. The experimental block consisted of thirty trials with a break after every ten trials. An illustration of the Frogger task can be found in Figure 5 below. Each trial started with no cars on the screen, and a frog positioned in the centre of the screen. The frog could only move vertically and only when the force transducer was squeezed. The aim was to move the frog so that it safely crossed between the two cars (there were only ever two on the screen at a time) and reached the finish line. The cars appeared and travelled across the screen at a constant speed of 3 pixels per 0.166 seconds. The distance between the cars, however, varied between a distance of 200-400 pixels, which was enough space for the frog to cross between the cars but also meant that participants had to continually assess and act according to the changing environment. Each trial lasted a minimum of four seconds dependent on when the participant decided to 'cross'. The next trial started when either when a frog hit a car, when a crossing was missed, or the finish line was met. The task lasted approximately 15 minutes including instructions and any questions.

Figure 6- Frogger Task Appearance



The behavioural outcome measure taken was the proportion of unsuccessful crossing errors made (i.e. a car hit the frog). The neurological outcome measures produced from spectrogram analysis (see 4.2.7 for details) were: pre-movement beta desynchronisation comprised the difference ratio between mean resting beta (1 to1.5 seconds prior to movement) power and post-movement beta desynchronisation (0 to 0.5 seconds); and post-movement beta rebound comprised of the mean difference ratio between mean beta power (0 to 0.5 seconds after movement) and mean beta power (1.5 to 2 seconds after movement). These difference ratios were taken from the successful Frogger trials for contralateral pre-movement desynchronisation, ipsilateral pre- movement desynchronisation, contralateral post movement rebound, and ipsilateral post movement rebound.

4.2.6.2 Pedestrian Behaviour and Predictors

The pedestrian behaviour measure used was the proportion far-side unsafe crossing errors (taken from the pedestrian simulation task in Chapter 2, see Chapter 2 for more details). The pedestrian predictors used were variables that were identified as significant and predictive of unsafe crossing behaviour in Chapter 2. These predictors were start-up delay average (the time taken between a safe gap in the pedestrian simulation appearing and the participant starting to cross in seconds), start-up delay coefficient of variance (coefficient of variance taken from pedestrian simulation start-up delay outcome), walking speed (normal walking speed in metres per second while walking 7 metres), processing speed inspection times (UFOV subtest), and spatial planning (number of successful problems solved on the stockings of Cambridge task). See Chapter 2 for more information on these behavioural methods.

4.2.7 Procedure

Participants from Study 1 were invited back to take part in the brain imaging study (Study 2). Before the task commenced, a further consent form was signed, and all metal objects were removed from their person. Participants were required to take part in a Frogger-like pedestrian task (4.2.6.1). Once this was completed, participants were taken to have a structural brain image in the MRI, and then debriefed. Before data could be analysed, data pre-processing was conducted to remove artefact noise and prepare for data analysis. To remove unpreventable, non-biological external interference, the raw data recorded was first max filtered, using the Taulu & Hari (2009) temporal signal-space separation (tsss) method, with the addition of movement compensation (using the polhemus head coils as a reference point in the MEG scanner) (Elekta Neuromag Oy). This method was computed using Elekta Neuromag Data Analysis (DANA) software and divided the data into segments (enough

segments so as to allow sufficient temporal differences between the brain signals and artefacts) and processed each segment individually. The Maxfilter software further separated the segments into internal, intermediate, and external parts by signal space separation (sss), and then temporally compared them. Brain signals that were temporally uncorrelated were identified as an artefact and were removed (See Taulu & Hari, 2009 for more information). Once Maxfiltered, both the original and the max filtered data files were simultaneously manually screened (using Elekta Neuromag DANA Graph software) for residual artefacts that may have correlated with the internal brain signals. Max filter was run again when necessary, only this time excluding bad or noisy channels that were still present. This method provided a good signal-to-noise ratio for source analysis whilst still removing a variety of external signal confounds (Taulu & Hari, 2009). Event triggers were then created to mark when the frog crossed the road (i.e. when the force transducer was squeezed). These triggers were manually created using the electromyography (EMG) and Neuromag DANA Graph software. The three dimensional scalp and fiducial coil head digitisation was then used to coregister their MEG recording with their anatomical MR image using a modified surface-matching algorithm by Adjamian, et al., 2004 (Hall, Prokic, McAllister, et al., 2014; McAllister, et al., 2013).

Beta power changes before and after movement were then analysed using the Synthetic Aperature Magnetometry ® (SAM) beamforming method in Matlab (Hall, Prokic, McAllister, et al., 2014; Hillebrand, et al., 2005; Vrba & Johnson, 2001). Next, specific beta power activity locations or 'hotspots' in the contralateral and ipsilateral motor cortex (target region of interest) were selected and saved using DANA MRIView software. Specific spatially filtered beamformers were then run using these localised source beta power hotspots, or "virtual electrodes" (McAllister, et al., 2013; Robinson & Rose, 1992). Mean

beta spectral plots were obtained from these virtual electrode beamformers in Matlab (based on method by Hall, Prokic, McAllister, et al., 2014, and Jurkiewicz, et al., 2006). Time-zero was the time at which the force transducer was squeezed, and pre- and post-movement beta power was defined as the mean beta power 2 seconds either side of time zero.

4.2.8 Plan of Analyses

The performance groups that were compared were: age, proportion of frogger errors, proportion far-side crossing errors, start-up delay average, start-up delay coefficient of variance, walking speed, processing speed, and spatial planning (see 4.2.6.2 for details about the group divisions). To compare pre-movement beta desynchronisation (difference ratio between rest and initiation) between performance groups, between participants t-tests were conducted. A between participant t-test was also conducted to compare post-movement beta rebound (difference ratio between initiation and rebound) between performance groups. To explore beta laterality between the contralateral and ipsilateral hemispheres pre-and post-movement within performance groups, a series of within participant t-tests were performed.

4.3 Results

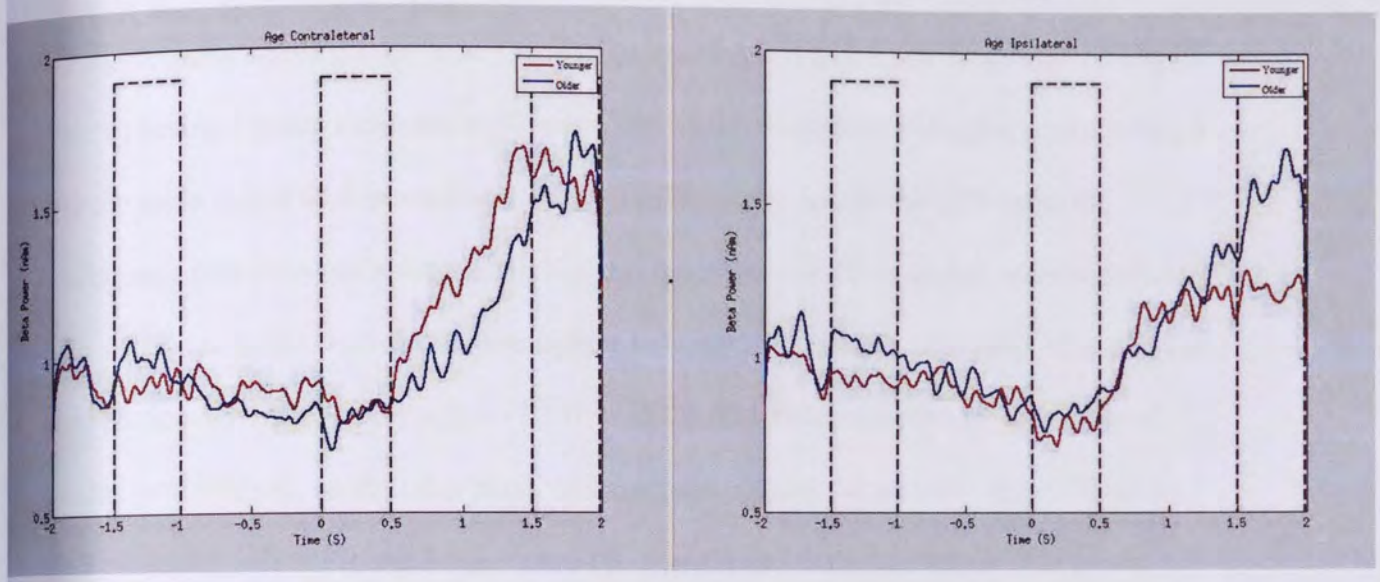
4.3.1: Hypothesis 1- There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in older adults compared to younger adults

The difference ratio between mean resting beta power and mean desynchronised beta power during movement initiation was not found to be significant ($t(9) = -1.376$, $p=.202$). In addition, post movement rebound, i.e. the difference ratio between mean desynchronised beta power and mean beta rebound, was also not found to be significant ($t(9) = .464$, $p=.653$). However, Figure 6 illustrates that younger adults (red line) produced a faster post movement rebound at 0.5 seconds compared to beginning at approximately 0.7 seconds in older adults in the contralateral hemisphere (left graph) suggesting faster movement recovery in younger adults.

As shown in Figure 6, younger adults displayed a reduced ipsilateral post-movement beta rebound compared to the contralateral hemisphere (mean difference= .2583 nAm, marginal effect; $t (5) =2.262$, $p=.073$), suggesting dominance in the contralateral hemisphere. Older adults, on the other hand, displayed beta symmetry, i.e. no significant mean absolute beta power difference between the ipsilateral and contralateral hemispheres ($t (4) =1.337$, $p>.005$) during post-movement beta rebound, thus demonstrating laterality.

These results partially support the above hypothesis as a reduced beta laterality trend was found in older adults post movement. However, higher preparatory and post movement beta rebound power changes in older adults than in younger adults was not supported.

Figure 7- Age differences in mean beta power in the contralateral and ipsilateral hemispheres pre-, during, and post-movement whilst performing the Frogger task



Mean beta power (in nAm) in motor cortex (M1) across trials whilst performing the Frogger task in the contralateral hemisphere (left) and the ipsilateral hemisphere (right) between age groups: younger (red) and older (blue) adults. Three rectangular points are highlighted on the figure indicating pre movement (-1.5 to -1seconds), movement initiation (0 to 0.5 seconds), and post movement (1.5 to 2 seconds) cut offs. Figure 3 shows younger adults beta levels rebound faster than older adults post movement contralaterally, and older adults employ both hemispheres whilst performing the Frogger task.

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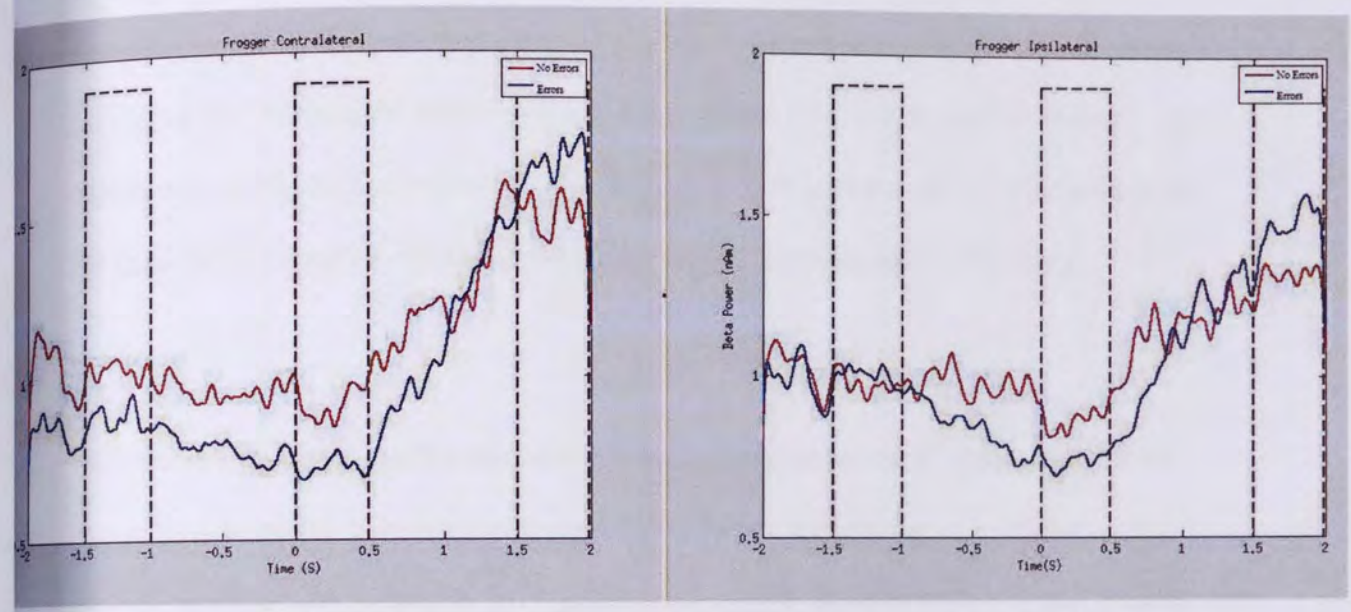
4.3.2: Hypothesis 2- There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people making more pedestrian judgement errors than those making fewer

Frogger performance groups were found to be age-matched with lower proportion of frogger errors having a group mean age of 62 years, and higher proportion of frogger errors having a group mean age of 65.6 years (Table 9). Preparatory mean beta power difference, the difference ratio between mean resting beta and desynchronised beta power, was not found to be significant in the contralateral hemisphere between people with a high proportion and low proportion of frogger errors ($t(9) = -1.267$, $p=.237$). The difference ratio for contralateral mean beta rebound, on the other hand, was marginally higher (mean difference= .30 nAm, $t(9) = -2.135$, $p=.062$) in the frogger error group compared to the no frogger error group.

As shown in Figure 7, those who made no Frogger errors were found to display a significant difference between hemispheres post movement ($t(5) = -3.127$, $p=.026$), whereas those who did make Frogger errors showed no significant mean hemispheric difference ($t(4) = -1.189$, $p=.300$). Thus, participants making Frogger errors demonstrated beta symmetry, and participants that did not make Frogger errors demonstrated hemispheric asymmetry, and so supporting the notion that there are differences in hemispheric laterality between groups.

These results partially support the above hypothesis as reduced frogger performance was found to be linked to increasing bilaterality and changes in beta power activity. However, beta power changes were only found in post-movement beta rebound and this pattern was found to be higher rather than lower contrary to prediction.

Figure 8- Frogger error group differences in mean beta power in the contralateral and ipsilateral hemispheres pre-, during, and post-movement whilst performing the Frogger task



Mean beta power (in nAm) in motor cortex (M1) across trials whilst performing the Frogger task in the contralateral hemisphere (left) and the ipsilateral hemisphere (right) between Frogger error groups: no errors (red) and errors (blue). Three rectangular points are highlighted on the figure indicating pre movement (-1.5 to -1seconds), movement initiation (0 to 0.5 seconds), and post movement (1.5 to 2 seconds) cut offs. Figure 4 shows that those in the no Frogger error group had higher resting beta and lower post-movement rebound in the contralateral hemisphere compared to those in the Frogger errors group (opposite pattern to prediction). Also those who made Frogger errors employed both hemispheres to complete the Frogger task.

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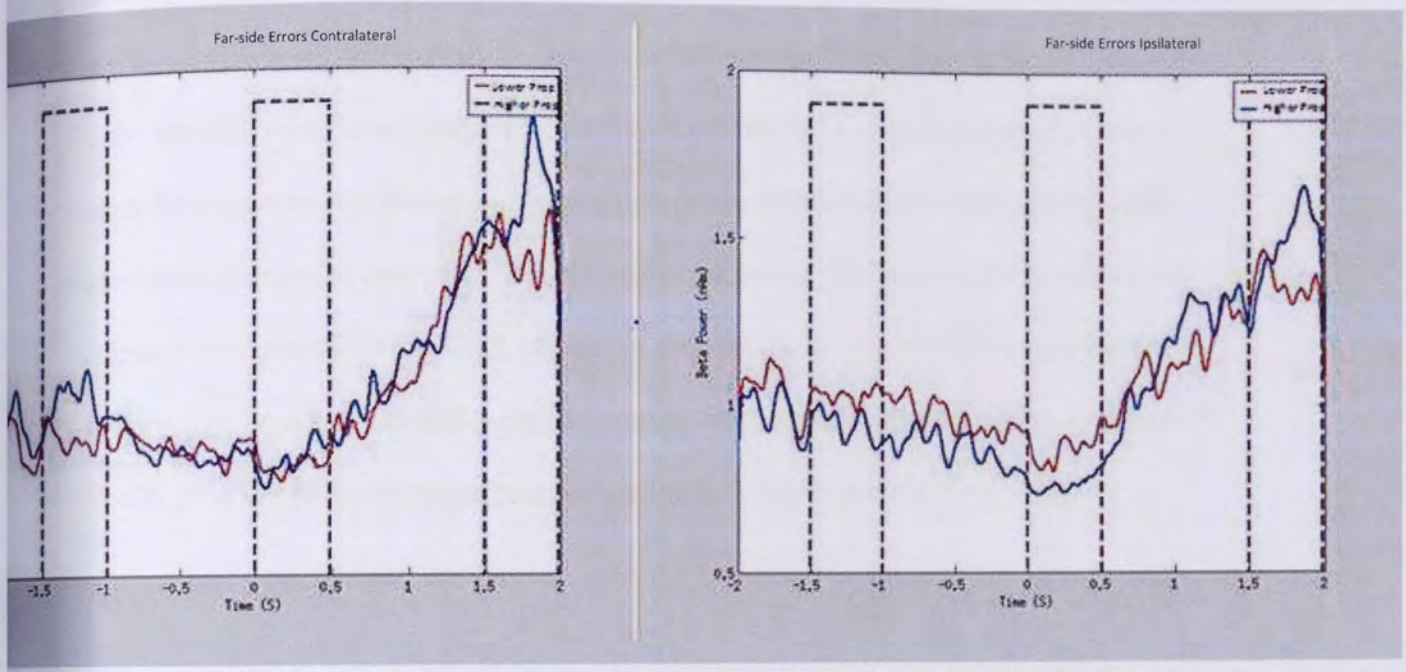
For far-side unsafe pedestrian crossing errors, a different pattern emerged. Unlike the beta power activity results found for frogger performance groups, no significant differences were found for far-side unsafe crossing groups for contralateral pre-movement beta ($t(9) = .834$, $p = .426$) or for contralateral post-movement beta rebound ($t(9) = .250$, $p = .808$) despite appearances in Figure 8 which shows a peak increase in beta power activity post-movement for those making a higher proportion of unsafe far-side crossing errors (blue line).

Differences were found, on the other hand, between far-side error performance groups for hemispheric laterality. Lower far-side error group demonstrated bilaterality ($t(4) = -1.693$, $p = .166$), whereas higher far-side error group demonstrated laterality ($t(5) = -3.466$, $p = .018$). These results for hemispheric laterality are the opposite direction to frogger performance and prediction, i.e. those making more far-side unsafe crossing errors would possess demonstrate greater hemispheric symmetry.

These results do not support the above hypothesis for beta power activity pre-and post-movement or for laterality, however, these results could indicate that either different processes are taking place for far-side pedestrian judgements compared to near-side (frogger task involved judging one lane of traffic), or that individuals making a higher proportion of far-side crossing errors are transitioning to impairment and have not recruited additional neural networks as yet.

Figure 9- Proportion of far-side unsafe crossing performance group differences in mean beta power in the contralateral and ipsilateral hemispheres pre-, during, and post-movement whilst performing the Frogger task



Mean beta power (in nAm) in motor cortex (M1) across trials whilst performing the Frogger task in the contralateral hemisphere (left) and the ipsilateral hemisphere (right) between proportion far-side error groups: lower proportion (red) and higher proportion (blue). Three rectangular points are highlighted on the figure indicating pre movement (-1.5 to -1seconds), movement initiation (0 to 0.5 seconds), and post movement (1.5 to 2 seconds) cut offs. Figure 5 shows that those making a lower proportion of far-side crossing errors displayed higher ipsilateral baseline beta and showed greater hemispheric laterality to complete the Frogger task (contrary to predictions).

4.6.3: Hypothesis 3- There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower mean start-up delay

The slower start-up delay average performance contained a significantly older sample (mean age=71 years) than the faster start-up delay group (mean age 57.5 years) (Table 9). However, despite this difference in age and the behavioural differences in motor initiation between groups there were no significant age-related beta power differences between start-up delay performance groups for contralateral preparatory beta power ($t(5.641) = -.280$, $p>.05$ or post movement beta rebound ($t(9) = .889$, $p>.05$). In addition, no significant differences were found for start-up delay variability performance groups for contralateral preparatory beta ($t(9) = -1.426$, $p>.05$ or post movement beta rebound ($t(9) = -1.766$, $p>.05$).

No significant differences were found between start-up delay groups in hemispheric laterality with faster start-up delay group ($t(5) = 1.970$, $p>.05$ and slower start-up delay group ($t(4) = 1.976$, $p>.05$) both demonstrating similar contralateral and ipsilateral beta power activity. Start-up delay variability, on the other hand, did display hemispheric differences. For this sample, the least variable start-up delay group demonstrated similar contralateral and ipsilateral beta power hemispheric activity ($t(4) = 1.394$, $p>.05$), whereas the more variable start-up delay group was found to have a more dominant contralateral hemisphere ($t(5) = 2.636$, $p=.046$). These results are opposite to the above hypothesis suggesting that the more variable start-up delay performers will be increasingly using the ipsilateral hemisphere (hemispheric bilaterality).

In summary, start-up delay performance in this sample was only linked to hemispheric laterality. Start-up delay average performers used both hemispheres, whereas start-up delay variability groups showed that the more successful performers recruited additional neural

networks. These results do not support the notion that there worsened start-up delay performance are linked to increased preparatory beta power, reduced post movement rebound, and increasing hemispheric laterality.

4.3.4: Hypothesis 4- There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower walking speed

The slower walking speed group was slightly older (mean= 69.3 years) than the faster walking speed performance group (mean=59 years) (Table 9), however, this difference was not found to be significant ($t(9) = -1.724$, $p=.119$). No significant differences were found between walking speed groups in terms of difference ratios for preparatory beta ($t(6.082) = -.445$, $p>.05$) or post-movement beta rebound ($t(9) = -.120$, $p>.05$).

Similarly to start-up delay variability performance, those with a better/faster walking speed performance recruited both hemispheres ($t(5) = -1.612$, $p=.168$), whereas slower walkers had demonstrated a dominant contralateral hemisphere ($t(4) = 12.498$, $p=.067$). These results are in the opposite direction to the above hypothesis that those with slower walking speeds would recruit both hemispheres.

4.3.5: Hypothesis 5- There will be higher preparatory beta power, reduced beta rebound and lower beta asymmetry in people with slower processing speed and lower spatial planning performance

There were no significant differences found between processing speed inspection times for pre-movement beta ($t(9) = .763$, $p = .468$) or post-movement beta rebound $t(9) = .789$, $p = .453$). In addition, no differences in beta power activity were found between spatial planning performance groups pre-movement ($t(9) = .213$, $p = .837$) or post-movement ($t(9) = -1.867$, $p = .099$).

In support of the above hypothesis, a marginal effect was found between hemispheres for those with faster processing speed inspection times demonstrating a dominant contralateral hemisphere ($t(6) = 2.204$, $p = .070$). In contrast, those with slower processing speed inspection times did not find significant differences between hemispheres ($t(2) = 2.199$, $p = .159$), suggesting hemispheric bilaterality. Contrary to expectations, no differences were found between spatial planning performance groups for hemispheric lateralisation with both the lower spatial planning ability group ($t(5) = 2.025$, $p = .099$) and the higher spatial planning ability group ($t(3) = 2.285$, $p = .106$) demonstrating hemispheric bilaterality.

In summary, Frogger error groups differed contralaterally for post movement beta rebound, with those in the Frogger error group displaying a greater rebound (rather than lower as expected) than those who did not make any Frogger errors. There were no differences found between performance groups for pre-movement and post-movement beta power activity, however, for age, proportion of far-side pedestrian errors, start-up delay average &variability, walking speed, processing speed, or spatial planning. Differing hemispheric lateralisation patterns were found for differing performance groups. Younger adults, those making a lower proportion of frogger errors, and those with faster processing speed inspection times were

found to have a dominant contralateral hemisphere. In contrast, older adults, those making a higher proportion of frogger errors, and those with slower processing speed inspection times demonstrated hemispheric bilaterality.

The opposite pattern (in opposition to expectations) was found for proportion of far-side unsafe crossings, start-up delay variability, and walking speed, whereby better performers in these measures showed bilaterality and those with worsened performance predominately used the contralateral hemisphere. Start-up delay average groups, on the other hand, showed that both faster and slower start-up delay groups recruited both hemispheres.

4.4 Discussion

This study was a proof of concept study to see if pedestrian planning during a 'Frogger road crossing' task and variables identified as important in unsafe pedestrian errors in Chapter 2 would exhibit reliable biological indicators that could contribute towards prediction and prevention of unsafe pedestrian behaviour.

As expected, age differences were found in hemispheric lateralisation surrounding movement whereby older adults demonstrated beta symmetry and the younger sample employed beta hemispheric bilaterality. This finding supports research by authors such as Rossiter et al. (2014) and Park & Lorenz (2009) and could indicate that increased frontal functional activity is as a result of compensatory neural scaffolding, or a dedifferentiation of neural specificity to adapt to an increasing reduction in gray and white matter with age.

Contrary to previous research (such as Hall, et al., 2011), however, no significant age group differences were found for preparatory beta power and post movement beta rebound. However, this may be explained by the majority of participants in the older adult group being female (previous research has discovered older women demonstrating greater difficulties in areas such as walking speed, and balance: Butler, Menant, Tiedemann, & Lord, 2009 ; Scaglioni-Solano & Arago´n-Vargas, 2015) and using a median split to divide into age groups.

Despite a ceiling effect being found for 'Frogger' error numbers, those who did not make errors were found to demonstrate higher post movement rebound in the contralateral hemisphere. This may indicate that increasing pedestrian errors are as a result of maladaptive beta power activity and as beta rebound was significantly higher it could mean that it would take longer to reach normal resting beta power afterwards or begin movement desynchronisation again when movements are in quick succession. Interestingly, the majority of the participants who made 'Frogger' errors were female in this sample, and being female was related to increased near-side errors in Chapter 2. This could indicate that these pedestrian judgements are partially an age effect as the women were generally older than the men in this sample, or it could indicate that there are differences in neural changes between men and women.

Hemispheric lateralisation was found to have a differential relationship for near-side crossing errors (frogger task used one lane of 'traffic') and far-side pedestrian crossing errors. Increased proportion of near-side errors was linked to an increasing recruitment of the ipsilateral hemisphere in order to perform the frogger task similarly well to those with a

lower proportion of frogger errors. The reverse pattern was found for far-side errors whereby those making a higher proportion of far-side errors predominately used the contralateral hemisphere, and those making a lower proportion of far-side errors recruited both hemispheres. One possible reason for this contradiction in observed hemispheric patterns between Frogger and pedestrian simulator performance groups may be that different processes are required for one lane of traffic planning (i.e. Frogger task) compared to two lanes of traffic planning (pedestrian simulation). Alternatively, it could be that those making more far-side unsafe crossings are transitioning to impairment and have not as yet recruited additional neural networks to perform similarly well to those making less far-side errors or less near-side errors, particularly as those making less far-side errors used both hemispheres. This could indicate that the reduced number of near-side errors with increasing age may be due to hemispheric bilaterality to compensate for global slowing. These findings partially support the theory proposed by Foerch & Steinmetz (2009) that unsafe pedestrian crossings, particularly at the far-side of the road side may be as a result of difficulties in the right hemisphere (this was the dominant side for the majority of the sample) which would lead to difficulties in the contralateral left field of view. Evidence for a reduction in right side motor cortex ability was demonstrated by changes in beta power post-movement in the Frogger task. In addition, far-side errors were more common when additional neural networks had not been recruited from the ipsilateral hemisphere, suggesting that the right hemisphere alone is not sufficient to perform the task well.

The pedestrian predictors identified in Chapter 2 also demonstrated hemispheric changes in lateralisation. Similarly to the frogger task, processing speed also showed that those with slower processing speed inspection times increasingly recruiting the ipsilateral hemisphere. These results support the notion of a global slowing with age (Salthouse, 1996) which may

extend to difficulties in the motor cortex. As processing speed was found to be predictive of near-side unsafe crossing errors in Chapter 2, these results could indicate that near-side unsafe crossings are a result of increasing global slowing and not yet recruiting additional neural networks to compensate. Walking speed and start-up delay variability, on the other hand, performed more similarly to far-side unsafe crossings whereby better performers recruited both hemispheres and those with worsened performance mainly used the contralateral hemisphere. These results suggest that despite the better performers are doing so as a result of hemispheric bilaterality. If these individuals are still transitioning towards increasing hemispheric laterality, this could explain why the ratio of far-side pedestrian casualties compared to near-side casualties have been found to decrease after the age of 85 years (Dunbar, 2012).

The biggest weakness of this study was sample size which was partially due to sampling difficulties, with only 11 participants out of 104 from study 1 (Chapter 2) being willing and able to take part. As a result, the study was conducted using a small sample size (a problem for statistical power) and distinct extremes of mobility abilities and pedestrian behaviours could not be examined. Some of the non-significant differences or similar group findings could be as a result of the groups being too similar in performance and/or in age as median splits were required for used to divide the groups.

The frogger task also only consisted of one lane of traffic and had a near ceiling effect suggesting that the task was mainly measuring near-side errors and was perhaps not difficult enough to investigate whether neuronal and hemispheric changes are present in complex pedestrian judgements. An additional block of trials with a second lane of traffic for the

'frog' to cross could be added to see if there are different beta power signatures between preparing for near-side and far-side crossing choices, Alternatively, an EEG could be employed whilst completing the road crossing simulation to provide a more realistic representation of motor cortex beta power activity in a more naturalistic setting.

Some differences in beta power activity in participants using Frogger between those with high versus low far-side crossing errors were found in this study, which is promising, and may warrant further exploration. Future research would benefit from a larger participant sample with extremes of pedestrian crossing error and pedestrian predictor abilities, with extra care to age and gender match the groups to separate out these confounding variables. Due to the smaller sample size, there was not the statistical power to perform extensive analysis such as voxel-based morphometry correlations typically used for parametric mapping of beta power activity. One of the difficulties in recruiting participants for study 2 was that some of the older adults were anxious about the scanners. Of those who were willing to take part, a number of participants were unsuitable due to not meeting the health and safety criteria. Future research may consider first selecting those suitable and willing to take part in MEG and MRI and then do the offline tasks (such as walking speed, and cognitive tasks).

To conclude, this proof of concept study found that differences in beta power signatures can be found between performance groups divided by the presence or absence of behavioural road crossing errors. These findings may have implications for future research towards predicting, preventing, and perhaps treating older adults at risk of pedestrian injury.

5 Identifying predictors of fear of falling, life space, and quality of life measures

Objective

In addition death and injury, mobility decline (such as pedestrian errors in Chapter 2, and falls in Chapter 3) and cognition can negatively impact on quality of life and activity avoidance. Further, fall prevalence in Chapter 3 was not significantly linked to mobility and cognition alone, and may be further explained by a fear of falling. The objective of the study was to determine the role of mobility and cognition on fear of falling and life space mobility, and the impact on quality of life measures

Methods

A series of questionnaires (including falls efficacy, life space mobility, and quality of life) were completed by half of the Study 1 participants, and were compared to Study 1 mobility (including unsafe pedestrian crossings, safe crossings missed, and falls), and cognitive measures.

Results and Conclusions

Fear of falling was significantly predicted by mobility decline (sit-to-stand and mobility score), pedestrian anxiety, previous falls, and cognition (spatial working memory, processing speed, and reaction time) and accounted for 68.1% of the variance. Life space mobility, however, was predicted by mobility (mobility score and pedestrian anxiety) and close family & friends, and accounted for 11.1% of life space mobility variance. 48.5% of quality of life variance was explained by mobility (sit-to-stand times and pedestrian anxiety), close family & friends, and cognition (reaction time and processing speed). These results suggest that mobility, social community, and possibly a realisation of slowed cognition are key to QOL.

5.1 Introduction: Prevalence and Implications

Chapter 3 was unsuccessful in significantly predicting fall history in this participant sample, with postural sway (perturbation average) and set shifting only explaining 9-13% of fall variance. This suggests that more factors may contribute towards fall prevalence than mobility and cognition alone. Falls are increasingly common with increasing age and can cause serious or fatal injuries in older adults (Rubenstein, 2006).

A common by- product of falling is a fear of falling, and this can affect up to sixty percent of 60-79 year olds (Niino, Tsuzuku, Ando, & Shimokata, 2000; Howland, Lachman, Peterson, et al., 1998). Although fear of falling is a common result of having experienced a fall, it can also be present in those who have not fallen, and not all older adults who have fallen (within the previous 12 months) will become fearful (Myers, Powell, Maki, et. al, 1996). Fear of falling has been found to be a risk factor for future falls (de Vries, Peeters, Lips, & Deeg, 2013; Delbaere, Close, Heim, et al., 2010; Hadjistavropoulos, Martin, Sharpe, et al., 2007). For instance, a fear of falling may lead to avoidance of certain movements, such as avoiding going upstairs or moving around the house unless necessary. In a study by Filiatrault & Desrosiers (2009), it was found that 50% of those fearful of falling would pause before getting up from a bed and would slow their walking speed. Restriction of movement may lead to muscle weakness and atypical gait (Rubenstein, 2006). Painter, Allison, Dhingra, et al. (2012) found that activity restriction predicted fear of falling, and that activity restriction was related to anxiety and depression in older adults. This suggests that the fear of falling phenomenon is more complex than merely a result of having a fall, and that fear of falling may contribute towards explaining the presence of falls.

Fear of falling and activity restriction, however, may not necessarily be as a result of mobility reduction. Cumming, Salkeld, Thomas, & Szonyl (2000) found a relationship was found between fear of falling and activities of daily living even once age, sex, recent falls, walking aid use and physical health, with the more fearful of falling older adults are (measured using falls efficacy scale, FES) the fewer activities of daily living are performed. This suggests that fear of falling may be multifaceted and that fear even in the absence of mobility impairments may limit activities of daily living.

Further to daily activities, fear of falling can impact on older adults travel patterns. Life space mobility is defined as the area in which a person travels on a daily basis from rooms in the house to other counties and countries (Baker, Bodner, & Allman, 2003). WRVS (2012) found that out of those who took part in a questionnaire, 17% of over 80's were concerned about leaving the house for fear of falling, and 5% of over 75's only leaving the house if accompanied. Older women were found to have more fear of falling (Filiatrault & Desrosiers, 2009) and had a smaller life space than men (Byles, Leigh, Vo, Forder, & Curryer, 2015).

To date, no significant body of work has combined behavioural methods, with relevant neuropsychological features such as motor initiation, quality of life, and fear of falling measures. Together, they may provide important diagnostic and prognostic indicators of impaired function (and adaptation/compensation) with which to inform intervention. The purpose of this study was to determine the predictive relationships for fear of falling, life space mobility, quality of life, and social restriction, with age, gender, mobility measures (including falls), cognition, and pedestrian behaviour collected in Chapter 2.

5.1.1 Impact of Life Space Mobility and Fear of Falling on Quality of Life Measures

Fear of falling is one of the main disabling components of ageing, as it prevents the optimal level of functioning for the older adult, such as reduced social and physical activity (Tennstedt, Howland, Lachman, et al., 1998). Concerns about physical harm, lasting functional disability, and loss of independence, along with social embarrassment and damage to identity were the main commonly feared consequences of falling (Yardley, & Smith, 2002). Life space mobility has also been found to be significantly associated with quality of life. Quality of life (using LEIPAD questionnaire: De Leo, Dickstra, Lonnqvist, et al., 1998) was found to be reduced in individuals who perceived there to be more outdoor environmental barriers (such as travel distances, traffic, and terrain), who were anxious of going outdoors, had slower walking speed, and were not as physically active as desired (Rantakokko, Iwarsson, Kauppinen, et al., 2010). Therefore, a reduction or even a perceived reduction in life space mobility can reduce feelings of wellbeing.

In addition, reduced life space mobility is associated with increased prevalence of depressive symptoms in older adults. Polku, Mikkola, Portegijs, et al., (2014) found that the relationship between life space mobility and depression were mediated by gender. When the depression was divided into its four sub-components (low feelings, physical symptoms such as low appetite, positive feelings such as feeling hopeful, and interpersonal problems) it was found that this relationship between life space mobility and depression was mediated by walking difficulties and health conditions.These results suggest that a combination of reduced mobility, reduced life space, and fear of falling may have a negative impact on quality of life. This chapter determined the extent to which mobility (including falls and behaviour), life space, and fear of falling could predict quality of life with increasing age.

Reduced life space range can also have a negative impact on social isolation. Rantakokko, Iwarsson, Vahaluoto, et al., (2014) found that in an extensive home interview of 848 older adults (aged, 75-90 years), 28% of participants reported feelings of loneliness sometimes or often. Those who reported feelings of loneliness were found to have reduced independence (impact on participation and autonomy questionnaire), increased number of perceived outdoor environmental barriers, difficulty walking 2km, and a reduced sense of autonomy. Functional (basic ADL's, avoidance of engagement in social & physical activities; using SAFFE scale) and social factors, such as social embarrassment and damage to identity, were important with increasing age and increasing postural instability. Fear of damage to identity and physical harm and disability, along with general fear of falling predicted future avoidance of activities at Time 2 (6 months after initial meeting). The authors speculate that fear of damage to identity may explain some of the association between fear of falling and avoidance of social situations.

Objective and perceived social isolation has also been found to be a risk factor for mortality (Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015). These results suggest that in uncovering the causes of fear of falling and reduced life space mobility there may be opportunities to reducing social isolation, increasing quality of life, and perhaps increasing healthy lifespan via reduced falls and loneliness. This chapter specifically examined whether fear of falling, or life space mobility was more predictive of quality of life, or whether it could be attributed to a combination of both. In addition, the predictive value of social connections was examined to determine whether it predicted quality of life even when mobility, cognition, fear of falling, and life space mobility had been accounted for.

There are many possible causes and/or contributing factors towards both fear of falling and life space mobility but the exact cause and most predictive relationship is as yet not fully understood. As indicated in Chapter 3, falls were related to mobility (as measured by walking speed) and cognition (selective attention and within participant variability), however only walking speed moderately predicted the presence of falls within the previous 12 months (see Chapter 3 for full results). With previous literature indicating a predictive and causal role of fear of falling with falls (de Vries, Peeters, Lips, & Deeg, 2013; Delbaere, Close, Heim, et al., 2010; Hadjistavropoulos, Martin, Sharpe, et al., 2007), this chapter investigated whether fear of falling, and maybe life space mobility, may be a better predictor of falls than mobility and cognition in this participant sample. In addition, the role of psychological factors, cognition and mobility was explored to uncover predictive relationships of fear of falling and reduced life space mobility.

5.1.2 Link between Fear of Falling and Life Space Mobility with Mobility Difficulties

Mobility and physical activity have previously been found to be associated with fear of falling. People with higher levels of physical activity, and enhanced balance, using the Berg Balance scale, which includes items such as standing from a seated position (Berg, Wood-Dauphinee, Williams, & Maki, 1992), were found to be less fearful of falling (using the Falls Efficacy Scale, Tinetti et al., 1990), (McAuley, Milhalko, & Rosengren, 1997). Moreover, fear of falling was also found to be reduced with exercise interventions designed to increase falls self-efficacy (Li, Fisher, Harmer, & McAuley, 2005) and further investigation in mobility and fear of falling may be useful for devising interventions to reduce this fear.

In addition, those more fearful of falling had poorer balance control (Berg balance scale; Berg, Wood-Dauphinee, Williams, & Maki, 1992) and lower extremity function (timed up

and go and 50ft speed walk) (Li, Fisher, Harmer, McAuley, & Wilson, 2003). Further to current fall anxiety, balance and sensory issues can predict future fear of falling to occur. In a sample of women twin pairs aged 63-76 years old, out of those who reported themselves as not being afraid at baseline, 41% subsequently developed a fear of falling three years later. This fear of falling was predicted by a combination of self reported vision, hearing, and balance difficulties (measured via a Likert scale question of how much they agree with having these difficulties), even if participants had not experienced a fall (Viljanen, Kulmala, Rantakokko, Koskenvuo, Kaprio, & Rantanen, 2013). These results suggest that fear of falling can be caused by age-related changes even in the absence of previous falls.

Besides balance and lower extremity function, age-related changes in walking may also contribute towards a fear of falling. Previous literature has indicated that fear of falling is linked to gait difficulties. Maki (1997) found that fear of falling was significantly related to shorter gait stride lengths, increased stride-to-stride variability (both measured by saturating pads underneath special slippers with ink and measuring stride properties on the paper walkway), and slower gait speed, even though these gait measures were not significantly predictive of future falls up to a year later. In addition, slower gait speed and stride variability was shown to be highly related. The author suggests that this slowing in speed may be at least partially as a result of compensating for stride variability (Maki, 1997). Also, Ayoubi, Launay, Kabeshova, et al., (2014) found that falls and fear of falling on their own, however, were not found to be predictive of walking speed stride-by-stride variability (measured using GAITRite) in older adults (aged 65.5-75.5 years), rather, combined fear of falling with previous falls were associated with increased walking speed variability. These results imply that the relationship between mobility (in this case walking speed), falls, and fear of falling are more complex than reduced mobility and previous falls causing fear, and vice versa. This

could suggest that performance variability in mobility, such as perturbation variability may also be linked to fear of falling.

Besides fear of falling, life space mobility has also been linked to mobility difficulties in older adults. Longitudinal life space data (using the University of Alabama at Birmingham Study of Aging Life Space Assessment) in older adults was found to mediate activities of daily living (such as ability to climb the stairs, walking, and getting outside) and health related quality of life (using a version of the SF-12), even when age, sex, race, education, and smoking status were accounted for (Bentley, Brown, McGwin, et al., 2013). People who avoid activities because of fear of falling may also become frailer. Avoidance of activities of daily life in older adults (aged 61-92 years) was found to be related to reduced mobility performance (Physical Performance Test, including reaching and walking), muscle strength, and centre of gravity (Delbaere, Crombez, Vanderstraeten, Willems, Cambier, 2004). Further, life space mobility has been found to be related to reduced sit-to-stand speed, tandem standing balance, and walking speed (using the Short Physical Performance Battery, SPPB; Guralnik, Simonsick, Ferrucci, et al., 1994) (Portegijs, Rantakokko, Mikkola, Viljanen, & Rantanen, 2014), suggesting that a combination of psychological and physical factors can restrict one's life space. Autonomy and physical performance explained one third of life space mobility. These relationships were more profound in women. Further, reduced life space mobility was previously been found to be associated with and predictive of frailty (measure including slowed walking, weak grip, low physical activity) (Xue, Fried, Glass, Laffan, & Chaves, 2007). This chapter directly examined the predictive contributions of mobility and fear of falling on life space mobility.

These studies suggest that fear of falling, and life space mobility may be related to a reduction in mobility (such as balance, sit-to-stand ability, and walking speed). However, as falls do not necessarily result in a fear of falling, or a life space restriction, and likewise those who are fearful of falling have not always experienced a fall within the previous year (Myers, Powell, Maki, et. al, 1996), there may be more factors involved in the development of fear of falling and life space restriction than mobility alone. Further, as mobility was found to be related to cognitive function in Chapter 3, there may be an element of cognition involved too. This chapter focussed on balance, chair rises, walking speed and self-reported mobility, along with quality of life measures and activity restriction in order to uncover these complexities in fear of falling.

5.1.3 Relationship between Fear of Falling and Life Space Mobility with Road Behaviour

As research into mobility has found a link with fear of falling (see 5.1.3), and Chapter 2 found walking speed and start-up delay to be related to and predictive of unsafe crossing behaviour, fear of falling may also relate to aspects of pedestrian behaviour. In a study by Avineri, Shinar, & Susilo (2012), fear of falling across three age groups (18-35 years, 36-64 years, and 65+ years) was assessed in relation to observed pedestrian behaviour at two real world crosswalks (a signalised two-way road, and an unsignallised one-way road). Using a fixed video camera during midweek off-peak times (10am-2pm), walking speed, and downward head pitches (as opposed to looking directly at the road and traffic, and as such a measure of visual inattention) were recorded. After having been observed crossing the road, participants were approached for an optional face-to-face survey including questions such as age, gender, whether they were in a hurry, had vision problems, whether they had previously been involved in a road incident, were fearful of falling (Likert scale), and how often they cross at that point.

Results showed that fear of falling was predictive of an increased number of downward head pitches (i.e. demonstrated less attention towards the road) whilst crossing the road, but not factors such as age or crossing speed. Crossing speed did not appear to be influenced by fear of falling in this sample; rather increased age (faster walking was observed in the 18-35 year group, and slower walking was observed in the 65+ year group) and gender (predominately females) were the biggest predictors of crossing speed. Previous road incidents were not found to be predictive of downward head pitches. However, visual inattention or looking behaviour does not directly address whether the crossing gaps taken would have been safe for that individual. The authors also did not explore compensation behaviours regarding whether safe crossing gaps that could have been taken were missed as a result of being anxious of falling (Avineri, Shinar, & Susilo, 2012). This chapter directly investigated this issue using a simulated road crossing environment data from Chapter 2 to assess the role and predictive value of fear of falling on the proportion of unsafe crossing errors made, and the proportion of safe crossing gaps missed. Maybe begin to introduce your hypotheses.

5.1.4 Relationship between Fear of Falling and Life Space Mobility with Cognition

Literature has also implied the role of cognition in fear of falling and life space mobility. Increased dual task costs (walking while talking) have been observed in older adults with a fear of falling and a lower balance confidence compared to those with higher balance confidence and no fear of falling (Liu-Ambrose, Katarynych, et al., 2009). However, only age, time to walk 40ft, and global cognition were accounted for, and not other mobility functions such as balance, despite investigating balance confidence, or lower extremity strength which would indicate frailty. Further, O'Halloran, Pénard, Galli, et al. (2011) found that mean reaction time and within participant variability in a sustained attention task (sustained attention to response task; SART) was related to fear of falling (falls efficacy

questionnaire) and previous falls in older adults. In addition to attentional resources and variability, Schott (2014) found that the executive function set shifting (measured using the trail making test) was related to balance confidence (using activities specific balance confidence scale). These findings suggest that reduced attentional and executive function resources may at least partially contribute towards a fear of falling in older adults. However, these studies have only examined a limited amount of cognitive functions, mainly focusing on global cognitive change.

Cognition has also been linked to life space mobility restriction. Sartori, Wadley, Clay, Parisi, Rebok, & Crowe (2012) explored the relationship between cognitive functions, including memory (composite of Rivermead behavioural memory test paragraph recall, Hopkins verbal learning test, Rey auditory verbal learning test), processing speed (Useful Field of View composite), reasoning (identify letter, and word series problems composite), with life space questionnaire, daily activities (everyday problems test, observed tasks of daily living, timed instrumental activities of daily living), and personal control beliefs (Locus of Control). All three cognitive domains strongly and independently predicted life space in older adults.

To the best of the author's knowledge, to date few studies have incorporated an extensive battery of cognitive tests to further examine cognitive causes of fear of falling despite evidence for attentional reserve issues. This chapter employed a wide battery of cognitive and executive function tasks with the aim to uncover predictive relationships with fear of falling.

The hypotheses that were tested were:

1) Lower fear of falling scores, larger life space mobility and higher quality of life scores will be correlated with reduced previous falls, better pedestrian behaviour (proportion of errors and proportion of missed safe crossings), mobility, start-up delay and cognition

2) There will be significant correlations between fear of falling and life space mobility with quality of life measures (i.e. perceived life space difficulty, loneliness and satisfaction with life)

3) Mobility (including previous falls and pedestrian behaviour), cognition and quality of life measures will have a strong linear relationship with fear of falling

4) Mobility (including previous falls and pedestrian behaviour), cognition and quality of life measures (including fear of falling) will have a strong linear relationship with life space mobility

5) Mobility, cognition, fear of falling and life space mobility will have a strong linear relationship with quality of life score

6) Mobility, cognition and quality of life measures (specifically fear of falling) will have a strong linear relationship with previous falls

5.2 Method

5.2.1 Design

A regression design was used to find predictive relationships between variables. The dependent variables measured were fear of falling, life space mobility, previous fall number, and quality of life. The potential predictive measures used were age, cognitive measures (spatial planning, spatial working memory, inhibition, updating, set switching, reaction time, within participant variability), and visual attention measures (processing speed, divided attention, selective attention), mobility (walking speed, mobility score, sit-to-stand, perturbation average, perturbation variability), start-up delay, pedestrian behaviour (proportion unsafe crossing errors, proportion safe crossing gaps missed), and quality of life measures (quality of life, satisfaction with life, loneliness, social community, communication frequency, perceived life space difficulty, fear of falling, life space mobility). Correlation analyses determined which of the predictive measures were included in the regression analyses.

5.2.2 Participant Sample

Participants from Study 1 were invited back to take part in a QoL questionnaire. For the Fear of Falling and Quality of Life Questionnaire study, all the participants from the original sample were sent three questionnaires (Appendix 5), a consent form and debrief form (Appendix 4), through the post with a postage paid return envelope. Participants were given the option to opt in to the study and return the questionnaires. A total of 56 participants, aged 46-88 years (mean=67.4 years, SD= 9.73), completed and returned the questionnaires. Out of this sample, 82.1% reported being at least a little fearful of falling. 17.9% of the sample had fallen within the previous 12 months. 62.5% of the respondents were female.

5.2.3 Ethical Considerations

This study was approved by the Aston University Life and Health Sciences Ethics Committee. Participants were reminded of their right to withdraw at any point up to two weeks after returning the questionnaires without any adverse consequences, and that they have the choice to opt in if they wish. All participants were given information regarding the study, and were required to complete a consent form. Data use and storage complied by the standards of the Data Protection Act (1998). Participants used the same participant codes as Study 1 to ensure confidentiality but also to match the data from Study 1. Questionnaire originals were kept in a secure, locked office. Data analysis was conducted on a password protected computer, and only the participant code was used against their data.

5.2.4 Measures

Mobility measures (walking speed, mobility score, sit-to-stand, perturbation average & variability; 2.2.6.1 & 2.1.6.2), cognitive & visual attention measures (processing speed, divided attention, selective attention, spatial planning, spatial working memory, updating, inhibition, set shifting,, choice reaction time, within participant variability; 2.2.6.3), and pedestrian behaviour measures (proportion unsafe crossing errors, proportion safe crossing gaps missed; 2.1.6.4), from Study 1 (Chapter 2) were used, along with new questionnaire assessments as described below.

The complete Falls Efficacy Scale- International (FES-I) questionnaire (Tinetti, Richman, & Powell, 1990) was used to measure fear of falling (Appendix 5). Tinetti, et al. (1990) argued that this measure is more valuable and informative than merely asking participants if they are fearful of falling in a 'yes or no' format. The questionnaire contained the full 16 questions

regarding how concerned participants are about falling under various circumstances, such as getting out of a chair or going to the shops. A higher number on this measure meant that the participant was more fearful of falling.

The Life Space Questionnaire (Stalvey, et al, 1999) was adapted from American English into English (e.g. yard to garden) (see Appendix 5). The Life Space Mobility Questionnaire has previously been found to have high test-retest reliability (Kammerlind, Fristedt, Bravell, & Fransson, 2014). Each life space area visited (yes or no answer) within the last 3 days was summed up to provide the outcome score. The questions ranged from leaving their bedroom to leaving the country. A higher score meant that the participants had a large life space area.

To measure quality of life, four questions from the ASCOT (adult social care outcomes toolkit; Social Care Related QoL questionnaire) (Netten, et al, 2011) was used (see Appendix 5). These four questions covered how much control participants felt they had over their daily life, whether they were able to do the activities they wished to, how anxious they felt, and their feelings regarding their social status. These statements were weighted in accordance to standardised protocol and summed together to provide one outcome measure. A larger score meant that participants had a higher perceived quality of life.

One question (with three statements) from Satisfaction with Life Scale was used (Diener, Emmons, Larsen, & Griffin, 1985) (see Appendix 5). The questions related to how ideal their life was, the conditions of their life, and how satisfied participants were with their life, using a likert scale. The scores on each of these statements were summed together and provided one

outcome measure. A higher score meant that the participants were more satisfied with their lives.

Six questions from the UCLA Loneliness Scale (Russell, Peplau, & Ferguson, 1978) were used (Appendix 5). The questions covered feelings of loneliness & isolation, number of social interactions with family & friends, and participants recorded their responses using a Likert scale. Three outcome measures were obtained: total social community score (number of friends and family), total communication (with family and friends), and how lonely they perceived themselves. For these measures, lower scores meant that participants had better social community and communication.

5.2.5 Procedure

Participants received a consent form, debrief form, study information, and two questionnaires (listed in 2.5.6) through the post and those that were interested returned their responses on a prepaid envelope.

5.2.6 Plan of Analyses

In order to test hypothesis 1 (Lower fear of falling scores, larger life space mobility and higher quality of life scores will be correlated with reduced previous falls, better pedestrian behaviour, mobility, start-up delay and cognition) and hypothesis 2 (There will be significant correlations between fear of falling and life space mobility with quality of life measures) partial correlations controlling for age and gender were conducted.

Hypothesis 3 (Mobility, cognition and quality of life measures will have a strong linear relationship with fear of falling), hypothesis 4 (Mobility, cognition and quality of life measures will have a strong linear relationship with life space mobility) and hypothesis 5 (Mobility, cognition, fear of falling and life space mobility will have a strong linear relationship with quality of life score) were conducted using stepwise regressions.

Finally, hypothesis 6 (Mobility, cognition and quality of life measures (specifically fear of falling) will have a strong linear relationship with previous falls) employed a stepwise logistic regression. The missing values within the multiple regression analysis were replaced with mean values (Rubin, 2004).

5.3 Results

5.3.1 Hypothesis 1- Lower fear of falling scores, larger life space mobility and higher quality of life scores will be correlated with reduced previous falls, better pedestrian behaviour (proportion of errors and proportion of missed safe crossings), mobility, start-up delay and cognition

Age was not related to fear of falling, life space mobility, or quality of life. Gender was, however, related to quality of life only ($r = -.347$, $p < .001$), with men in this sample reporting greater quality of life than women. As demonstrated in Table 11, slower sit-to-stand times were also linked to a reduced quality of life. This relationship between quality of life and sit-to-stand times remained significant when gender was controlled for ($r\ (53) = -.335$, $p = .012$), suggesting that gender and sit-to-stand times independently relate to quality of life.

Fear of falling, but not life space mobility was related to falls within previous year, Fear of falling was also correlated with reduced walking speed, increased self-reported mobility difficulties, slower sit-to-stand times, further perturbation distance, reduced spatial working memory, and reduced reaction time. Life space mobility was not significantly related to mobility difficulties or cognition. Instead, an increased life space area, as opposed to a reduced life space mobility area as predicted, was positively related to a higher proportion of available crossing gaps missed. Neither fear of falling, nor life space mobility were related to proportion of unsafe crossing errors. These results partially support the above hypothesis as fear of falling is related to multiple cognitive and mobility components, including the presence of a previous fall. Life space mobility, on the other hand, was related to pedestrian behaviour only. Further, quality of life is independently related to lower extremity strength and gender, but not cognition. Start-up delay was not related to any of these measures.

Table 11- Correlation Matrix Previous Falls, Pedestrian Behaviour, Mobility and Start-up Delay with Life Space and Fear of Falling

Variable N=56	Unsafe Errors	Safe Missed	Falls	WS	Mob Score	STS	Pert Ave	Pert COV	SUD	SUD COV	PS	DA	SA	SP	SWM	In	Up	Set Shift	RT	WPV
Fear of Falling	.027	.069	.378**	-.303*	.501**	.616**	.279*	-.081	.227	-.057	-.142	.142	.150	-.150	-.305*	.095	-.084	-.044	.400**	.197
Life Space	-.129	.302*	.112	-.053	.142	-.114	-.215	-.111	.132	-.170	-.015	.143	.121	-.060	.130	.074	.076	.044	.031	.211
Mobility Quality of Life	-.213	.227	-.039	.167	-.126	-.304*	-.181	-.156	-.005	-.099	-.169	-.065	-.052	.020	-.003	.227	.037	.112	.089	-.076

*= Significant at .05 level **=Significant at .01 level

Unsafe Errors= Proportion Unsafe Pedestrian Crossings, Safe Missed= Proportion Safe Crossings Missed, SUD= Start-up Delay Average, SUD COV= Start-up Delay Coefficient of Variance, WS= Walking Speed, Mob= Mobility, STS=Sit-to-Stand, Pert= Perturbation, Ave= Average, PS= Processing Speed, DA= Divided Attention, SA= Selective Attention, SP= Spatial Planning, SWM= Spatial Working Memory, In= Inhibition, Up= Updating, Set Shift= Set Shifting Commissions, RT= Reaction Time, WPV= RT Within Participant Variability

5.3.3 Hypothesis 2- There will be significant correlations between fear of falling and life space mobility with quality of life measures (i.e. perceived life space difficulty, loneliness and satisfaction with life)

As shown in Table 12, increased fear of falling was positively related to an increased perceived life space difficulty. However, no significant relationship was found with actual life space mobility area (Table 12). This suggests that fear of falling may make individuals feel that their life space is more difficult but not necessarily reduce it. Further, the more fearful of having a fall an individual was, the lonelier they felt they were, and the smaller close social community they reported having.

An increase in close social community, on the other hand, was positively related to an increased life space area. Total communication with close family and friends was linked to life space mobility only, with a reduction in communication being linked to increased life space mobility. This could imply that those individuals with less communication are visiting close family and friends instead.

Increased quality of life score was found to be significantly positively related to an increased number of close family and friends and increased life space mobility area, and negatively related to a reduction in fear of falling. Satisfaction with life score, however, was not significantly related to either fear of falling or life space mobility. These results support the hypothesis that fear of falling and life space mobility are implicated for quality of life in older adults, including loneliness. As cognition and mobility (Table11) have also been found to relate to these measures, interventions in these areas could also increase quality of life.

Although fear of falling was not related to proportion of safe crossings missed (Table 11), reduced life space difficulty was related to an increased proportion of safe pedestrian crossings missed (r (54) = -.343, p=.010). This could indicate that caution at the roadside and reduced fear of falling could be beneficial for increasing life space area.

Table 12- Correlation Matrix Quality & Satisfaction with Life, Life Space Difficulty, and Loneliness & Social Inclusion Measures, with Life Space, and Fear of Falling, controlling for Gender

ariables =56)	Life Space Mobility	Quality of Life	Satisfaction with Life	Life Space Difficulty	Loneliness Scale	Total Communication	Total Social Community
ear of alling	-..073	-.265*	-.195	.331*	.338*	.130	-.338*
ife Space lobility		.375**	.146	-.162	-.060	-.280*	.287*
uality of ife				-.223	-.310*	-.231	.421**

*= Significant at .05 level **=Significant at .01 level

5.3.4 Hypothesis 3- Mobility (including previous falls and pedestrian behaviour), cognition and quality of life measures will have a strong linear relationship with fear of falling

To answer the above hypothesis regarding predictors of fear of falling, a stepwise regression was conducted. When all the mobility, motor initiation, and cognitive measures along with life space mobility were entered into the model, a total of 15 steps each with one variable per step were produced. Considering 56 participants took part in this study, this many variables and steps would reduce the model's statistical power. For this reason, a principle components analysis was then conducted to reduce the number of variables entered into the stepwise regression. The principle components analysis was conducted so as to force the variables into two fixed factors. The variables in the component matrix that were loaded strongly (i.e. above .4) in the same factor as fear of falling were as follows: age, walking speed, self-reported mobility score, sit-to-stand, perturbation average (transformed), falls, proportion of total unsafe pedestrian crossings

(transformed), proportion safe pedestrian crossings missed, start-up delay average, processing speed (transformed), divided attention (transformed), selective attention, choice reaction time (transformed), and spatial working memory. The steps produced in the new stepwise regression can be seen in Table 13.

The overall model for predicting fear of falling was found to be significant (F (7, 47) =14.343, p<.001) and accounted for 68.1% of fear of falling variance. Sit-to-stand alone predicted 37.9% (Table 13). All seven steps significantly contributed towards fear of falling: sit-to-stand F (1, 53) =32.332, p=<.001; mobility score F (1, 52) =5.399, p=.024; safe pedestrian crossings missed F (1, 51) =5.860, p=.019; previous falls F (1, 50) =5.722, p=.021; processing speed F (1, 49) =7.386, p=.009; reaction time F (1, 48) =6.078, p=.017; spatial working memory F (1, 47) =4.489, p=.039 (individual percentage variance added displayed in Table 13). These results support the above hypothesis that mobility measures, including previous falls, and cognition are predictive of fear of falling.

Table 13- Predictive Contribution of each Step in explaining Fear of Falling

Model Steps	Variable	R^2	^ R^2	Beta	Sig.
1 Mobility 1	Sit-to-Stand	.379**	.379**	.616**	<.001
2 Mobility 2	Sit-to-Stand	.437**	.058*	.488**	<.001
	Mobility Score			.273*	.024
3 Pedestrian Behaviour	Sit-to-Stand	.495**	.058*	.497**	<.001
	Mobility Score			.343**	.005
	Safe Crossings Missed			.252*	.019
4 Falls	Sit-to-Stand	.547**	.052*	.432**	<.001
	Mobility Score			.350*	.003
	Safe Crossings Missed			.243*	.018
	Falls			.236*	.021
5 Visual Attention	Sit-to-Stand	.606**	.059**	.438**	<.001
	Mobility Score			.358**	.001
	Safe Crossings Missed			.243*	.013
	Falls			.279**	.005
	Processing Speed			-.248**	.009
6 Cognition 1	Sit-to-Stand	.651**	.044*	.352**	.002
	Mobility Score			.338**	.001
	Safe Crossings Missed			.257**	.006
	Falls			.281**	.003
	Processing Speed			-.308**	.001
	Choice Reaction Time			.243*	.017
7 Cognition 2	Sit-to-Stand	.681**	.030*	.321**	.003
	Mobility Score			.333**	.001
	Safe Crossings Missed			.237**	.009
	Falls			.291**	.002
	Processing Speed			-.341**	<.001
	Choice Reaction Time			.213*	.032
	Spatial Working Memory			-.187*	.039

*= Significant at .05 level **=Significant at .01 level ^ R^2= R^2 change

5.3.5 Hypothesis 4- Mobility (including previous falls and pedestrian behaviour), cognition and quality of life measures (including fear of falling) will have a strong linear relationship with life space mobility

A stepwise regression was conducted to determine the predictors of life space mobility. The following variables were entered: age, gender, previous falls, walking speed, mobility score, sit-to-stand, perturbation average (transformed), perturbation coefficient of variance (transformed), processing speed (transformed), divided attention (transformed), selective attention, spatial planning, spatial working memory, updating, set shifting (transformed), inhibition, reaction time (transformed), within participant variability (transformed), start-up delay average, start-up delay coefficient of variance, proportion unsafe pedestrian crossings made (transformed), proportion safe pedestrian crossings missed, fear of falling, loneliness score, total communication , and total close community. Total communication consisted of the frequency in which participants were in contact with friends and family, and total close community was the sum of close friends and family they reported to have. The stepwise regression produced can be seen in Table 14.

The whole model was significant (F (3, 54) =7.550, p=<.001) and explained 30.8% of the variance. Each individual step significantly contributed to explaining life space mobility variance: total communication F (1, 53) =6.625, p=.013; proportion safe crossings missed F (1, 52) =6.212, p=.016 and additional 9.5%, mobility score F (1, 51) =7.479, p=.009). In addition, all three predictors were found to be significant throughout (Table 14). These results partially support the above hypothesis as mobility, pedestrian behaviour, and social network, but not cognition were predictive of life space mobility.

Table 14- Predictive Contribution of each Step in explaining Life Space Mobility

Model Steps	Variable	R^2	^ R^2	Beta	Sig.
1 Spatial Network	Total Communication	.111*	.111*	.333*	.012
2 Pedestrian Behaviour	Total Communication	.206**	.095*	.339**	.008
	Safe Crossings Missed			.308*	.016
3 Mobility	Total Communication	.308**	.102**	.407**	.001
	Safe Crossings Missed			.409**	.002
	Mobility Score			.341**	.009

*= Significant at .05 level **=Significant at .01 level ^ R^2= R^2 change

5.3.6 Hypothesis 5- Mobility, cognition, fear of falling and life space mobility will have a strong linear relationship with quality of life score

To answer the above hypothesis regarding the predictive contributions of mobility, cognition, fear of falling, and life space mobility to quality of life, a stepwise regression was conducted. The following variables were entered: age, gender, previous falls, walking speed, mobility score, sit-to-stand, perturbation average (transformed), perturbation coefficient of variance (transformed), processing speed (transformed), divided attention (transformed), selective attention, spatial planning, spatial working memory, updating, set shifting (transformed), inhibition, reaction time (transformed), within participant variability (transformed), start-up delay average, start-up delay coefficient of variance, proportion unsafe pedestrian crossings made (transformed), proportion safe pedestrian crossings missed, fear of falling, life space mobility, loneliness score, total communication , total close community, and perceived life space difficulty. The steps produced can be seen in Table 15.

The total model was found to be significant (F (5, 49) =9.243, p=<.001) in predicting quality of life and explained 48.5% of quality of life variance. Total close community alone predicted 23.5% of quality of life (Table 15). All five steps were significant contributors (Table 15). These results partially support the above hypothesis as mobility (including pedestrian behaviour),

cognition and social networks, but not fear of falling and life space mobility predicts reduced quality of life.

Table 15- Predictive Contribution of each Step in explaining Quality of Life

Model Steps	Variable	R^2	^ R^2	Beta	Sig.
1 Spatial Network	Total Communication	.235**	.235**	.485**	<.001
2 Mobility	Total Communication	.321**	.086*	.478**	<.001
	Sit-to-Stand			-.294*	.013
3 Cognition	Total Communication	.387**	.065*	.479**	<.001
	Sit-to-Stand			-.424**	.001
	Choice Reaction Time			.287*	.024
4 Pedestrian Behaviour	Total Communication	.438**	.052*	.484**	<.001
	Sit-to-Stand			-.407**	.001
	Choice Reaction Time			.312*	.012
	Safe Crossings Missed			.230*	.037
5 Visual Attention	Total Communication	.485**	.047*	.487**	<.001
	Sit-to-Stand			-.407	.001**
	Choice Reaction Time			.377**	.003
	Safe Crossings Missed			.237*	.027
	Processing Speed			-.226*	.039

*= Significant at .05 level **=Significant at .01 level ^ R^2= R^2 change

5.3.7 Hypothesis 6- Mobility, cognition and quality of life measures (specifically fear of falling) will have a strong linear relationship with previous falls

Previously in Chapter 3, set shifting and perturbation average were individually predictive of reported falls within the last year, but the entire model was not found to be significant suggesting that mobility and cognition alone were not predictive of falls. A stepwise logistic regression was performed including both set shifting (transformed) and perturbation average (transformed) along with fear of falling to assess whether the addition of fear of falling would produce a significant predictive model of the likelihood that a participant would report a fall. The stepwise regression produced one step, perturbation average.

The full model containing perturbation average was still not found to be significant (χ^2 (7) =4.472, p=.724) in distinguishing between fallers and non-fallers. The model as a whole explained between 8.0% (Cox & Snell R square) and 13.2% (Nagelkerke R square) of fall variance (Table 16). The model, however, was able to correctly classified 82.1% of cases before even entering perturbation average. As shown in Table 16, perturbation average was a significant independent predictor of the presence of falls. These results do not support the notion that mobility, cognition, and fear of falling are predictive in distinguishing between previous fallers and non-fallers.

Table 16- Predictive Contribution of each Step in explaining Fall variance

Variable	R^2	Wald	Sig.	Exp (B)
	.080-.132			
Perturbation Average		4.408	.036	24.214

*= Significant at .05 level **=Significant at .01 level

5.4 Discussion

The aim of this chapter was to examine the role of mobility and cognition on fear of falling (FOF) and life space mobility; also to uncover the role of mobility, cognition, life space mobility and fear of falling on quality of life measures. The implications of these findings could be to employ prevention and intervention and encourage active mobility so as to avoid further frailty.

Fear of falling was related to and predicted by a combination of mobility ability (previous falls, sit-to-stand, and pedestrian anxiety) and cognitive deficits (spatial working memory, choice reaction time, and processing speed) and explained 68.1% of fear of falling variance. However, mobility alone (including sit-to-stand, mobility score, safe crossings missed, and falls) predicted 60.6% of the variance. This supports Maki (1997)'s findings suggesting that age-related walking

decline has a role in fear of falling, and also previous literature reporting a fear of falling after experiencing a fall (Niino, et al., 2000; Howland, et al., 1998). Further, these results support previous literature indicating the role of reaction time and reduced processing speed was linked to the occurrence of a fear of falling (O'Halloran, et al., 2011) and executive functions (Schott, 2014) with increasing age. However, no relationships were found with balance, or road crossing behaviour other than in terms of missing safe pedestrian crossings, unlike findings by Berg et al. (1992) and Avineri, et al. (2012) respectively. These results suggest that a combination of general falls and increasing frailty, and to a lesser degree cognition, are important for the onset of a fear of falling in older adults.

Life space mobility, on the other hand, was not found to be linked to cognition at all, contradicting studies by Sartori, et al. (2011). Instead life space mobility was predicted by anxiety at the road side (proportion safe crossing gaps missed), and total number of close family and friends (supporting Rantakokko, et al., 2010), and self-reported mobility score, and explained 30.8% of life space mobility. Total number of persons in an individual's close social network alone predicted 11.1% of life space mobility variance. These findings suggest that having a larger social circle, less anxiety at the roadside, and good general mobility have a positive impact on the distance travelled on a regular basis in older adults.

Quality of life was not linked to fear of falling (contradicting Li et al., 2003), and life space mobility (contradicting Rantakokko, et al., 2010). Instead, quality of life was found to be predicted by mobility (sit-to-stand times and safe pedestrian crossings missed), cognition (slowed reaction time and processing speed), and close community, and combined were significant in explaining 48.5% of quality of life variance in this sample. Therefore, it could be inferred that

training to improve mobility, cognition, and increasing social networks could help improve quality of life with advancing age.

Mobility score was found to be predictive of fear of falling and life space mobility which would indicate that fear and restricted life space is linked to an awareness of their changing mobility ability. This could be useful in identifying the target population in need of intervention. The perceived mobility questionnaire, however, only used only covered a small number of statements regarding ease of being able to take the stairs, the ability to walk half a mile, and the presence of any ailment that may impact on walking. Also this measure allowed for ceiling effects and so some of the fluidity in normal mobility performance may have been lost, particularly with a smaller sample size. Future research may benefit from exploring each statement separately and/or in more detail, and recruit a larger number of participants, as this may have implications for treatment and prevention.

These findings also suggest that the total close community is important in maintaining activity levels, and thus preventing frailty and increasing quality of life. However, these results do not indicate whether the reduced life space mobility or the reduced social circle was present first. In identifying the direction of this relationship, it may help in providing an intervention and prevent reduced life space and quality of life.

Processing speed and reaction time was also a common component of fear of falling and quality of life. These measures were also identified as predictors of some types of unsafe pedestrian crossings (near-side unsafe), and thus suggests that global slowing is negatively impacting on

several aspects of older adults life and quality of life. In preventing a decline in processing speed, and general frailty, this could have a wide ranging positive benefit for older adults.

To conclude, perceived mobility ability along with a fall within the past year was at least partially responsible for a fear of falling in this participant sample. Further, it was general anxiety in one's mobility ability rather than fear of falling, and a reduced social circle that restricted life space. These results have implications for prediction, prevention, and treatment. In addition, they demonstrate that both issues are very separate entities, and as such require different strategies. Falls and quality of life still requires further explanation.

6 Overall Discussion

This thesis investigated the question 'what is the relationship between cognitive and neuropsychological markers, and the ability to adapt to mobility changes in older age?' In order to achieve this, a series of studies were conducted with a participant sample aged 45-88 years. Table 17 summarises the findings from each experiment in this thesis and comments on the question examined in each.

Table 17- Overall Thesis Results and Discussion

Chapter Number / Study Title	Results	Conclusions
2 Examining links between cognitive markers, movement initiation & change, and pedestrian safety in older adults	An age effect was found whereby older adults made more far-side unsafe crossing errors than near-side unsafe crossing errors. 49.4% of near-side unsafe crossing error was predicted by processing speed, walking speed, and start-up delay variability. Start-up delay variability alone predicted 38.2% of near-side error variance. 54.8% of far-side unsafe crossing error was predicted by spatial planning, walking speed, start-up delay average, and start-up delay variability. Walking speed alone predicted 41.4% of the variance. Start-up delay was predicted by walking speed only, and explained 30.5% of start-up delay variance.	Different cognitive measures are employed and required dependent on the side of the road being crossed. These measures could be useful in providing personalised prediction and treatment plans. Walking speed is both a direct and indirect component of unsafe crossing behaviour, and a consistent predictor. This is a quick and cost-effective test and has the potential to be predicted and rehabilitated. Further research into the components of walking speed could be beneficial for preventing all types of unsafe pedestrian crossings.
3 Identifying predictors of walking speed and fall prevalence in older adults	Age was found to be related to walking speed but not recent falls in this sample. Walking speed was predicted by self-rated mobility score, sit-to-stand times, start-up delay average, and within participant variability. These variables explained 53.2% of walking speed variance. Mobility score alone predicted 31.9% of walking speed.	Older adults may be self-aware in terms of their changing mobility status as self-reported mobility score was highly predictive of walking speed. This could be useful in identifying and preventing unsafe pedestrian crossings, falls, and further frailty. Physical frailty along with cognitive within participant variability and start-up delay are predictive of walking speed. It

	The model for fall history was not found to be significant. However, the variables identified as important in the stepwise logistic regression were set shifting and perturbation average. Walking speed was found to be related to but not predictive of fall history in this sample.	is unclear, however, what comes first out of reduced walking speed and increased start-up delay. Falls can be partially explained by an inability to switch attention when necessary, such as attending to recovering balance. Further research into falls is required to create a better and significant understanding of fall occurrence. Age-related changes but not necessarily age is linked to reduced walking speed and the presence of falls.
4 Does Beta Power Change Influence Motor Initiation and Crossing Ability with Age?	Those with a greater number of frogger errors (one lane traffic computer task) displayed a greater beta rebound post movement. Other participant groupings did not find significant differences in either pre-movement or post-movement beta power activity. Younger adults, participants with lower proportion frogger errors, and with faster processing speed scores demonstrated the expected hemispheric laterality in the contralateral hemisphere. Hemispheric plasticity was observed in older adults, people with higher proportion frogger errors, and slower processing speed whereby they demonstrated hemispheric bilaterality. The opposite pattern was found for far-side pedestrian errors, less variable start-up delay, and walking speed whereby participants performing worse demonstrated laterality and the high performance groups showing bilaterality. Start-up delay average and spatial planning showed that both performance groups demonstrated bilaterality.	Consistent with previous literature, increased age and reduced processing speed was linked to increasing reliance on both the contralateral and ipsilateral hemispheres. This proof of concept study found that despite the behavioural ceiling effect in the frogger task, differences were found in the beta power signatures. These potential biological indicators were found in post-movement recovery and in hemispheric symmetry. This suggests that the frogger task is a suitable test for detecting biological indicators for unsafe pedestrian errors. The reverse pattern of hemispheric laterality between frogger errors and processing speed (a near-side error predictor) compared with proportion of far-side unsafe crossings and some Chapter 2 pedestrian predictors may be as a result of different lane crossing judgements. If this be the case, this could significant in predicting, preventing, and treating at risk older adults.

5 The relationship between fear of falling and life space mobility with cognitive and mobility measures, life space, activity avoidance, and quality of life in older adults	Fear of falling was predicted by both cognition (processing speed, reaction time, and spatial working memory) and mobility (falls and self-reported mobility). In addition anxiety at the roadside (safe crossings missed) also predicted fear of falling. Fear of falling, however, did not significantly predict fall history. Life space mobility was mainly influenced by mobility (self-rated mobility score) and social networks. Social networks, anxiety at the roadside, mobility (sit-to-stand), and cognition (processing speed and reaction time) predicted quality of life. Age was not found to be related to fear of falling, life space mobility, or quality of life. Men reported a higher quality of life compared to women.	Being aware of mobility changes (self-rated mobility score) was linked to a fear of falling and reduced life space area travelled on a regular basis. However, it was frailty (sit-to-stand) that reduced quality of life. Processing speed, a predictor of near-side crossing errors in Chapter 2, has been identified yet again as a predictor of more negative factors associated with ageing. This could suggest that testing for changes and training visual attention may have multiple positive benefits for older adults. Providing mobility training in areas such as walking speed (self-rated mobility score includes items regarding difficulty walking), and sit-to-stand, along with increasing social networks may have a positive impact on confidence and wellbeing in older adults.

6.1 Links between cognitive markers, movement initiation & change, and pedestrian safety in older adults

Pedestrian fatality statistics indicate that older adults are more likely to be involved in a pedestrian collision at the far-side of the road (see Chapter 2 for a review). Previous research has not studied lane specific errors separately despite previous research and pedestrian fatality statistics suggesting that there may be differing processes in near-side and far-side crossing errors. Chapter 2 directly tested this assumption. These potential differing processes were hypothesised to be attentional measures (visual attention and within participant variability) & balance affecting near-side errors, and walking speed, start-up delay & executive functions such as spatial planning affecting far side errors (see Chapter 2 for a review of the literature). The first experimental chapter (Chapter 2) examined the extent to which mobility, motor initiation, and cognitive function predicted pedestrian collisions, particularly identifying differential relationships with near-side and far-side pedestrian collisions.

Although age was not found to be a significant predictor of lane specific errors, an age effect was found with older adults making more far-side unsafe crossing errors than near-side unsafe crossing errors. This is consistent with fatality statistics (Fontaine & Gourlet, 1997; Oxley, et al, 1997) and previous research using a simulated pedestrian environment (Dommes & Cavallo, et al, 2014), thus suggesting that this sample is representative of the targeted population cohort. Further, as age increased from middle age, the proportion of total unsafe crossings also increased. Gender was also found to be related to, but not predictive of, pedestrian errors with women being more likely to make more total and near-side errors than men. This gender difference could be as a result of differing amounts of driving experience between men and women as previously found by Holland & Hill (2010). Driving experience was not measured in this sample, however, and may be useful to include in future research to determine whether it is indeed increased familiarity with road navigation that is contributing towards gender differences in pedestrian crossing judgments.

Lane specific processes were found for cognition only. Cognition differentially predicted pedestrian lane errors with effective visual attention (processing speed) being implicated as important for safe near-side pedestrian crossings, and spatial planning being important for far-side pedestrian crossings. These findings support the notion that reduced attentional capacity can lead to difficulties at the near-side of the road, whereas an inability to effectively plan can lead to errors at the far-side of the road. The role of visual attention has previously been found in total (no lane specific divide) unsafe crossing (Dommes, Cavallo, & Oxley, 2013; Dommes & Cavallo, 2011) but these results demonstrate that processing speed is specific for the near-side of the road. Spatial planning has not previously been directly investigated in terms of road crossing errors, rather just the influence of car speed and distance in a one lane simulated road environment

(Lobjois & Cavallo, 2007). This is the first study to directly test and demonstrate that spatial planning is important in navigating two lanes of traffic.

Mobility and motor initiation, on the other hand, were consistent predictors for both near-side and far-side unsafe crossings. When start-up delay was examined independently, walking speed was found to be the sole predictor. This implies that walking speed has a both a direct and indirect impact on unsafe pedestrian crossings. This could imply that physical frailty may be an important predictor, not just of fatality in any given collision, but also of the likelihood of those collisions occurring in the first place. As this is a common predictor of all types of unsafe crossings and also start-up delay (another consistent factor in unsafe crossings), this could make further research into walking speed beneficial. Further research into walking speed was conducted in Chapter 3.

The implications of this study are that a safe crossing gap may not be safe even before older adults begin to cross due to ineffective spatial planning. This may be as a result of either underestimating one's own changed walking speed (Holland & Hill, 2010) or not being aware of a slowing in motor initiation, or due to reduced attentional resources being available to such perform executive functions. Once a crossing gap has been chosen, it may not be safely completed due to experiencing a longer delay in beginning to walk which could make crossing within the allotted time even less possible. Further, older adults walking speeds are slower thus meaning that they may not be able to compensate, i.e. walk faster, for planning errors and start-up delays. Also, an attentional lapse may prevent those at risk from reaching the midsection of the road. These measures, however, have the potential to be remediated. Speed of processing training, for example, has previously been found to improve all three subtests of the UFOV, instrumental activities of daily living, and safer driving performance for at least two years

afterwards (Ball, Edwards, & Ross, 2007), and so may help prevent near-side unsafe crossings. Further, executive function planning training in tasks such as the modified Craik & Bialystok breakfast cooking task (Wang, Chang, & Su, 2011), has previously been found to increase planning performance, prospective memory, updating ability, and set shifting ability in older adults compared to the control group. Perceptual training has been found to reduce start-up delay in children (Thomson, Tolmie, Foot, Whelan, Sarvary, & Morrison, 2005) and may be generalised to adults. Walking speed has also previously been found to be remedied by a combination of resistance and balance training (Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo, 2012). This is a positive outcome for the prediction, prevention, and remediation of unsafe crossings in older adults.

6.2 Predictors of walking speed and fall prevalence in older adults

Walking speed was a salient mobility predictor of unsafe pedestrian crossings and start-up delay in Chapter 2. In addition, falls are very prevalent with increasing age and have serious impacts on older adults. Emerging research has linked attentional within participant variability with falls and walking speed (see Chapter 3 for a review), although results in the literature have been inconsistent to date for walking speed, with significant relationships currently only being found in half of the research studies published. Further, spatial planning and spatial working memory had not been investigated with regards to relationships with walking speed and falls despite similar spatial abilities being linked to decline in other mobility facets, such as balance (see Chapter 3). This chapter examined whether walking speed reduction and fall prevalence was a result of physical frailty and slowed motor initiation or cognitive impairment or a combination of all three.

The presence of self-reported mobility score as a predictor of walking speed may indicate that participants are aware of a change in their case of walking and mobility. This measure asked participants if they can walk quarter mile, if they have difficulty using the stairs, and whether they have any illness/injury which affects their walking. Additionally, with the presence of sit-to-stand times as a predictor of walking speed, it could imply that slowed walking speed may be partially caused by frailty due to reduced lower extremity strength (sit-to-stand times). This is a concern if it is frail older adults (due to reduced walking speed) that are more likely to make an incorrect pedestrian crossing judgement (findings in Chapter 2). However, it is promising that these older adults at risk may be aware of a change in their mobility capabilities which could have a positive impact on potential future intervention measures by identifying the target population.

In addition to an increasing frailty (as assessed by sit-to-stand), within participant variability and start-up delay were also found to be important components of walking speed suggesting that cognition is also an important component in reduced walking speed. Spatial planning and spatial working memory were not found to be a significant predictor of walking speed, however. Therefore, these results show that it is a combination of mobility decline, motor initiation, and cognition (namely variable attentional resources) that contribute towards slowed walking speed. With previous studies referring to walking speed as a sign of frailty (see Chapter 2 for a review), these results could suggest that 'cognitive frailty' may also be a risk too.

However, start-up delay is predicted by walking speed, and walking speed can be partially predicted by start-up delay. This circular finding raises questions regarding whether reduced walking speed or an increased delay in beginning to walk occurs first. It may be possible that people have a slowed/changed initiation even separate from walking speed. Chapter 4 examined

neuronal and hemispheric power during a computer based road crossing judgment task. Neuronal and hemispheric activation was then compared between proportions of unsafe crossing errors made and also between people with different pedestrian predictor performance (people stratified by their performance on pedestrian crossings tasks), which included start-up delay and walking speed.

The same variables of physical, start-up delay, and cognitive predictors of falls were examined as with walking speed. Unlike walking speed, start-up delay was not found to be predictive of recent fall history. In addition, different cognitive and mobility measures were identified as important in predicting falls compared to walking speed. Previous falls were instead predicted by set shifting ability and perturbation average. These results suggest that a difficulty in diverting attention to relevant information in combination with a difficulty in compensating for an offset in balance are important components of falls. Although not predictive of falls, walking speed was significantly correlated to recent fall history. Remediation training for walking speed (combination of resistance and balance training, Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo, 2012) can also improve balance ability. Further, executive function planning training in tasks such as the modified Craik & Bialystok breakfast cooking task (Wang, Chang, & Su, 2011), has been found to improve set shifting ability. Therefore, in predicting and training unsafe pedestrian crossing behaviour, it may also have a beneficial impact on preventing falls, and vice versa. However, despite these significant independent predictors this model was not found to be significant in predicting whether a person will have fall or not. Therefore, further research into what predicts falls is required. Previous research has found that being fearful of falling can contribute towards future falls (de Vries, Peeters, Lips, & Deeg, 2013; Delbaere, Close, Heim, et al., 2010; Hadjistavropoulos, Martin, Sharpe, et al., 2007) and as such may make the predictive model for

falls significant. Chapter 5 examined whether fear of falling along with perturbation average and set shifting ability could produce a predictive model for falls.

6.3 Beta power's influence on motor control and crossing ability in older adults

Study number 3 (Chapter 4) was a proof of concept study to examine whether pedestrian planning using a computer based test, and variables identified as important in unsafe pedestrian crossings in Chapter 2 (walking speed, start-up delay average & variability, processing speed, and spatial planning) would exhibit reliable biological indicators. It has been hypothesised that unsafe pedestrian crossings in older adults may be as a result of maladaptive neuronal and functional changes in the right hemisphere and thus may affect the processing of the left half of their environment (Foerch & Steinmetz, 2009). Further, adults with Parkinson's disease have been found to make unsafe crossing decisions (Lin, Ou, Wu, & Liu, 2013) and Parkinson's disease has been linked to an increased pre-movement beta desynchronisation and reduced post-movement beta rebound (See Chapter 4). With this in mind, considering similar changes in beta power activity pre-and post-movement with age, then similar maladaptive activation with unsafe crossing choices may be detected in older adults also.

Consistent with previous research, age-related changes with age were found in hemispheric activation. That is, both hemispheres were employed to perform the computerised frogger road crossing task in older adults, but expected hemispheric laterality was used in younger adults. No differences were found, however, in pre- and post-movement beta power activity between younger and older adults, contrary to (see Chapter 4). This lack of distinct pre-and post-movement beta power activity may be as a result of small sample sizes requiring an age division of 65years and under for the younger sample.

The computer based frogger crossing task was successful in producing distinct hemispheric differences between performance groups with those with a lower proportion of frogger errors demonstrating hemispheric laterality, and those produced a higher proportion of frogger errors employing both hemispheres. These findings were observed despite a near ceiling effect for frogger performance. This could mean that reduced attentional resources are available to those making more errors (particularly at the near-side of the road as this task only employed one lane of 'traffic') and thus additional regions are being recruited to perform similarly. In addition, the frogger crossing task was also able to demonstrate a difference in post-movement beta rebound between groups, whereby those making more errors producing a higher beta rebound. This could mean that there is a longer time to 'recover' and reach beta baseline power to initiate movement again. However, significant differences were not found between frogger performance groups for desynchronisation in this sample, and none of the other Chapter 2 pedestrian predictors demonstrated a difference in desynchronisation or beta rebound power. Future research could reduce the rest time in between trials to examine whether beta power 'recovery' time is a factor in motor initiation and pedestrian errors. Also, larger sample sizes that have been divided into distinct movement and pedestrian performance groups may be able to observe such differences in pre-and post-movement beta power activity.

Interestingly, an opposite hemispheric lateralisation pattern can be found for far-side unsafe crossing errors (data taken from Chapter 2). Instead of those who made a lower proportion of unsafe far-side crossing errors employing mainly the contralateral hemisphere like with those making a lower proportion of frogger errors, both hemispheres were employed. Further, those who made a higher proportion of unsafe far-side crossing errors demonstrated hemispheric bilaterality. This could suggest that those making more far-side errors are transitioning to frailty and as yet have not begun to recruit additional neural networks to continue performing

cognitively demanding tasks, such as crossing the road. These findings may suggest that different beta power and hemispheric signatures are involved in near-side and far-side unsafe crossings, along with different cognitive functions (processing speed for near-side and spatial planning for far-side errors, Chapter 2). In support of this, differences in hemispheric lateralisation were also found for processing speed, whereby those with faster processing speed inspection times predominately used the contralateral hemisphere, whereas slower processing speed was linked to hemispheric bilaterality. Processing speed was found to be predictive of errors at the near-side of the road, and followed similar patterns to the frogger task which only used one lane of traffic. These results suggest that both hemispheres may be required in order to perform well in two-lane road crossing judgements. Further research with two lanes of traffic in the frogger task may help determine whether these are indeed different beta power signatures for different lanes of traffic.

In Chapter 3, there was a circular relationship whereby start-up delay was predictive of and predicted by walking speed and so raising the question as to what may be present first. When participants were divided into groups on the basis of start-up delay, there was no difference between the groups in hemispheric lateralisation suggesting that both groups were equally using both hemispheres. Walking speed, on the other hand, found that faster walkers recruited both hemispheres whereas slower walkers were still mainly using the contralateral hemisphere. This could suggest that people with slower start-up delay average groups were beginning to adapt to reduced attentional resources by recruiting both hemispheres before walking speed fully adapted and therefore could go some way towards determining whether increasing start-up delay or slowed walking speed occurs first (circular finding discovered in Chapter 2 and 3).

Overall, these results in Chapter 4 suggest that a reliable biological indicator may be present for unsafe crossing behaviour. However, with such a small sample size, and as the computer crossing task only displayed a simple one lane crossing scenario, further research is needed with a selection of computer based one and two lane roads to determine if this could aid in predicting and preventing unsafe crossing errors.

6.4 Predictors of fear of falling, life space mobility, and quality of life measures in older adults

In addition to injury and mortality, changes in mobility can also have an impact on morbidity and general well-being in older adults (see Chapter 5). This in turn can have a negative impact on mobility as it could increase frailty in older adults (see Chapter 5). Further, the model employed to predict falls in Chapter 3 was not found to be significant and previous research has linked fear of falling and reduced mobility (see Chapter 5) with increasing falls. Therefore, fear of falling and life space mobility, along with set shifting and perturbation ability may produce a predictive model of falls occurring. To date, no significant body of work has combined behavioural methods with relevant neuropsychological features such as motor initiation with quality of life, and fear of falling measures.

Results demonstrated that both those fearful of falling and with reduced life space mobility were aware of mobility changes (self-reported mobility score). This could be beneficial in identifying those at risk of reducing their daily activities and thus increasing the risk of further frailty decline. Fear of falling was found to be predicted by both cognition and mobility (including previous falls and caution at the roadside). Walking speed was significantly correlated with but was not predictive of fear of falling. The cognitive measures identified were processing speed, which has been linked to unsafe near-side crossings in Chapter 2 and changed hemispheric beta power

signatures in Chapter 4, along with reaction time and a sub-executive function spatial working memory. Therefore, in training for processing speed and spatial ability, it may reduce fear of falling as well as unsafe crossings with increasing age. To date, interventions for fear of falling has mainly focused on increasing mobility measures only, such as balance and walking speed (see Chapter 5).

Life space mobility, on the other hand, was mainly predicted by mobility (self-reported mobility) and social networks. It is unclear whether reduced life space mobility was the cause of a reduced social network or whether a reduced social network reduced the life space area inhabited. Future research could perhaps disentangle this relationship to direct interventions.

Despite significant correlations between quality of life with fear of falling and life space mobility, these measures were not predictive of quality of life. Instead, quality of life was predicted by frailty (i.e. sit-to-stand times), cognition (processing speed, and reaction time), social networks, and caution at the roadside (proportion of safe pedestrian crossings missed determined by their walking speed). Increasing mobility and slower visual attention (processing speed) inspection times may in fact increase quality of life, as well as reduce fear of falling, unsafe crossings, and mobility decline.

These results are promising in terms of increased number of social groups or social interventions for older adults may be beneficial in reducing frailty due to increased movement. In addition, confidence at the road side (some adults missing safe crossing gaps) may be increased with interventions for unsafe crossings in older adults, and thus increase the life space inhabited.

6.5 Summary

Walking speed was a consistent predictive component of near- and far-side unsafe pedestrian crossing behaviour and start-up delay average with increasing age. Walking speed was also related to but not predictive of fear of falling. However, some of the items on the self-reported mobility score (that was predictive of fear of falling and life space mobility) included difficulty in walking and so walking speed remediation training may also be beneficial in reducing fear of falling and increasing life space mobility. Walking speed was not found to be linked to quality of life, instead a link was found with increasing frailty (sit-to-stand times). Resistance and balance training to remediate walking speed, therefore may also increase lower extremity strength and thus increase quality of life as well as reduce unsafe crossings, and increase well being in older adults.

Attentional within participant variability, and variability in start-up delay were found to be predictive of walking speed and unsafe crossing behaviour (both near-side and far-side errors) respectively. This suggests that emerging research in this area linking attentional variability and mobility may indeed be important in maintaining safe mobility and independence with increasing age. Future research may benefit from determining whether remediation in attentional variability or resistance and balance training, or a combination of both is required for effective remediation for reduced walking speed and unsafe crossing behaviour.

Processing speed was found to be linked to near-side unsafe crossings, hemispheric activation changes, fear of falling, and reduced quality of life. Spatial planning was predictive of unsafe crossings at the far-side of the road, and spatial working memory was predictive of fear of falling. In training these measures, it may help reduce the presence of falls and fear of falling, unsafe

crossings, and frailty in older adults. Further research into potential remediation programmes may be useful to identify the most effective training task or tasks. In addition, future research may benefit from examining beta power signatures with a larger participant sample and further investigations as to whether slowed motor initiation in older adults with higher unsafe crossing decisions have other parkinsons related symptoms and therefore on to the medication suggestion. As medication (such as Zolpidem, Hall et al., 2014) has been found to alleviate Parkinson's symptoms, and Parkinson's has been linked to both unsafe crossings and difficulty in movement, treatment may include medication in older adults that struggle the most.

Rehabilitation of walking speed may help improve start-up delay & reduce variability of start-up times, reduce attentional lapses, and most importantly promote safer pedestrian crossings. Emerging evidence confirms the influence of exercise interventions on such measures: in a systematic review by Hortobágyi, Lesinski, Gäbler et al. (2015), resistance training, coordination training, and multimodal training, were found to each increase walking speed by a comparable amount in older adults over the ages of 65 years. Further, balance exercises have been found to increase walking speed, balance, reduce sit-to-stand times, falls and fear of falling in pre-frail older adults (Arantes, Dias, Fonseca, et al., 2015). Future research may explore the impact of physical training on road crossing accuracy, exploring relationships between attention variability, motor control, and walking speed with pedestrian behaviour. Alternatively, another factor that has not been explained or accounted for, that cannot be linked to age, may be present in this group (e.g. modal mode of transport and driving history) which could be explored.

The results suggest that lane-specific unsafe pedestrian crossing errors were found to differ in terms of cognition and motor cortex activity, with near-side unsafe crossings being linked to

processing speed, hemispheric bilateralisation, and neural overcompensation post-movement, whereas far-side unsafe errors were linked to spatial planning difficulties and not employing neural compensation methods (hemisphereic bilateralisation). This thesis was unable to produce a significant model to predict falls, however, postural sway was found to be important. Overall, the findings indicate that frailty (particularly walking speed or walking speed difficulty), processing speed, and attentional within participant variability (including motor initiation variability) are salient predictors of participant safety (mainly pedestrian crossing errors) and wellbeing with increasing age.

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Appendix 1- Study 1 and 2 Partipant Poster, Participant Information Sheets, Consent Forms, Debrief Forms, and Ethical Approval

Aston Research Centre for Healthy Ageing

Aston University

Are you 45 or older? We need your help!

Adults(45+) are invited to participate in a mobility study about the relationship between processes in the brain, movement responses, and pedestrian behaviour across the lifespan.

The aim of the study is to understand the causes of **falls, mobility difficulties, and pedestrian incidents** with the aim of **prevention**

The study involves crossing the road in a safe indoor simulator, mobility tasks (standing from a chair, walking straight, stopping & turning, and a balance task), and fun computer tasks (computer skills not needed).

The study will take no longer than **2.5 hours** and you will receive £7.50 towards travel.

If you wish to take part/want further information, please contact Jennifer Geraghty:
geraghtj@aston.ac.uk
0121 204 4250

Aston University

Aston Triangle
Birmingham
B4 7ET
United Kingdom

15th March 2012

Name & Address

Dear Name,

I am a research scientist based in the School of Life and Health Sciences and ARCHA at Aston University, studying mobility changes in older age. One of our research teams, led by Dr. Carol Holland, is looking at the influence of mental processes and brain activity on the ability to adapt to mobility changes, for example in walking or crossing the road in a safe indoor simulator, in adults aged 45-59, 60-74, 75+ years. I am contacting you as you have expressed an interest in participating in future research studies with the ARCHA group. I am in the process of recruiting volunteers to a study titled 'What is the relationship between cognitive and neuropsychological markers, and the ability to adapt to mobility changes?' and would like to know if you wish to take part. Anyone over the age of 45 is welcome to participate. The details of the study can be found attached to this letter.

Travel expenses (up to £7.50) can be reimbursed for this study. Times and dates can be arranged at your convenience.

This study has received favourable opinion from the Aston University Research Ethics Committee. All information gathered during the research study will remain anonymous and kept in strict confidence.

Aston University
Birmingham

PARTICIPANT INFORMATION SHEET

STUDY TITLE – **'What is the relationship between cognitive and neuropsychological markers and the ability to adapt to mobility changes in older age?'**

WHY HAVE I BEEN INVITED?

You have been given this information because you expressed an interest in finding out more about this work via Aston University's website, advert or an ARCHA event you attended.

WILL I BE ABLE TO PARTICIPATE?

Due to the nature of the study, individuals with a history of neurological problems such as a stroke, or visual impairments that cannot be corrected with spectacles or contact lens, such as tunnel vision, will not be able to take part.

WHAT IS THE STUDY?

The aim of the study is to see what the relationship is between mental processes and brain activity with the ability to adapt to mobility changes in older age. Loss of mobility is a major determinant of reduction in health and wellbeing in later life, linked with depression and independence reduction. In adults aged 45+, a series of methods will assess various aspects of movement initiation and adaptation along with a variety of cognitive tests. This will be a one-time study with no follow up.

WHAT WILL I BE ASKED TO DO?

1. Questionnaire

You will be asked to fill in a short questionnaire with some general information and some details regarding your mobility. If there are any questions that you feel reluctant to answer then please leave them blank. The questionnaire will take less than 2 minutes to complete.

2. Cognitive Assessments

The cognitive assessments will be conducted using a touch screen computer (you don't have to press a lot of keys!). This section will take approximately 1hr ¼ to complete, including time for your questions. Volunteers are welcome to ask for a break at any point. The tasks should not be challenging, but we are expecting differences in performance.

These tests will be assessing the following:

- Aspects of Attention and Central Vision;
- Aspects of Memory and Planning;
- Reaction Speed and Processing Speed;
- Learning and Rule change;
- Inhibition.

3. Mobility Tasks

For these tasks, you will have small, non-invasive markers placed on certain points of your body over your clothes (such as shoulders, knees). The movement of the markers will be recorded using motion capture cameras. For this, slight modest adjustment of some clothing may need to be made. This section will take approximately 45 minutes to complete. If you have difficulty in completing any of the mobility tasks, you can either do a shortened version of the task or choose to miss it out.

- Time taken to get from a seated position to a standing position (completed 5 times);
- Normal Walking Speed test (walking twice along a 7m path);

- Walking task where you will be required to stop, start, and turn when instructed (completed 2 times each);
- Postural stability/Balance task where you will be given a gentle push in the back to offset your balance (completed 3 times). There will be a couple of stable chairs positioned carefully and a researcher to hold onto to regain your balance if necessary. This procedure has been used before with no adverse effects.

4. Pedestrian Simulation

This consists of a short video of a road scene where you will be asked to indicate when you would cross a road. You will need to stand to do this. This will take approximately 15 minutes to complete.

WHAT WILL YOU DO WITH MY INFORMATION?

When we have gathered all the information for all the people who take part in the study, we will analyse the data to find out what predicts mobility difficulties with increasing age. We will write articles for scientific journals and present the findings in other ways, such as at conferences. In sharing this information it will not be possible for anyone to know that any information is about you.

WHAT HAPPENS NEXT?

If you are interested in taking part or discussing this information, please contact us (details are included in this sheet). If you decide to take part, we will conduct the data gathering as outlined above. If you would like to take part, please read the consent form that the researcher will give you then please complete the consent form and return to the researcher.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

We hope this study will uncover the mental processes that predict mobility changes with the intention of trying to find a treatment for people who begin to have serious problems with this in later life.

WHAT ARE THE RISKS OF TAKING PART?

There may be a slight risk of losing balance and falling over in the mobility tasks. However, there will be a couple of chairs and a sresearcher to hold onto if you feel like you are about to fall. Alternatively, if you have difficulty in completing any of the mobility tasks, you can either do a shortened version of the task or choose to miss it out.

WILL MY TAKING PART IN THE STUDY BE KEPT CONFIDENTIAL?

Data use and storage will comply by the standards of the Data Protection Act (1998). The confidentiality of personal information and the anonymity of all volunteers involved in this investigation will be preserved in the following way:

All responses will remain anonymous and confidential and your data will not be linked to your name. You will be assigned with a participant code to ensure that information cannot be linked back to you except by yourself and the researcher; this code can also be used if you decide to withdraw your information after the study has finished.

Your questionnaire data will be kept in a secure place and your computer data will be kept on a password protected computer. Only the researcher and supervisors will have access to this data. The data will be destroyed within five years of competition.

WHAT IF THERE IS A PROBLEM AND WHO DO I CONTACT IF THERE IS? If you have a concern about any aspect of this study, you should ask to speak to the researchers who will do their best to answer your questions. If there are still any aspects of the research that has been carried out that you are unhappy about, you are free to contact the Secretary of Aston University Ethics Committee on email j.g.walter@aston.ac.uk or telephone 0121 204 4869.

WHAT ABOUT IF I DON'T WANT TO PARTICIPATE?

Participation is entirely voluntary and you have the right to withdraw from the study at any point without penalty. If you feel uncomfortable or decide not to carry on with the study for any reason, you have the right to withdraw from the study at any time. If you do decide to withdraw during the study, we will destroy any data collected up to that point.

If you decide afterwards that you choose to withdraw data, you can contact us with your participant identification number and we can do this up to the point of data analysis is commenced, that is two weeks after your participation. You do not need to give any

reasons for this and there will be no adverse consequences. Contact details will be provided in the debrief form once the study has been completed/terminated.

WHERE WILL THE ASSESSMENTS TAKE PLACE AND WILL I HAVE SOME ASSISTANCE FOR TRAVEL EXPENSES?

The study will take place at Aston University in the Psychology laboratories (for which a set rate of £7.50 travel expenses will be paid).

WHO HAS REVIEWED THE STUDY? All research in the University is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, wellbeing and dignity. This study has been reviewed and given favourable opinion by Aston University Research Ethics Committee.

If you have difficulties understanding this sheet please ask for assistance

FURTHER INFORMATION AND CONTACT DETAILS –

For information about the research and to make appointments, contact: Miss Jennifer Geraghty geraghtj@aston.ac.uk.

If you have any further questions, you can also contact the supervisor, Dr. Carol Holland, c.holland1@aston.ac.uk, 0121 204 4063.

Thank you for taking time to read about this study.

Carol Holland

Dr Carol Holland- Senior Lecturer, Deputy Director Aston Research Centre for Healthy Ageing, Aston University

Jennifer Geraghty- Ph.D. Student, funded by Aston Research Centre for Healthy Ageing, Aston University

Aston University
Birmingham

THE CONSENT FORM (Participant Copy)

Participant Identification Number for this study: _____

Title of Project: **'What is the relationship between cognitive and neuropsychological markers and the ability to adapt to mobility changes in older age?'**

Principal Investigator: Jennifer Geraghty email: geraghtj@aston.ac.uk

Main Supervisor: Dr Carol Holland email: c.holland1@aston.ac.uk

Associate Supervisors: Dr Kim Rochelle, Dr Stephen Hall, Prof. Paul Furlong

Please initial, rather than tick boxes

☐ 1. I confirm that I have read and understand the information sheet dated .....for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

☐ 2. I understand that my participation is voluntary and that I am free to withdraw at any time during the study without giving any reason and without penalty. I also understand that if I decide to withdraw my data after my participation I have 14 days to do so.

☐ 3. I understand that data collected during the study will only be looked at by the principal investigator and named supervisors from Aston University. I give permission for these individuals to have access to my data collected during the study.

☐ 4. I understand that data use and storage will comply by the standards of the Data Protection act (1998) whereby all my responses will remain anonymous and confidential.

☐ 5. I understand the risks of the study and I am happy with the procedures in place to reduce them.

☐ 6. I agree to take part in the above study.

_____	_____	_____
Name of Participant	Signature	Date
_____	_____	_____
Name of Investigator		
Participant number:		

'What is the relationship between cognitive and neuropsychological markers and the ability to adapt to mobility changes in older age?'

Thank you for taking part in this study, your data will be kept anonymous and confidential.

Mobility difficulties in older adults can lead to a reduction in health and psychological well-being. The aim of the study is to see what the relationship is between mental processes and brain activity with the ability to adapt to mobility changes in older age.

The movement assessments were looking at how able you are to perform various movements involving balance and gait (the way you move). The computer tasks were testing current cognitive processes which have been found to affect peoples' ability to initiate and change movement effectively in older age. The Pedestrian Simulation was testing how well you were able to identify safe road crossing spaces and how effectively these spaces were used in terms of how quickly movement was initiated and completed.

Please be aware that if you decide to withdraw data, you can contact us with your participant identification number and we can do this up to the point of the data analysis is commenced, that is two weeks after your participation. Any information you have shared would then be destroyed. You do not need to give any explanation for this. If you would like to do this, please contact myself, Jennifer Geraghty, at geraghtj@aston.ac.uk with your participant code. Alternatively you can contact my main supervisor, Carol Holland, by email at c.holland1@aston.ac.uk or by phone at 0121 204 4063.

If you have any further questions or concerns, please contact us in the first instance who may advise you to contact your doctor. If you have any further concerns that have not been satisfied by contacting myself or Dr. Carol Holland, please contact the Secretary of the Ethics Committee, John Walters by email at j.g.walter@aston.ac.uk or by phone at 0121 204 4869.

Aston University Ethics Committee
Aston University
Aston Triangle
Birmingham
B4 7ET
Telephone +44 (0)121 204 3000
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Chairperson: Ms Nichola Soare

Secretary: Mr John Walter

18th May 2012

Jennifer Geraghty

School of Life and Health Sciences

Dear Jennifer

Study Title: Links between cognitive markers and movement initiation and change requirements

REC Reference: Ethics Application 588

Protocol Number:

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

The project is approved until the completion date specified on the form (September 9 2014) provided it is commenced within two years of the date of this letter and you are required to notify the Committee when the project is completed.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
University Ethics Application Form	One	01/03/2012
Risk Assessment and Control Form	One	01/03/2012
Consent Form for Volunteers	One	01/03/2012
Participation Information Sheet	One	01/03/2012
Consent Form Participant Copy	Two	19/03/2012
Consent Form Investigator Copy	Two	19/03/2012
Participation Information Sheet	Two	19/03/2012

Appendix 2- General Mobility Score Questionnaire

Participant Number .....

Demographic Questionnaire

Please answer in the space provided

1	What is your Age?	
2	What is your Gender?	
3	How many times have you fallen over within the last 12 months?	

Please tick the appropriate box		Yes	No
4	Can you walk a quarter of a mile?		
5	Can you manage the stairs easily?		
6a	Do you have any illness or injury which may affect your walking?		
6b	Details?		

Appendix 3- MEG Study 3 Participant Information Sheets, Imaging Study Screening Sheets, Consent Form, and Ethical Approval

Aston University
Life & Health Sciences

Aston Triangle
Birmingham
B4 7ET
United Kingdom

15th March 2012

Name & Address

Dear Name,

I am a research scientist based in the School of Life and Health Sciences and ARCHA at Aston University, studying mobility changes in older age. You recently took part in a study titled 'What is the relationship between cognitive and neuropsychological markers, and the ability to adapt to mobility changes?' and expressed an interest in participating in future studies with the ARCHA group. I am writing to you to tell you about a new study taking place exploring this relationship further and would like to know if you wish to take part. Anyone over the age of 45 is welcome to participate. The study is titled 'Investigating the relationship between brain waves, cognition, and motor control', and involves taking part in a few computer tasks whilst recording your brain activity. The details of the study can be found attached to this letter. The study can include the use of a drug named Zolpidem, at a dose much lower than would be prescribed by a doctor (often for sleeping problems), however, this is NOT compulsory (a description of the study without the drug is also included), so we would be very happy to hear from you even if you wouldn't want to take it

Travel expenses (up to £7.50) can be reimbursed for this study, with further expenses arrangements if you take part in the longer zolpidem component. Times and dates can be arranged at your convenience.

This study has received favourable opinion from the Aston University Research Ethics Committee. All information gathered during the research study will remain anonymous and kept in strict confidence.

Aston University

Content has been removed for copyright reasons

RESEARCH PARTICIPANT INFORMATION SHEET

Investigating the relationship between brain waves, cognition, and motor control.

You are being invited to take part in a research project that will be conducted at Aston University. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this

What is the purpose of the project?

Your brain works by means of tiny electrical signals, which are often called "brain waves" or "brain activitv". A MEG system (MEG stands for *Magnetoencephalography*), can measure brain activity and the scans produce an "activity map" of your brain. We plan to map your brain activity in the primary motor cortex, responsible for movements, during simple motor tasks, as part of a series of studies examining how control of movement may change with increasing age. Understanding these processes in a range of people may help us understand more about problems where movement becomes more difficult, such as in Parkinson's disease.

Why have I been chosen?

You have been asked to participate, as we require volunteers in the age range 45 – 80.

Do I have to take part?

You are under no obligation to take part in this study. If after reading this information sheet and asking any additional questions, you do not feel comfortable taking part in the experiment you do not have to. If you do decide to take part, you are free to withdraw from the study at any point, without having to give a reason. If you do withdraw from the study your personal data will be destroyed and, therefore, excluded from any of the results reported. If you decide not to take part or withdraw from the study it will not affect the standard of care you receive in any way, nor will it affect your relationship with any of the staff at the Aston University.

What will happen to me if I decide to take part?

If you do decide to take part you will be asked to sign an informed consent form stating your agreement to take part and you will be provided with a copy of this together with this information sheet for your records. In addition to this you will be asked to read an information sheet, and complete a copy of the MEG safety screen and a copy of the MRI safety screen, which will confirm your eligibility to participate.

Alcohol and caffeine have the ability to alter intrinsic brain rhythms; therefore it is important that you refrain from consuming alcohol for 24 hours and caffeine (e.g. tea and coffee) for 4 hours before MEG testing.

We will arrange for you to come to the Aston Brain Centre (ABC) situated at Aston University for a recording session, which will last for approximately 3 hours. This will provide enough time to fully explain the procedures, familiarise you with the MEG and MRI equipment and conduct the experiment. During the experiment we will record a baseline measure of resting brain activity before asking you to complete some simple tasks. If you feel comfortable with the experiment you will be asked to participate in 1 MEG session and 1 MRI session.

It is important to note that you are free to stop participating at any time without providing any advance notice nor an explanation.

What are the possible disadvantages and risks of taking part?

MEG and MRI involve the introduction and measurement of magnetic fields, which may be incompatible with metallic objects and electrical devices. Therefore, with the exception of dental fillings, any metal or electrical devices in your body that cannot be removed should be discussed with the researcher(s) before each study. Also, if you are pregnant or think you may be pregnant you must not take part in this study as the effects of magnetic fields are not known on the developing baby. The MEG safety questionnaire will require you to confirm this, please complete this honestly for your own safety. If you are uncertain of any answers, please contact Dr. Emma Prokic via email: e.prokic@aston.ac.uk or telephone 0121 204 5247.

What are the possible benefits of taking part?

Although there are no direct benefits from the procedures we use, your data will be used to help us determine whether there is a link between cognition, brain activity, and mobility difficulties.

What if new information becomes available?

If any new information becomes available, and if this affects the study, you will be notified immediately of any changes. You can then make an informed decision as to whether you wish to continue with the study.

What happens when the research study stops?

All data is kept on a secure internal server with an anonymous participant number so there is no identifying information tied to your results. Data will be analysed and kept for 7 years after the study ends.

Will my taking part in this project be kept confidential?

All information that is collected about you during the course of the research will be anonymous and stored securely and with strict confidentiality.

What will happen to the results of the research project and how will participant anonymity be protected?

All data collected during the course of the research will only be used for the purposes of the study. We aim to publish the results of this study in a scientific journal. We may also present the results at a scientific conference or a seminar in a university or publish results on our website. It will not be possible to identify you in any report or publication. We would be happy to discuss the results of the study with you and to send you a copy of the published results.

Who has reviewed the project?

The principal investigators organising the study are Professor Paul Furlong, Dr Stephen Hall, and Dr Carol Holland with Dr Emma Prokic, and Jennifer Geraghty as co-investigators. All researchers are based in the School of Life and Health Sciences at Aston University. The research study has been funded by the Aston Research Centre for Healthy Ageing (ARCHA) and Parkinson's Disease Society (PDS) and has been reviewed by Aston University's Ethics Committee.

Who do I Contact for further information or if something goes wrong?

If something goes wrong (i.e you are unable to attend a session) or if you require further information on the study before taking part please feel free to contact Jennifer Geraghty via geraghtj@aston.ac.uk or telephone 0121 204 4250. Alternatively, contact Dr. Prokic via email: e.prokic@aston.ac.uk or telephone 0121 204 5247.

Who do I contact if I wish to make a complaint about the way in which the research is conducted?

If you have any concerns about the way in which the study has been conducted, you should contact the Secretary of the University Research Ethics Committee on j.g.walter@aston.ac.uk or telephone 0121 2044665.

Aston University

Aston Brain Centre

MEG Information Sheet

What is MEG?

Your brain works by means of tiny electrical signals, which are often called "brain waves" or "brain activity". A MEG system (MEG stands for *Magnetoencephalography*) can measure brain activity and the scans produce an "activity map" of your brain. MEG doesn't hurt, and there are no known side effects. You won't feel any differently afterwards, and you won't need to change your activities or rest after your scan.

What sort of information does MEG provide?

People have MEG recordings for many different reasons. Sometimes their doctor sends them for a recording to help decide how to best treat them. Some people volunteer for a recording to help in research. MEG recordings can help answer questions such as:

1. *What activity is the brain producing and where in the brain does it come from?* For example, MEG can be used to measure brain activity associated with relaxation, migraine, or epilepsy.

2. *Which part of the brain undertakes different tasks?* For example, MEG can determine exactly which bit of your brain controls actions such as speaking or moving arms and legs.

3. *How does the brain work?* MEG researchers are working to further understand the way in which the brain functions, both normally, and when something goes wrong.

What will happen during my MEG recording?

When you arrive, one of the MEG team will meet you, explain what will happen, and answer any questions you have.

Before your recording you will be asked to remove any metal objects you are wearing; this is because metal objects interfere with the MEG system. Metal objects include mobile phones, watches, coins, credit cards, jewellery, glasses, and clothes that contain metal (e.g. tops with zips, bras, shoes). It is therefore a good idea to wear as little metal as possible when you come for your recording – a tracksuit or similar is ideal. Also, some make-up contains metal fragments so therefore we also ask that you do not wear any make-up when you come for your recording.

You will then have 5 small sensors attached to your head (3 on your forehead and one behind each ear), which record where your head is in the scanner, and a special pen is traced around your head. This is so that an accurate computer picture of the shape of your head can be produced.

You will then be taken into the special room where the MEG system is – this room has been specially designed to reduce artefacts from the environment so the small brain waves can be recorded by the system. In the MEG room you will sit on a chair, which moves you up slightly so that the top of your head is in the MEG helmet. (A picture of this is shown to the right).

Somebody will be with you all the time, and if you would like a friend or relative to sit with you, just ask one of the MEG team. The MEG system is very quiet, so you will be told when the recording starts, and to keep very still during the scan. You may be asked to perform a task while you are being scanned, such as tapping your fingers, or looking at pictures.

How long will my MEG recording take?

Different types of recording take different amounts of time. As a rough guide, you can expect to be in the MEG unit for around 1-3 hours for a clinical recording, and between 1-2 hours for a research study.

What happens to my results?

After your recording you may have other tests done, such as an MRI (this stands for Magnetic Resonance Imaging and gives a picture of the structure of your brain). You will be given details of these tests separately. Your MEG recording takes a long time to analyse, so you won't be given any results on the day (although you can ask to see your brain activity on the computer screen). If your MEG recording is for clinical reasons, the results of your recording will be sent to your doctor, who will contact you when they are ready. You will probably have other tests done and your doctor will use the information from all the tests to help decide on the best way of treating you. If your MEG scan was for research (not arranged by your doctor), then there are no results, as your recording is simply used to help find out about how the brain works.

Do I need to do anything before my MEG recording?

Generally, you do not need to do anything before your scan: you can eat and drink normally and do everything you normally do. You should dress in comfortable clothes and avoid wearing any clothes that contain metal. If you are on medication, you should continue to take it as normal UNLESS your doctor has told you not to. If you have a mobile phone, you should turn it off when you arrive at the MEG unit, as it interferes with the MEG system.

Where is the MEG system?

The MEG system is in the Aston Brain Centre at Aston University in the centre of Birmingham. At the University you should go to the Aston Brain Centre and use the phone at the front door to tell the team of your arrival. You will then be directed to a waiting room. There are some free car parking spaces next to the Aston Brain Centre; please ask for a permit when you arrive as this needs to be displayed in your vehicle. If your doctor has arranged for an ambulance or taxi to collect you, and it does not arrive, please telephone to let us know.

What is the difference between a clinical and a research recording?

Both clinical and research work is carried out at the MEG unit, and the procedures are very similar. Someone having a clinical recording is referred by their doctor, and the results are used to answer a specific question that will help their doctor make a diagnosis, or decide on the best course of treatment. Their results are sent to their doctor. Someone having a research recording has volunteered to take part in a research project that aims to find out more about how the brain works, or to improve a clinical test. The researchers analyse the MEG recording, but there are no results. Only doctors can refer people to have a clinical recording, but anybody can volunteer for a research recording. Please tell one of the MEG team if you would like to know more about current research projects, or would like to volunteer to take part in research.

Remember

- MEG doesn't hurt and it isn't harmful.
- The MEG team are very friendly – just ask if you want them to explain something to you or if you are unsure about anything.
- Try not to wear any metal, and if you have contact lenses, wear them instead of your glasses.
- You can telephone or email Dr Stan Worthen (0121 204 4169; s.f.worthen@aston.ac.uk) or Dr Caroline Witton (0121 204 4087; c.witton@aston.ac.uk) before your appointment if you want to speak to somebody about your MEG recording.

Screening Form for a MEG recording – Adult

The following section is to be filled in by the MEG investigator

Name of participant:	
Time and Date of MEG scan:	
Principal MEG Approved User:	
Brief description of the study:	
MEG lab reference:	
Time to complete the MEG recording:	

The following questions are to be filled in by the participant.

The MEG is very sensitive to metal and we therefore need to ensure that no metal is taken near the system. The information provided will be treated as strictly confidential and will be held in secure conditions. If you are unsure of the answer to any of the questions, please ask a member of the MEG staff.

Date of Birth:	Male/Female:
Address:	Name and Address of GP:
Right or Left Handed:	Glasses: Yes / No Contact Lenses: Yes / No
Please provide details of any metal (other than tooth Fillings) that has been, or is currently in your body (e.g. pacemakers, metal plates, surgical clips, bone pins, shrapnel etc).	
Please describe any previous or current neurological problems?	
Please describe any surgery that you have had done:	
Please describe any serious illnesses such as Heart Disease, Diabetes, High Blood Pressure, Cancer, or Epilepsy?	
Please confirm that you have removed all metal (e.g. jewellery, watches, belts etc)	

To be Completed by the Participant

I have read and understood the questions above and have answered them correctly

Signed ..... Name ..... Date.....

To be completed by a MEG Approved User

I confirm that the participant has been properly screened

Signed ..... Name ..... Date.....

Aston University

Aston University - Magnetic Resonance Imaging Unit PATIENT SCREENING FORM

NAME OF PATICIPANT..... Sex: M / F

Date of birth..... Weight in kg..... or Stones/lbs .....

Please read the following questions CAREFULLY and provide answers. For a very small number of individuals, being scanned can endanger comfort, health or even life. The purpose of these questions is to make sure that you are not such a person.

If you have ever performed or been exposed to welding, grinding, filing, sawing or drilling of metal, either occupationally or recreationally at ANY TIME IN YOUR LIFE, you will need to have x-rays of your eyes (orbit x-rays) completed prior to your MRI scan. Your safety in the magnetic environment is our primary concern. THIS IS VERY IMPORTANT. Please notify Aston MRI Centre staff immediately.

You have the right to withdraw from the screening and subsequent scanning if you find the questions unacceptably intrusive (you can also request same gender screening). The information you provide will be treated as strictly confidential and will be held in secure conditions. If you are unsure of the answer to any of the questions, please ASK the person who gave you this form or the person who will be performing the scan. Definitions of some of the more technical terms are given overleaf.

Please answer all questions	Circle your answer
1. Have you been fitted with a pacemaker, artificial heart valve, cochlear implant or any other implanted device?	YES/NO
2. Have you any surgical clips, aneurysm clips, shunts or stents in your body?	YES/NO
3. Have you been exposed in your life to metal debris as a result of welding, grinding, filing, sawing or drilling of metal, either occupationally or recreationally?	YES/NO
4. Have you ever had any metal fragments in your eyes?	YES/NO
5. Do you wear a hearing aid?	YES/NO
6. Have you ever had any metal fragments, e.g. shrapnel, in any other part of your body?	YES/NO
7. Have you any surgically implanted metal in any part of your body (eg. joint replacement or bone reconstruction)?	YES/NO
8. Have you ever had any surgery that might have involved metal implants of which you are not aware?	YES/NO
9. Is there any possibility that you might be pregnant?	YES/NO
10. Have you been sterilised using clips?	YES/NO
11. Do you have a contraceptive coil (IUD) installed?	YES/NO
12. Do you have any dental work (including dentures, crowns, bridgework, braces) in your mouth, other than simple fillings?	YES/NO
13. Have you ever suffered from any of epilepsy, diabetes or thermoregulatory problems?	YES/NO
14. Have you ever suffered from any heart disease?	YES/NO
15. Do you have any Tattoos? Do you have any permanent eye make-up?	YES/NO
16. Are you wearing any skin patches? (eg. Nicotine)	YES/NO

I wish to be screened by the same gender YES/NO*

I have read and understood the questions above and have answered them correctly.

SIGNED..... DATE.....

In the presence of ..... (Name) ..... (Signature)

Name and address of your GP:.....

Aston University

MRI Information Form for Research Participants – Anatomical Imaging

These notes give some information about an MRI study in which you are invited to take part.

MRI is a method for producing images of the brain. It involves placing the participant inside a large, powerful magnet, which forms part of the brain scanner. Radiofrequency signals are also used as part of the imaging process.

As far as we know, this procedure poses no direct health risks. However, the Department of Health advises that certain people should NOT be scanned. Because the scanner magnet is very powerful, it can interfere with heart pacemakers and clips or other metal items which have been implanted into the body by a surgeon, or with body-piercing items. If you have had surgery which may have involved the use of metal items you should NOT take part. Note that only ferromagnetic materials (eg steel) are likely to cause significant problems. Thus normal dental amalgam fillings do not prohibit you from being scanned, though a dental plate which contains metal would do so, and you would be asked to remove it. You will be asked to remove metal from your pockets (coins, keys, etc), remove articles of clothing which have metal fasteners (belts, bras, etc), as well as most jewellery. Watches and credit cards should not be taken into the scanner since it can interfere with their operation. You will be asked to complete a questionnaire (the Initial Screening Form) which asks about these and other matters to determine whether it is safe for you to be scanned. In addition, you are asked to give the name and address of your Family Doctor. This is because there is a very small chance that the scan could reveal something which required investigation by a doctor. If that happens, we would contact your doctor directly. By signing the consent form, you authorise us to do this. You will also be asked to complete a second, shorter, screening form immediately before the scan.

To be scanned, you will lie on your back on a narrow bed on runners, on which you will be moved until your head is inside the magnet. The scanning process itself creates intermittent loud noises, and you must wear ear-plugs or sound-attenuating headphones. We are able to talk to you while you are in the scanner through an intercom. If you are likely to become very uneasy in this relatively confined space (suffer from claustrophobia), you should NOT take part in the study. If you do take part and this happens, you will be able to alert the staff by activating an alarm and will then be removed from the scanner quickly. It is important that you keep your head as still as possible during the scan, and to help you with this, your head will be partially restrained with padded headrests. We shall ask you to relax your head and keep it still for the period of the scan. If this becomes unacceptably difficult or uncomfortable, you may demand to be removed from the scanner.

The whole procedure will typically take about 20 minutes, plus another 15 minutes to discuss with you the purposes of the study and answer any questions about it which you may raise. **You will be able to say that you wish to stop the testing and leave at any time, without giving a reason**. This would not affect your relationship with the staff or University in any way. The study will not benefit you directly, and does not form part of any medical diagnosis or treatment. If you agree to participate you will be asked to sign the initial screening form that accompanies this information sheet, in the presence of an appropriate member of staff (or other witness, who should countersign the form giving their name and address, if this is not practical). It is perfectly in order for you to take time to consider whether to participate, or discuss the study with other people, before signing. After signing, you will still have the right to withdraw at any time before or during the experiment, without giving a reason.

The images of your brain will be held securely and you will not be identified by name in any publications that might arise from the study. The information in the two screening forms will also be treated as strictly confidential and the forms will be held securely until eventually destroyed.

Please feel free to ask any questions about any aspect of the study or the scanning procedure before completing the initial screening form.

COPY CONSENT FORM for PARTICIPANTS

NAME OF PARTICIPANT _____
DATE OF BIRTH:

Study Number:

Patient Identification Number for this trial:

Title of Project: Investigating the relationship between brain waves, cognition, and motor control.

Project investigators: Prof Paul Furlong, Dr. Carol Holland, Dr. Emma Prokic, Jennifer Geraghty

Please initial (tick) the boxes:

1. I confirm that I have read and understand the information sheet for this study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I agree to take part in the above study. ☐

_____	_____	_____
Name of Patient	Date	Signature
_____	_____	_____
Name of Person taking consent (If different from researcher)	Date	Signature
_____	_____	_____
Investigator	Date	Signature

Aston University Ethics Committee
Aston University
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Chairperson: Ms Nichola Seare

Secretary: Mr John Walter

4th July 2012

Dr Stephen Hall

School of Life and Health Sciences

Dear Stephen

Study Title: Investigating the effect of GABAergic modulation on cortical oscillations during motor performance.

REC Reference: Ethics Application 358

Protocol Number:

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

The project is approved until the completion date specified on the form (31st December 2015) provided it is commenced within two years of the date of this letter and you are required to notify the Committee when the project is completed.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
University Ethics Application Form	One	10/05/2012
Risk Assessment Form - Laboratory	One	10/05/2012
Risk Assessment Form - Diazepam	One	10/05/2012
Risk Assessment Form - Zolpidem	One	10/05/2012
Risk Assessment Form - Zopiclone	One	10/05/2012
Further References Document	One	10/05/2012
Drug Screening Form	One	10/05/2012

Drug Information Sheet	One	10/05/2012
Research Participant Information Sheet	One	10/05/2012
MEG Information Sheet	One	10/05/2012
Consent Form for a MEG recording	One	10/05/2012
GP Letter	One	25/06/2012
Dependency Document	One	25/06/2012
Drug Screening Form	Two	25/06/2012
Research Participant Information Sheet	Two	25/06/2012
Insurance Confirmation	One	25/06/2012
Research Participant Information Sheet	Three	05/07/2012
Simplified Participant Information Sheet	One	04/07/2012

Statement of compliance

The Committee operates in accordance with the Aston University Ethics policy and procedures

http://www1.aston.ac.uk/registry/for-staff/regsandpolicies/ethics-policy-and-procedures/

Reporting Requirements

The details of the investigation will be placed on file. You should notify the Secretary of the University Ethics Committee of any adverse events which occur in connection with this study and/or which may alter its ethical consideration, and/or any difficulties experienced by the volunteer subjects.

If you intend to make any future protocol amendments these must be approved by the Ethics Committee prior to implementation. You should also seek approval for any extension of the approved completion date.

Membership

The members of the University Ethics Committee present at the meeting are listed below:

- Dr Carolyn Rowe, Lecturer in Politics, Aston University
- Ms Nichola Seare, AHRIC Director, Aston University
- Mr John Walter, Director of Governance, Aston University

REC reference: **Ethics Application 358**
Please quote this number on all correspondence

With the Committee's best wishes for the success of the project

Yours sincerely

J G Walter

Secretary of the Ethics Committee
Email: j.g.walter@aston.ac.uk

Cc. Sponsor

Aston University

28th January 2014

Dr Stephen Hall
Life & Health Sciences

Dear Stephen

Study Title: Investigating the relationship between brain waves, cognition, and motor control

Reference Number: Project 358

Protocol Number:

I am writing to inform you that the Chair of the Ethics Committee has approved on behalf of the Committee, the minor proposed changes to the above project as described in Jennifer Geraghty's email and attachment of 12th December 2013, namely the update to the project title and the modifications to the participant information sheet and consent form to accommodate the slight change in procedure for them.

Yours sincerely

JG Walter

Mr John Walter
Secretary to the Ethics Committee

Appendix 4- Study 4 Participant Information Sheets, Imaging Study Screening Sheets, Consent Form, Debrief Form, and Ethical Approval

Aston University
Birmingham

PARTICIPANT INFORMATION SHEET

STUDY TITLE – **'The relationship between fear of falling, quality of life, and mobility in older adults?'**

WHY HAVE I BEEN INVITED?

You have been given this information because you expressed an interest in finding out more about this work via Aston University's website, advert or an ARCHA event you attended. In addition, you have taken part in a previous study involving mobility difficulties and pedestrian behaviour. Everybody who took part in the previous study has been invited back. This study acts as an optional follow up.

WILL I BE ABLE TO PARTICIPATE?

Due to the nature of the study, individuals with a history of neurological problems such as a stroke, or visual impairments that cannot be corrected with spectacles or contact lens, such as tunnel vision, will not be able to take part.

WHAT IS THE STUDY?

The aim of the study is to explore the relationship between fear of falling, quality of life, and mobility difficulties in older adults. Loss of mobility is a major determinant of reduction in health and wellbeing in later life, linked with depression and independence reduction. In adults aged 45+, a series of questions will assess various aspects of how you perceive your life, your social and physical restrictions, along with how likely you are to be fearful of falling in certain circumstances. These questions will be related to previous data with regards to your movement initiation and adaptation, and a variety of cognitive tests. This will be a one-time study with no follow up.

WHAT WILL I BE ASKED TO DO?

1. Questionnaire

You will be asked to fill in a short questionnaire asking for some details regarding your mobility, how your mobility restricts your social life and everyday tasks, as well as how you perceive the general quality of your life. If there are any questions that

you feel reluctant to answer then please leave them blank. The questionnaire will take approximately 10 minutes to complete.

There will be:

- 4 multiple choice questions regarding how you perceive your quality of life. These questions will include how much control you feel you have over aspects of your life; activities; if you are anxious; and social involvement.

- 16 questions about how likely you are to feel fearful of falling in a specific situation, such as preparing meals, or walking up a slope.

- 16 questions about your physical travel over a 3 day period, your social life, and your life satisfaction.

WHAT WILL YOU DO WITH MY INFORMATION?

When we have gathered all the information for all the people who take part in the study, we will analyse the data to find out what the relationship between fear of falling, quality of life, and mobility difficulties with increasing age. We will write articles for scientific journals and present the findings in other ways, such as at conferences. In sharing this information it will not be possible for anyone to know that any information is about you.

WHAT HAPPENS NEXT?

If you are interested in taking part or discussing this information, please contact us (details are included in this sheet). If you decide to take part, we will conduct the data gathering as outlined above. If you would like to take part, please read the consent form that the researcher will give you then please complete the consent form and return to the researcher.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

We hope this study will uncover the mental processes that predict mobility changes with the intention of trying to find a treatment for people who begin to have serious problems with this in later life.

WHAT ARE THE RISKS OF TAKING PART?

There may be questions in which you feel uncomfortable answering. Any questions you do not wish to answer you may leave blank. Alternatively, you may decide to opt out of the study completely. You may withdraw from the study up until two weeks after returning the questionnaire.

WILL MY TAKING PART IN THE STUDY BE KEPT CONFIDENTIAL?

Data use and storage will comply by the standards of the Data Protection Act (1998). The confidentiality of personal information and the anonymity of all volunteers involved in this investigation will be preserved in the following way:

All responses will remain anonymous and confidential and your data will not be linked to your name. You will be assigned with a participant code to ensure that information cannot be linked back to you except by yourself and the researcher; this code can also be used if you decide to withdraw your information after the study has finished.

Your questionnaire data will be kept in a secure place and your computer data will be kept on a password protected computer. Only the researcher and supervisors will have access to this data. The data will be destroyed within five years of competition.

WHAT IF THERE IS A PROBLEM AND WHO DO I CONTACT IF THERE IS? If you have a concern about any aspect of this study, you should ask to speak to the researchers who will do their best to answer your questions. If there are still any aspects of the research that has been carried out that you are unhappy about, you are free to contact the Secretary of Aston University Ethics Committee on email j.g.walter@aston.ac.uk or telephone 0121 204 4869.

WHAT ABOUT IF I DON'T WANT TO PARTICIPATE?

Participation is entirely voluntary and you have the right to withdraw from the study at any point without penalty. If you feel uncomfortable or decide not to carry on with the study for any reason, you have the right to withdraw from the study at any time. If you do decide to withdraw during the study, we will destroy any data collected up to that point.

If you decide afterwards that you choose to withdraw data, you can contact us with your participant identification number and we can do this up to the point of data analysis is commenced, that is two weeks after your participation. You do not need to give any reasons for this and there will be no adverse consequences. Contact details will be provided in the debrief form once the study has been completed/terminated.

WHERE WILL THE ASSESSMENTS TAKE PLACE AND WILL I HAVE SOME ASSISTANCE FOR TRAVEL EXPENSES?

The study will take place in the comfort of your own home or a private place of your choosing. You will not be required to travel.

WHO HAS REVIEWED THE STUDY? All research in the University is looked at by an independent group of people, called a Research Ethics Committee to protect your safety, rights, wellbeing and dignity. This study has been reviewed and given favourable opinion by Aston University Research Ethics Committee.

If you have difficulties understanding this sheet please ask for assistance

FURTHER INFORMATION AND CONTACT DETAILS –

For information about the research and to make appointments, contact: Miss Jennifer Geraghty geraghtj@aston.ac.uk.

If you have any further questions, you can also contact the supervisor, Dr. Carol Holland, c.holland1@aston.ac.uk, 0121 204 4063.

Thank you for taking time to read about this study.

Carol Holland

Dr Carol Holland- Senior Lecturer, Deputy Director Aston Research Centre for Healthy Ageing, Aston University

Jennifer Geraghty- Ph.D. Student, funded by Aston Research Centre for Healthy Ageing, Aston University

Aston University
Birmingham

THE CONSENT FORM (Participant Copy)

Participant Identification Number for this study: _____

Title of Project: **'What is the relationship between fear of falling, quality of life, and mobility in older age?'**

Principal Investigator: Jennifer Geraghty email: geraghtj@aston.ac.uk

Main Supervisor: Dr Carol Holland email: c.holland1@aston.ac.uk

Associate Supervisors: Prof. Paul Furlong

Please initial, rather than tick boxes

☐ 1. I confirm that I have read and understand the information sheet dated .....for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

☐ 2. I understand that my participation is voluntary and that I am free to withdraw at any time during the study without giving any reason and without penalty. I also understand that if I decide to withdraw my data after my participation I have 14 days to do so.

☐ 3. I understand that data collected during the study will only be looked at by the principal investigator and named supervisors from Aston University. I give permission for these individuals to have access to my data collected during the study.

☐ 4. I understand that data use and storage will comply by the standards of the Data Protection act (1998) whereby all my responses will remain anonymous and confidential.

☐ 5. I understand the risks of the study and I am happy with the procedures in place to reduce them.

☐ 6. I agree to take part in the above study.

_____	_____	_____
Name of Participant	Signature	Date
_____	_____	_____
Name of Investigator		

Participant number:

'What is the relationship between fear of falling, quality of life, and mobility in older age?'

Thank you for taking part in this study, your data will be kept anonymous and confidential.

Mobility difficulties in older adults can lead to a reduction in health and psychological well-being. The purpose of this study is to see if there is a relationship between fear of falling, quality of life, and social restriction with the mobility measures, cognition, and pedestrian behaviour collected in a previous study.

The questions were looking at how much control you feel you have over your life and activities, how anxious you feel, and about your social interactions. Further questions were looking into the quantity and quality of your social interactions, along with the ease of accessing local services. Finally, they explored how far you travelled over the past 3 days in general to look at your usual movements. The next questionnaire you did was The Falls Efficacy Scale questionnaire which looks into how afraid you are about falling under certain circumstances and how that has an impact on your daily life. These questionnaires were explored in relation to a previous study you completed that looked into the relationship between mobility changes, pedestrian behaviour, and cognition.

Please be aware that if you decide to withdraw data, you can contact us with your participant identification number and we can do this up to the point the data analysis commences, which is two weeks after your participation. Any information you have shared would then be destroyed. You do not need to give any explanation for this. If you would like to do this, please contact myself, Jennifer Geraghty, at geraghtj@aston.ac.uk **with your participant code. Alternatively you can contact my main supervisor, Carol Holland, by email at** c.holland1@aston.ac.uk **or by phone at 0121 204 4063.**

If you have any further questions or concerns, please contact us in the first instance, but if you are worried about health aspect . If you have any further concerns that have not been satisfied by contacting myself or Dr. Carol Holland, please contact the Secretary of the Ethics Committee, John Walters by email at j.g.walter@aston.ac.uk or by phone at 0121 204 4869.

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Memo

Life and Health Sciences Research Ethics Committee's Decision Letter

To: Dr Carol Holland

Cc: Rachel Gilles, administrator to the Life and Health Sciences Research Ethics Committee

From: Dr Leon Davies

Deputy Chair of the Life and Health Sciences Research Ethics Committee

Date: 27/11/2014

Subject: Project #715: What is the relationship between fear of falling, quality of life, and mobility in older age?

Thank you for your resubmission. The additional information for the above proposal has been considered by the Deputy Chair of the LHS Ethics Committee.

Please see below for details of the decision and the approved documents.

Reviewer's recommendation: Approved

Please see the tabled list below of approved documents:

Documentation	Version/s	Date	Approved
Participant Information sheets	Participant Information Sheet_ version 2_27_11_14	27/11/2014	✔
Consent form	Consent Forms_questionnaires_Final_27_11_14	27/11/2014	✔
Risk Assessment	questionnaire_risk_assessment_and_control_form	20/05/2014	✔
Debriefing Material	Debrief Form_questionnaires_27_11_14	27/11/2014	✔
Response to reviewers	questionnaire_ethics_letter	06/11/2014	✔
Questionnaires	Questionnaires-Final_27_11_14	27/11/2014	✔

After starting your research please notify the LHS Research Ethics Committee of any of the following:

Substantial amendments. Any amendment should be sent as a Word document, with the amendment highlighted. The amendment request must be accompanied by all amended documents, e.g. protocols, participant information sheets, consent forms etc. Please include a version number and amended date to the file name of any amended documentation (e.g. "Ethics Application #100 Protocol v2 amended 17/02/12.doc").

New Investigators

The end of the study

Please email all notifications and reports to lhs_ethics@aston.ac.uk and quote the original project reference number with all correspondence.

Ethics documents can be downloaded from: http://www.ethics.aston.ac.uk/documents-all. Please note that these documents can ONLY be opened using Mozilla Firefox or the latest Internet Explorer version (IE9).

Statement of Compliance

The Committee is constituted in accordance with the Government Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK. In accord with University Regulation REG/11/203(2), this application was considered to have low potential risk and was reviewed by three appropriately qualified members, including the Chair of the Life and Health Sciences Ethics Committee.

Yours sincerely,

Dr Leon Dawes
Deputy Chair of the LHS Ethics Committee

Appendix 5- Study 4 Quality of Life, Fear of Falling, and Life Space Mobility Questionnaires

Quality of Life and Fear of Falling Questionnaires

Please note that you do not have to answer any questions which you do not feel comfortable answering. All questions require a tick box response unless stated otherwise.

Participant Name: _____

Participant Age: _____

Questionnaire 1

I would like to ask you some questions about how you feel about certain aspects of your life. For each of these questions, please tick next to the appropriate statement that describes you best.

Tick one box per question

1. Control over daily life

- ☐ I have as much control over my life as I want
- ☐ Sometimes I don't feel I have as much control over my life as I want
- ☐ I have no control over my daily life

2. Occupation

- ☐ I do the activities I want to do
- ☐ I do some of the activities I want to do
- ☐ I don't do any of the activities I want to do

3. Anxiety

- ☐ I feel free from worry and concerns on a day-to-day basis
- ☐ I sometimes feel worried and concerned
- ☐ I feel very worried and concerned on a daily basis

4. Social Participation and Involvement

- ☐ My social situation and relationships are as good as I want
- ☐ Sometimes I feel my social situation and relationships are not as good as I want
- ☐ I feel socially isolated and often feel lonely

5. Please say how much you agree or disagree with the following statements by ticking the relevant box on each line.

Tick one box on each line

	Strongly agree	Agree	Slightly agree	Neither agree or disagree	Slightly disagree	Disagree	Strongly disagree
In most ways my life is close to ideal							
The conditions of my life are excellent							
I am satisfied with my life							

6. The next questions are about how you feel about different aspects of your life. For each one, please day how often you feel this way.

Tick one box on each line	Hardly ever or never	Some of the time	Often
How often do you feel you lack companionship?			
How often do you feel left out?			
How often do you feel isolated from others?			
How often do you feel in tune with the people around you?			

7. On average, how often do you do each of the following with any family members, not counting any who live with you?

Tick one box on each line	Three or more times a week	Once or twice a week	Once or twice a month	Every few months	Once or twice a year	Less than once a year or never
Meet up (include both arranged and chance meetings)						
Speak on the phone						
Write or email						

8. How many family members would you say you have a close relationship with?

9. On average, how often do you do each of the following with any of your friends, not counting any who live with you?

	Tick one box on each line					
	Three or more times a week	Once or twice a week	Once or twice a month	Every few months	Once or twice a year	Less than once a year or never
Meet up (include both arranged and chance meetings)						
Speak on the phone						
Write or email						

10. How many of your friends would you say you have a close relationship with?

11. How easy or difficult would it be for you to get to each of the following places, using your usual form of transport?

	Tick one box on each line				
	Very easy	Quite easy	Quite difficult	Very difficult	Does not apply
Bank or cash point					
Chiropodist					
Dentist					
General Practitioner					
Hospital					
Local Shops					
Optician					
Post Office					
Shopping Centre					
Supermarket					

12. I would now like to ask you some questions about your activities during the past 3 days. Please tick to indicate whether you have done one of these activities during the past 3 days.

Tick one box on each line	Yes	No
a. Have you been to other rooms of your house besides the room where you sleep?		
b. Have you been to an area immediately outside your home such as your porch, deck or balcony, hallway of an apartment building or garage?		
c. Have you been to an area outside your home such as a garden, courtyard, driveway, or parking space?		
d. Have you been to places in your immediate neighbourhood, but beyond your own property or apartment building?		
e. Have you been to places inside your immediate village, town, or community?		
f. Have you been to places outside your immediate village, town, or community?		
g. Have you been to places outside of your county?		
h. Have you been to places outside of England but within the UK?		
i. Have you been outside of the UK?		

Questionnaire 2: Falls Efficacy Scale- International

I would like to ask some questions about how concerned you are about the possibility of falling. For each of the following activities, please tick the opinion closest to your own to show how concerned you are that you might fall if you did this activity. Please reply thinking about how you usually do the activity. If you currently don't do the activity (example: if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity.

	Tick one box on each line			
	Not concerned at all	Somewhat concerned	Fairly concerned	Very concerned
1. Cleaning the house (e.g. sweep, vacuum, dust)				
2. Getting dressed or undressed				
3. Preparing simple meals				
4. Taking a bath or shower				
5. Going to the shop				
6. Getting in or out of a chair				
7. Going up or down stairs				
8. Walking around the neighbourhood				
9. Reaching for something above your head or on the ground				

Tick one box on each line				
	Not concerned at all	Somewhat concerned	Fairly concerned	Very concerned
10. Going to answer the telephone before it stops ringing				
11. Walking on a slippery surface (wet or icy)				
12. Visiting a friend or relative				
13. Walking in a place with crowds				
14. Walking on an uneven surface				
15. Walking up or down a slope				
16. Going out to a social event (e.g. religious service, family gathering, or club meeting)				

Thank you for taking part!

Questions taken from

The Falls Efficacy Scale-International (FES-I)

ASCOT adult social care outcomes toolkit

ELSA English Longitudinal Study of Ageing

The Life Space Questionnaire: A Measure of the Extent of Mobility of Older Adults