

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

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Objective

The purpose of this study was to determine the extent to which mobility indices (such as walking speed and postural sway), motor initiation, and cognitive function, specifically executive functions, including spatial planning, visual attention, and within participant variability, differentially predicted 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.

1.0 Introduction

1.1 Pedestrian Incidents and Fatalities

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.

1.2 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) 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. Various authors have suggested that these data imply 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 near-side errors may also demonstrate a lack of general attentional control in very old age. The current study examined the potential differential 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.

1.3 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 left) 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. This implied that mobility and motor initiation are major components of unsafe crossings, but also suggested differing effects between genders. 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. This paper 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.

1.4 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 moving environment, navigational planning (as measured using a zoo mapping test), has previously been found to correlate with a reduced ability to successfully navigate a virtual reality shopping environment in older adults (Sangani, Koenig, Kizony, & Weiss, 2013). Planning ability, such as that measured by the Tower of London

task (Shallice, 1982) is commonly used as a measure of executive function, also loading on working memory for older adults (Phillips, Gilhooly, Logie et al., 2003). This measure has further been shown to be related to freezing of gait in Parkinson's disease (Ferrari, Lagravinese, Pelosin et al., 2015). In addition to being able to begin moving upon making a decision to do so, pedestrian decisions involve mentally appraising action sequences and consequences prior to physically engaging in the task, that is the essence of planning. In this study, a touch screen version of the Tower of London, the Stockings of Cambridge task (CANTAB) is used to assess 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 linked with visual attention (Useful Field of View, see below for details), and driving hazard observation measures by Anstey, Horswill, Wood, & Hatherly, (2012), indicating a role in the traffic environment. This paper 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,

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

1.5 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 tasks 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, episodic memory, fluid cognitive abilities (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, & Khugpath, 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 paper therefore hypothesises 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 generally focus 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 paper will directly assess 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) An age effect is present for the presence of more far-side unsafe crossing errors than near-side crossing errors.
- 1b) An age and gender relationship is present for unsafe crossing behaviours (i.e. near- and far- side errors, and start-up delay)
- 2) Mobility difficulties, start-up delay, and cognitive function will differentially relate to near-side and far-side errors.
- 3) Mobility and cognition will have differing predictive values for near-side unsafe, and far-side unsafe crossing decisions.
- 4) Mobility and cognition will have differing predictive values towards Start-up Delay.

2.0 Method

2.1 Design

The study uses an observational 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 Plan of Analyses

To measure Hypothesis 1a (An age effect is present in the proportion of near-side and far-side unsafe crossings), 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 (An age and gender relationship is present for unsafe crossing behaviours) was measured using correlational analyses. A partial correlation matrix was conducted, controlling for age and gender, to measure Hypothesis 2 (Mobility difficulties, start-up delay, and cognitive function are differentially related to near-side and far-side unsafe crossing behaviour). A series of stepwise regressions were employed to test Hypothesis 3 (Mobility and Executive Function will have differing predictive values for near-side and far-side unsafe crossing behaviours) and Hypothesis 4 (Mobility and Executive Function will have differing predictive values towards 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, perturbation coefficient of variance, start-up delay average and start-up delay coefficient of variance (except for the start-up delay

regression), processing speed, divided attention, selective attention, updating, spatial planning, spatial working memory, inhibition, set-shifting, reaction time, and cognitive within participant variability. 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.

2.3 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 and any queries were addressed before continuing. Following the consent form, a self-report demographic questionnaire 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 about the nature of the study.

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 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 (mean age=66.5 years, SD=9.89). 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 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.

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.

2.6 Materials and Test Assessments

2.6.1 General Mobility Score & Walking Speed

A self-report, paper based mobility questionnaire (Holland & Hill, 2010) was used to achieve a score for general participant mobility. 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.

2.6.2 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). 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. 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.

2.6.3 Visual Attention & Cognitive 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. 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. 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. 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 taken 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 were reaction time, the average time taken to respond in milliseconds, and within participant variability, using the CRT coefficient of variance (mean CRT divided by CRT standard deviation).

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. 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 maximum possible number of

safe crossing gaps that could be safely achieved was 35, although the traffic stream was continuous giving all participants the opportunity to choose unsafe gaps. The minimum number of safe crossings which could be achieved by even the slowest of walkers was 9 crossings. 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, the proportion of unsafe crossings was used as the dependent variable. This was calculated as a proportion of number of unsafe crossings out of the total number of crossings made by that person (both safe and unsafe). This was further divided into proportion of near-side unsafe crossings and proportion of far-side unsafe crossings. In addition, start-up delay time (the time taken from a safe gap appearing and the participant starting to cross) was also taken.

2.7 Ethical Considerations

This study was reviewed and approved by Aston University Research Ethics Committee. 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).

3.0 Results

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).

3.2 Hypothesis 1a: An age effect is present for the presence of more far-side unsafe crossing errors than near-side crossing errors.

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 ($F(1, 101) = 0.276, p > .05$). This suggests that the age effect accounts 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 does not interact with lane direction, and error proportion differences are removed once age has been controlled for, these results support the above hypothesis that there is an age effect on unsafe crossings direction.

3.3 Hypothesis 1b: An age and gender relationship is present for unsafe crossing behaviours (i.e. near- and far- side errors, and start-up delay)

Correlation analyses showed that gender was significantly positively related to proportion of near-side unsafe errors and total unsafe errors, i.e., women made more total and near-side

crossing errors than men. Gender was not significantly correlated with far-side errors or start-up delay. Increasing age, on the other hand, was positively related to more far-side and total unsafe errors, but not to more near side errors (see Table 1 for the Age, Gender, & Pedestrian Behaviour matrix). Increased age but not gender was linked to longer start-up delays.

Table 1 about here

3.4 Hypothesis 2: Mobility difficulties, Start-up Delay, and Cognitive Function will differentially relate to near-side and far-side errors.

Correlation analyses controlling for age and gender to partial out effects found in Hypothesis 1, are shown in see Table 2. These demonstrated that walking speed and mobility score were significantly correlated with proportion of total, and far-side unsafe crossing errors, but not for near-side errors. The relationships indicated that worsened performance in these measures was related to an increased proportion of unsafe crossings. Near-side and total errors were also significantly related to start-up delay variability, perturbation variability, with a non-significant trend for inhibition ($p = .075$). Total and far-side errors were related to start-up delay average and sit-to-stand times. Far-side errors only showed a trend ($p=.066$) with selective attention. These results suggest differential relationships between near-side and far-side unsafe crossing choices with measures of mobility, start-up delay, and cognition. 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 there is a differential relationship between mobility, start-up delay, and cognition with unsafe crossing behaviours. In summary, walking speed and self-rated mobility score was a common factor for all unsafe crossing behaviours. Further, far-side errors were more related to reduced mobility, increased start-up delay, reaction time, and worsened visual attention (selective attention), and near-side was more related to increased variability in mobility and reduced inhibition ability. Start-up delay was linked to reduced mobility and reaction time.

Table 2 about here

3.6 Hypothesis 3: Mobility and Cognitive functions will have differing predictive values for near-side unsafe, and far-side unsafe crossing decisions.

Two stepwise regressions (one for near-side errors, and one for far-side) were conducted to determine the predictors of near-side, and far-side unsafe behaviour. The following variables were entered into the models: age, gender, walking speed, self-rated mobility score, sit-to-stand times, perturbation average, perturbation coefficient of variance, start-up delay average, start-up delay coefficient of variance, processing speed, divided attention, selective attention, updating, spatial planning, spatial working memory, inhibition, set-shifting, reaction time, and cognitive within participant variability.

The steps and order of entry produced by the stepwise regression for near-side crossing were as follows:

- 1) Start-up Delay (start-up delay coefficient of variance);
- 2) Mobility (walking speed)
- 3) Visual Attention (processing speed)

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 3). 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 3 about here

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 were as follows:

1. Mobility (walking speed);
2. Start-up delay 1 (start-up delay average);
3. Start-up delay 2 (start-up delay coefficient of variance);
4. Cognition (spatial planning)

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 4). 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 an additional 2.1% once mobility and start-up delay steps had been accounted for.

Table 4 about here

In summary the hypothesis was supported in that differing mobility and cognitive functions contributed towards different types of unsafe crossing behaviour. Although walking speed and start-up delay measures were strong independent predictors for both far-side crossing errors and near-side errors, UFOV (particularly processing speed) was predictive of near-side unsafe crossings, whereas spatial planning was predictive of far-side unsafe crossings.

3.7 Hypothesis 4: Mobility and Cognitive functions will have differing predictive values towards 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. The following step and order of entry was produced:

- 1) Mobility (walking speed);

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 5). In summary the hypothesis was only partially supported as mobility, but not cognition, was predictive of start-up delay.

Table 5 about here

4.0 Discussion

The purpose of the study was to compare the impact of cognitive and mobility function on pedestrian crossing safety, comparing the contributions of these indices to crossing errors 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 correlated with far-side unsafe errors only. This supports the suggestion 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 highly influential independent predictor in all unsafe crossing behaviours (near-side, far-side, and start-up delay) replicating findings by Holland & Hill (2010), and Dommès, Cavallo, & Oxley (2013), whereby walking speed was one of the most salient predictors of total unsafe crossings. 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 results implied 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 average was found to be a strong predictor for far-side errors, but not for near-side errors. This is supportive of findings that start-up delay is a large 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 ability can have 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, even though a correlational relationship was not found. This confirms that the component of spatial information processing that is involved in making road crossing decisions is executive planning function, the ability to appraise action and potential consequences prior to making a decision to move. While performance on the related planning measure, the Tower of London, was found to be related to 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.

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.

4.2 Future Directions

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. In addition, future research could perhaps control for walking speed, and thus see what cognitive abilities cannot be related to the demands of walking or start-up delay.

4.3 Conclusion

To conclude, age was only found to be a marginal factor in unsafe crossing behaviour (lane errors). Rather, walking speed, motor initiation and variability, planning and aspects of attention were key. Practical implications for this are that these elements have the ability to be predicted and trained or rehabilitated. 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.

4.4 Conflicts of Interest

There are no conflicts of interest associated with this study.

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Table 1- Correlation Matrix Age and Gender with Pedestrian Behaviour Measures

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

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

Table 2- 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	SP	SWM	In	Up	SetS	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*	.182T	.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	.198T	.029	.017	-.026	-.003
Prop. Far-Side Unsafe	.552**	.053	-.614**	.351**	.405**	.134	.123	-.054	.005	.190T	.172	-.038	.069	.171	.098	.172	.133

*= Significant at .05 level **=Significant at .01 level T=trend ($p=.051-.075$)

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

Table 3- Predictive Contribution of each Step in explaining Total Proportion of Near-Side Unsafe crossing variance (N=103)

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

*= Significant at .05 level **=Significant at .01 level ^ R²= R² change
 COV= Coefficient of Variance COV= Coefficient of Variance

Table 4- Predictive Contribution of each Step in explaining Total Proportion of Far-Side Unsafe crossing variance (N=103)

Model Steps	Variable	R ²	^ R ²	Beta	Sig.
<i>1 Mobility</i>	Walking Speed	.414**	.414**	-.644	<.001
<i>2 Start-up Delay 1</i>	Walking Speed	.485**	.071**	-.467	<.001
	Start-up Delay Ave			.319	.001
<i>3 Start-up Delay 2</i>	Walking Speed	.527**	.042**	-.426	<.001
	Start-up Delay Ave			.412	<.001
	Start-up Delay COV			.218	.005
<i>4 Cognition</i>	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 ^ R²= R² change
 RT= Reaction Time COV= Coefficient of Variance Ave= Average

Table 5- Predictive Contribution of each Step in explaining Total Proportion of Start-up Delay variance (N=103)

Model Steps	Variable	R ²	Beta	P Value
		.305**		
<i>Mobility</i>	Walking Speed		-.552**	<.001

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