Visual correlates of balance and mobility in older adults: Can visual attention training improve performance?

by

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AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contribution

I would like to acknowledge the names of my co-authors who contributed to this thesis:

- Dr. Susan Leat, PhD
- Dr. Lori Ann Vallis, PhD

Abstract

Falls among older adults is a serious problem facing our aging population. It is estimated that one in every three older adults aged 70+ fall every year; some of these experience multiple falls. Thirty five percent of fallers aged 65 - 70 years experience severe injuries, and this rises to 76% in the 80+ age group. Falls can cause deterioration of health, loss of independence, or even death. The first purpose of this thesis (Experiment 1) was to examine the possible link between balance, mobility, fear of falling, and aspects of vision including binocular vision (BV) status and visual attention, measured with a useful field of view test (UFV) and the Attended Field of View (AFOV). In this cross section study I was interested in measures of vision, which have been less studied or not been considered before, specifically tests of BV and visual attention. These were chosen, as previous research had shown that BV disorders are very common in older adults, and that there is an association between a number of functional tasks and visual attention. Associations with balance and mobility would be a significant finding because BV disorders are often treatable and visual attention is trainable.

Balance and mobility were assessed using the One Legged Stance test (OLST), the 5 Meter Walk test (5MWT) and the Sit to Stand test (STST). Fear of falling was measured with the Falls Efficacy Scale-International (FES-I). Visual measures included distance, intermediate and near visual acuity (VA), contrast sensitivity, stereoacuity, BV measurements, UFV and AFOV. Seventy-two adults aged 70 and older took part in the study (mean age 80.3 ± 5.9 years). The results showed that abnormal BV, poor intermediate VA and errors on the UFV were all significant predictors of reduced performance in mobility and balance. Univariate

regression showed that reduced performance on the OLST and the STST was significantly correlated with abnormal BV and intermediate VA. The 5MWT and the FES-I were also predicted by poor intermediate VA. In addition, the OLST, STST and the 5MWT were all associated with the UFV errors. Multiple regression models included the following: OLST performance was related to BV and eye movement disorders, stereoacuity and UFV errors, STST was related to intermediate VA and 5MWT was related to distance VA.

The association between balance and visual attention led me to hypothesize that training visual attention may improve balance and thereby reduce falls. Falls prevention programs typically include vision, exercise, environment modification, education intervention or a combination of these interventions grouped together. The most effective programs may be those that have a multifactorial approach. However, the impact of visual attention training aimed at improving balance and/or mobility has not yet been studied. Therefore, the second purpose of this thesis (Experiment 2) was to investigation of whether visual attention training can improve balance and/or mobility in older adults, with the goal that this may transfer to reducing falls.

Experiment 2 was a randomized controlled trial (RCT) in which 15 participants were randomly assigned to a visual attention training group and 15 to a control group. Visual attention training was undertaken with versions of a selective attention useful field of view test (UFV) and attended field of view (AFOV) test. The training sessions were 45 minutes duration, undertaken twice a week for three weeks. The outcome measures were sway using a force plate platform (AMTI AccuGAIT; 200 Hz), the mini Balance Evaluation Systems Test (mini-

BESTest), the One Legged Stance test (OLST), the 5 Meter Walk test (5MWT), the Sit to Stand test (STST), the Timed Up and Go test without (TUG) and with a concurrent cognitive task (TUGco). It was found that visual attention significantly improved after training ($p< 0.01$). However, a mixed ANOVA (2x groups, 2x visits, 5x trials) showed no main effect of visit or group or any interaction for any of the force plate platform parameters; medial lateral (ML) or anterior posterior (AP) center of pressure (CoP) standard deviation, ML and AP CoP maximum sway, ML and AP CoP range of sway and the cumulative path length for sway ($p>0.05$ in all cases) in eyes open and eyes closed conditions. A mixed ANOVA (2x group, 2x visits) of the changes over time for the other balance and mobility assessment tools also showed no improvement after the visual attention training (Mini-BESTest, $p=0.25$: 5MWT, $p=0.28$: OLST, $p=0.31$: STST, $p=0.029$: TUG, $p=0.08$: TUGco, $p=0.21$).

To conclude, a variety of measures of visual function were shown to be related to poor performance in balance and mobility tasks. Poor BV, distance and intermediate VA and visual attention were among these measures. It is important that eye care practitioners who work with older adults be aware of these associations, question older adults about a history of falls or walking and balance problems, and ensure that the vision of older people is optimally managed. Although visual attention itself was improved by the training, there was no improvement in either mobility or balance and no difference between the intervention and the control groups post visual attention training. It was concluded that UFV and AFOV visual attention training alone is not effective to improve balance and mobility; a training program that includes movement and visual attention may be needed to obtain improvement in balance and mobility.

Since a substantial portion of the older adult population fall every year the results of this study are important as it supports the notion that a multi-component approach is still the recommended route to reduce the risk of falls.

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Dedication

To my dear parents Fatima and Matoog. To my beloved wife Shahd and my daughter Reema.

To my sister Bayan. To my brothers Abdulaziz, Abdullah, Abdulmajeed and Ahmad.

I could not have done this without your love and support. I am lucky and grateful to have you all in my life.

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Chapter 1

Introduction and literature review

1.1 Epidemiology

Falls and loss of balance are very common among older adults and are considered a major health concern for the elderly. According to the Kellogg International Working Group on the Prevention of Falls by the Elderly (Gibson, Andres, Isaacs, Radebaugh, & Wormpetersen, 1987), falls are defined as “unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure.” Falls are not random events and have been linked to multiple risk factors that are globally prominent in the population of older adults. It is estimated that 22 to 40% of older adults aged 70 years and above fall each year and this is consistent among countries (Hausdorff, Rios, & Edelberg, 2001; Lord & Dayhew, 2001; Lord et al., 2003; Luukinen, Koski, Hiltunen, & Kivelä, 1994; Stevens et al., 2012; Tinetti, Speechley, & Ginter, 1988). Due to their frailer health, the annual falls rates in nursing home settings is much higher, reaching 58% (Lord et al., 2003). Falls are a significant concern for the older adult population due to the possible devastating effects of falls on the individual and their families. According to the Public Health Agency of Canada, falls are the leading cause of injury-related hospitalization among older adults (Public Health Agency of Canada, 2014). Annually, 256,000 Canadians are admitted to the emergency room for a fall-related injury, and over 78,000 are hospitalized (Public Health Agency of Canada, 2014). Over 50 % of older adults who have experienced a fall report a fall-related injury (Bergland & Wyller, 2004; Nevitt, Cummings, Kidd, & Black, 1989), while 24% of older adults who experienced a fall had a serious injury. Fall-related injuries can be minor, such as cuts, scrapes, blisters or bruises, or can be devastating, serious injuries, such as concussions, fractures or dislocations (Public Health Agency of Canada, 2014; Tinetti et al., 1988). The most common fall-related injuries among Canadian seniors are fractures (35%), sprains or strains (30%), and scrapes, bruises or blisters (19%) (Public Health Agency of Canada, 2014). Falls are the main cause of hip fractures in older adults, which in turn lead to mortality in 20% to 30% of cases (Dunn, Sadkowsky, & Jelfs, 2002; Ioannidis et al., 2009; Jiang et al., 2005; Moran, Wenn, Sikand, & Taylor, 2005). In addition to the physical health deterioration experienced after a fall, falling can have a negative effect on mental health. Sustaining a fall can lead to a fear of falling, depression, isolation, anxiety, confusion and a loss of independence (Bergland, Jarnlo, & Laake, 2003; Dunn, Furner, & Miles, 1993; Friedman, Munoz, West, Rubin, & Fried, 2002; Iinattiniemi, Jokelainen, & Luukinen, 2009; Salgado, Lord, Ehrlich, Janji, & Rahman, 2004; Tinetti & Williams, 1998).

However, the physical and mental negative consequences for the individual are not the only effects of falling. There is also a substantial financial burden on the healthcare system. In Canada, the direct cost of falls in older adults was $2.0 billion in 2004, and the cost of falls was 3.7 times greater for older adults (aged $\geq$ 65 years) than adults aged between 25-65 years (SMARTRISK, 2009). An examination of the data regarding falls statistics in Canada concerning fall- related injuries and deaths in 2003 compared to 2010 (Public Health Agency of Canada, 2014), revealed that the incidence of both fall-related injuries and deaths had increased over time.

Also, the population is aging. An examination of the latest population census (Statistics Canada) revealed that, in 2015, Canadian seniors > 65 years exceeded the number of younger individuals between the ages of 0-14 years by 0.1%. This number is projected to increase by 4% in 2024 to reach 20.1% of the total Canadian population (Statistics Canada). Therefore, due to this shift towards an older demographic, it is likely that the number of fall-related injuries and deaths in Canada will accordingly increase. It is, therefore, obvious that falls will not only affect the relevant individuals and their families but will also have an effect on society. If falls could be prevented or if the management of falls could be improved, resources devoted to treating fall-related injuries could be directed to other areas that might be more beneficial to the community.

Falls have been correlated with many risk factors, such as gait or balance instability, visual impairment, fear of falling, increasing age, female sex, fall history, urinary incontinence, depression, cognitive impairment and polypharmacy (Black & Wood, 2005; Friedman et al., 2002; Oliver, Daly, Martin, & McMurdo, 2004; Rubenstein, Josephson, & Robbins, 1994; Tinetti et al., 1988). The more risk factors a person has, the more likely s/he will experience a fall (Tinetti et al., 1988).

1.2 Vision and aging

Changes in normal visual function with age

Visual acuity is known to be affected by age. In the Salisbury Eye Evaluation study, a population sample of 2520 participants, showed a linear decline in visual acuity between ages 65 and 85 years, and this decline was worse in women than men (Rubin et al., 1997). In a smaller sample size, Elliot and colleagues (1995) noted a reduction in visual acuity as a function of age. They found that visual acuity was at its best between the ages of 25 to 29 years (average Snellen acuity 6/4), and progressively worsened in persons aged 75 years and above (average Snellen acuity of 6/6). In the Beaver Dam Eye Study (R. Klein, B. Klein, Lee, Cruickshanks, & Gangnon, 2006), the authors studied the changes of visual acuity in 4068 subjects over the period of 15 years. They observed a one-line loss in visual acuity in participants aged 43 to 54 years old in comparison with the results of their baseline visit 15 years prior years, while a three-line loss was noted in participants aged 75 years and over. Low contrast visual acuity is also affected by age. It is estimated that the difference between high and low contrast visual acuity at the age of 60 is eight letters, while at the age of 90 the difference is 18 letters demonstrating that low contrast visual acuity is more affected by age than high contrast visual acuity (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Moreover, low contrast visual acuity in reduced illumination and visual acuity in glare have also been observed to deteriorate with advancing age (Haegerstrom-Portnoy, 2005).

Photopic contrast sensitivity declines with increasing age (Haegerstrom-Portnoy, 2005; Rubin et al., 1997). Contrast sensitivity between people aged 20 years and those aged 70 years is significantly different; those aged 20 years have better contrast sensitivity (D. Elliott, 1987; S. Elliott et al., 2009). In the Salisbury Eye Evaluation Study, it was found that there is a linear decline in contrast sensitivity with increasing age, by 0.1 log contrast sensitivity per decade. Contrast sensitivity begins to decrease after the age of 40 years, and this deterioration is more severe with advancing age. The decline in photopic contrast sensitivity is seen at intermediate to high frequencies; two cycles/degree and higher. However, sensitivity at low frequencies remains unaffected with age (Owsley, Sekuler, & Siemsen, 1983). Young observers in their 20s are most sensitive to spatial frequencies between 3-4 cycles/degree. Aging shifts the peak of the contrast sensitivity to lower spatial frequencies (Mei, Leat, & Hovis, 2007; Owsley et al., 1983), shifting from four cycles/degree to two cycles/degree for subjects over the age of 60 (Arundale, 1978; Owsley et al., 1983). The decrease in contrast sensitivity has been attributed to various factors. These factors can be separated into optical and neural. Optical factors include a decrease in retinal illuminance due to pupillary miosis (Loewenfeld, 1979) and an increase in the density of the crystalline lens (Pokorny, Smith, & Lutze, 1987). In addition, there is a concurrent increase in optical aberrations and intraocular light scatter (Artal, Guirao, Berrio, Piers, & Norrby, 2003) and the type of intraocular lens used can affect image contrast (Montés-Micó, España, Bueno, Charman, & Menezo, 2004). Some researchers attribute most of the loss to optical change (Burton, Owsley, & Sloane, 1993; Owsley et al., 1983). Others attributed the decrease in contrast sensitivity to neural factors such as the decline in the ganglion and rod cell densities (Curcio, Millican, Allen, & Kalina, 1993; Harwerth & Wheat, 2008; Jackson, Owsley, Price Cordle, & Finley, 1998). Owsley (2001) concluded that the optical factors have the greatest impact for the photopic contrast sensitivity losses.

A substantial delay in *dark adaptation* and a decrease in final sensitivity have been frequently noted in older adults (Jackson, Owsley, & McGwin, 1999; Jackson & Owsley, 2000; Sturr, Zhang, Taub, Hannon, & Jackowski, 1997). The reduction in dark adaption has been attributed to a delay in rhodopsin regeneration (Jackson et al., 1999; Lamb & Pugh, 2004). The rate of sensitivity recovery decreases by 0.02 log units/minute for each decade of life, and the time required for rhodopsin regeneration increases with age at an estimated 8.4 seconds per decade (Jackson et al., 1999).

There is evidence that *visual field* sensitivity declines with advancing age. A generalized depression of the visual field with age has been observed, with reports indicating a more pronounced loss in peripheral areas of the visual field, especially in the superior hemisphere (Haas, Flammer, & Schneider, 1986; Heijl, Lindgren, & Olsson, 1987; Katz & Sommer, 1986; Schlottmann, De Cilla, Greenfield, Caprioli, & Garway-Heath, 2004). This decline in sensitivity has been reported to commence as early as 20 years and to continue to decline after this (Haas et al., 1986).

Stereopsis is another visual function that decreases with age. Both near and far stereoacuity can be affected (Garnham & Sloper, 2006; Lee & Koo, 2005). Haegerstrom-Portnoy et al. (1999) showed that 40% of 70-year-old subjects and 80% of 90-year-old participants have a stereoacuity worse than 85 seconds of arc. Haegerstrom-Portnoy (2005) demonstrated in a more recent study that only 55% of 900 older adults between the ages of 58 and 102 years old were able to pass this lenient criterion of 85 seconds of arc. Garnham and Sloper (2006) found that there is a mild decline in stereoacuity due to age, but that the magnitude of this decline varies depending on which test was implemented. Some have suggested that the change in stereoacuity in older adults is due to a reduction in the function of the cortical disparity detectors. Others have suggested that age-related changes in ocular function may be the cause (i.e., the information sent to the visual cortex may be compromised). Additionally, some have attributed the loss due to difficulties in overcoming the dissociative effect of various tests on fusion (Brown, Yap, & Fan, 1993; Garnham & Sloper, 2006; Schneck, Haegerstrom-Portnoy, Lott, & Brabyn, 2000; Wright & Wormald, 1992).

The overall prevalence of *binocular vision and eye movement disorders* has been shown to be high in older adults, with an increasing number of disorders present with progressing age (Leat et al., 2013). It has been estimated that 30% of adults aged 70-79 years and 38% of adults > 80 years of age have a binocular vision and/or eye movement disorder (Leat et al., 2013). More specifically, aging can cause a decline in *oculomotor function* in most measures when compared to younger adults. Saccades are rapid eye movements that change the point of fixation from one point to the other (Purves et al., 2001). Older adults experience a reduction in saccadic reaction time, velocity and accuracy when compared to adults aged 20-30 years (Moschner & Baloh, 1994; Munoz, Broughton, Goldring, & Armstrong, 1998; Sharpe & Zackon, 1987). Saccadic eye movements change across the lifespan such that children and older adults have the longest saccadic reaction time and lowest peak velocity (Irving, Steinbach, Lillakas, Babu, & Hutchings, 2006). Smooth pursuits are slower eye movements used to maintain the image of a moving target on the fovea (Purves et al., 2001). A reduction in smooth pursuit gain is observed in older adults, and the gap between younger and older observers is reported to rise with increasing target velocity and acceleration (Moschner & Baloh, 1994; Paige, 1994). Optokinetic nystagmus is an involuntary eye movement that manifests when there is a slow movement of a large part of the visual environment. This reflex is characterized as a smooth pursuit in the direction of the moving target and a rapid saccade in the opposite direction (Daroff & Aminoff, 2014; Purves et al., 2001). Another eye reflex is the vestibulo-ocular reflex which is a compensatory eye movement to help stabilize the eyes and prevent retinal image slippage when the head or body moves (Purves et al., 2001). Both optokinetic nystagmus and the vestibulo-ocular reflex gain are observed to decrease with age (Baloh, Jacobson, & Socotch, 1993; Kerber, Ishiyama, & Baloh, 2006; Paige, 1994; Valmaggia et al., 2004).

The presence of *glare* has been shown to more seriously impact visual function in older, compared to younger, adults (Bailey & Bullimore, 1991; Haegerstrom-Portnoy et al., 1999; Haegerstrom-Portnoy, 2005). The presence of glare has been demonstrated to affect visual acuity (Haegerstrom-Portnoy et al., 1999), scotopic contrast sensitivity (Hohberger, Laemmer, Adler, Juenemann, & Horn, 2007) and color discrimination (Steen, Whitaker, Elliott, & Wild, 1994). Haegerstrom-Portnoy (2005) tested different measures of visual function, such as, visual acuity, contrast sensitivity, stereoacuity and color discrimination and reported that the two visual functions most affected by aging are vision in glare and glare recovery time, which were 18x and 16x more affected respectively than in adults under 60 years. This reduction in visual function in the presence of glare is thought to be the result of increased intraocular light scatter, which can produce a veiling luminance on the retinal image (Bailey & Bullimore, 1991; Steen et al., 1994).

To conclude this section, a number of normal physiological changes occur in the visual system with increasing age and these changes can affect visual function. However, all these functions are not equally effected by age (Haegerstrom-Portnoy, 2005). The presence of an ocular disease that is more common in older adults, such as age related macular degeneration glaucoma or cataract, will have an even more pronounced effect on the visual function.

1.3 Measures of visual attention

When we look at the visual environment around us, we are presented with a tremendous amount of perceptual information that cannot effectively be processed simultaneously due to the limited capacity humans have for processing visual information. Visual attention allows us to select and determine which information is needed at a particular time in order to analyze the important components of the image. Attention was defined by the psychologist William James (1890) as "attention is….the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others." Having efficient, accurate and reliable visual attention selection in extracting the needed information is crucial, for example when objects with different visual cues, (color, shape, contrast, orientation or texture) appear in the cluttered visual environment. The environment can be overloaded with complex and crowded information that can restrict the visual system’s prompt analysis of the perceived information. In order for the visual system to cope with this barrage of information, the brain first selects information that is relevant to the behavior or action observed and ignores unimportant information that is not needed at the time of the observation (Goldstein, 2008).

Spatial visual attention is the process of directing attention to a certain location in space (Carrasco, 2011). Attention can be oriented by either moving the eyes toward the location of attention or by mentally shifting attention to the periphery without moving the eyes (Posner, 1980). The deployment of attention helps in monitoring visual space in everyday activities such as driving, walking and recreation. It can direct attention in parallel to more than one location and can initiate an eye movement to where relevant information was detected (Hoffman & Subramaniam, 1995; Perry & Zeki, 2000; Van der Stigchel & Theeuwes, 2007).

1.3.1 Changes of visual attention with age

Visual attention, which is one aspect of visual processing, has been shown to deteriorate with age. Older adults require more time to process visual information especially in the presence of a cluttered visual environment, where more time and effort is required to process incoming visual input (Ball, Beard, Roenker, Miller, & Griggs, 1988; Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004; Sekuler, Bennett, Mamelak, 2000). The performance of visual attention can be examined by evaluating the functional field of view (FFOV). The functional field of view (FFOV) is “the region from which useful information can be acquired during a given eye fixation” (Henderson & Ferreira, 2013). Previous researchers developed a number of tests that can be used to measure the FFOV in older adults. One of the most common approaches is the Useful Field of View (UFOV®) (Ball, Edwards, & Ross, 2007; Ball & Owsley, 1993; Leat & Lovie-Kitchin, 2008; Owsley, 1994). The UFOV® is a computer-based test in which a target is presented and localization of the target in the presence or absence of distractors or multi-tasking is required. In the literature, the paradigms used for assessing the useful field of view are: processing speed, focused attention, divided attention and selective attention. Processing speed measures the observer’s ability to discriminate a centrally located target without the presence of a peripheral targets or distractors. Focused attention is when the participant is asked to discriminate a single target, either presented centrally or eccentrically. Divided attention requires the participant to simultaneously identify a centrally located target and localize a peripheral target without the presence of distractors. Finally, selective attention, uses a similar paradigm as divided attention but the peripheral target is embedded amongst distractors (Richards, Bennett, & Sekuler, 2006; Sekuler, Bennett, Mamelak, 2000; Visual Awareness Research Group, Inc).

Sekuler and Ball (1986) noticed that many older adults report difficulties in a cluttered visual scene. For example, finding a friend in a crowded area or finding a street sign among other signs. They pursued this by studying the effect of aging on visual attention in older adults. Their results can be summarized into three sections. First, aging has no significant effect on focused attention (localizing a single target). Second, divided and selective attention are both affected by age. Third, selective attention is more challenging for older adults than divided attention, compared to younger adults, especially with increasing eccentricity. This indicates that age has an effect on processing information in the visual field especially in the presence of visual distractions and that older participants have limited capacity for dividing their attention. Seiple et al. (1996) found that older adults' performance on a divided attention task was poorer than middle-aged or younger participants. This effect of aging on visual attention has been shown to change across the life span and was noted to start as early as 20 years (Sekuler et al., 2000). These age-related changes have been attributed to insufficiencies in capacity to process visual information and do visual search (Owsley, 2013).

1.3.2 Associations between visual attention and function

A large body of work has emerged studying the association between different functional measures and visual attention. Owsley & McGwin (2004) showed that impairment in the UFOV® was associated with mobility manoeuvers evaluated with the Performance Oriented Mobility Assessment tool (POMA). This association remained significant even after controlling for other cofounders, such as, age, sex, race, and number of medical conditions. Roth, Goode, Clay, and Ball (2003) investigated the link between visual attention measured with the UFOV® and self-reported physical activity. Participants who were more physically active had a better ability to perform the visual attention test. After controlling for age and other cofounders, only regular involvement in moderate and high exercise was associated with preserved visual attention ability. Interestingly, functional reach (forward reaching), which is a measure of balance that can predict recurrent falls in older adults (Duncan, Studenski, Chandler, & Prescott, 1992), has been shown to correlate with visual attention (Riolo, 2004).

Visual attention was also a predictor for bumping into obstacles while navigating on a 32.8 meter mobility course (Broman et al., 2004). Only divided attention testing was used in this study, which mimics real life situations (i.e. dividing attention between where the person is walking and a peripheral obstacle that needs to be avoided). Stalvey, Owsley, Sloane, and Ball, (1999) used the life space questionnaire, which is a functional assessment tool that evaluates the extent of how much an older person moves in their typical life space during a certain time-frame. It was found that a restrictive life space was associated with difficulties in performing the UFOV®. These studies all indicated that those who have a reduction in their visual attention capabilities have limited mobility. However, these associations do not imply causation; the causation could go either way, or be caused by another factor.

A reduction in the ability to perform the UFOV® has also been shown to affect normal day-to-day activities. Owsley and colleagues showed that reduced visual attention performance measured with the UFOV® was associated with an increased time for completing instrumental activities of daily living (Timed IADL). These activities include reading a can label, finding a phone number in a telephone book, making coin change, finding two items on a shelf or reading medicine label directions (Owsley, Sloane, McGwin, & Ball, 2002).

Poor visual attention is also associated with a reduction in driving competency (Ball et al., 2006). Retrospective and prospective automotive crash data showed that a 40% reduction in the UFOV® score yielded a two times greater likelihood that an older adult would be involved in a vehicle crash (Owsley et al., 1998; Rubin et al., 2007; Sims, McGwin, Allman, Ball, &

Owsley, 2000). Further reduction of 41 to 60% and >60% in performance of the UFOV® displayed a higher risk of non-injurious car crash involvement by 4.6 times and 7.1 times, respectively. For injurious car crashes for these percentiles, the odds of involvement was even higher, demonstrating an increased risk of 16.5 times and 21.5 times, respectively. Wood (2002) used a different approach and evaluated driving performance on a closed circuit, where participants were required to complete different driving tasks. These tasks include circuit signs and hazard recognition, hazard avoidance, gap clearance, traffic cones maneuvering, and the time the participant needed to circuit the track. It was found that the UFOV® was one of the predictors of driving performance.

Other tests that are less common in measuring the FFOV have emerged, such as the Attended Field of View (AFOV) (Coeckelbergh, Brouwer, Cornelissen, Van Wolffelaar, & Kooijman, 2002; Coeckelbergh et al., 2004). The AFOV uses a visual search paradigm and assesses the area of functional visual field while allowing head and eye movements during testing. It was suggested that the AFOV mimics everyday life viewing situations where head and eye movements occur. The AFOV was also correlated to age (Coeckelbergh et al., 2004) and driving performance measured with a driving simulator (Coeckelbergh et al., 2002).

1.3.3 Training visual attention

Visual attention training is the processes of using the UFOV or similar program to train a person's ability to process visual information faster and more efficiently. These programs could utilize any visual attention paradigm, task and/or duration to improve and "speed up" the ability to perform the visual attention test (Ball et al., 2002; Ball et al., 2007; Ball et al., 1988; Edwards et al., 2005; Richards et al., 2006; Sekuler & Ball, 1986; Vance et al., 2007; Wadley et al., 2006). Visual attention has been shown to be amenable to training. Sekular and Ball (1986) investigated the effect of practice aimed at improving the ability to perform the UFOV®. They found that daily sessions over a 5-day training period produced an improvement in older participants' visual attention ability. However, their performance was still significantly worse than younger observers. Ball and colleagues (1988) also investigated the effect of a 5-day practice on younger, middle aged and older adults and found that a general enhancement in the UFOV® score was observed in all groups and eccentricities except the 10 ^{o} eccentricity for the younger adults, which was attributed to a floor effect. They noted also that after practice the performance of older adults resembled that of middle aged participants prior to practice. Richards et al. (2006) reported similar results and found that both younger and older adults benefited from practice. This practice effect can last for 6 months after the training sessions (Ball et al., 1988). Others found this training effect to endure for up to 5 weeks (Sekuler & Ball, 1986), 2 years (Ball et al., 2002) or 5 years (Willis et al., 2006). This effect of practice can also transfer from one location to the other across the FFOV (Richards et al., 2006).

This area of study was further pursued to see whether this training effect transfers to other domains, such as health and functional abilities. Visual attention training was found to improve the effectiveness of completing everyday visual tasks demonstrated in a better performance of the Timed Instrumental Activities of Daily Living (IADL) (Edwards et al., 2005; Edwards et al., 2002). Long term benefits of training were demonstrated 10 years after baseline training, where the trained cohort reported less difficulty in performing the IADL compared to the non-intervention group (Rebok et al., 2014). After visual attention training, participants had a lower risk of experiencing a deterioration in their health-related quality of life (HRQoL) than a control group (Wolinsky et al., 2006). Improvement in self-rated health (Wolinsky et al., 2010) and a lower risk of developing depression (Wolinsky et al., 2009) was accrued for trained participants. Ball et al. combined the data of 6 studies that studied the effect of visual attention training. They found that training has an immediate improvement on everyday instrumental abilities and driving performance (Ball et al., 2007).

It can be seen that visual attention training is effective during later adulthood, and can have a pronounced positive outcome on the individual, especially those who have greater difficulty performing the UFOV® (Edwards et al., 2005).

1.4 Balance control systems and their correlation with falls

Postural stability is the ability of a person to keep his/her body in a balanced posture so as to prevent an unintended loss of position in space. Unintended loss of position includes forwards, backwards, or sideways leaning that could result in a fall. Postural stability can be defined as the “ability to control the center of mass in relation to the base of support” (Shumway-Cook & Woollacott, 2007). Balance or postural control is a complicated motor mechanism receiving input from various systems in the body. The three main systems that are considered the most important in maintaining balance are the vestibular, somatosensory and visual systems (Paulus, Straube, & Brandt, 1987; Paulus, Straube, & Brandt, 1984; Winter, 1995b). These three systems work in harmony to maintain postural stability. Any reduction or deficiency in the input of any one of these three systems can lead to an increased reliance on the other systems to maintain stability (Elliot et al., 1995). If the other systems cannot provide that additional input, the body may lose balance, resulting in a fall.

Because of the close relationship between balance and falls, the following section will discuss the vestibular, somatosensory and visual systems and their input in maintaining equilibrium.

1.4.1 The vestibular system

This system provides input of angular head orientation through the semicircular canals of the inner ear and utricles and saccules to monitor linear head movements and the acceleration of gravity (Konrad, Girardi, & Helfert, 1999). In other words, this system provides two inputs that aid in maintaining balance; which way is up and in which direction the body is going. The vestibular system helps the eyes to maintain their position on a stationary target in the presence of body and head movement. The vestibular system neurons are in a constant state of excitement in relation to head position, whether the body is in a steady state (static equilibrium) or moving (dynamic equilibrium) (Kandel, Schwartz, & Jessell, 1991). When the body moves, afferent inputs from the three main balance systems (the vestibular, somatosensory and visual) are transferred to the vestibular nuclei and cerebellum. This creates a rapid efferent connection between the three motor reflexes derived from the vestibular system, namely the vestibulo-ocular (eyes), the vestibulospinal (spinal cord), and the vestibulocollic (head position) reflexes, providing the information required for the body to act suddenly and effectively to maintain stability and prevent a fall (Kandel et al., 1991). A large number of studies have emphasized the primary importance of head stabilization, orientation and acceleration in maintaining balance; all of these are controlled by the vestibular system (Pozzo, Berthoz, & Lefort, 1990; Wilson & Jones, 1979). However, others have suggested that the vestibular system primarily controls balance by keeping the center of mass within safe limits rather than by preserving head position in space (Day, Severac Cauquil, Bartolomei, Pastor, & Lyon, 1997).

Increasing age is associated with vestibular dysfunction (Neuhauser et al., 2005; Sloane, Coeytaux, Beck, & Dallara, 2001). There is a reduction of up to 40% in the number of the vestibular sensory cells (Rosenhall, 1973) and a 37% reduction in the number of nerve fibers within the vestibular system with increasing age (Bergström, 1973), and this can have a significant effect on balance. Impairments in the vestibular system may affect up to 35% of the population aged 40 years and older (Agrawal, Carey, Santina, Schubert, & Minor, 2009), and can cause balance disturbances and falls. These disturbances may be due to the inability of the head to maintain a vertical orientation or a correct position in space. People with vestibular impairments can suffer abnormal head and body righting reactions, gait ataxia, and challenges to balancing in challenging situations, such as during a one-leg stance, on a balance beam, or in a heel-to-toe stance (Fregly, 1974). It has been reported that 35% of patients with vestibular deficits older than 65 years experience falls due to vestibular deficits (Whitney, Hudak, & Marchetti, 2000). Patients with clinically symptomatic vestibular disorders have a 12-times increase in the odds of falling (Agrawal et al., 2009). The incidence of falls since the onset of the vestibular deficit is as much as 50% higher in patients with bilateral vestibular hypofunction when compared with the general population aged 65 to 74 years (Herdman, Blatt, Schubert, & Tusa, 2000). Pothula, Chew, Lesser, and Sharma (2004) found that the presence of vestibular disorders was common in a population that had unexplained falls when admitted to the emergency room. In addition, it was found that patients with Meniere's disease, which is a disorder that affects the inner ear and causes vertigo, who were frequent fallers did not report any falls after receiving treatment for their condition (Ödkvist & Bergenius, 1988). Further studies of the vestibular system have demonstrated its important involvement in locomotion. Participants with vestibular deficiencies, such as acoustic neuroma (a noncancerous tumor that grows on the vestibulocochlear nerve) (Cohen, 2000), and bilateral vestibular hypofunction (Tucker, Ramirez, Krebs, & Riley, 1998) have been shown to walk slower and to veer off paths earlier than healthy controls. This may be an additional factor leading to falls. Numerous studies have found that medical intervention (De Waele et al., 2002; Manrique-Huarte, Guillén-Grima, & Perez-Fernandez, 2011) or vestibular rehabilitation (head, eye, and body exercises) (Black, Angel, Pesznecker, & Gianna, 2000; Szturm, Ireland, & Lessing-Turner, 1994; Yardley, Beech, Zander, Evans, & Weinman, 1998) are significantly helpful in improving balance, and therefore in preventing falls.

1.4.2 The somatosensory system

The somatosensory system is complex network of nerve cells that involves the sensory modalities, such as touch, temperature, pressure, pain and proprioception (body position and movement). This system’s receptors are located everywhere in the body, covering the skin, bones and joints, skeletal muscles, cardiovascular system and the internal organs. In regards to balance, this network of receptors provides input of the position and movement of the head, body, arms, hands, legs and feet (Guerraz & Bronstein, 2008) and informs the body of any mechanical stimulus applied to its surface (Jančová, 2008). Therefore, the somatosensory system is crucial in maintaining equilibrium and balance. For instant, receptors in the mechanoreceptors (responsible for sensing mechanical pressure applied to the skin) signals changes in pressure applied to the surface of the feet. The proprioceptive input aids in sensing information that is generated from joints, tendons and muscles due to changes in the body movement and position (Guerraz & Bronstein, 2008; Lephart, Pincivero, Giraido, & Fu, 1997). When we move, the somatosensory system, with the help of other systems, is constantly adapting to reposition the center of body mass to maintain equilibrium. The somatosensory system works more closely with the vestibular than with any other system to maintain posture (Aiello, Rosati, Serra, Tugnoli, & Manca, 1983; A. Rubin, Liedgren, Ödkvist, Larsby, & Aschan, 1979; V. Wilson, 1991; Wilson et al., 1995) and it has been shown that the vestibular postural response to maintain balance greatly depends on input from the somatosensory system (Lund & Broberg, 1983; Nashner & Wolfson, 1974). These two systems use the same sensory channels in the nervous system to transmit signals regarding posture. In fact, these two systems interact physiologically, anatomically and functionally in the cerebellum, vestibular nuclei, thalamus, cortex, brain stem and spinal cord (Aiello et al., 1983; Rubin et al., 1979; Wilson, 1991; Wilson et al., 1995).

Several early studies showed that body posture was compromised when the proprioceptive input was compromised with pressure cuffs (Diener, Dichgans, Guschlbauer, & Mau, 1984;

Mauritz, Dietz, & Haller, 1980). Jeka and Lackner (1994) found that the amplitude of sway was significantly reduced when participants firmly held onto an apparatus. Pursuing this further, researchers have studied the effect of a touch as small as a fingertip on a stationary surface. These studies found that fingertip contact with stationary surrounding objects can reduce the amount of body oscillation and can be a powerful aid in the maintenance of balance (Holden, Ventura, & Lackner, 1994; Jeka, Schöner, Dijkstra, Ribeiro, & Lackner, 1997).

Age is a significant predictor for the deterioration of the somatosensory system (Lautenbacher, Kunz, Strate, Nielsen, & Arendt-Nielsen, 2005; Skinner, Barrack, & Cook, 1984), and there are various disorders that may compromise this system. For example, Mauritz, dietz and Haller (1980) found that there was a significant increase in sway in patients with somatosensory disorders that affects the peripheral nerves when compared to normal healthy adults. Dickstein, Shupert and Horak (2001) compared postural sway in three touching conditions: none, light touch (fingertip) and heavy touch (as much grip as you can give) in participants who had been diagnosed with somatosensory loss in the feet due to diabetic peripheral neuropathy. They found the anteroposterior and mediolateral sway in people with diabetic peripheral neuropathy was larger than in the healthy control subjects, especially when standing on a foam surface (which further decreases the proprioceptive input from the feet), although the results of light touch and heavy touch were identical for both groups. Patients with diabetic neuropathy have been shown to lose balance (Jeka & Lackner, 1994) and to be prone to falls (Cavanagh, Derr, Ulbrecht, Maser, & Orchard, 1992; Richardson & Ashton-Miller, 1996). Similarly, Rocchi, Chiari and Horak (2002) investigated the effects of Parkinson's disease, which also affects the somatosensory system, and showed that these participants swayed more than healthy subjects.

Interventions for people with somatosensory deficits include performing balance and strengthening exercises, medication that can reduce tremors in patients with Parkinson's disease, the use of walking aids and wearing supportive shoes (Bronte-Stewart, Minn, Rodrigues, Buckley, & Nashner, 2002; Joyce & Kirby, 1991; Rozzi, Lephart, Sterner, & Kuligowski, 1999; Wolf et al., 1996).

1.4.3 The visual system

Accurate information from the visual system is an important element in maintaining postural stability as it provides the nervous system with reference and self-awareness of the body's position in space and with respect to the surrounding objects, to help plan the body's locomotion and to negotiate obstacles safely. It was suggested by Travis (1945) and Edwards (1946) that the input from the visual system reduces body sway by 50%. Other researchers have suggested that the visual system sub-serves the fine tuning of posture (Brown, Shumway-Cook, & Woollacott, 1999). The visual system is unique in its functions when compared to the vestibular or the somatosensory systems, as it can detect both self and object motion, while the somatosensory and vestibular systems can only identify self-motion. The majority of relevant studies have shown that any impairment or reduction in visual information will lead to compromised balance (Paulus et al., 1984; Pyykko, Jantti, & Aalto, 1990), although Elliott et al. (Elliot et al., 1995) found that the other systems will compensate for this reduction. Visual stabilization commences with two inputs; optic flow and eye movement information (Guerraz & Bronstein, 2008). Optic flow is the change in motion of the image projected on the retina as the observer moves through space (Royden & Moore, 2012). This provides visual information that helps control the anterior-posterior body sway (Guerraz & Bronstein, 2008). This was investigated by the moving room experience, where the participant's visual environment (room walls) can be moved in relative to a fixed frame (floor). The manipulation of the surroundings created a similar observation of what is experienced with an optical flow pattern. Postural sway was observed in the same forward-backward direction as the moving room (Guerraz & Bronstein, 2008). Another input is eye movement information, which provides medial-lateral sway information, through motion parallax of objects at different distances (Guerraz & Bronstein, 2008). This input, with the help of the other two sensory inputs (somatosensory and vestibular), provides information that will assist in making a balancing correction so as to maintain body position and prevent a fall.

1.4.3.1 Associations between vision and balance

As early as 1846, Romberg (1846) studied the link between vision and balance. They asked participants to stand with their feet close together and their arms by their sides (the Romberg test). When participants were asked to close their eyes, balance was compromised and sway was observed, showing the importance of visual input on postural balance. Paulus et al. (1984) found that body sway decreased by 200% when the eyes were open compared to a blind condition. Although a person can remain upright in the dark, it has been noted that body oscillation decreases when a small LED light is present in front of the patient who is standing in the dark compared to full darkness (Paulus et al., 1984). The study of the effects of illumination on balance dates to at least 1946, when Edwards (1946) measured balance in daylight and under an intensity of 12.57 lumens. Body sway increased in the dark by 32.8% when compared to daylight. Kapteyn, Bles, Brandt and Wist (1979) measured sway under scotopic levels through to photopic levels. Sway decreased by 10% from scotopic to photopic vision.

An increased postural imbalance of approximately 40 to 60% has been shown to be correlated with decreased visual acuities of 20/200 and 20/650, respectively (Paulus et al., 1984). Furthermore, balance assessed with the Berg balance scale has been shown to be affected by a decline in visual acuity to 20/60 or worse. Further impairment in balance control was noted in participants with visual acuity worse than 20/200 (Lee & Scudds, 2003). Other visual factors that can affect body oscillation include the place and size of a target and retinal image velocity (Paulus et al., 1984), contrast sensitivity (Ivers, Cumming, Mitchell, & Attebo, 1998; B. Klein, R. Klein, Lee, & Cruickshanks, 1998), visual fields (Black, Wood, & Lovie-Kitchin, 2011) and depth perception or stereopsis (Lord & Menz, 2000; Nevitt et al., 1989).

Studies have also found that eye disease, such as cataract (Ivers et al., 2003; Ivers et al., 1998), glaucoma (Guse & Porinsky, 2003) and diabetic retinopathy (Ivers, Cumming, Mitchell, & Peduto, 2001) can compromise balance and increase the risk of a fall. This provides more evidence of the involvement of visual input in balance control.

Brandt, Dichgans and Koenig (1979) found that the peripheral visual field dominates the perception of self-motion. Black, Wood, Lovie-Kitchin and Newman (2008) reported that inferior field loss was particularly predictive of sway on a foam surface, when somatosensory input is reduced, and Guse and Porinsky (2003) demonstrated that glaucoma is a cause of fall-related hospitalizations. However, Turano, Herdman, and Dagnelie (1993) investigated the contribution of vision in postural control in participants with retinitis pigmentosa (RP), which results in peripheral field loss. Their experiment revealed that people with retinitis pigmentosa have a smaller visual contribution to balance when compared to participants with normal vision, and that this visual contribution decreased with disease progression. In participants with normal vision, the contribution to balance decreased with simulated visual field constriction, and the contribution from vision in the controls with constricted fields was often greater than those with RP. In fact, those with RP sometimes had a destabilizing effect of vision. Other researchers have also suggested that the other systems seem to compensate somewhat for the input from vision in people with visual impairment (Anand, Buckley, Scally, & Elliott, 2003; Elliot et al., 1995; Lord, Clark, & Webster, 1991). On the other hand, according to Hallemans, Ortibus, Meire, & Aerts (2010) normally sighted individuals showed better locomotion control than adults with visual impairment, but when the normally sighted were blindfolded they had similar gait patterns to those who had sustained a visual loss.

Paulus et al. (1984) demonstrated that the central 30^0 of the visual field plays a more important role in providing better stability control than the peripheral field. This is likely due to the involvement of central visual functions that have been shown to contribute to postural stability, such as visual acuity (Paulus et al., 1984) and image displacement threshold (Paulus, Straube, Krafczyk, & Brandt, 1989). Accordingly, it might be expected that if the central visual field is compromised, less visual input is delivered to postural control. This was confirmed in a further study by Turano, Dagnelie, and Herdman (1996) group in participants with age-related macular degeneration. The results of this study indicated that participants who suffered central visual field loss had less visual contribution to balance control. These studies show that peripheral or central visual field loss either due to an ocular disease or simulated visual field constriction can cause deterioration in balance control. However, individuals with visual field defect due to an ocular disease tend to control their balance better than those who have normal vision with simulated visual field loss. This suggests that patients with a visual field defect have adapted in some way to their visual impairment and other mechanisms are implemented to compensate for this loss. This is interesting and agrees with previous work which showed that the lack of accurate visual input due to an ocular disease can be compensated by other balance systems (somatosensory and vestibular) to adequately maintain balance control (Elliot et al., 1995).

The type of spectacle correction can be a factor for loss of balance and lead to falls. Lord et al. (2002) found that participants wearing multifocal glasses were more than twice as likely to experience a fall as those who wear single vision glasses, especially during stepping tasks, such as walking up or down stairs (Lord, Dayhew, & Howland, 2002). This is unsurprising, as older adults often look through the near portion of their spectacles, which is designed for near visual tasks, instead of the distance portion when negotiating steps or obstacles (Menant, George, Sandery, Fitzpatrick, & Lord, 2009; Timmis, Johnson, Elliott, & Buckley, 2010). The use of multifocal lenses was found to decrease the ability and speed for the negotiation of ground level obstacles while completing a walking course (Menant et al., 2009). This was attributed to inadequate compensatory head movements during the use of multifocal glasses. Recently, the use of distance single vision glasses and intermediate (1.50DS of reading add) progressive addition lenses (PALs) has been shown to provide equally better gait safety in stairs negotiations than full addition bifocals and PALs (Elliott, Hotchkiss, Scally, Foster, & Buckley, 2016). Intermediate PALs can be helpful by providing some reading ability and avoid alternating between two sets of glasses. Therefore, they provide more benefits than single vision glasses, which were suggested by Haran et al. (2010). Furthermore, Elliott and Chapman (2010) demonstrated that the magnification effects of lenses can change the gait and placement of the feet on stairs, suggesting that larger changes in spectacle prescription may be associated with an increased loss of balance and risk of falls. Recently, Black and colleagues (2016) examined the effect of a +2.50DS optical blur on stepping precision. Stepping inaccuracies were larger with optical blur in comparison to best-correction glasses. This information is valuable, as +2.50DS is commonly used for reading by presbyopes, and stepping error may cause an incorrect judgment of a step and cause a loss of balance. Others have shown variability in vertical toe clearance and foot placement and that patients were more likely to trip due to optical blur (Johnson, Buckley, Scally, & Elliott, 2007; L. Johnson, Buckley, Harley, & Elliott, 2008).

1.5 Falls, Fractures and vision

The association between the visual system and its role in maintaining balance was discussed in section 1.4.3 of this thesis. In the literature, many studies of the relationship between specific visual functions and falls have been undertaken in order to show which aspects of visual function are more important, and to further understand the link between these two variables. This section is an overview of the different visual functions and their association with falls.

1.5.1 Visual acuity

Visual acuity has been frequently studied with regard to its correlation with falls and loss of balance. Visual acuity refers to a measurement of vision for fine detail, and several reports have demonstrated that reduced visual acuity is a risk factor for falls in community dwelling older adults and those in intermediate care facilities (Close et al., 1999; Jack, Smith, Neoh, Lye, & McGalliard, 1995; B. Klein, Moss, R. Klein, Lee, & Cruickshanks, 2003; Lord & Dayhew, 2001; Tinetti, Williams, & Mayewski, 1986). The Beaver Dam Eye Study showed that adults above the age of 60 years with a visual acuity poorer than 6/7.5 were approximately two times more likely to report multiple falls (Klein et al., 1998). The Blue Mountains Study reported similar results for those who had 6/9 visual acuity or poorer (Ivers et al., 1998). Furthermore, Coleman et al. (2004) reported that, after a five-year follow up period, 43% of women aged 65 years and older who presented with a loss of two lines or more on the Bailey–Lovie chart were recurrent fallers. They also showed that the likelihood of frequent falls was greater in participants who present with a loss of one or more letters on the visual acuity chart than those who had no changes or who had improvement in their visual acuity. A reduction in visual acuity has also been shown to be one of the causes of fall-related injuries among older individuals. Koski, Luukinen, Laippala and Kivelä (1998) found that poor visual acuity was correlated with fall-related injuries in seniors aged 70 years and above and who needed assistance with activities of daily living. However, this was not the case for older adults living independently. Furthermore, a high risk of hip fracture, which has serious consequences if sustained by a senior, has been observed in older adults who have poor visual acuity (Dargent-Molina et al., 1996; Felson et al., 1989; Ivers, Norton, Cumming, Butler, & Campbell, 2000). The EPIDOS study reported that the strength of this correlation rose with increased visual deficit (Dargent-Molina et al., 1996). On the other hand, Lamoureux and colleagues (2010) found that visual acuity was not a predictor of falls. The risk of hip fracture is estimated to be 1.73 times higher for seniors with a visual acuity of 6/9, while this risk increases to 2.17 times higher for individuals who have a visual acuity of 6/30 or poorer (Felson et al., 1989). Similar results were found in the Framingham study, where the fall-related fracture rate was higher in participants who had visual acuity poorer than 6/9 than in those who had a visual acuity of 6/7.5 or better (Felson et al., 1989). However, Cummings and colleagues (1995) described a large longitudinal study of 9516 female participants in which visual acuity was not associated with hip fractures, although other aspects of vision (contrast sensitivity and stereoacuity) were related.

Interestingly, Close et al. (1999) found that 59% of older adults admitted to the hospital ER due to a fall had a visual acuity poorer than 6/12, while Jack and colleagues (1995) found that one in every two patients admitted after a fall had a visual acuity poorer than 6/18. These two studies emphasize the importance of visual acuity screening of older adults upon admission to a hospital ER, as a number of visual conditions can be corrected, which in turn can decrease the fall risk.

Lord and Dayhew (2001) found that those who had moderate vision in one eye and poor vision in the other eye, or poor vision in both eyes, had the highest fall rate when compared to those who had good vision in both eyes or poorer vision in both eyes. In the Framingham Eye Study individuals who had impaired vison in one eye and good vision in the other had a higher risk of fall-related fractures than those who had similar visual impairments in both eyes (Felson et al., 1989). However, others have been unable to find any clear association between asymmetrical visual acuity and hip fractures, falls or fear of falling (Ivers et al., 2000; Klein et al., 2003).

1.5.2 Contrast sensitivity

The environment around us is filled with visual information presented at different spatial frequencies and contrast levels. Therefore, optimal contrast sensitivity may be more important in negotiating hazards and obstacles than visual acuity, and thus may be more related to falls. Anand et al. (2003) found that under somatosensory input disturbance, postural instability was observed with alterations in contrast sensitivity. They found that lower, rather than higher, spatial frequency targets provide improved balance control. Others have reported similar results, emphasizing that contrast sensitivity is a better predictor for postural imbalance than visual acuity (Cummings et al., 1995; Lord & Menz, 2000; Turano, Rubin, Herdman, Chee, & Fried, 1994).

With regards to falls, Lord and colleagues demonstrated that reduced contrast sensitivity is correlated with multiple falls (Lord & Dayhew, 2001; Lord, Ward, Williams, & Anstey, 1994; Lord et al., 1991). In the Blue Mountain study compromised contrast sensitivity was associated with having two or more falls (Klein et al., 1998). Furthermore, a recent systemic review found a strong relationship between poor contrast sensitivity and recurrent falls (Salonen & Kivelä, 2012).

Poor contrast sensitivity has been shown to be a risk factor for fall-related injuries in seniors in several large studies (Cummings et al., 1995; Klein et al., 1998). Other studies have shown that fractures were not predicted by poor contrast sensitivity (Cauley et al., 2016; De Boer et al., 2004), although an association between falls and contrast sensitivity was found (De Boer et al., 2004).

1.5.3 Stereopsis and depth perception

The importance of stereoacuity and depth perception and their role in postural control has been established (Lord & Menz, 2000). A number of studies have explored fall risk factors and have found that stereopsis or depth perception contribute to fall risk. Nevitt et al. (1989) found that impaired stereoacuity, measured with the Randot test, was associated with older adults being frequent fallers. Lord and Dayhew (2001) found that depth perception, measured with the

Howard Dohlman apparatus, was the best predictor among other measures of visual function, such as, visual acuity, contrast sensitivity and stereoacuity for recurrent falls. In addition, reduced stereoacuity, defined as 215 seconds of arc or poorer measured with the Frisby stereotest, was one of the risk factors identified for recurrent fallers. Monocular blur, which would reduce stereopsis, has also been shown to disturb the ability to precisely judge the height of steps (Vale, Buckley, & Elliott, 2008). The results of these studies suggest the importance of stereopsis, which describes the ability to judge distances, aids in obstacle and hazard avoidance and in step negotiation. However, others have failed to find evidence to support the correlation between stereopsis and falls measured with the Randot stereoacuity test (Friedman et al., 2002). Regarding fractures, reduced depth perception was one of the risk factors for hip fractures among older women, with a 1.5 times increased risk (Cummings et al., 1995). In a case control study, Ivers et al. (2000) examined the association between hip fractures and stereoacuity, and found that having a stereoacuity of 50 seconds of arc or poorer resulted in a three times higher risk of hip fracture. However, others have been unable to find any association with depth perception and hip fractures (Dargent-Molina et al., 1996).

1.5.4 Visual field

Studies of simulated field restriction show that simulated restricted visual fields in normally-sighted adults influences postural stability (Paulus et al., 1984; Turano et al., 1993). Visual field loss has been shown to be a falls risk factor in a number of large studies (Black et al., 2011; Brandt et al., 1973; Ivers et al., 1998; Klein et al., 2003; Patino et al., 2010). In the Rotterdam study, older adults with unilateral or bilateral visual field loss were six times more likely to be frequent fallers than those without a loss (Ramrattan et al., 2001). The risk of falls was also present in glaucoma patients who had visual field loss (Haymes, LeBlanc, Nicolela, Chiasson, & Chauhan, 2007). Black et al. (2011) found that the greater the visual field impairment, especially in the inferior field, the more frequently falls occur. In their study they merged the results of the Humphery Field Analyser from both eyes to form an “integrated visual field” extending 120° horizontally with a total of 96 points. They found that a 10-point area missed in the inferior binocular visual field caused an elevation in the fall risk by 62%. This is interesting, as occluding the inferior visual field has been shown to cause an increase in the head pitch angle, a decrease in the step size and a slowing of the walking speed while walking on a complex multi-surface terrain (Marigold & Patla, 2008). This indicates the importance of the inferior visual field in providing valuable information in gait planning, obstacle avoidance and detection, and as a result, in the prevention of falling. Coleman et al. (2007) found that the greater the binocular visual field deficit, the greater the odds of becoming a frequent faller, even after adjusting for age, cognitive function and other confounders. Central field loss, specifically due to age related macular generation has also been shown to increase the risk of fall in older adults (Pedula et al., 2015). In contrast, Friedman (2002) found no association between visual field reduction measured with Humphrey Field Analyzer and falls.

In regards to fall-related injuries, in a large study of 4583 women, Coleman and colleagues (2009) revealed that binocular visual field loss was associated with hip and non-hip fractures. In Black et al’s (2011) study inferior field loss was the only visual risk factor to be correlated with fall-related injuries. Visual field loss assessed with the Humphrey field analyser increased the risk of hip fracture by 5.5 times (Ivers et al., 2003). In contrast, in the Rotterdam study, field loss was not a risk for hip fracture in older adults (Ramrattan et al., 2001). This could be attributed to the low number of reported hip fractures in their population.

To conclude this section, the discrepancies seen in the outcomes of these studies can be attributed to the application of different designs, visual measures included, populations, settings and data collection techniques. However, the overall findings suggest the importance of vision, and imply that the optimum management of visual conditions that are common in older adults, such as cataract, glaucoma, diabetic retinopathy and retinal detachment, is important. In addition, establishing a useful clinical cut-off for different visual risk factors for of falls and injury may help detect those who are at risk of falls and prevent injuries.

1.6 Balance assessment tools and their association with vision

Due to the high cost of injurious falls**,** and the crucial need to provide cost effective services, clinicians and researchers have developed balance assessment tools to guide them in identifying people with poor postural stability and who are at risk of falling, and to help direct health service providers to target prevention to those who need it. Numerous methods have been developed by clinicians and researchers to evaluate posture and mobility. These can be divided into functional assessment, systems assessment, and quantitative assessment tools (Mancini & Horak, 2010) The aim of this section is to give a general summary, rather than a comprehensive review, of the commonly used balance assessment approaches and their correlation with vision.

1.6.1 Functional assessment tools

This type of approach is used both clinically and in research contexts to determine the status of balance and if changes have occurred after an intervention program. This approach typically rates motor performance either by using a rating scale or by timing a patient's motor performance. Some examples of this type of assessment are the Activities Specific Balance Confidence Scale (ABC) (Lajoie & Gallagher, 2004), the Independent Mobility Questionnaire (Turano, Geruschat, Stahl, & Massof, 1999), the Sit-to-Stand test (Buatois et al., 2010), the Timed Up and Go test (Podsiadlo & Richardson, 1991) and the One-Legged Stance test (Jacobs, Horak, Tran, & Nutt, 2006). The ABC is a questionnaire that rates the subject's confidence in maintaining balance for different motor tasks. It can be rated from 0% (no confidence) to 100% (full confidence) (Lajoie & Gallagher, 2004). In contrast, the One-Legged Stance test is a physical test that requires the participant to stand on one leg while being timed (Jacobs et al., 2006). The results from the functional assessment tools, however, are subjective, which may lead to biased results. Unfortunately, these tools are not sensitive to small deteriorations in balance and may not be sensitive to slight levels of deficit regarding those patients who have a low risk of falling.

1.6.2 System assessment

This type of approach is used by clinicians or researchers when the underlying cause of the balance problem must be known in order to prescribe appropriate treatment. Two examples of this approach are the Mini-Balance Evaluation System Test (Mini-BESTest) (Franchignoni, Horak, Godi, Nardone, & Giordano, 2010; Godi et al., 2013) and the Physiological Profile Approach test (PPA) (Lord, Menz, & Tiedemann, 2003). The Mini-BESTest compromises 14 short balance tests divided under four domains of balance control; 1) anticipatory body control, 2) reactive postural control, 3) sensory orientation and 4) balance during dynamic gait. In contrast, the PPA test focuses on measuring any physiological deficit that can be the cause of balance loss (Lord et al., 2003). These include tests of vision, feet and leg sensation, reaction time and sway. However, this approach suffers some limitations. For example, any subjective assessment tool can suffer from tester bias, which may not lead to an accurate outcome. In addition, the tests are complex and can be time-consuming for both the patient and the clinician. This may lead to poor results due to fatigue, and in the context of research, may result in participants withdrawing their consent from test participation.

1.6.3 Quantitative assessment

In this approach, a quantitative assessment of postural balance is acquired. Quantitative assessment can be measured in a number of ways. Sway can be quantified by measuring ground reaction forces and moments to calculate the centers of pressure while participants stand on a force plate platform (Winter, 1995b) or more recently, a Nintendo Wii balance board (Young, Ferguson, Brault, & Craig, 2011). Other methods measure acceleration in one or several directions using an accelerometer sensor (Godfrey, Conway, Meagher, & OLaighin, 2008), or angular motion in one or several directions using gyroscope sensors (Aminian, Najafi, Büla, Leyvraz, & Robert, 2002). These sensors can be placed on the head, trunk, lower back, thigh or the foot (Wrisley et al., 2007). The advantage of a quantitative approach is that an objective value is obtained that can be easily used statistically, that is more sensitive to change and is less likely to have a floor effect. The quantitative approach has a number of drawbacks, including the cost, the time needed for testing and training, the space needed for the equipment, and the sampling duration and frequency due to different technologies used and how these can affect the outcomes of the data (Visser, Carpenter, Van der Kooij, & Bloem, 2008).

In conclusion, the method preferred depends on the application. Each approach will provide a specific kind of information. It may be better for clinicians to use the functional approach because of their need for a fast and easy way to measure balance. However, when the interest is in understanding the cause of postural imbalance, the use of the system assessment becomes crucial. While for researchers, the use of the quantitative approach to obtain a greater amount of information that is then available for future data analysis may be appropriate.

1.7 Fear of falling

After experiencing a fall, many older adults develop psychological challenges directly linked to falls. Among these challenges are a fear of falling, depression, isolation, anxiety, confusion and a loss of independence (Bergland et al., 2003; Dunn et al., 1993; Friedman et al., 2002; Iinattiniemi et al., 2009; Salgado et al., 2004; Tinetti & Williams, 1998). Fear of falling is common; it is estimated that more than 50% of older adults develop a fear of falling (Howland et al., 1998; Zijlstra et al., 2007). Fear of falling was first described by Bhala, O'Donnell and Thoppil (1982) as ptophobia, which means a phobic reaction to standing or walking. They found that, following a fall, their participants associated walking and standing with a fear of falling. Later, Murphy and Isaacs classified this as a post-fall syndrome, and noted the development of fear in those who had sustained a falling episode (Murphy & Isaacs, 1982). Tinetti and Powell (1993) defined fear of falling as a "lasting concern about falling that leads to an individual avoiding activities that he/she remains capable of performing." Since that time, a number of researchers have identified different risk factors for fear of falling, and it has now been recognized as a challenge faced by many older adults. Similar to falls, fear of falling seems to be multifactorial in nature, as different risk factors contribute to the presence of fear of falling in the older adult population. Fear of falling appears to increase with age and is more prevalent in females and those living alone than in those living in a community (Friedman et al., 2002; Scheffer, Schuurmans, Van Dijk, Van Der Hooft, & De Rooij, 2008; Stojanovic et al., 2015; Vellas, Wayne, Romero, Baumgartner, & Garry, 1997).

The association between fear of falling and falls is established, and this relationship can be considered bidirectional, as a previous fall can lead to fear of falling and vice versa (Fletcher & Hirdes, 2004; Friedman et al., 2002; Lach, 2005; Li, Fisher, Harmer, McAuley, & Wilson, 2003). As a result, those who express this fear can develop anxiety (Painter et al., 2012), undertake less activity (Bruce, Devine, & Prince, 2002; Howland et al., 1993), develop depression (Arfken, Lach, Birge, & Miller, 1994), become isolated (Howland et al., 1998), have a poor self-reported visual status (Donoghue et al., 2014; Howland et al., 1998), have poorer balance and mobility (Arfken et al., 1994; Li et al., 2003; Suzuki, Ohyama, Yamada, & Kanamori, 2002), have increased frailty (Arfken et al., 1994) and experience a reduced quality of life (Li et al., 2003). It should also be noted that fear of falling can be found in seniors who have not experienced a fall (Howland et al., 1993; Murphy, Dubin, & Gill, 2003).

Different tools and measurement techniques have been developed to diagnose fear of falling in older adults. A simple yes/no question/answer or the “fear or no fear” format has been used to assess fear of falling (Friedman et al., 2002). This method is straight forward but is does not indicate the degree and severity of fear of falls. Others have utilized scales that assess fear of falling, in which a participant can quantify their level of concern about falling in different situations in or outside their home using a scale. Some examples are the Falls Efficacy Scale (FES) (Tinetti, Richman, & Powell, 1990), the Falls Efficacy Scale – International (FES-I) (Kempen et al., 2007; L. Yardley et al., 2005), the Modified Falls Efficacy Scale (MFES) (Hill, Schwarz, Kalogeropoulos, & Gibson, 1996), the Survey of Activities and Fear of Falling in the Elderly (SAFE) (Lachman et al., 1998), and the University of Illinois at Chicago Fear of Falling Measure (UICFFM) (Velozo & Peterson, 2001).

1.8 Prevention program for falls

Since falls are a major cause of concern for both older adults and the healthcare system, falls prevention is an important matter that must be addressed. Previous studies on fall prevention have typically included either an intervention that targets vision, exercise, environment modification, education intervention or a combination of these interventions. However, the type of program that is most effective in reducing falls has been a controversial issue in the literature in the previous decade. In this section, a brief overview of the intervention programs that aim to reduce the risk of falls and fall-related injuries will be presented.

1.8.1 Exercise intervention

Exercise programs have included balance training, muscle strength, endurance, flexibility, tai chi and cardiovascular exercises (American and British Geriatrics Society and American Academy of Orthopedic Surgeons Panel on Falls Prevention, 2001; Cameron et al., 2012; Chang et al., 2004; Gillespie et al., 2012; Kenny et al., 2011; Li et al., 2005). The most effective exercise programs seem to be those with multi-components and that incorporate training balance, muscle strength, coordination and gait (Gillespie et al., 2012; Kenny et al., 2011). The duration and the intensity of the exercises implemented in these studies varied considerably and the recommendations vary between 1-3 times a week over 12 to 25 weeks (Kenny et al., 2011; Sherrington et al., 2008; Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). In community-dwelling older adults multi-component exercise programs that are administered in either a supervised group exercise setting or an individual home-based setting have reduced the fall rate by 29% and 32%, respectively, while the risk of falling decreased 15% and 22%, respectively (Gillespie et al., 2012). In contrast, in institutionalized populations (nursing homes or hospitalized seniors), studies of the effect of exercise intervention on reducing the rate of falls are inconsistent, and differing conclusions have been drawn. Some studies found a decrease in the risk of falls, while others found exercise to increase the risk of falls (Cameron et al., 2012; Faber, Bosscher, Paw, & Van Wieringen, 2006; Morgan, Virnig, Duque, Abdel-Moty, & Devito, 2004; Schoenfelder, 2000). This discrepancy in the results may have arisen due to the factors of participant frailty, level of activity and type of exercise used (low or high intensity). Those who were frailer and those who were more active appear to have less improvement (Cameron et al., 2012).

1.8.2 Visual intervention

It would be anticipated that visual intervention would reduce the risk of loss of balance and consequently falls. However, there are very few randomized controlled trials of the effect of visual intervention and the literature regarding an effective visual intervention to prevent falls is lacking. Day et al. (2002) found in their randomized controlled trial that a visual intervention in the form of referring participants to an eye care specialist depending on their existing condition did not reduce the rate of falls. However, although 52% of their sample population was required to visit the eye specialist, only 5% actually received treatment. Thus the rate of actually receiving a true intervention was very low, which would explain the lack of effect. In the study by Cummings et al. (2007), only 44% of the intervention group received visual intervention, which included lens prescription updates, ophthalmic treatment of ocular diseases and occupational therapist referrals for home modification. A greater number of falls were noted in the intervention group than the control group. Further analysis revealed that a high proportion (72%) of the control group visited their optometrist or ophthalmologist during the follow-up period, causing contamination in the control group data. The authors concluded that the study was flawed. Haran et al. (2010) found that providing single vision glasses with tints for older adults who were already wearing multifocal glasses gave no overall reduction in falls. However, further analysis showed that those who were active outdoors benefitted from a reduction in the fall rate and the number of injurious falls. Interestingly, they found an increase in falls in the intervention group for those who rarely did outside activities. However, there were some limitations to this study. First, the examiners asked participants to wear their bifocal glasses when standing up from a chair or when performing a walking task that required a change in focus. In other words, this study did not require single vision lenses to be worn at all times. Their results are, therefore, contaminated by the use of multifocal lenses. Furthermore, the information session regarding the proper use of glasses was provided to the intervention group but not to the control group. This can be considered a behavioral intervention and may have played a role. Furthermore, the glasses that were prescribed to the intervention group were tinted, which may have been a factor in the final results. Thus the studies about intervention with glasses are mixed and not strong, and further study is required.

The links reported in the literature between falls and cataract surgery are also mixed. Some studies have found that cataract surgery decreases the risk of falls (Brannan et al., 2003; Schwartz et al., 2005; Tseng, Yu, Lum, & Coleman, 2012), others have reported an increase in falls (Meuleners, Fraser, Ng, & Morlet, 2014), while others found no change (Harwood et al., 2005; McGwin, Gewant, Modjarrad, Hall, & Owsley, 2006). Harwood et al. found a reduction in multiple falls and the risk of fractures after cataract surgery. Second eye cataract surgery showed no benefit (Foss et al., 2006).

1.8.3 Multifactorial intervention

A number of risk factors contribute to the incidence of falls. Falls are due to the failure of a complex system to maintain body equilibrium (Nowak & Hubbard, 2009). Falls in older adults are multifactorial in nature and various interacting factors contribute to the increased risk of falls rather than one underlying factor. Therefore, the use of a multifactorial risk abatement approach in reducing falls is warranted (Cameron et al., 2012; Clemson et al., 2004; Davison, Bond, Dawson, Steen, & Kenny, 2005; Day et al., 2002; Fitzharris, Day, Lord, Gordon, & Fildes, 2010; Gillespie et al., 2012). This intervention seems to be the most effective when offered to those who have previously experienced a fall (Costello, Edelstein & Fispo, 2008) and is recommended by the American and British Geriatrics Society (2001 and 2011). These programs typically include balance, mobility and strength training, ophthalmic intervention, medication adjustment, home assessment and/or education programs. Clemson et al. (2004) implemented a program of balance and strength exercises, behavioral education, home safety and medication management interventions to all in the intervention arm, and found a 31% falls reduction in community-based seniors. The use of exercise and protein supplements showed an 89% falls reduction in the intervention group (Swanenburg, De Bruin, Stauffacher, Mulder, & Uebelhart, 2007). Day et al. (2002) demonstrated a 33% decrease in falls with the combination of exercise, vision and home safety intervention, while a 24% reduction in falls was observed when only exercise and home safety interventions were implemented. Other researchers used the same concept (multifactorial intervention) and reported positive outcomes in falls reduction (Spink et al., 2011; Von Stengel, Kemmler, Engelke, & Kalender, 2011). In addition, the use of individualized (customizable) interventions was effective in reducing the rate of falls and falls-induced injuries by 28% and 26%, respectively (Palvanen et al., 2014). Another study, which used an individualized intervention, noted similar results, reporting a 36% reduction in falls (Davison et al., 2005). Analysis of pooled data in a large systemic review revealed that multifactorial intervention that included either approaches (general and customizable intervention) leads to a decline in the rate of falls but not to the risk of falling (Gillespie et al., 2012). The rate of falls compares the total number of falls per person for the time the falls history was observed, while the falls risk ratio compares the number of people who fell once or more.

In nursing home settings, analysis of the pooled data of seven studies of the effectiveness of multifactorial intervention in falls rate and falls risk showed some probable benefits in falls reduction, although the results were inconclusive (Cameron et al., 2012). Others have found similar results (Kenny et al., 2011). The most recent meta-analysis of randomized controlled trials conducted in nursing home settings supported the use of multifactorial interventions in reducing the number of falls and the number of recurrent fallers (Vlaeyen et al., 2015). In hospital settings, the analysis of pooled data demonstrated a decline in the rate of falling but not the risk of falls with multiple component interventions including various components (Cameron et al., 2012).

Recently, the use of computer-based virtual reality consoles such as the Nintendo Wii platform has become popular in physical therapy and nursing home settings. These consoles include physical and visual feedback training components to improve older adults' balance. Multiple studies have demonstrated improvements in balance after visual feedback training including physical exercise (Bateni, 2012; Nicholson, McKean, Lowe, Fawcett, & Burkett, 2015; Pluchino, Lee, Asfour, Roos, & Signorile, 2012; Singh et al., 2012; Toulotte, Toursel, & Olivier, 2012). These results are promising, as the current consensus is that improving balance through balance, walking and strength exercises can reduce the risk of falls (Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo, 2013; Karlsson, Vonschewelov, Karlsson, Coster, & Rosengen, 2013; Madureira et al., 2007; Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). Providing this in a game setting may improve compliance and the visual attention component, which is known to be trainable (Ball et al., 1988; Richards et al., 2006; Sekuler & Ball, 1986), may also result in improvements. In nursing home settings, utilizing computer-based virtual reality consoles reduces the risk of falls more than conventional balance training (Fu, Gao, Tung, Tsang, & Kwan, 2015). However, caution should be applied in generalizing the results of these studies to the general population, and further work in this field is needed.

Chapter 2

Research objectives

2.1 Purpose

The main purpose of this thesis is to study the possible link between balance and mobility with measures of vision that have been less studied or not been considered before, and to investigate if visual attention training can improve balance and mobility and reduce the risk of falls.

In the literature, researchers found that falls and loss of balance have a strong association with reduced visual acuity (Close et al., 1999; Jack et al., 1995), contrast sensitivity (Ivers et al., 1998; Klein et al., 1998), depth perception or stereopsis (Lord & Menz, 2000; Nevitt et al., 1989), and visual fields (Black et al., 2011; Ivers et al., 1998). All of these findings indicate the importance of optimizing vision for safer navigation and falls reduction. Poor depth perception or stereopsis may be caused by abnormal binocular vision. However, binocular vision (BV) and eye movement disorders in older adults have received little attention in relation to balance and mobility or risk of falls, and are frequently the cause of reduced stereopsis. So it seemed more direct to investigate the more primary visual function. The first research question is whether there is an association between BV and eye movements disorders and balance and mobility in older adults. Regarding visual attention, although there are a few studies of visual attention and its relation with aspects of balance and mobility as described in Chapter 1, its direct relation with balance or walking in older adults has not been investigated yet. The second research question is whether reduced visual attention can predict poor performance in balance and mobility.

Therefore, the purpose of the study described in Chapter 4 is to investigate the association between tests of balance, mobility, and fear of falling with measures of vision which have not been studied before or have been less studied, specifically tests of binocular vision and visual attention. These were chosen, as they may be treatable or trainable respectively. Measurement of visual acuity at the intermediate distance where people look when placing the next step, was also included, as this may be more related to mobility than either distance or near visual acuity.

The general methods are described in Chapter 3. Chapter 5 describes some additional analyses. A group of participants with visual impairment (low vision patients) were also recruited to the study described in Chapter 4 and their results are described in Chapter 5. The same experiment protocol as in Chapter 4 was used.

In Chapter 6, the correlation between different forms of the visual attention tests is investigated. In particular visual attention evaluated with a useful field of view test (UFV) (Ball & Owsley, 1993; Leat & Lovie-Kitchin, 2008; Owsley, 1994) is compared with attention measured with the Attended Field of View (AFOV) (Coeckelbergh et al., 2004). The Attended Field of View allows the participant to make eye movements to search for the target and may therefore be more related to everyday life than the UFV, which presents targets briefly so that an eye movement is not possible. This correlation has never been investigated before.

Chapter 7 describes an investigation of whether visual attention training can improve balance and/or mobility in older adults, with the goal that this may transfer to reducing falls. The research question investigated in this chapter is can visual attention training improve balance and mobility performance in older adults?

2.2 Research hypotheses

The hypotheses of this thesis project are:

1. Poor visual attention, as measured with the computerized UFV or AFOV, will predict balance (measured with the Sit to Stand test and the One Legged Stance test), mobility (measured by the 5 Meter Walk test) and/or the fear of falling (measured with the Falls Efficacy Scale-International) in the older adult population.
2. The presence of binocular vision disorders will predict balance (measured with the Sit to Stand test and the One Legged Stance test), mobility (measured by the 5 Meter Walk test) and/or the fear of falling (measured with the Falls Efficacy Scale-International) in the older adult population.
3. Visual measures in visually impaired participants will predict balance (measured with the Sit to Stand test and the One Legged Stance test), mobility (measured by the 5 Meter Walk test) and/or the fear of falling (measured with the Falls Efficacy Scale-International).
4. There will be a correlation between the Useful Field of View (UFV) and the Attended Field of View (AFOV).

5. Training older adults with a structured visual attention task will result in improved balance and mobility in older adults.

2.3 Study design

Hypotheses 1 to 4 (experiment 1) were studied with a cross sectional design and are described in Chapters 4, 5 and 6. Hypothesis 5 (experiment 2) was studied with a randomized controlled trial design and this is described in Chapter 7.

Chapter 3

General Methods

3.1 Participants

The participants without visual impairment (low vision) recruited in experiment 1 (Chapters 4, and 6) and experiment 2 (Chapter 7) of this thesis consisted of relatively healthy older adults living independently in the community without any assistance. However, in experiment 1 older adults who are residents of an assisted living home who might have needed some help with their daily life activities were included in the sample. Community dwelling participants were recruited from the Primary Care Clinic at the School of Optometry and Vision Science at the University of Waterloo and attended the School to take part in the study. Participants from residential homes were recruited from retirement homes across the Waterloo/Kitchener area and the study took place at their retirement homes. Exclusion criteria were binocular visual acuity worse than 6/12 (to exclude those with low vision [based on the North America definition of low vision [Maberley et al., 2006)]), not fluent in English, diagnosed with cognitive impairment according to their file at the Primary Care Clinic or the Residential home and unable to walk independently without a walker or a cane.

In experiment 1 (Chapter 5) a second group of participants with low vision was recruited. The study sample consisted of older adults with visual impairment (low vision) who are relatively healthy and living independently in the community. The group with visual impairment were recruited from the Low Vision Clinic at the School of Optometry and Vision Science at the University of Waterloo and attended the School to take part in the study. The participants were included in the study if their binocular visual acuity was worse than 6/12 and better than 6/60, were able to speak English, were not diagnosed with cognitive impairment according to their file at the Low Vision Clinic and were able to walk independently without a walker or a cane.

The files of potential participants from the Primary Care Clinic and Low Vision Clinic at the School of Optometry and Vision Science at the University of Waterloo were checked to see whether they pass the inclusion criteria and had written consent to be contacted regarding research studies within their files. If they did qualify, an information letter was sent by mail explaining the study. A follow up phone call was made to answer any questions they might have, ask if they were willing to participate and if so to book an appointment for their participation in the study. For retirement home residents a different method of recruitment was used. The retirement community director would invite potential participants who passed the exclusion criteria according to their file, to a talk in which the study and what was involved was explained. At the end of the talk those who were interested in participating would receive the same letter of information. All participants provided written consent for their involvement in the study. The study was reviewed and received clearance through a University of Waterloo Research Ethics Committee.

Preliminary information, such as the general health and ocular history, number of medications and spectacle prescription, was gathered with a verbal list of questions at the beginning of the study. For general health, the participant was asked if they had hypertension, hypotension, heart disease, diabetes, cancer, depression, respiratory disorders, circulatory disorders, thyroid disorders, high cholesterol, hearing problems, a previous stroke, musculoskeletal disorders or any other health conditions. For ocular history the following were recorded; a diagnosis of glaucoma, cataract, diabetic retinopathy, retinal vein or artery occlusion, any other retinal problem, floaters or if the participant had had cataract surgery. These variables were coded as a yes/no response. For general health and ocular health, the number of disorders of each person was counted. Participants who had 8+ general health disorders were assigned with a default value of 8.

3.2 Experiment 1: Association between vision and balance and mobility (normally sighted individuals)

The following section provides details of the various tests used in experiment 1 for the normal sighted participants (Chapter 4). This was a cross-sectional study.

3.2.1 Visual attention

Visual attention was measured with a useful field of view test (UFV) (Ball et al., 1988; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986) including 2 subtests (UFV1 and UFV2) and the Attended Field of View (AFOV) (Coeckelbergh et al., 2004). Testing was conducted under binocular viewing conditions and participants were provided with their best near spectacle prescription required for the working distance in a trial frame.

3.2.1.1 Apparatus

The stimuli were displayed on a 22 inch Samsung LCD monitor (1280x800 pixels) that was connected to an Intel Pentium Dual core processor (2.17 Ghz) laptop. Python programming language was used to run the experiment, which was controlled and displayed by Experiment Builder software (SR Research). The screen was placed 50cm away from the participant. A mouse was used by the examiner to input the response made by the participant after the targets were presented.

3.2.1.2 Procedure

In all the visual attention tests the white targets and distracters (when included) were presented on a computer monitor with grey background and had 50% contrast (Weber's contrast) as measured with a Minolta cs-100 photometer. The viewing distance was 50 cms. The UFV target was a triangle, had a total angular subtense of 1.37 x 1.2 degrees (82 minutes of arc x 72 minutes of arc) and the width of the line was 0.23 degrees (13.8 minutes of arc, equivalent to 6/83m Snellen acuity). The circular distractors subtended 1.39 degrees (83 minutes of arc) and the width of the line was 0.34 degrees (20.6 minutes of arc, equivalent to 6/124m Snellen acuity). The Landolt C targets in the AFOV also subtended 1.39 degrees (83 minutes of arc) and the width of the line was 0.34 degrees (20.6 minutes of arc, equivalent to 6/124m Snellen acuity). The gap of the Landolt C target used in the AFOV was 0.23 degrees. There were 24 potential locations of the target located at three possible eccentricities 4, 8 and 12 degrees, and eight possible radii oriented at 0, 45, 90, 135, 180, 225, 270, 315 degrees. There was no central target in any of the visual attention tasks as using a central task has little effect on performance on the UFV (Leat & Lovie-Kitchin, 2006). The order of presentation of the target location was randomized.

3.2.1.3 UFV1

At the start of the session, the UFV1 procedure was explained verbally to each participant and pictures of the test were displayed on the computer screen to illustrate the procedure. The participants were asked to identify the location of a white triangle. The target was presented for 160 milliseconds to preclude any eye movement during the target presentation (Irving et al., 2006). Once the testing started, written step by step instructions were presented on the screen to facilitate the flow of the program. Participants were instructed to look at the center of the screen and to press any key on the keyboard when they are ready to start. Once the program started, a black circle on a grey background first appeared (Figure 3-1). Following this, the test screen with the target (triangle) appeared (Figure 3-1). A masking screen followed the test screen in order to eliminate any after-images caused by the test screen (Figure 3-1). The response screen was presented next and showed 24 circles which matched all possible positions of the stimulus and the participants were asked to point to the location of the triangle and to guess if they were unsure. The location of their response was recorded so that errors could be calculated in terms of exact location being correct (direction and eccentricity) or the direction only being correct (ignoring the eccentricity). An arcsine transformation was performed on all the UFV data as has been done by others (Ball et al., 1988; Leat & Lovie-Kitchin, 2008). Once they responded, the procedure was repeated with the next trial. There were three trials for each target location, resulting in a total of 72 trials. For those who could not see the target from the outset, they were allowed to perform practice trials until they first report seeing the target.

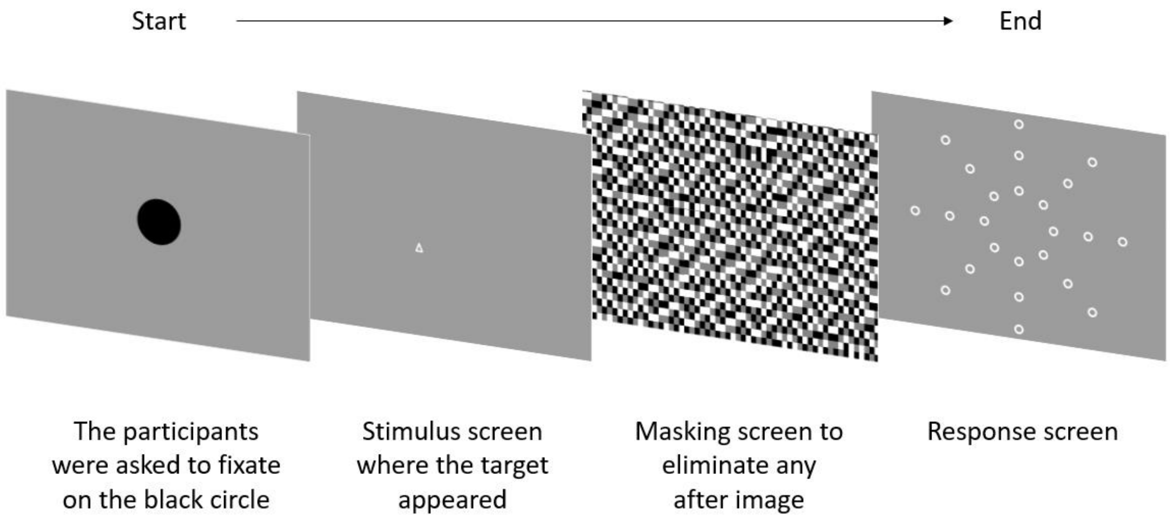

Figure 3-1: UFV1 test protocol. The target (triangle) was presented with no distractors.

3.2.1.4 UFV2

For the UFV2, the same triangle target as UFV1 was used, but it was placed amongst 23 circles, which acted as distractors (Figure 3-2). The participants were asked to locate the triangle embedded among the circles (distractors) (Figure 3-2). The testing procedure was similar in other respects to that used in UFV1. The location of their response was recorded so that errors could be calculated in terms of exact location being correct (direction and eccentricity) or the direction only being correct (ignoring the eccentricity). An arcsine transformation was performed on all the UFV data as has been done by others (Ball et al., 1988; Leat & Lovie-Kitchin, 2008).

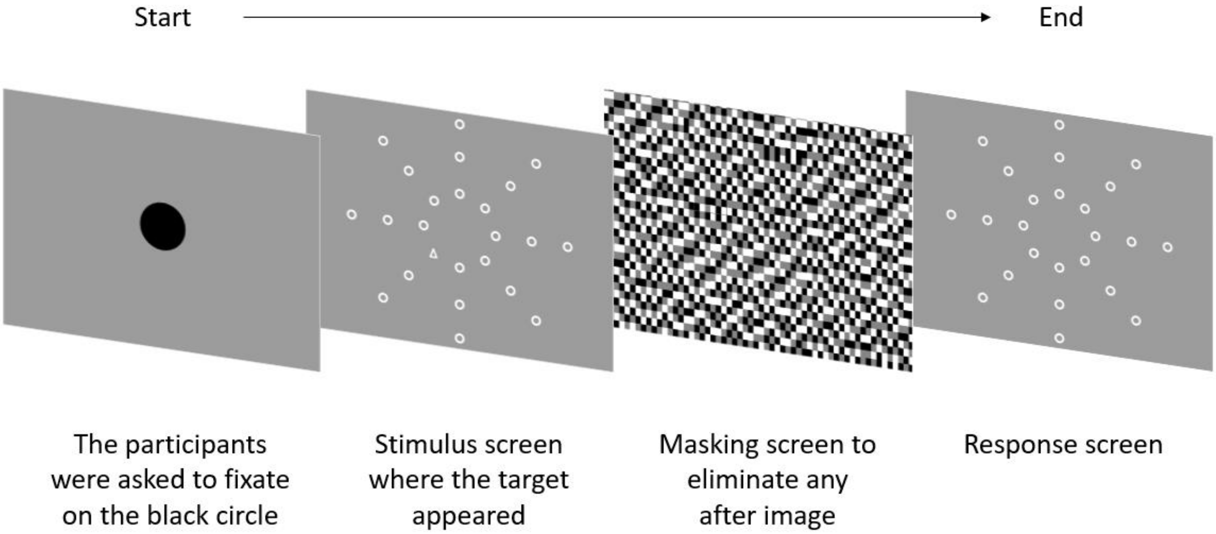

Figure 3-2: UFV 2 test protocol. The target (triangle) is presented with distractors.

3.2.1.5 AFOV

The AFOV test was designed according to Coeckelbergh and colleagues' design (Figure 3-3) (Coeckelbergh et al., 2004). In this test participants were asked to locate a Landolt C amongst 23 circles. The AFOV implements a similar procedure to that of the UFV to measure the area of functional visual field from which useful visual information can be extracted. However, it revokes the short presentation time used with the UFV to prevent eye movements and allows eye and head movements. An additional difference between the UFV used in the present study and the AFOV is that the score for the UFV is in percent errors and the score for the AFOV is a threshold in milliseconds to find the target. Coeckelbergh et al. contend that the AFOV mimics everyday life viewing situations in which eye and head movements occur. The gap of the Landolt C was randomly oriented up, right, left, and down. In order to shorten the test and not to fatigue the participants, targets were only presented in 9 out of the 24 possible locations as described for the UFV (Figure 3-4). The participants were not informed that only 9 locations were to be tested, and were not aware of this when questioned afterwards. Each target was assigned with a number to facilitate the analysis. During the test the duration of the stimulus was varied to determine a threshold in milliseconds. This was done by running an interleaved one up and one down staircase of the presentation time for each of the 9 locations. Each location's staircase was independent of the others. The order of presentation of the nine locations was randomized. The presentation time started at a full second, hence allowing eye and head movements and the step size was 0.1 log unit. The number of trials at each location was 30 trials, so that the total number of trials was 270 trials. These values were chosen after preliminary trials which showed that a threshold was approached after this number of trials and starting from this duration. The final threshold was determined by plotting trial duration against the trial number and taking the average of the reversals of the last section of the plot. The values included in this averaging were based on the following criteria a) at least 8 reversals, b) the minimum slope for the regression line.

The AFOV procedure was explained verbally and pictures were used to demonstrate the procedure to each participant at the start of the session. It was similar to the testing procedure in the UFV with the exception that a Landolt C, instead of a triangle, was the target in this program and the durations were long enough for the participant to make an eye movement.

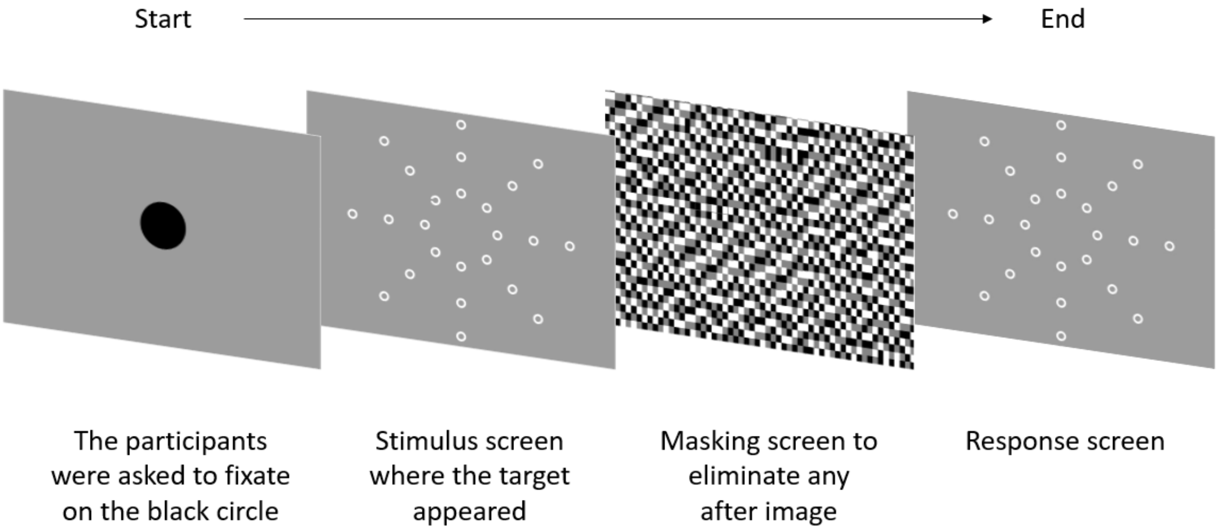

Figure 3-3: AFOV test protocol. The target (Landolt C) is presented with distractors. In this example the Landolt C is located in the first ring in the upper left direction.

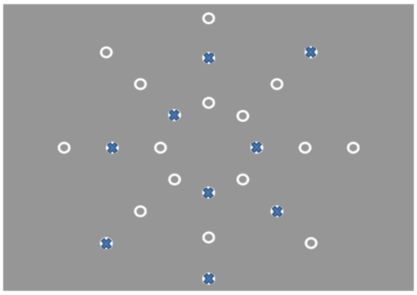

Figure 3-4: locations where the targets were presented are marked in crosses.

The order of these visual attention tests (UFV1, UFV2 and AFOV) was standardized instead of randomized (Leat & Lovie-Kitchin, 2008). This was because of the strong practice effect in these types of tasks (Ball et al., 1988; Sekuler & Ball, 1986). Ball demonstrated that practice improved the localization of targets on the UFV when conducted after 6 months from the original trial and that this practice effect is transferable between different forms of the test

(Ball et al., 1988). Moreover, Richards et al. found that both younger and older adults benefited from practice and the improvement in performance was seen nine days after the primary visit (Richards et al., 2006). Leat et al. (2006) (through personal communication with J.Wood, 2003) mentioned that the effect of practice can be observed during one session. Therefore, it was decided to run the UFV1 first, since it was the easiest (no distractors), then move to the more challenging UFV2, and end the visual attention session by conducting the most difficult of all, the AFOV. By doing this, the practice effect would be equal between participants, and any reduction in the performance in any of the tests, especially the challenging ones, would not be due to less practice. Moreover, fatigue is another issue that can be equated between participants if the test order is standardized rather than randomized. All of the above can help reduce the variability in the results, so that any potential correlation with other tests would not be influenced by these factors as well as other sources of variability.

3.2.2 Vision tests

3.2.2.1 Distance Visual acuity

Binocular distance visual acuity was measured with the participant's distance habitual spectacles using a high contrast Bailey-Lovie logMAR acuity chart at a distance of 3 meters (Bailey & Lovie, 1976). All participants were asked to start reading from the largest row and were asked to guess the letters when they were not sure. The testing was stopped at the line where they could only read 2 letters (out of the 5) correct. The test luminance was 80cd/m^2.

Visual acuity was recorded by using the by-letter scoring system, where each letter was equal to 0.02 logMAR (Hazel & Elliott, 2002).

3.2.2.2 Intermediate Visual Acuity

In this study, intermediate visual acuity through the distance and near segment of the multifocal lens was measured in order to correlation with balance and mobility. Visual acuity was assessed with the high contrast Bailey-Lovie chart placed on the floor 135cm away from the participant. This distance is approximately two walking steps, which has been shown to be the critical distance for negotiating hazards while walking (Patla & Vickers, 2003). Another reason for including this measure is that older people may look through either the distance or near portion of their spectacles when negotiating steps (Timmis et al., 2010). Visual acuity was measured with the same procedure and scoring system as for distance visual acuity, but with the participant viewing through the distance and then the reading spectacle prescription, which were placed in the trial frame, so as to control the power of the lens through which participants viewed. Both prescriptions were used to standardize the method of data collection as 48% of the sample were bifocal wearers while 52% were distributed between single vision, trifocals and progressive lenses wearers. Two charts with different letter sequences were alternated in order to reduce the effects of memory and chart type.

3.2.2.3 Contrast Sensitivity

Contrast sensitivity was measured using the Pelli-Robson chart (Pelli & Robson, 1988) (Figure 3-5). The chart consists of 8 lines of random letters with different contrast levels. Each line comprises 2 triplets (6 letters). Each triplet is of a lower contrast, as the participant reads down the chart. The highest contrast on the chart is 100% while the lowest is 0.6%. The chart was placed 1m away from the participant and the chart luminance was 80cd/m^2. Participants wore their habitual spectacles and they were allowed to view through either the distance, intermediate or near portion of the lens, whichever appeared clearer to them. Slight head movement was allowed. Participants started reading the high contrast letters first and stopped when they could only read one letter correct in a triplet. When participants approached their threshold they were asked to guess the letters when they were not sure. Contrast sensitivity was recorded by using a by-letter scoring system, where each letter is worth 0.05 log units (Elliott, Sanderson, & Conkey, 1990). The final score was computed by multiplying 0.05 log units by the number of letters identified correctly, not including the first triplet, which has a contrast sensitivity value of 0 log units. This method of scoring has been shown to a reliable method of measuring contrast sensitivity when using the Pelli-Robson chart (Elliott et al., 1990).

Figure 3-5: The Pelli-Robson contrast sensitivity chart. The numbers on the side of the chart represents the log contrast sensitivity level for that particular triplet. (Image courtesy of Precision Vision)

3.2.2.4 Binocular vision measurement

Stereoacuity

Stereopsis was measured using the Frisby Stereotest (Haag-Streit.UK) (Rosner & Clift, 1984). The Frisby Stereotest is a near stereo test printed on three perspex plates which have 1.5, 3 and 6mm thickness and are 17cm x 17cm in height and width (Figure 3-6). On each plate there are four squares with random triangle patterns, where one of those squares has a central stereoscopic circle made out of triangles printed on the opposite side of the plate.

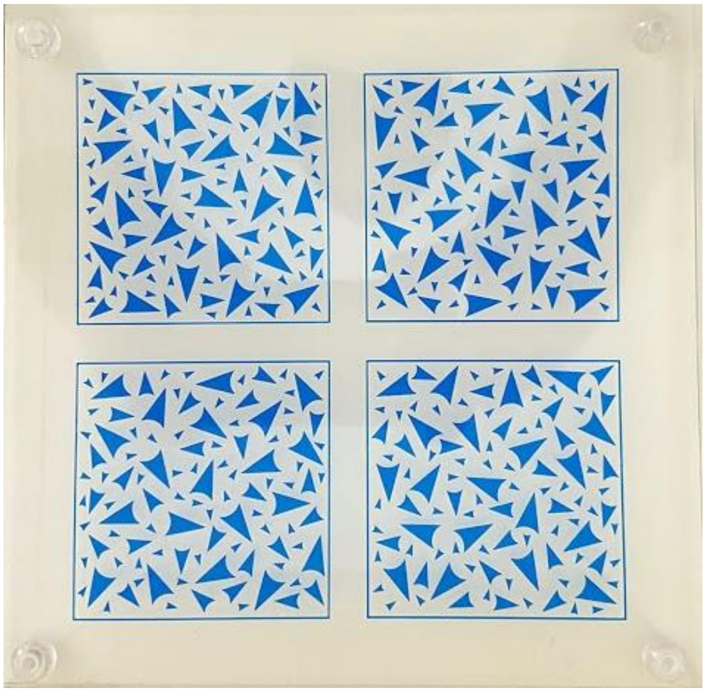

Figure 3-6:The Frisby Stereotest

By using the different plates at different working distances the retinal disparity will change and a stereothreshold can be measured (Table 3-1). Testing is done by placing the plate on the board attached to the testing box and tilting it so that it is perpendicular to the line of sight (Figure 3-7). The plates were presented with crossed disparity and the examiner started with the thickest plate (6mm) and asked the participant to look at the plate and point with his/her finger to which square has the round shaped image that is popping out. When the target was identified correctly the examiner progressed to the thinner plates.

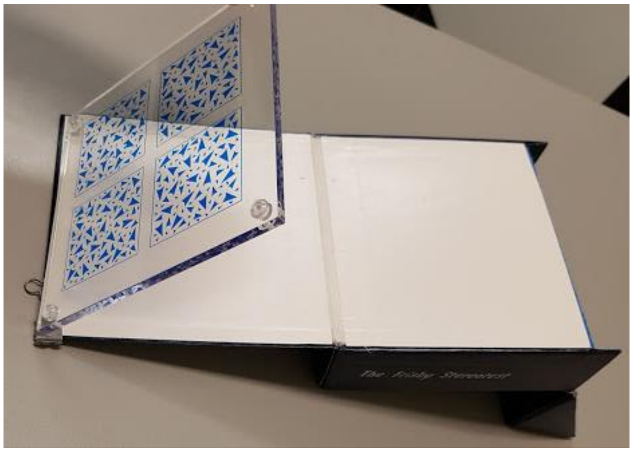

Figure 3-7: Stereoacuity measured with the Frisby Stereotest

The test stopped when the participant could no longer accurately point to the location of the target. The range of the stereoacuity measured with the Frisby Stereotest is between 20 and 600 seconds of arc. The final stereoacuity recorded was the lowest disparity perceived by the participant before making errors. At the participant threshold when the participant could no longer accurately identify the required target the plate was removed from the participants' sight, rotated and then represented 3 times with the target location varied for assurance. The smallest disparity at which the participant was correct in 2 out of the 3 times was scored as the final threshold. The participants wore their habitual spectacles throughout the entire testing and they were allowed to view through either the distance or near portion of the lens.

Table 3-1: Stereoacuity in seconds of arc for different plates according to viewing distance.

Viewing distance	6mm plate	3mm plate	1.5mm plate
30	600	300	150
40	340	170	85
50	215	110	55
60	150	75	40
70	110	55	30
80	85	40	20

The Worth 4 Dot Test

The Worth 4 dot test for suppression (Roper-Hall, 2004; Worth, 1915) is a test which indicates whether the person is suppressing one eye, fusing both eyes or experiencing diplopia. It comprises four circular lighted dots of different colors. This test was conducted at two distances; 33cm and 4 meters. For the distance target the upper stimulus was the white target while the central ones were red and the bottom target was green (Figure 3-8). For the near version the upper stimulus was white while the central ones were green and the bottom target was the red (Figure 3-9). The participant was asked to wear a pair of glasses with a red filter over the right eye and a green filter over the left eye. These glasses were worn on top of the participant’s habitual distance or near spectacles depending on the distance at which the test was conducted.

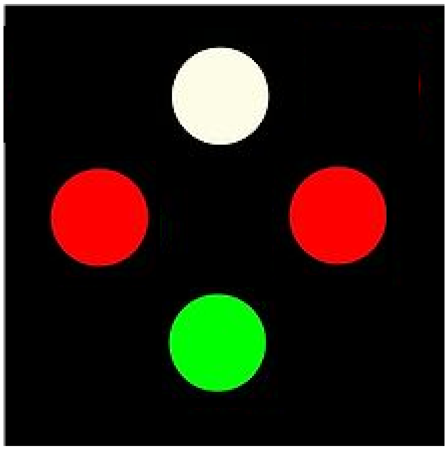

Figure 3-8: The Worth four dot test target for the distance examination

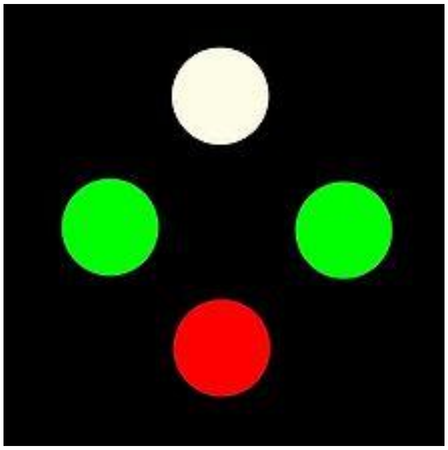

Figure 3-9: The Worth four dot test target for the near examination

The test was done under two lighting conditions; in normal room lighting and in the dark. In normal lighting the participant still has binocular fusional clues in the periphery such as the examiner or the Worth four dot test box. However, in the dark, these fusional clues are lost and the white light in the Worth four dot test becomes the only clue that can promote fusion. Thus the test becomes more dissociating in the dark and the participant's fusional ability will be more stressed under the dark condition (Wright, Spiegel, & Hengst, 2013). The participant was required to indicate if they saw 2 or 3 colored dots (indicating suppression of one eye), 4 dots (indicating fusion) or 5 dots (indicating diplopia).

3.2.2.5 Other Binocular Vision and Eye Movements Measurements

Other assessments of the status of binocular vison and eye movements were measured and included the following:

A unilateral and alternating cover test was performed to determine any binocular vision disorders, such as strabismus or heterophoria (Scheiman & Wick, 2014). In this test a cover was used to cover each of the participant's eyes while s/he looked at a distance (3 meters) or a near target (30 cm) to check for any ocular deviation. The target used for the near distance was a small image of a standing boy on the tip of a fixation stick. The amount of prism needed to neutralize any strabismus or heterophoria was recorded. In addition, the cover test was conducted in all directions of gaze to check for any incommitancy.

Near point of convergence (NPC) was also recorded (Scheiman & Wick, 2014). The participant was asked to look at a small target while the examiner brought the target closer to the participant's nose. The participant was instructed to report when the target became double. The distance from the eyes where the target doubled or one eye deviated out was recorded in centimeters.

Fusional reserves, assess motor fusion and is the maximum fusional vergence which allows the maintenance of binocular single vision. The value is recorded in prism diopters (Stidwill

& Fletcher, 2011). The break and recovery points were measured in free space with a prism bar only if the following were found:

- Distance exophoria larger than 2 prism dioptres
- Near exophoria larger than 8 prism dioptes
- Any esophoria
- Vertical phoria larger than 2 prism dioptres
- NPC larger than 10 centimeters

Ocular motility was assessed with the broad H test (Grosvenor & Grosvenor, 2007) and saccades and pursuit eye movements were evaluated by observation. In the broad H test for ocular motility the participant was asked to follow a small target which was moved by the examiner into the different positions of gaze to check any abnormalities in eye movements or obvious incommitancy.

In addition, saccades and pursuit eye movements were observed. In this test the participant was asked to follow and pursue a slow moving target (pursuit) and then change fixation from one target to the other (saccade movement) (Stidwill & Fletcher, 2011). Head tilt was also recorded if observed.

Definition of Binocular Vision and Eye Movement Disorder

A participant was considered positive for having a binocular vision or eye movement disorder if he/she had one or more of the following conditions (based on the criteria of Leat et al., 2013). The final outcome for the binocular vision and eye movement disorder was a dichotomous score of either having met this criteria or not.

- Stereoacuity worse than 60 seconds of arc
- Any strabismus
- Vertical phoria larger than 2 prism dioptres in the primary position at distance or near and not compensated according to Sheard's and Morgan's fusional reserve criterion (Morgan, 1944; Sheard, 1930)
- Distance exophoria larger than 4 prism dioptres in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Morgan, 1944; Sheard, 1930)
- Any esophoria in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Morgan, 1944; Sheard, 1930)
- Near exophoria larger than 8 prism dioptres in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Morgan, 1944; Sheard, 1930)
- Vertical incommitancy as measured by cover test larger than 1 prism dioptre
- Horizontal incommitancy as measured by cover test larger than 5 prism dioptres
- Any incommitancy seen on the motility test
- Any suppression or unfused (diplopic) response with the Worth 4 Dot test

- Any abnormal motility including abnormal observation of saccades or pursuits
- A near point of convergence greater than 10 centimeters

3.2.3 Balance and mobility tests

3.2.3.1 One Legged Stance test (OLST)

To date, there is no standardized method for administrating the OLST, and there have been a number of studies in the literature, which have each used a different method to run the test. The OLST is a clinical tool that has been used in the assessment of postural balance, falls and injurious falls (Vellas et al., 1997; Hurvitz, Richardson, Werner, Ruhl, & Dixon, 2000). In this study the procedure was derived from different studies and chosen to gain reliable and consistent outcomes and to reduce any variability as much as possible. The OLST was performed on a smooth hard floor. Brigs and colleagues found that there was no significant difference between left vs. right or dominant vs. non-dominant foot while performing the OLST, nor between shoes off or on (Briggs, Gossman, Birch, Drews, & Shaddeau, 1989). Therefore, participants were asked to decide on which leg they prefer to stand and the test was done with their shoes on. Before the procedure began, the examiner demonstrated the test procedure in front of each participant while explaining the procedure verbally. First, participants were instructed to stand on both feet in a relaxed stance and then to "*Lift one leg, it doesn't matter which leg, up in front of you with your arms next to your body.* The participants were asked to fixate on a target in front of them and to maintain their balance for up to 30 seconds (Figure 3-10).

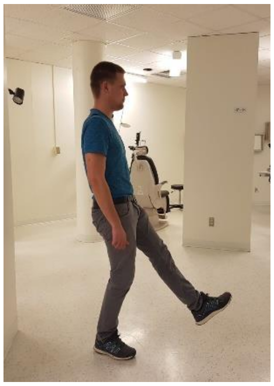

Figure 3-10: The One Legged Stance test.

The use of any assistive devices to help them control or sustain their balance was not permitted. As soon as the participant lifted one leg and said “go”, the examiner checked visually if the participant was in the right pose and started the stop watch and would stop the test only if the participant lost his/her balance (stance foot moved), lowered the lifted leg or moved his/her arms. When the test started the examiner was standing close to the participant to help prevent falls or injuries in case of loss of balance. One trial was conducted for each participant and the test was terminated at 30 seconds. Their performance was timed and the best out of two trials was recorded as the duration they were able to maintain their balance up to 30 seconds.

3.2.3.2 Sit to Stand Test (STST)

There is a considerable variation in the literature on what is the best scoring system for the Sit to Stand test, and what height and type of chair should be used in the test. Therefore, the method chosen in this study was shown to be reliable in assessing falls risk, balance, and muscle strength (Buatois et al., 2008; Buatois et al., 2010; Lord, Murray, Chapman, Munro, & Tiedemann, 2002). In this study an armless standard height chair (44.5cm) with 1cm of padding was used and the participants were asked to wear their usual comfortable footwear. The examiner first explained the test procedure to the participant. Then the participant was asked to start the test in the seating position with their arms next to their body and their back against the chair's backrest. Then they were instructed as follows: "*I would like you to put your arms next to your body and to stand up and sit down 5 times as fast as you feel comfortable and safe*. *Please keep looking straight ahead and try not to use your arms to push up from the chair. You may start when I say Go."* (Figure 3-11)

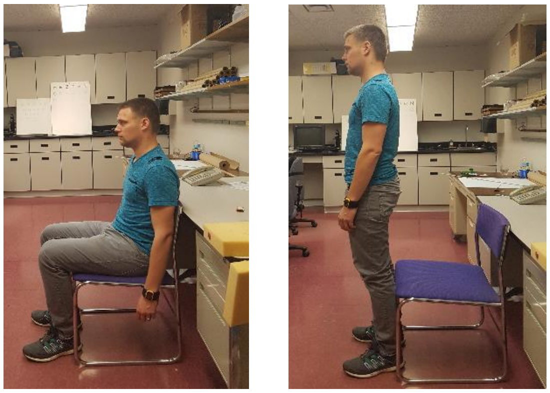

Figure 3-11: The Sit to Stand test

The task was demonstrated before they started and they were asked to stand up fully between each repetition and to not touch the back of the chair. If the participant did the first few repetitions incorrectly the examiner would stop the test and demonstrate the procedure, before starting again. The stopwatch started when the examiner said “Go” and stopped at the fifth repetition when the participant first touched the chair seat. During the test, the back of the chair was placed against a wall for better stability and support, and to avoid any falling incidents. The final outcome was the duration for the participant to complete the task.

3.2.3.3 The 5 Meter Walk Test (5MWT)

In the published literature and clinical practice there is little unanimity about the testing procedure of walking tests in terms of pace, protocol, type of floor and lighting and distance. The 5 Meter walk test was chosen because it has good reliability (ICC= 0.862) in predicting walking speed (Fulk & Echternach, 2008). In addition, this distance (5 meters) is convenient as it will not cause the participants undue fatigue. In this study, tape was used to mark a starting and finishing point for the 5 meter walking course. An additional 1.50 meters (equivalent to 3 walking steps) at the beginning and the end of the course was added to allow some space for acceleration and deceleration. Therefore, the participants were asked to walk an 8 meter distance course but only the middle 5 meter distance was timed to measure the participant’s performance. The walking course was straight with no obstacles and was on a hard floor. The participants were instructed to “*Walk as fast as you feel comfortable and safe for 5 meters. I will tell you when to start and when to stop.*” (Figure 3-12) The examiner followed the participant along the course and started the stopwatch when the leading foot crossed the first tape mark which marked the beginning of the 5 meters and stopped it as soon as the leading foot crossed the end of the 5 meters, although participants continued to walk to the end of the 8 meters. The time taken was the outcome measure.

Figure 3-12: The 5 Meter Walk test.

3.2.4 Fear of Falling

Falls Efficacy Scale- International (FES-I)

Fear of falling was assessed using the Falls Efficacy Scale-International questionnaire (FES-I) developed by Yardley 2005 and colleagues. It is comprised of 16 questions assessing how concerned the individual is about falling while doing a task in or outside the house. Participants had four options to respond to each question; 1. Not at all concerned, 2. Somewhat concerned, 3. Fairly concerned or 4. Very concerned. A forced choice procedure was implemented where the participants had to give a response. In the case that they do not practice the activity in question the participants were instructed to give their thoughts of how concerned they are if they had to do the activity. The test was done verbally with the examiner marking the response on the question sheet. The items on the questionnaire are in Table 3-2.

Table 3-2: The FES-I questionnaire items

<table>
<tr><th colspan="2">Participants are asked in the following form: How concerned are you about the possibility of falling while….</th></tr>
<tr><td>1. Cleaning the house (e.g., sweep, vacuum or 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 in the neighborhood</td><td>9. Reaching for something above your head or on the ground
10. Going to answer the telephone before it stops ringing
11. Walking on a slippery surface (e.g., wet or icy)
12. Visiting a friend or relative
13. Walking in a place with crowds
14. Walking on an uneven surface (e.g., rocky ground, poorly maintained pavement)
15. Walking up or down a slope
16. Going out to a social event (e.g., religious service, family)</td></tr>
</table>

3.3 Experiment 1: Cross sectional study (individuals with visual impairment)

For participants with visual impairment taking part in experiment 1 (Chapter 5) the same experiment protocol was implemented as for the participants who were normally sighted, as describe above (section 3.2). However, running the visual attention tests was not possible, as many could not resolve the detail in these tests.

3.4 Experiment 2: Randomized controlled trial of visual attention training

The following section provides details of the tasks used in experiment 2 (Chapter 7). For those tasks that were identical to those in experiment 1, the reader will be referred to those sections for more details.

3.4.1 Protocol

In experiment 2 (Chapter 7) after the baseline assessment participants were randomly assigned to one of the two groups in the study. Randomization was stratified by age (70-79 and 80+ years) and gender. One group received the visual attention training while the other was asked to continue their everyday activities as usual. The training sessions took place at the School of Optometry and Vision Science. The training sessions were conducted twice a week for 3 weeks to a total of 6 sessions. Each session involved 45 minutes of visual attention training, using UFV2 and AFOV stimuli which were similar, but not the same, as at baseline and ranged in difficulty (Figure 3-13). There were 7 different UFV2 targets and 3 different AFOV targets. The difficulty level was determined with a pilot study and the training started with the easier and moved to the harder levels. The different targets and conditions used in the training sessions are shown in the Appendix.

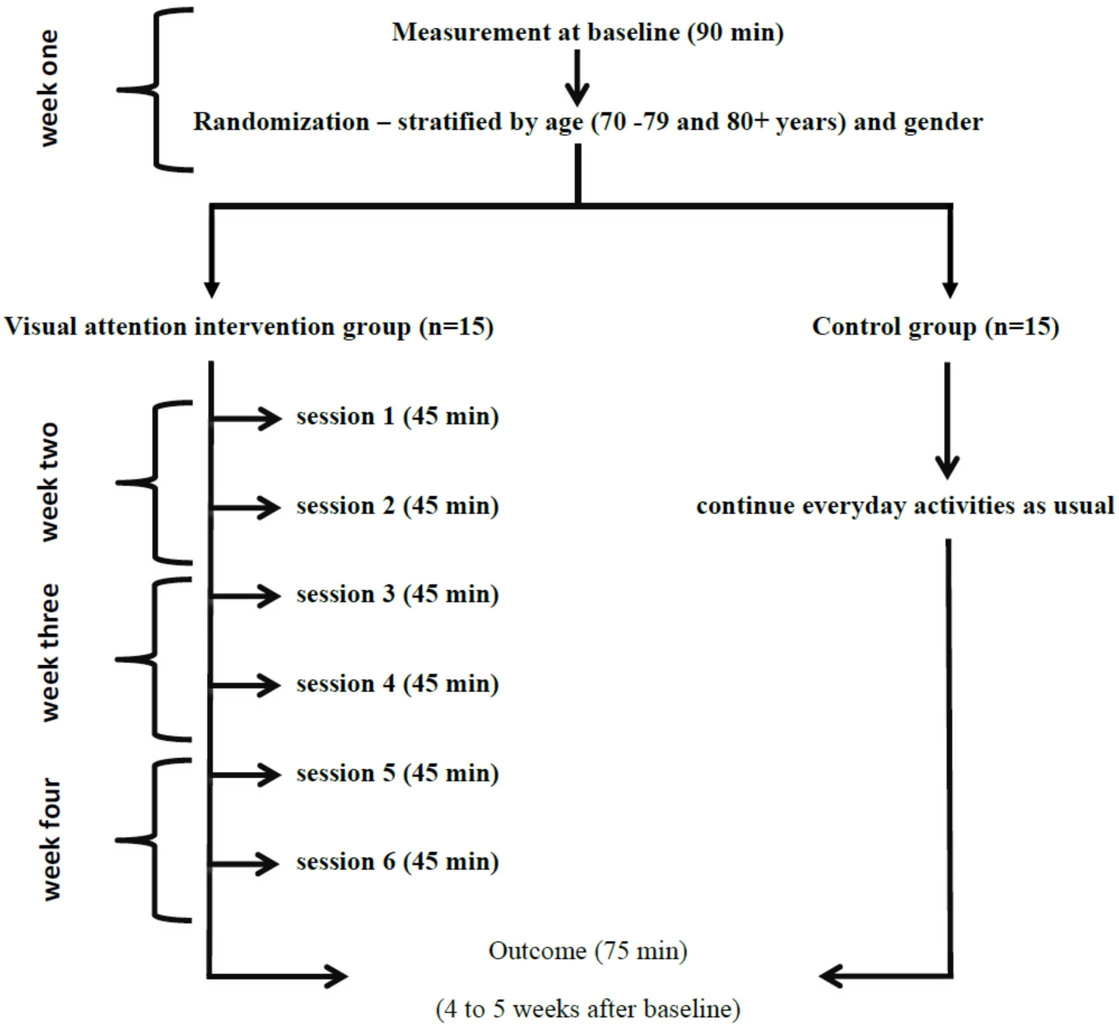

Figure 3-13: Experiment 2 protocol

3.4.2 Visual attention

The visual attention tests used at baseline and outcome visits in experiment 2 were identical to those described in section 3.2.1 of this thesis. However, for the UFV in experiment 2 the target was presented for 200 milliseconds instead of the 160 milliseconds used in experiment 1. It was found that using 160 milliseconds as the presentation duration was too fast for this cohort. Therefore, a slower presentation time (200 milliseconds) was used, which is still faster than a saccadic eye movement in older adults.

3.4.3 Balance and mobility tests

In experiment 2 all the balance and mobility tasks were administered with shoes off. The difference here between experiment 1 and 2 is due to the different tests of balance added in experiment 2, which require footwear removal. Therefore, it was decided to conduct all the balance tests in experiment 2 with shoes off.

The One Legged Stance test, the Sit to Stand test and the 5 Meter walk test were conducted as in experiment 1 (see section 3.2.3). In addition, the following were included as part of experiment 2.

3.4.3.1 The Timed Up and Go test

The Timed Up and Go test (TUG) is a mobility task that has been shown to give reliable results for functional mobility in older adults (Jacobs et al., 2006). In this assessment tool two conditions were performed; the TUG alone and the TUG with a cognitive task (TUGco). In the TUG a 22.9 cm height black box was placed 3 meters away from the participant (Franchignoni et al., 2010). Then the participant was instructed to *"stand up and walk to the black box, turn around, walk back to your chair and sit down. Try not to use your arms to push up from the chair."* In the TUGco the same procedure was implemented but with the addition of a mental arithmetic task. *The participants were instructed "to start counting from 100 and subtract 3 and keep subtracting 3. As soon as I say go you may stand up and start the test. Please keep subtracting until you get back to the chair. Remember not to push up with your arms."* The participants were given the "go" command after 3 steps of subtraction. The final measure recorded for both was the duration they were able to complete the test.

3.4.3.2 The mini Balance Evaluation System's Test

The mini Balance Evaluation System's Test (mini-BESTest) (Franchignoni et al., 2010) is a composite test and was included as it is a clinical balance assessment tool that measures the integrity of 4 different balance control systems in the body. This test was developed to improve and shorten the lengthy BESTest (Horak, Wrisley, & Frank, 2009). Previous reports have found that this assessment tool has a high inter-rater reliability and test-retest reliability and is an accurate tool for identifying fallers (Duncan et al., 2013; Godi et al., 2013; Leddy, Crowner, & Earhart, 2011). In addition, the mini-BESTest has been shown to have less of a ceiling effect when compared to the older and well known Berg Balance Scale (Godi et al., 2013), which makes it better at identifying any significant improvement in balance function. It consists of 14 short balance tests divided under 4 domains of balance control. In all the tasks performed in the mini-BESTest the examiner scores the participants performance on a 3 scale score to grade the performance on each component performed in the mini-BESTest, where "0" is considered severe impairment, "1" moderate impairment and "2" is normal function. The final score is the sum of those scores to a maximum score of 28. All the testing was done with the patients' habitual glasses prescription and with their shoes off. This test was used in experiment

2. All the instructions in bold below were taken exactly from the mini-BESTest instruction sheet. Those in italics were a paraphrase to simplify the instructions.

The first part assesses anticipatory body control by measuring the following:

1- The Sit to Stand Test. The participants were asked to *"cross your arms and not use them to assist you in getting up from your chair. Please do not let your legs lean against the chair. You may stand up when you are ready."* The outcome of this version of the Sit to Stand test is different form the one mentioned above as the outcome was not how fast they could do the task, but a grade based on the examiner's observation of the participant's movement and how easy the task was to perform without any assistance, The grade was on the 3 scale classification mentioned above.
2- Rise to Toes test. In this test participants were asked to *"**place your feet shoulder width apart and your hands on your hips. Can you rise as high as you can on your toes, and stay there while I count out loud to 3? Try to maintain this position until I tell you to stop.**"* The participants were graded on their stability and maintenance of this posture.
3- Stand on One Leg. Participants were asked to *"place your hands on your hip and lift your leg up behind you. Keep this position until I tell you to stop and keep looking straight at the target on the wall."* The participants were asked to do this test for both feet and two trials for each foot was recorded. Each trial was conducted for 20 seconds.

The second part of this tool is the reactive postural control. It consists of the following:

4- Compensatory Stepping Correction-forward Test. Participants were asked to *“place your feet shoulder width apart with arms at your side. Lean forward toward and against my hands, I will put my hands against your shoulders. I will count to three. When I say three I will let go. When I do let go do whatever you need to, to prevent loss of balance, even if you take a step.”* The examiner then observed the participant’s correctional response to maintain his/her balance and graded their response accordingly (Figure 3-14a).

5- Compensatory Stepping Correction-backward Test. As above, but participants were asked to stand and lean backward onto the examiner’s hand. The examiner then let go. The participant’s correctional response to maintain his/her balance was noted (Figure 3-14b).

6- Compensatory Stepping Correction-lateral Test. Participants were asked to *“stand with your feet together and arms at your side and lean to your side beyond your limit against my arm. I will count to three. When I say three I will let go. When I do please do whatever necessary to avoid a loss of balance even if you take a step.”* The participant’s correctional response to maintain his/her balance was noted. The test was done on both sides (Figure 3-14c).

The third examines sensory orientation by examining the following:

7- Stance (A) Test. Participants were asked to *“stand with your feet together, hands on your hips. Keep looking straight at the letters on the wall and keep this pose until I tell you to stop.”* The test was run on a firm surface with eyes open for 30 seconds.

Performance was graded based on the time the patient could maintain this pose (Figure 3-15a).

8- Stance (B) Test. The same procedure as Stance (A) but with eyes closed and on a foam surface (Figure 3-15b).

9- Stance (C) Test. Participants were asked to stand on an inclined ramp with their toes toward the top of the ramp with their eyes closed for 30 seconds (Figure 3-15c).

The final group of tests were to assess balance during dynamic gait:

10- Change in Gait Speed Test. This is a walking test where participants were asked to *"start walking at your normal speed. When I tell you to walk fast, change your walking pace to the fastest you can and when I say "slow" start walking slowly."* The examiner observed their change in pace and noted any imbalance in posture while completing the task and graded their response accordingly.

11- Walk with Head Turns Test. Participants were asked to *"start walking at your normal speed. When I say right please turn your head right while you keep walking in a straight line. And when I say left please turn you head left while still walking in a straight line."* An observation of any change in gait speed or balance was noted and recorded accordingly.

12- Walk with Pivot Turns Test. Participants started to walk at their normal and were asked to *"**when I tell you to 'turn, turn as quickly as you can, face the opposite direction, and stop. After the turn, your feet should be close together.**"* The task should be performed with speed and intact balance for higher points to be awarded.

13- Step over obstacles Test. Participants were asked to walk at their normal speed and *“**When you get to the black box, please step over it, not around it and then keep walking.**”* The box (23cm height) was placed 10 feet away from where they began to walk. The ability to step over the box with intact balance and no change in gait speed was the ideal performance for this task.

14- In the Timed Up and Go test (TUG), two conditions were performed; the TUG alone and the TUG with a cognitive task (TUGco). The testing procedure for both tests is described above in section 3.4.3.1. However, the final measure recorded here is based on the difference in time taken for task completion between the TUG and the TUGco.

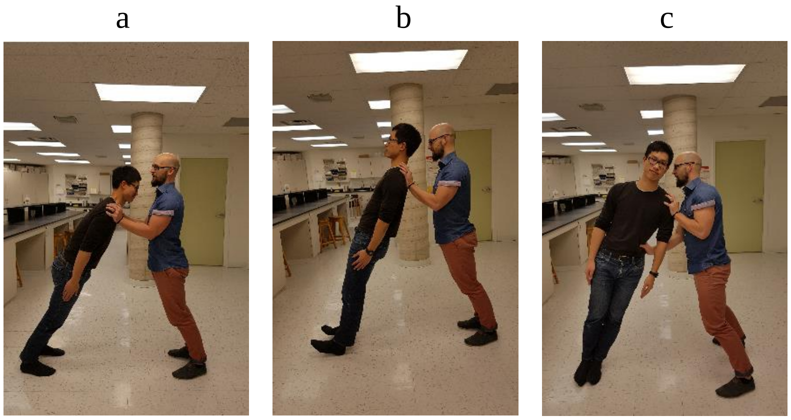

Figure 3-14: The mini-BESTest a. Compensatory Stepping Correction-forward b. Compensatory Stepping Correction-backward c. Compensatory Stepping Correction-lateral

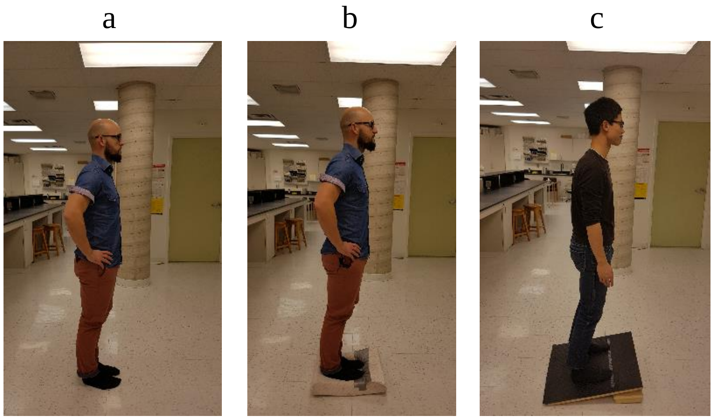

Figure 3-15: The mini-BESTest a. Stance (A) b. Stance (B) c. Stance (c)

3.4.3.3 Sway (Experiment 2)

Sway was measured using the portable AMTI AccuGAIT force plate platform (200 Hz) (http://www.amti.biz/) to record ground reaction forces and moments as participants stood in quiet stance, while barefoot, on the force plate. To ensure the consistency of the base of support throughout all the sessions and trials, each participant's preferred foot position was traced on paper that covered the surface of the plate; this foot tracing was reused at the outcome visit to ensure that the participant was standing in the same position at baseline and outcome visits. Postural sway was recorded for two test conditions; eyes open and eyes closed (Figure 3-16).

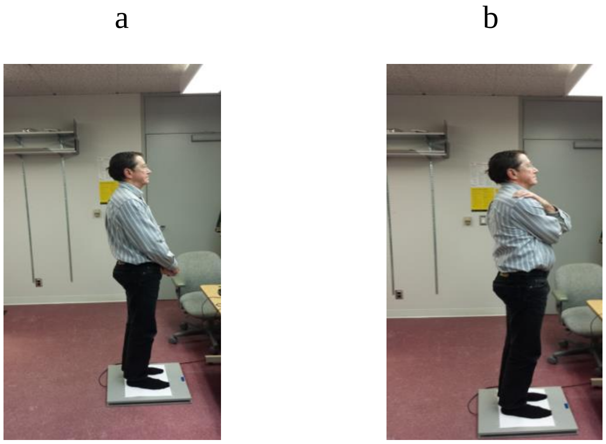

Figure 3-16: Sway measured on the Force Plate Platform a. Eyes Open b. Eyes Closed

Both conditions were undertaken without shoes. In the eyes open measurement participants were asked to stand on the force plate platform with eyes open and arms next to their body. Participants were instructed to look straight ahead at a fixation target placed 1 meter away in front of them, while wearing their habitual glasses. When the test started they were asked to maintain their balance for 60 seconds, which was repeated for 5 trials. In the eyes closed condition, participants were asked to stand, to cross their arms across their chest and keep their head straight. During the stance participants were instructed to try to control their balance for 30 seconds, and this was repeated for 3 trials, if possible. The first 5 and last 5 seconds of the data were removed, and then a 6 Hz low pass (dual pass) Butterworth filter was used to remove any noise in the data. The outcome measures were the standard deviation of the medial lateral (ML) and anterior posterior (AP) center of pressure (CoP), ML and AP CoP maximum sway, ML and AP CoP range (range = maximum excursion in “+ve” direction – maximum excursion in “–ve“ direction) and the cumulative path length in centimeters (Winter, 1995a). Any trial that was 3 standard deviations away from the mean was excluded from these postural analyses.

For all the balance and mobility tasks in this study, a safety spotter stood next to the participant minimize the risk of falling and incurring an injury during test sessions. Participants were allowed to rest in between tests to reduce the effects of fatigue.

Chapter 4

Binocular vision disorders and visual attention: association with balance and mobility in older adults

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Authors' contribution

Author	Concept/Design	Acquisition of Data	Analysis	Write up/Publication
Althomali	✓	✓	✓	✓
Leat	✓	Advised	Advised	Edited

Overview

Understanding which aspects of vision are related to falls is important. We examine the associations between tests of balance, mobility, fear of falling (FES-1) and aspects of vision in 72 adults aged 70+. Balance and mobility were examined using the One Legged Stance test (OLST), the Sit to Stand test (STST) and the 5 Meter Walk test (5MWT). Visual measures included visual acuity (VA), contrast sensitivity, stereoacuity, binocular vision (BV) measurements, Useful field of View (UFV) and Attended Field of View (AFOV). Reduced performance on the OLST and the STST was significantly correlated with abnormal BV and poorer intermediate VA. Poorer function on the 5MWT and the FES-I was also predicted by poor intermediate VA and poorer performance on the OLST, STST and the 5MWT was associated with UFV errors. The results are of high importance as many BV disorders are treatable and visual attention is trainable.

4.1 Introduction

Balance or postural control is a complex motor mechanism receiving input from various systems in the body. Balance is the ability to maintain position, undertake activities and retain good mobility (the ability to move safely and efficiently within the environment without falling). The three main systems that are considered the most important in maintaining balance are the vestibular, somatosensory and visual systems (Shumway-Cook & Woollacott, 2007). The sensory inputs from these systems are integrated in the central nervous system and a motor signal is provided that enables a person to maintain balance. Poor balance is one of the main causes of falls among older adults (Choy, Brauer, & Nitz, 2003; Lord & Ward 1994; Lord & Clark, 1996), which are serious and common among older adults. It is estimated that 30% of community-dwelling adults aged 70 and above lose balance and fall every year, and that 60% of nursing home residents fall at least once a year (Lord et al., 2003). Some of these older adults experience multiple falls (Lord & Ward 1994; Lord & Dayhew, 2001). Injury due to falls is frequent, and can cause loss of independence (Cumming et al., 2000), threaten mobility (Tinetti, Leon, Doucette, & Baker, 1994), impair daily function and health status (Davidson, Merrilees, Wilkinson, McKie, & Gilchrist, 2001) and lead to institutionalization (Koski, Luukinen, Laippala, & Kivelä, 2000; Tinetti, Speechley, & Ginter, 1988) and even death (Alegre-Lopez, Cordero-Guevara, Alonso-Valdivielso, & Fernandez-Melon, 2005; Dunn, Sadkowsky, & Jelfs, 2002; Tinetti et al., 1994). According to Statistics Canada (2015), falls in older adults is a growing problem, as due to improved quality of life and better access to health care, the number of older adults above the age of 65 is increasing. Therefore, due to this shift towards an older demographic, it is likely that the number of fall-related injuries and deaths in Canada will increase, with significant personal and social costs and consequences.

A previous fall can lead to fear of falling, which is a common issue faced by older adults (Friedman, Munoz, West, Rubin, & Fried, 2002). It is estimated that more than 50% of older adults develop fear of falling (Howland et al., 1998; Zijlstra et al., 2007), and fear of falling itself is associated with reduced balance, mobility and falls (Arfken, Lach, Birge, & Miller, 1994; Friedman et al., 2002; Howland et al., 1993; Li, Fisher, Harmer, McAuley, & Wilson, 2003).

An intact visual input provides the nervous system with reference and self-awareness of the body's position in space and with respect to surrounding objects and is important for balance control and the prevention of falls. There is evidence that there is an increased reliance on the visual input with increasing age due to age deterioration in the vestibular and somatosensory systems input (Choy et al., 2003; Era et al., 2006). However, with advancing age there is also increasing impairment of many aspects of vision (Ball, Beard, Roenker, Miller, & Griggs, 1988; Elliott, Whitaker, & MacVeigh, 1990; R. Klein, B. Klein, Linton, & De Mets, 1991; Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988; Leat et al., 2013). Many of these visual aging changes have been shown to increase postural instability and increase the risk for falls. Two large-scale cross-sectional studies of older adults, the Beaver Dam Study and the Blue Mountains study, have shown an increase risk of falls in people with reduced visual acuity (Klein et al., 1998, Ivers et al., 1998). In a large prospective study, Coleman et al. (2004) reported that 43% of women aged 65 years and older with VA loss were recurrent fallers.

Reduced contrast sensitivity was also shown to be a predictor of recurrent falls in several studies (Klein et al., 1998; Lord & Dayhew, 2001; Lord, Ward, Williams, & Anstey, 1994; Lord et al., 1991) and a recent systemic review confirmed a strong relationship between poor contrast sensitivity and recurrent falls (Salonen & Kivelä, 2012). Visual field loss has been shown to be a falls risk factor in a number of studies (Black et al., 2011; Brandt et al., 1973; Ivers et al., 1998; Klein et al., 2003; Patino et al., 2010). Stereoacuity/poor depth perception, which describe the ability to judge distances, have been shown to be a predictor of postural sway (Lord & Menz, 2000) and contribute to falls risk. (Lord & Menz, 2000; Nevitt et al., 1989; Lord and Dayhew, 2001). Monocular blur, which would reduce stereopsis, has also been shown to disturb the ability to precisely judge the height of steps (Vale, Buckley, & Elliott, 2008). In another large epidemiological study, the Framingham Eye Study, individuals who had impaired vison in one eye and good vision in the other had a higher risk of fall-related fractures compared to those with similar visual impairments in both eyes (Felson et al., 1989). Poor stereopsis is often the result of binocular vision (BV) disorders while poor monocular visual acuity can cause decreased fusional ability, and lead to sensory strabismus (Scheiman & Wick, 2014). BV and eye movement disorders become more prevalent with age (Leat et al., 2013), and are common in older adults (30% of adults aged 70 to 79 and 38% of adults over 80 years old have a BV disorder).

Visual attention, which is one aspect of visual processing, has also been associated with errors on a mobility course in a general population of older adults (Broman et al., 2004) and with walking speed and number of errors for a visually impaired population (Leat & Lovie-

Kitchin, 2008). It has also been shown to be associated with tests which include balance and mobility maneuvers (Owsley & McGwin, 2004) and with participation in moderate and regular exercise (Roth, Goode, Clay, & Ball, 2003).

All of these findings indicate the importance of optimizing vision for safer mobility and falls reduction. BV disorders have received little attention regarding the relationship to balance and mobility or risk of falls and are frequently the cause of reduced stereopsis. So it seemed more direct to investigate the more primary visual function. Regarding visual attention, although there are a few studies of visual attention and its relation with aspects of mobility as described above, its direct relation with balance or walking in older adults has not been investigated yet. In particular, we were interested in visual attention measured with a useful field of view test (UFV) as it has been used extensively (Ball & Owsley, 1993; Leat & Lovie-Kitchin, 2008; Owsley, 1994) and the Attended Field of View (AFOV) (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004) as it allows the participant to make eye and head movements to search for the target and may therefore be more related to everyday life than the UFV, which presents targets so briefly that eye or head movements are not possible. Therefore, the purpose of the present cross-sectional study is to investigate the association between tests of balance, walking, and fear of falling with measures of vision which have been less studied or not been considered before, specifically tests of BV and visual attention. These were chosen, as they are maybe treatable or trainable respectively. The association between stereopsis and falls demonstrates a link between more complex "higher" outcomes. We wished to investigate whether this association can be demonstrated at the level of more basic functions (BV disorders and tests of some basic components of balance and mobility). For comparison, we also included other measures of vision that have previously been used in such studies, plus visual acuity (VA) at the intermediate distance, where people look to place the next step, as this may be more related to mobility than either distance or near VA. The hypotheses of this study are that the presence of BV disorders and poor visual attention, as measured with the computerized UFV or AFOV, will predict balance (measured with the Sit to Stand test and the One Legged Stance test), mobility (measured by the 5 Meter Walk test) and/or the fear of falling (measured with the Falls Efficacy Scale-International) in the older adult population. These balance and mobility assessment tools were chosen because they can be used clinically, require no equipment, are inexpensive and typically require little training to conduct yet, reliable in assessing balance or mobility and are currently used in falls assessment (Vellas et al., 1997; Hurvitz, Richardson, Werner, Ruhl, & Dixon, 2000; Buatois et al., 2008; Buatois et al., 2010; Lord, Murray, Chapman, Munro, & Tiedemann, 2002; Fulk & Echternach, 2008; De Rekeneire et al. 2003).

4.2 Methods

Participants

Seventy two participants took part in the study (mean age 80.3 yrs ± 5.9) and 57% of the sample were female. Three participants were excluded for the following reasons: one had peripheral neuropathy in the feet, one was a cane user and one had excessive difficulty controlling his balance for unknown reasons. The participants consisted of relatively healthy older adults, aged 70+, living independently in the community and older adults who were residents of assisted living homes. Participants were recruited from the Primary Care Clinic at the School of Optometry and Vision Science at the University of Waterloo and attended the School to take part in the study. The participants from residential homes were recruited from retirement homes across the Waterloo/Kitchener area and the study took place at their retirement homes. Exclusion criteria were binocular visual acuity worse than 6/12 (to exclude those with low vision (based on the North America definition of low vision, Maberley et al. 2006), not fluent in English (so as to standardize the forms and questionnaires for all the participants), diagnosed with cognitive impairment according to their file at the Residential home or the Primary Care Clinic or unable to walk independently without a walker or a cane. Preliminary information, such as the general health and ocular history, number of medications and spectacle prescription, was gathered at the beginning of the study. For general health, the participant was asked if they had hypertension, hypotension, heart disease, diabetes, cancer, depression, respiratory disorders, circulatory disorders, thyroid disorders, high cholesterol, hearing problems, a previous stroke or any other health conditions. For ocular history the following were recorded; a diagnosis of glaucoma, cataract, diabetic retinopathy, retinal vein or artery occlusion, any other retinal problem, floaters or had had cataract surgery. These variables were coded as a yes/no response. For general health and ocular health, the number of disorders of each person was counted. Two people had 8+ general health disorders and these were coded with a default value of 8.

This study was reviewed and received clearance through a University of Waterloo Research Ethics Committee.

Initial visual tests

Binocular distance VA was measured with the habitual spectacles using a high contrast Bailey-Lovie logMAR acuity chart at a distance of 3 meters using by-letter scoring (Bailey & Lovie, 1976). In this study we also wanted to know how vision through different areas of the multifocal lens affects balance and mobility. Therefore, intermediate VA was assessed with the Bailey-Lovie chart placed on the floor 135cm away from the participant. This distance is approximately two walking steps, which has been shown to be the critical distance for negotiating hazards while walking (Patla & Vickers, 2003). VA was recorded while viewing through the distance and also the reading spectacle prescription, which were placed in the trial frame, so as to control the prescription participants used. Both prescriptions were used as older people often look through the bottom (reading) portion of their spectacles, regardless of the type of lens (single, bifocal or progressive lens), instead of the top (distance) portion, when negotiating steps (Timmis, Johnson, Elliott, & Buckley, 2010). Two charts with different letter sequences were alternated in order to reduce the effects of memory and chart type.

Contrast sensitivity (CS) was measured using the Pelli-Robson chart with by-letter scoring (Pelli & Robson, 1988). The chart was placed 1m away from the participant. Participants wore their habitual spectacles and they were allowed to view through either the distance or intermediate portion of the lens, whichever appeared clearer to them.

Binocular vision measurements

Stereopsis was measured using the Frisby Stereotest (Rosner & Clift, 1984) (Haag-Streit UK). The participant's task was to identify the circle seen in depth among four circles. The position of the disparity target was varied. The range of the stereoacuity measured with the Frisby Stereotest is between 20 and 600 seconds of arc. The final stereoacuity recorded was the smallest disparity perceived by the participant before making errors for three presentations. The participants wore their habitual spectacles throughout the entire testing and they were allowed to view through either the distance or near portion of the lens.

The Worth 4 dot test of suppression (Worth, 1915; Roper-Hall, 2004) was conducted at 2 distances; 33cm and 4 meters. The participant was asked to wear a pair of glasses with a red filter over the right eye and a green filter over the left eye. These glasses were worn on top of the participant's habitual distance or near spectacles depending on the distance at which the test was conducted. The participant was required to indicate if they saw 2 or 3 colored dots (indicating suppression of one eye), 4 dots (indicating fusion) or 5 dots (indicating diplopia).

Other assessments of the status of binocular vison included the following: unilateral and alternative cover test for strabismus and heterophoria while fixating in the primary position at distance, and while fixating in the primary position and 4 different directions of gaze at near, and near point of convergence (NPC). Fusional reserves (Stidwill & Fletcher, 2010) were measured if the following were found:

- Distance exophoria larger than 2 prism dioptres
- Near exophoria larger than 8 prism
- any esophoria
- vertical phoria larger than 2 prism dioptres
- NPC larger than 10 centimeters

The ocular motility was assessed with the broad H test and saccades and pursuit eye movements were evaluated by observation. A participant was considered positive for having a binocular vision or eye movement disorder if he/she had one or more of the following conditions (based on the criteria of Leat, 2013). The final outcome for the binocular vision and eye movement disorder was a dichotomous score of either having met these criteria or not.

- Stereoacuity worse than 60 seconds of arc (Rubin et al., 1994)
- Any strabismus
- Vertical phoria larger than 2 prism dioptres in the primary position at distance or near and not compensated according to Sheard's and Morgan's fusional reserve criterion (Sheard, 1930; Morgan, 1944).
- Distance exophoria larger than 4 prism dioptres in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Sheard, 1930; Morgan, 1944).
- Any esophoria in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Morgan, 1944; Sheard, 1930).

- Near exophoria larger than 8 prism dioptres in the primary position and not compensated according to Sheard's and Morgan's fusional reserve criterion (Sheard, 1930; Morgan, 1944).
- Vertical incommitancy larger than 1 prism dioptre
- Horizontal incommitancy larger than 5 prism dioptres
- Any incommitancy seen on the motility test
- Any suppression or unfused response with the Worth 4 Dot test
- Any abnormal motility including abnormal observation of saccades or pursuits
- A near point of convergence larger than 10 centimeters

Visual attention

Visual attention was measured with a useful field of view test (UFV) (Ball et al., 1988; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986) including 2 subtests (UFV1 and UFV2) and the Attended Field of View (AFOV) (Coeckelbergh et al., 2004).

In all the visual attention tests the white targets and distracters (when included) were presented on a computer monitor with grey background and having 50% contrast (Weber's contrast) measured with a Minolta cs-100 photometer. The viewing distance was 50 cms and the UFV target, which was a triangle, had a total angular subtense of 1.37 x 1.2 degrees (82 minutes of arc x 72 minutes of arc) and the width of the line was 0.23 degrees (13.8 minutes of arc, equivalent to 6/83m Snellen acuity). The circular distractors subtended 1.39 degrees (83 minutes of arc) as did the Landolt C targets in the AFOV and the width of the line was 0.34 degrees (20.6 minutes of arc, equivalent to 6/124m Snellen acuity). The gap of the Landolt C target used in the AFOV was 0.23 degrees. There were 24 potential locations of the target located at three possible eccentricities 4, 8 and 12 degrees, and eight possible radii oriented at 0, 45, 90, 135, 180, 225, 270, 315 degrees. There was no central target in any of the visual attention tasks as using a central task has little effect on performance on the UFV (Leat & Lovie-Kitchin, 2006). The order of presentation of the target location was randomized. Testing was conducted under binocular viewing conditions and participants were provided with their best near spectacle prescription required for that working distance in a trial frame.

For the UFV1 (Figure 4-1a) participants were asked to identify the location of a white triangle. The target was presented for 160 milliseconds to preclude any eye movement during the target presentation, and was followed by a visual mask. For the UFV2, the same triangle target as UFV1 was used, but it was placed amongst 23 circles, which acted as distractors (Figure 4-1b). Participants were asked to point to the location of the triangle on the screen and to guess if they were unsure. The location of their response was recorded so that errors could be calculated in terms of the direction being correct (ignoring the eccentricity). An arcsine transformation was performed on all the UFV data as has been done by others (Ball et al. 1988; Leat & Lovie-Kitchin, 2008).

The AFOV test was designed according to Coeckelbergh and colleagues (2004) (Figure 4-1c). In this test participants were asked to locate a Landolt C amongst 23 circles. The gap of the

Landolt C was randomly oriented up, right, left, or down. In order to shorten the test and prevent fatigue, targets were only presented in 9 out of the 24 possible locations in the AFOV (3 targets in each ring distributed evenly among the visual field sectors) (Figure 4-1d). The participants were not informed that only 9 locations were to be tested, and were not aware of this afterwards. During the test the duration of the stimulus was varied to determine a threshold in milliseconds. This was done by running an interleaved one up and one down staircase of the presentation time for each of the 9 locations. Each location's staircase was independent of the others. The order of presentation of the nine locations was randomized. The presentation time started at a full second, hence allowing eye and head movements and the step size was 0.1 log unit. The number of trials at each location was 30 trials, making a total of 270 trials. These numbers were chosen after preliminary testing which showed that a threshold was approached after this number of trials and starting from this duration. The final threshold was determined based on the following criteria a) at least 8 reversals, b) the minimum slope for the regression line when trial duration was plotted against time.

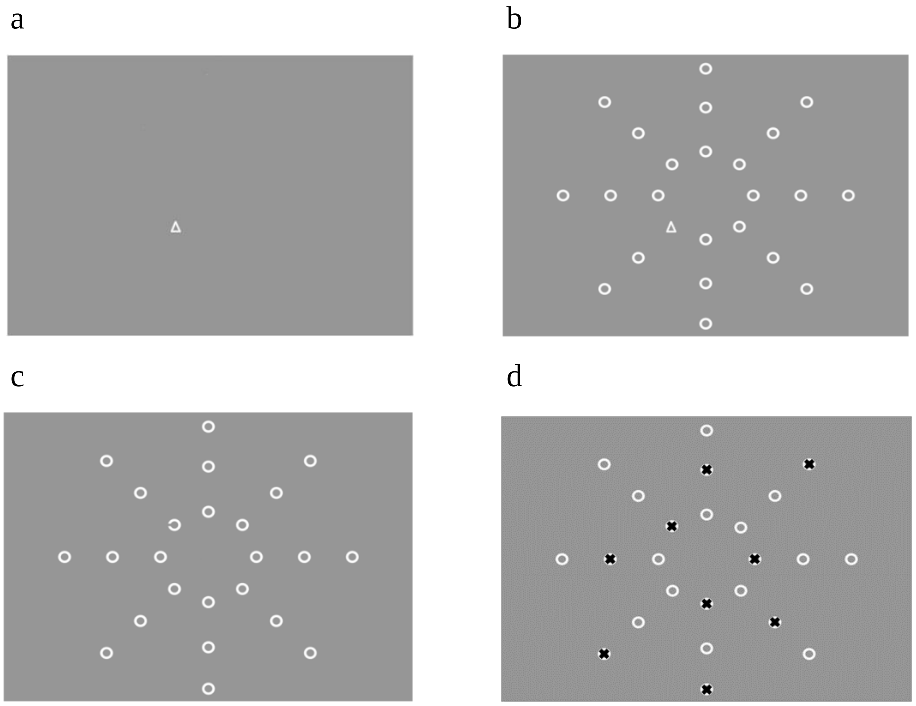

Figure 4-1:Visual attention tests. a**, UFV1: target presented with no distractors.** b**, UFV2: target presented with distractors.** c**, AFOV: target presented with distractors.** d**, AFOV: locations where the targets were presented are marked in crosses**

Balance and Mobility

Of the balance and mobility tests, the One Legged Stance test (OLST) was performed first. The OLST is a clinical tool that has been used in the assessment of postural balance, falls and injurious falls (Vellas et al., 1997; Hurvitz, Richardson, Werner, Ruhl, & Dixon, 2000). Since there is no significant difference between left vs. right or dominant vs. non-dominant foot while performing the OLST, or with shoes off or on (Briggs, Gossman, Birch, Drews, & Shaddeau1989), participants were asked to decide which leg they prefer to stand on and the test was performed wearing their shoes, on a smooth hard floor. Participants were asked to stand on both feet in a relaxed stance with their arms close to their body. The participants were then asked to lift one leg up and straight forward in front of their body while still maintaining their arms next to their body. Participants kept their eyes open during the test and fixated on a target in front of them. They were asked to maintain their balance and the trial was terminated at 30 seconds. Their performance was timed and the best out of two trials was recorded as the duration they were able to maintain their balance up to 30 seconds.

The Sit to Stand test (STST) was performed next. This clinical test was chosen as it has been shown to be reliable in assessing falls risk, balance, and muscle strength (Buatois et al., 2008; Buatois et al., 2010; Lord, Murray, Chapman, Munro, & Tiedemann, 2002). An armless standard height chair (44.5cm) with 1cm of padding was used and the participants were asked to wear their usual comfortable footwear. The participants were asked to start the test in the seating position with their arms next to their body and their back against the chair’s backrest. Then they were instructed to put their arms next to their body and to stand up and sit down 5 times as fast as they felt comfortable and safe. They were asked to keep looking straight ahead and not to use their arms to push up from the chair. The task was demonstrated before they started and they were asked to stand up fully between each repetition and to not touch the back of the chair. If the participant did the first repetitions incorrectly the examiner would stop the test and demonstrate the procedure, before starting again. The stopwatch started when the examiner said “Go” and stopped at the fifth repetition when the participants first touched the chair seat. The final outcome was the duration it took the participant to complete the task. Those who were unable to complete this task were excluded from the analysis of the STST test.

Thirdly, the 5 Meter Walk test (5MWT) was performed. This test was chosen because it has good reliability (ICC= 0.862) in predicting walking speed (Fulk & Echternach, 2008). A tape marked the starting and finishing point for the 5 meter walking course. An additional 1.50 meters (equivalent to 3 walking steps) at the beginning and the end of the course was included to allow some space for acceleration and deceleration. Therefore, an 8 meter walking distance was used but only the time taken to walk the middle 5 meter distance was measured. The walking course was straight with no obstacles and was on a hard floor. The participants were instructed to walk this course as fast as they felt comfortable and safe and to continue walking until they were asked to stop. The examiner was following the participant along the course and timed the start when the leading foot crossed the first tape mark and stopped as soon as the leading foot crossed the second tape mark. The time taken was the outcome measure.

Fear of Falling Questionnaire

Fear of falling was assessed using the Falls Efficacy Scale-International questionnaire (FES-I) (Kempen et al., 2007; Yardley et al., 2005). It is comprised of 16 questions assessing how concerned the individual is about falling while doing various daily living tasks in or outside the house. It uses a four level scale. It was administered verbally with the examiner marking the response on the question sheet.

Analysis

The primary outcome measures were fear of falling as measured by the FES-I and difficulty with mobility and balance as measured by the 5MWT, the STST and the OLST. Predictive factors were measures of vision, including binocular vision and eye movement disorders, visual acuity, contrast sensitivity, stereoacuity and visual attention tests (UFV and AFOV), plus demographic factors, such as sex, age, general health and number of medications. Unadjusted univariate linear regression analysis was followed by linear regression adjusted for age and then for age, sex, number of general health conditions and number of medications. The independent variables that were moderately close to reaching significant correlation in the unadjusted linear regression ($p < 0.2$) were entered in a multiple regression analyses model using a forward stepwise regression with p value of 0.2 to enter and 0.15 to remove. As many of the predictor variables might be correlated with each other, a variance inflation factor analysis was conducted to examine if the results of the multiple regressions were affected by multicollinearity. Data analysis was undertaken with Systat software (Systat Software, Inc. San Jose, CA, USA).

4.3 Results

The prevalence of binocular vision and eye movement disorders was 69%, while 53% of this sample had abnormal stereoacuity (worse than 60 seconds of arc). Table 4-1 shows the characteristics of the sample in this study.

Table 4-1: The characteristics of the 72 participants

Characteristic	Mean ± SD (Range)
Age, yrs	**80.3 ± 5.9 (71 - 93)**
Female, n (%)	**41 (57%)**
Height (cm)	**163 ± 12.9 (123 - 190)**
Number of general health conditions	**3.27 ± 1.92 (1-8)**
Number of eye conditions	**1.34 ± 0.98 (0 - 4)**
Percent wearing single vision/bifocals/trifocals/progressive lenses	**10%, 48%, 17%, 25%**
Distance VA (logMAR)	**0.045 ± 0.11 (-0.22 - 0.34)**
Intermediate VA (distance spectacles) (logMAR)	**0.13 ± 0.12 (-0.14 - 0.45)**
Intermediate VA (reading ADD) (logMAR)	**0.53 ± 0.22 (0.07 - 1)**
CS (log)	**1.60 ± 0.07 (1.35 - 1.7)**
Stereoacuity (sec. of arc)	**97 ± 135 (20-600)**
STST (seconds)	**16.2 ± 6 (9.68-39.19**
OLST (seconds)	**10.6 ± 10 (1-30)**
5MWT (seconds)	**4 ± 1.2 (2.5-9.7)**

Two participants were removed from the analysis of the STST due to the inability to perform the task. In the unadjusted univariate linear regression, longer duration in completing the STST was significantly correlated with binocular vision and eye movement disorders (p=0.014), worse intermediate VA (through the distance portion of the spectacles, p=0.005), poorer visual attention with the UFV2 (p=0.014), having had cataract surgery (p=0.005), higher chance of depression (p=0.04), worse general and eye health (p= 0.005 and p=0.034 respectively), more medications (p <0.001) and age (p=0.001). Table 4-2 shows the variables that were found to be significantly associated. All other variables were not significantly associated. After adjusting for age, poor performance in the STST was significantly associated with binocular vision and eye movement disorders (p=0.01), worse intermediate VA (through the distance portion of the spectacles, p=0.022), higher chance of depression (p=0.006), worse general health (p=0.009) and higher number of medications (p=0.001) (See Table 4-2). After adjusting for age, sex, number of general health conditions and the number medications, the STST was associated with worse intermediate VA (through the distance portion) (p=0.019) (See Table 4-2).

The final model of the stepwise multiple regression is shown in Table 4-3 (F [3,58]= 10.763, p<0.001, final $R^2 = 0.358$). In this model the STST was associated with more medications (p=0.002), worse intermediate VA (through the distance portion, p=0.002) and having had cataract surgery (either or both eyes) (p=0.016).

Table 4-2: Unadjusted and adjusted regression for the Sit to Stand test.

STST	Unadjusted	Adjusted for Age	Adjusted for Age/Sex/ General health/ No. of medications
Independent variable	r (p)	r (p)	r (p)
BV and eye movement disorders	0.297 (0.014)	0.284 (0.010)	0.195 (0.073)
Intermediate VA (distance spectacles)	0.345 (0.005)	0.273 (0.022)	0.270 (0.019)
Useful field of view (UFV2)	0.296 (0.014)	0.183 (0.126)	0.128 (0.272)
Cataract surgery	0.335 (0.005)	0.206 (0.089)	0.061 (0.636)
Depression	0.250 (0.04)	0.304 (0.006)	0.165 (0.164)
No. of General health conditions	0.338 (0.005)	0.291 (0.009)	n/a
No. of eye health conditions	0.258 (0.034)	0.217 (0.054)	0.140 (0.206)
No of Medications	0.431 (<0.001)	0.389 (0.001)	n/a
Age	0.406 (0.001)	n/a	n/a

Table 4-3: Multiple step-wise regression models for the STST for all the dependent variables

Dependent Variable	Predictor variable	Unadjusted R^2 at each step	Standardized Coefficient (β)	t	P value
STST	**No of Medications**	**0.183**	**0.350**	**3.219**	**0.002**
	Intermediate VA (distance spectacles)	**0.289**	**0.341**	**3.238**	**0.002**
	Cataract Surgery	**0.358**	**0.271**	**2.486**	**0.016**
Adjusted R^2 for the model= 0.324					**p for the model <0.001**

Compromised balance with the One Legged Stance test was found to be associated with binocular vision and eye movement disorders (p=0.019), worse intermediate VA (through the distance spectacle lens p=0.014), poor contrast sensitivity and stereoacuity (p=0.047 and p=0.003 respectively), poor visual attention with the UFV2 and the AFOV (p=0.001 and p <0.001 respectively), having had cataract surgery (p=0.024), hearing loss (p=0.004), more medications (p=0.004), shorter height (p=0.003) and age (p <0.001). Table 4-4 shows the variables that were found to be significantly associated. All other variables were not significantly associated. After age-adjustment, the OLST was still associated with binocular vision and eye movement disorders (p=0.001), stereoacuity (p=0.002), poor visual attention with the UFV2 (p=0.025) and AFOV (p=0.014), hearing loss (p=0.014) and more medications (p=0.004). (Table 4-4) When adjusted for other confounders (age, sex, poorer general health and the number of mediations), OLST was significantly associated binocular vision and eye movement disorders and stereopsis (p= 0.002 and p=0.003 respectively) (See table 4-4).

The final model for the step-wise multiple regression analysis for the OLST is shown in Table 4-5 (F [8,58]= 20.0.69, p<0.001, final R^2= 0.735). Poor balance measured with the OLST was predicted by age (p<0.001), binocular vision and eye movement disorders (p <0.001), more medications (p=0.005), having had cataract surgery (p=0.002), poor visual attention with the UFV 2 (p=0.006) and stereoacuity (p=0.049).

Table 4-4: Unadjusted and adjusted linear regression for the One Legged Stance test.

OLST	**Unadjusted**	**Adjusted for Age**	**Adjusted for Age/Sex/ General health/ No. of medications**
Independent variable	**r (p)**	**r (p)**	**r (p)**
BV and eye movement disorders	**-0.276 (0.019)**	**-0.300 (0.001)**	**-0.285 (0.002)**
Intermediate VA (through distance spectacles)	**-0.294 (0.014)**	**-0.177 (0.086)**	**-0.184 (0.071)**
Contrast sensitivity	**0.235 (0.047)**	**-0.579 (0.077)**	**0.127 (0.188)**
Stereoacuity	**-0.345 (0.003)**	**-0.300 (0.002)**	**-0.283 (0.003)**
Useful field of view (UFV2)	**-0.389 (0.001)**	**-0.224 (0.025)**	**-0.189 (0.061)**
Attended Field of View (AFOV)	**-0.442 (<0.001)**	**-0.251 (0.014)**	**-0.190 (0.070)**
Cataract surgery	**-0.265 (0.024)**	**-0.041 (0.699)**	**0.021 (0.851)**
Hearing loss	**-0.332 (0.004)**	**-0.087 (0.014)**	**-0.092 (0.434)**
No of Medications	**-0.347 (0.004)**	**-0.275 (0.004)**	**n/a**
Height	**0.358 (0.003)**	**0.191 (0.074)**	**0.146 (0.217)**
Age	**-0.598 (<0.001)**	**n/a**	**n/a**

Table 4-5: Multiple step-wise regression models for the OLST for all the dependent variables

Dependent Variable	Predictor variable	Unadjusted R^2 at each step	Standardized Coefficient (β)	t	P value
OLST	Age	0.314	-0.529	-6.741	<0.001
	BV and eye movement disorders	0.424	-0.306	-4.027	<0.001
	No of Medications	0.615	-0.208	-2.885	0.005
	Cataract Surgery	0.653	0.271	3.220	0.002
	Useful field of view (UFV2)	0.689	-0.215	-2.837	0.006
	Stereoacuity	0.710	-0.148	-2.009	0.049
Adjusted R^2 for the model = 0.698					p for the model <0.001

Mobility with the 5 Meter Walk test was associated with reduced VA at distance (p=0.002) and intermediate (through the distance spectacles, p =0.001), poor visual attention with the UFV2 and the AFOV (p=0.041 and p=0.008 respectively), having had cataract surgery (p<0.001), hearing loss (p=0.004), worse general health (p= 0.010) and age (p <0.001). In addition, females and shorter individuals walked more slowly in the 5MWT (p=0.002 and p <0.001 respectively). Table 4-6 shows the variables that were found to be significantly associated. All other variables were not significantly associated. After age-adjustment slower walking was associated with reduced distance VA (p=0.01) and intermediate VA (through the distance spectacles p=0.006). In addition, females (p=0.002) and shorter participants (p=0.001) walked slower. After also correcting for sex, poorer health and medications, slower times in the 5MWT were associated with distance VA (p=0.019) and intermediate VA (through the distance spectacles, p=0.010) (See Table 4-6).

Table 4-6: Unadjusted and adjusted linear regression for the 5 Meter Walk test.

5MWT	**Unadjusted**	**Adjusted for Age**	**Adjusted for Age/Sex/ General health/ No. of medications**
Independent variable	**r (p)**	**r (p)**	**r (p)**
Distance VA	**0.364 (0.002)**	**0.259 (0.010)**	**0.219 (0.019)**
Intermediate VA (distance spectacles)	**0.391 (0.001)**	**0.284 (0.006)**	**0.251 (0.010)**
Useful field of view (UFV2)	**0.244 (0.041)**	**0.075 (0.479)**	**0.052 (0.602)**
Attended Field of View (AFOV)	**0.314 (0.008)**	**0.117 (0.281)**	**0.089 (0.390)**
Cataract surgery	**0.393 (<0.001)**	**0.150 (0.167)**	**-0.082 (0.471)**
Hearing loss	**0.340 (0.004)**	**0.035 (0.753)**	**0.045 (0.691)**
No. of General health conditions	**0.303 (0.010)**	**0.225 (0.024)**	**n/a**
Sex	**0.355 (0.002)**	**0.297 (0.002)**	**n/a**
Height	**-0.494 (<0.001)**	**-0.351 (0.001)**	**-0.212 (0.062)**
Age	**0.563 (<0.001)**	**n/a**	**n/a**

Table 4-7: Multiple step-wise regression models for the 5MWT for all the dependent variables.

Dependent Variable	Predictor variable	Unadjusted R^2 at each step	Standardized Coefficient (β)	t	P value
5MWT	**Age**	**0.239**	**0.372**	**4.320**	**<0.001**
	Sex	**0.391**	**0.367**	**4.221**	**<0.001**
	No of Medications	**0.463**	**0.294**	**3.747**	**0.001**
	Distance VA	**0.510**	**0.269**	**3.155**	**0.002**
Adjusted R^2 for the model = 0.374					**p for the model <0.001**

The step-wise multiple regression model for the 5MWT is shown in table 4-7 (F [6,61]= 14.779, p<0.001, final R^2= 0.592). Slower walking speed in older adults was significantly related to age (p <0.001), sex (p<0.001), more medications (p=0.001) and distance VA (p=0.002).

Fear of falling as measured with the FES-I was associated with worse intermediate VA (through the spectacle's distance portion) (p=0.049), having had cataract surgery (p=0.005), worse general health (p=0.010), more medications (p=0.035) and age (p=0.01). In addition, females and shorter individuals showed more concern about falling (p=0.009 and p=0.007 respectively). Table 4-8 shows the variables that were found to be significantly associated. All other variables were not significantly associated. After adjusting for age, worse general health (p=0.024) and female sex (0.016) were the only predictors to remain significant (See table 4-8). In contrast, none of the factors that we measured remained significant after controlling for the other confounders.

The step-wise multiple regression model for the FES-I is shown in table 4-9. (F [3,68]= 8.9, $p<0.001$, final $R^2= 0.282$). Fear of falling was predicted by age ($p<0.001$), sex (p=0.011) and depression (p=0.21).

Table 4-8: Unadjusted and adjusted linear regression for the Falls Efficacy Scale-International questionnaire.

FES-I	Unadjusted	Adjusted for Age	Adjusted for Age/Sex/ General health/ No. of medications
Independent variable	r (p)	r (p)	r (p)
Intermediate VA (distance spectacle portion)	0.238 (0.049)	0.163 (0.163)	0.121 (0.284)
Cataract surgery	0.327 (0.007)	0.192 (0.109)	0.120 (0.960)
No. of General health conditions	0.301 (0.010)	0.249 (0.024)	n/a
No of Medications	0.255 (0.035)	0.214 (0.063)	n/a
Sex	0.391 (0.009)	0.265 (0.016)	n/a
Height	-0.324 (0.007)	-0.225 (0.061)	0.041
Age	0.391 (0.001)	n/a	n/a

Table 4-9: Multiple step-wise regression models for the FES-I for all the dependent variables.

Dependent Variable	**Predictor variable**	**Unadjusted R^2 at each step**	**Standardized Coefficient (β)**	**t**	**P value**
FES-I	**Age**	**0.153**	**0.379**	**3.662**	**<0.001**
	Sex	**0.223**	**0.270**	**2.614**	**0.011**
	Depression	**0.282**	**0.244**	**2.372**	**0.021**
Adjusted R^2 for the model = 0.25					**p for the model <0.001**

The variance inflation factor analyses revealed that the variance inflation factors ranged from 1.0 to 1.55, which indicates that the coefficients in our regression models are stable and not affected by multicollinearity (Hair, Anderson, Babin, & Black, 2010).

4.4 Discussion

In this study, the associations, which were expected from the literature, between balance and mobility with age, sex, medication use, and general health conditions were found, but also there are aspects of vision which contribute to these outcomes, even when corrected for these expected predictors. Some association was anticipated between vision and balance/mobility because the visual system is an important contributor to maintaining balance (Buckley, Heasley, Twigg, & Elliott, 2005; Paulus et al., 1984; Pyykko, Jantti, & Aalto, 1990).

Interestingly, some of the less frequently measured aspects of vision were among these that were associated.

An association between stereoacuity and depth perception with postural control (Lord & Menz, 2000) and falls risk (Nevitt et al., 1989; Lord & Dayhew, 2001; Cummings et al., 1995) has been reported, although not all studies have confirmed this association (Friedman et al., 2002, Freeman, Munoz, Rubin, & West, 2007). Previous work has shown the OLST performance to deteriorate with eyes closed compared to eyes open (Bohannon, Larkin, Cook, Gear, & Singer, 1984; Springer, Marin, Cyhan, Roberts, & Gill, 2007). In an OLST stance the body has a narrower base of support compared to bilateral stance and in the absence of vision an increased amount of corrective action in the ankle, knees, hip and trunk is needed for postural control (Riemann, Myers, & Lephart, 2003). In the present study stereopsis and binocular vision and eye movement disorders were found to be associated with the OLST. During the OLST, when participants are asked to stand still, it is possible that good stereopsis helps because depth information is available to reduce postural sway. Previous work showed that the mean time for standing on one leg for older adults is 17 seconds (Bohannon, 2006). In our study all those who had a stereoacuity of 150 seconds of arc or worse could not stand for 17 seconds (in fact the maximum OLST time was 6.5 seconds). This represents a positive predictive value of 100%. Presence of a BV or eye movement disorder was also predictive of poor OLST - 94% of participants with BV and eye movement disorders had a OLST of <17 seconds.

Binocular vision and eye movement disorders in older adults have received little attention. The high prevalence of these disorders (69% in the current study) is alarming, because many BV disorders can be managed with vision therapy, optical correction or surgery, and their correlation in this study with balance, suggests that eye care practitioners should be more proactive in preventing or treating such disorders, as suggested by Cummings et al (1995). This may improve balance for some patients and reduce the incidence of falls. Management of BV disorders may also improve stereopsis, which was also commonly reduced in this sample (53%) and a predictor in the model for the OLST. A further study would be needed to look at the different types of BV and eye movement disorders to determine which are most closely associated with poor balance and falls. It is also of interest to determine whether it is those that are amenable to treatment of recent onset that are more closely associated.

Recently, the STST has also been shown to be affected by the absence of the visual input (Siriphorn, Chamonchant, & Boonyong, 2015) and failure to sit and stand for 5 times in less than 15 seconds was associated with recurrent falls (Buatois et al., 2008) and in less than 10 seconds was associated with future disability (Makizako, 2017). In the current study, the STST was predicted by intermediate VA through the distance lenses, and indicates that participants used their distance portion of their spectacles during this task, yet they were viewing at an intermediate distance. From a clinical prediction point of view, all those who had an intermediate VA of 0.35 logMAR (approximately 20/40) or worse had a STST time of more than 15 seconds (the minimum STST time was 15.8 seconds). This represents a positive predictive value of 100%. The STST involves larger changes in the center of mass compared to the OLST, and so may explain why a “lower level” of visual function, i.e. VA was associated, rather than sensory stereopsis.

Several studies have demonstrated that reduced distance visual acuity is a risk factor for falls (Lord & Dayhew, 2001; Klein et al., 2003: Coleman et al., 2004) while others did not find an association (Stalenhoef, Diederiks, Knottnerus, Kester, & Crebolder, 2002). Adequate visual input is an important element in locomotion control and hazard negotiation (Patla, 1997). In this study distance VA was associated with mobility (5MWT) but not balance, which may be understood, since the 5MWT involved a clear corridor, with no steps or obstacles. Therefore participants may have tended to look ahead through their distance spectacle portion. However, distance and near VA were highly correlated, and it may be a question of chance which one has the higher correlation in any data set.

The association between the UFV and mobility impairment have been previously discussed (Owsley & McGwin, 2004). The association between the AFOV, balance or/and mobility has never been studied previously. Both types of visual attention tests used in this study (UFV and AFOV) are age dependant, due to slower visual processing with advancing age (Coeckelbergh et al, 2004; Sekuler & Ball, 1986). This may explain why, after adjusting for age, the visual attention tests lost their significant correlation with the STST and the 5MWT (Tables 2a and 4a), although their association with the OLST (table 3a) remained significant. However, in the full multiple regression model the UFV2 was a significant predictor of balance in addition to binocular vision and eye movement disorders and stereopsis (Table 3b).

The association with visual attention is important as visual processing skills are amenable to improvement with training, which can persist up to 2 years (Sekuler & Ball, 1986) or even up to 5 years (Willis et al., 2006). Ball et al. combined the data of 6 studies that investigated the effect of visual training on visual attention. They found that training can have an immediate improvement on everyday activities and driving performance (Ball, Edwards, & Ross, 2007). Other studies found that training of visual processing speed can improve the ability to complete everyday visual tasks (Edwards et al., 2005), improve health related quality of life (Wolinsky, Unverzagt, Smith, Jones, Wright, & Tennstedt, 2006), enhance driving abilities (Ball, Beard, Roenker, Miller, & Griggs, 1998) and reduce depression (Wolinsky et al., 2009). The present results suggest that such training could also improve balance and mobility, thereby reducing the number of falls in older adults. Therefore, future work in this field is necessary to see whether training older adults' visual processing can make these improvements.

In the current study we found the average fear of falling score for the participants to be 23.6, which puts this sample on the high concern side. Knowing that fear of falling can cause anxiety (Painter et al., 2012), less activity (Bruce, Devine, & Prince, 2002; Howland et al., 1993), depression (Arfken et al., 1994), isolation (Howland et al., 1998) and reduced quality of life (Li et al. 2003). It is not surprising that the FES-I in this study was strongly associated with general health in the adjusted analysis and predicted by age and depression (together with sex) in the stepwise regression. In the literature, the association between vision and fear of falling is not strong. Klein et al. (2003) found fear of falling was associated with visual acuity but other studies did not (Friedman et al., 2002; Donoghue et al. 2014). Other studies found an association with self-reported visual status and fear of falling (Donoghue et al. 2014: Howland et al. 1998). In the present study the only measure of vision that was associated with the FES-I was intermediate VA. However, this correlation did not remain significant once corrected for age. This weaker link with vision may be because the questionnaire responses are not a direct measure of mobility or balance performance and thus are more influenced by other factors.

Forty percent of our participants had undergone a cataract surgery in either one or both eyes. Interestingly, having had cataract surgery was a predictor for poorer performance in the STST in the regression model. This is not as expected, as cataract surgery is expected to improve vision and therefore improve balance. However, the links reported in the literature between falls and cataract surgery are mixed. Some studies found that cataract surgery decreased the risk of falls (Brannan et al., 2003; Schwartz et al., 2005; Tseng, Yu, Lum, & Coleman, 2012), while others found no change (Harwood et al. 2005; McGwin, Gewant, Modjarrad, Hall, & Owsley, 2006) although Harwood et al. found a reduction in multiple falls. Other studies reported that falls increased (Meuleners, Fraser, Ng, & Morlet, 2014). The present finding does not seem to be attributable to the effect of adjustment post-cataract surgery, since most of our sample underwent the surgery more than two years prior to the study. However, our finding might be attributed to pseudophakic dysphotopsias. It has been suggested that these may compromise the visual function of post cataract patients even when visual acuity is good (Kinard, Jarstad, & Olson 2013). This effect may depend on the type of intra-ocular lens used (Kershner, 2003; Mester, Dillinger, & Anterist, 2003). In our cohort the type of intra-ocular lens is not known.

Limitations

The main limitation of this study is the relatively small sample size and that balance and mobility were measured with clinical assessments. Measuring balance on a force plate platform would be a more quantified and accurate measure. However, despite this, associations were found between vision and balance and mobility.

4.5 Conclusion

To conclude, in this study several new visual parameters have been shown to be correlated with poor balance and mobility; visual attention, binocular vision and eye movement disorders, stereopsis, and intermediate or distance visual acuity. Since a substantial portion of the older population lose balance and fall every year, it is imperative that eye care practitioners who work with older adults be aware of these associations, question older adults about a history of falls or walking and balance problems, and ensure that the vision of older people is optimally managed. Similarly, it is important that all health care professionals working with older adults be aware of the links with vision. Studies which consider the impact of training or correction of these visual deficits on balance, mobility and falls are indicated and would increase our knowledge of effective interventions.

Chapter 5

Visual impairment and its effects on mobility and balance

5.1 Introduction

The number of visually impaired individuals in Canada is estimated to be around half a million Canadians. Every year more than 50,000 individuals suffer visual loss (CNIB). In chapter 4 the association between tests of balance, mobility, and fear of falling with measures of vision, including binocular vision and visual attention was investigated for individuals without visual impairment (VI). It was found that several new visual parameters to be correlated with poor balance and mobility; visual attention, binocular vision and eye movement disorders and intermediate visual acuity. This chapter will review the results from a population with visual impairment (low vision) who were also recruited to the study described in Chapter 4.

5.2 Methods

Participants

Participants who were recruited had an ocular diagnosis that would result in VI, were relatively healthy, older adults, aged 70+, and living independently in the community. They were recruited from the Primary Care and Low Vision Clinics at the School of Optometry and Vision Science at the University of Waterloo, and attended the School to take part in the study. Exclusion criteria were binocular visual acuity better than 6/12 and worse than 6/60, not able to speak English, diagnosed with cognitive impairment according to their file at the Primary Care Clinic and unable to walk independently without a walker or a cane. The same experiment protocol as in chapter 4 was used in this study, with the exception that the tests of visual attention were not included. These were not possible, as the targets were too small for many of these participants to detect.

Analysis

Due to the small sample size, the results were considered descriptively, comparing those with visual impairment with the participants in chapter 4 (normal vision). The demographic differences between the populations were analyzed with the two sample t-test (different variances). For those that were recorded in percentage (presence of binocular vision disorders) a 95% confidence interval range was calculated to see whether there is a significant difference between those with visual impairment versus those with normal sight .The primary measures were difficulty with mobility and balance as measured by the Sit to Stand test (STST), One Legged Stance test (OLST) and the 5 Meter Walk test (5MWT) and Fear of Falling (FES-I). In stereoacuity testing a score of 600 seconds of arc was assigned to participants who could not see the target. A Pearson correlation coefficient analysis was conducted to measure the correlation between continuous variables, while for dichotomous variables a Spearman correlation coefficient analysis was conducted.

5.3 Results

Nine participants took part in this study (mean age 82.2 yrs ± 7.55) and 55% were female. Table 5-1 shows a comparison between the participants in chapter 4 (normal vision) and those with visual impairment.

Table 5-1: Demographic comparison between normal vision and visually impaired participants.

	Normal vision (n=72)	**Low vision (n=9)**	**t-test (p value)**
Age (yrs) (mean ± SD,range)	80.3 ± 5.9, 71-93	82.2 ± 7.55, 71-93	0.49
height (cm)	163 ± 12.9	163 ± 11.7	0.94
# of general health conditions	3.3 ± 1.9	4.4 ± 1.2	0.02
# of medications	4.8 ± 3.6	7.75 ± 6	0.26
# of eye conditions	1.3 ± 1	2.9 ± 0.6	<0.001
Distance VA	0.04 ± 0.11	0.65 ± 0.3	<0.001
Intermediate VA (distance spectacles) (logMAR)	0.13 ± 0.12	0.7 ± 0.3	<0.001
Intermediate VA (reading ADD) (logMAR)	0.53 ± 0.22	0.92 ± 0.22	0.0013
CS (log)	1.60 ± 0.07	0.96 ± 0.31	<0.001
Stereoacuity (sec. of arc)	97 ± 135	600 ± 0. This was the default value i.e. all could not complete the test.	<0.001
Binocular vision disorders	69% (95% CI: 58 to 79%)	100% (95% CI: 65.5 to 100%)	NS
Fear of falling (score)	23.6	27	0.35
STST (seconds)	16.2 ± 6	17.9 ± 5.9	0.43
OLST (seconds)	10.6 ± 10	5.3 ±3.7	0.004
5MWT (seconds)	4 ± 1.2	5.6 ± 2.74	0.11

Firstly, the effect of age on the different balance and mobility tasks was investigated for both groups (Figure 5-1). In the normally sighted group, age was found to be significantly correlated with the STST, OLST and 5MWT ($p<0.001$ in all cases) (Figure 5-1). However, in the group with VI, age was not significantly associated with balance or mobility ($p>0.05$) (Figure 5-1). It is interesting to note that the VI group are mostly scattered within the values of the group with normal vision, with the exception of a few outliers.

The STST, OLST and the 5MWT in the normally sighted participants were associated with intermediate VA (distance spectacles) ($p=0.005$, 0.014 and <0.001 respectively) (Figure 5-2). Distance VA, on the other hand, was only significantly correlated with the 5MWT ($p=0.002$) but not the STST or the OLST ($p=0.1$ and 0.12 respectively) (Figure 5-3). However, in the group with VI, no significant correlation was found between the balance and mobility tasks and intermediate and distance VA ($p>0.05$) (Figures 5-2 and 5-3). This is probably due to the small sample size. However, it is interesting to note that for the OLST and the STST, the data for the intermediate VA (distance spectacles) and distance VA for the participants with VI does not follow the same trajectory as those with normal vision, although for the 5MWT, they do (Figures 5-2 and 5-3).

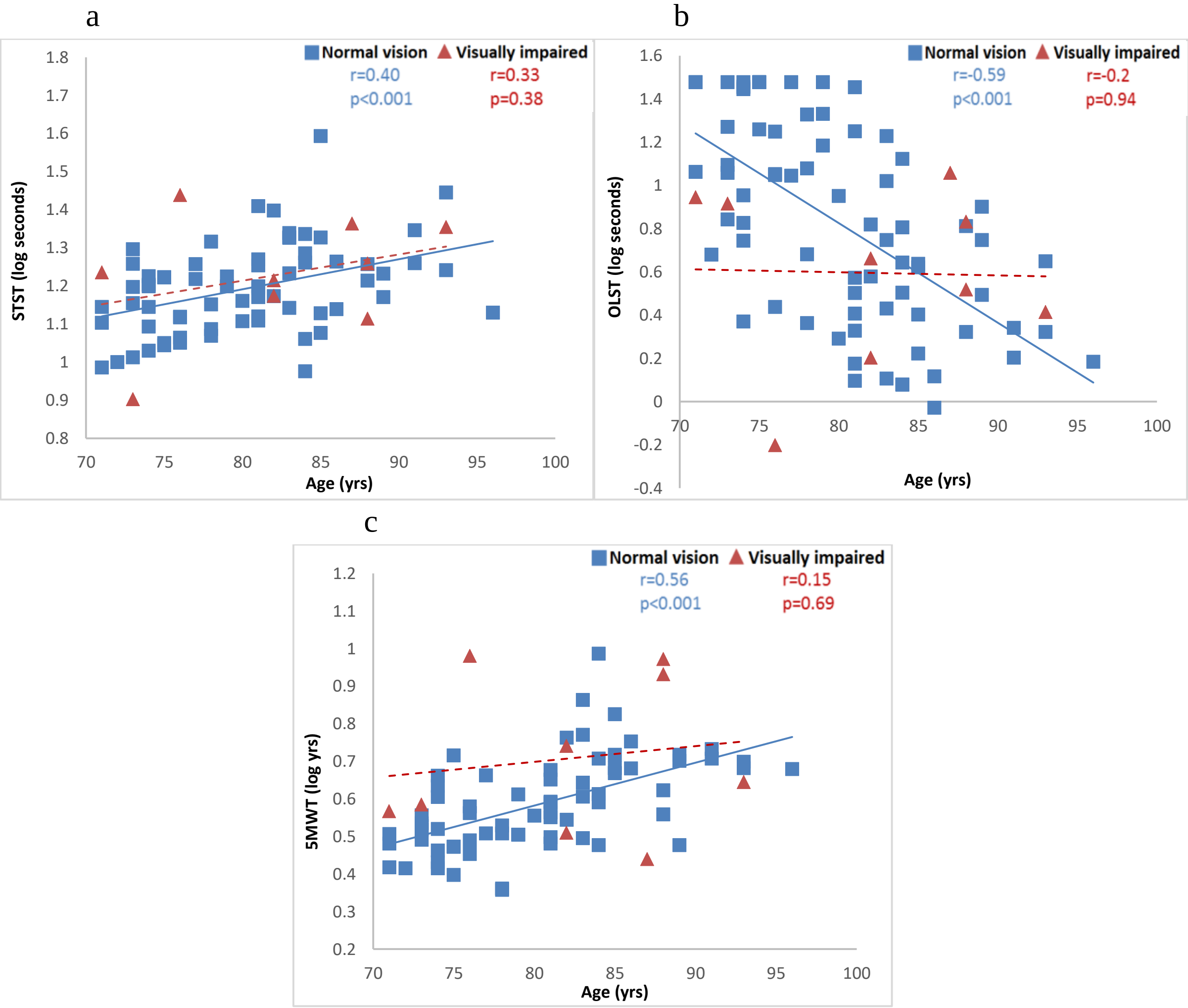

Figure 5-1: Scattergram showing the effect of age for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test. Blue squares = normal vision, red triangles = visually impaired

Contrast sensitivity in the normally sighted group was associated with the OLST (p=0.047) but not with the STST or 5MWT (p>0.05) (Figure 5-4). In the group with VI none of the balance or mobility tasks was correlated with contrast sensitivity (p>0.05) (Figure 5-4). It is interesting to note that the data of the participants with VI in all the balance and mobility tasks does not follow the same trajectory as those with normal vision.

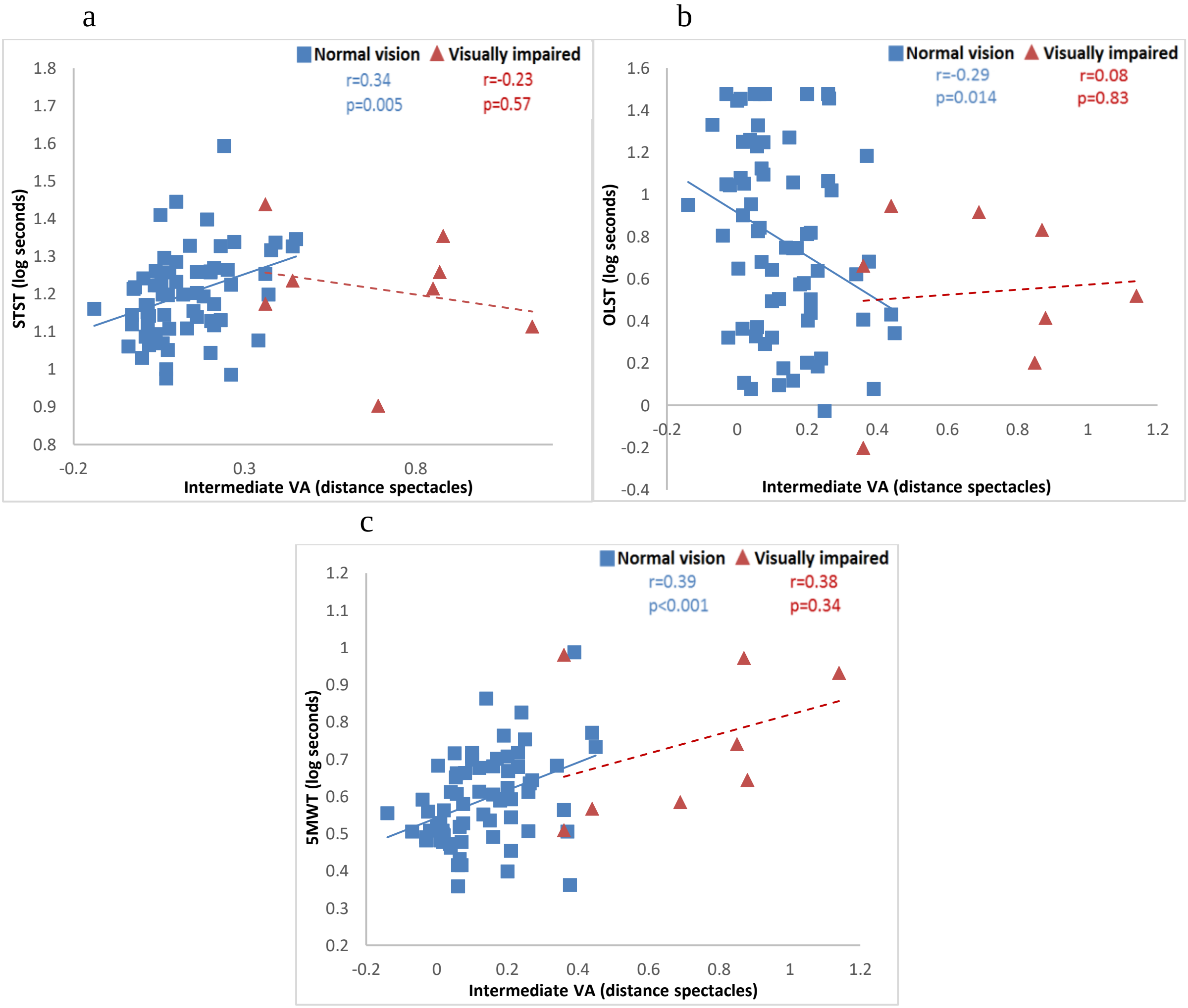

Figure 5-2: The effect of intermediate VA (distance portion) for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test. Blue squares = normal vision, red triangles = visually impaired

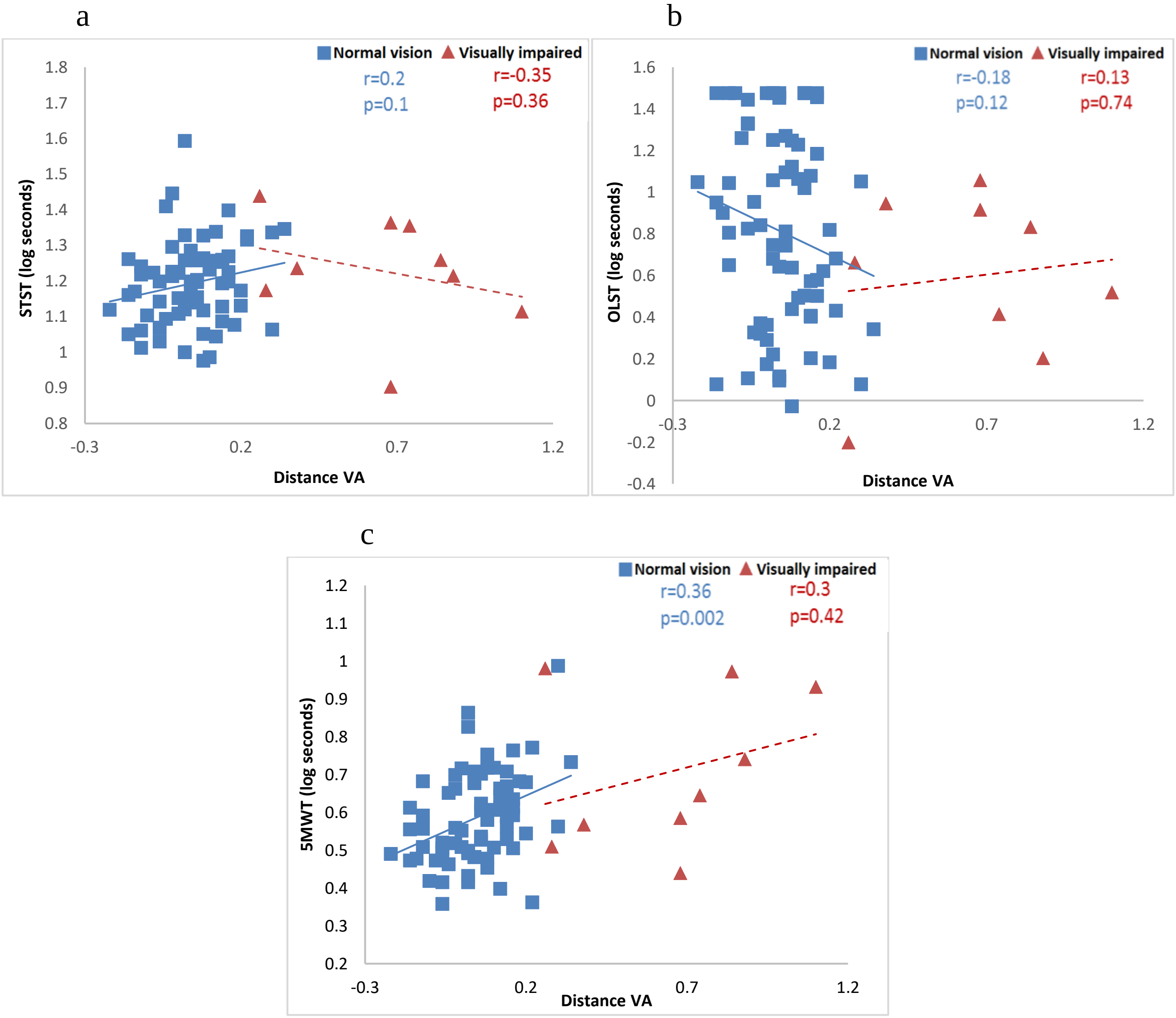

Figure 5-3: The effect of distance VA for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test. Blue squares = normal vision, red triangles = visually impaired

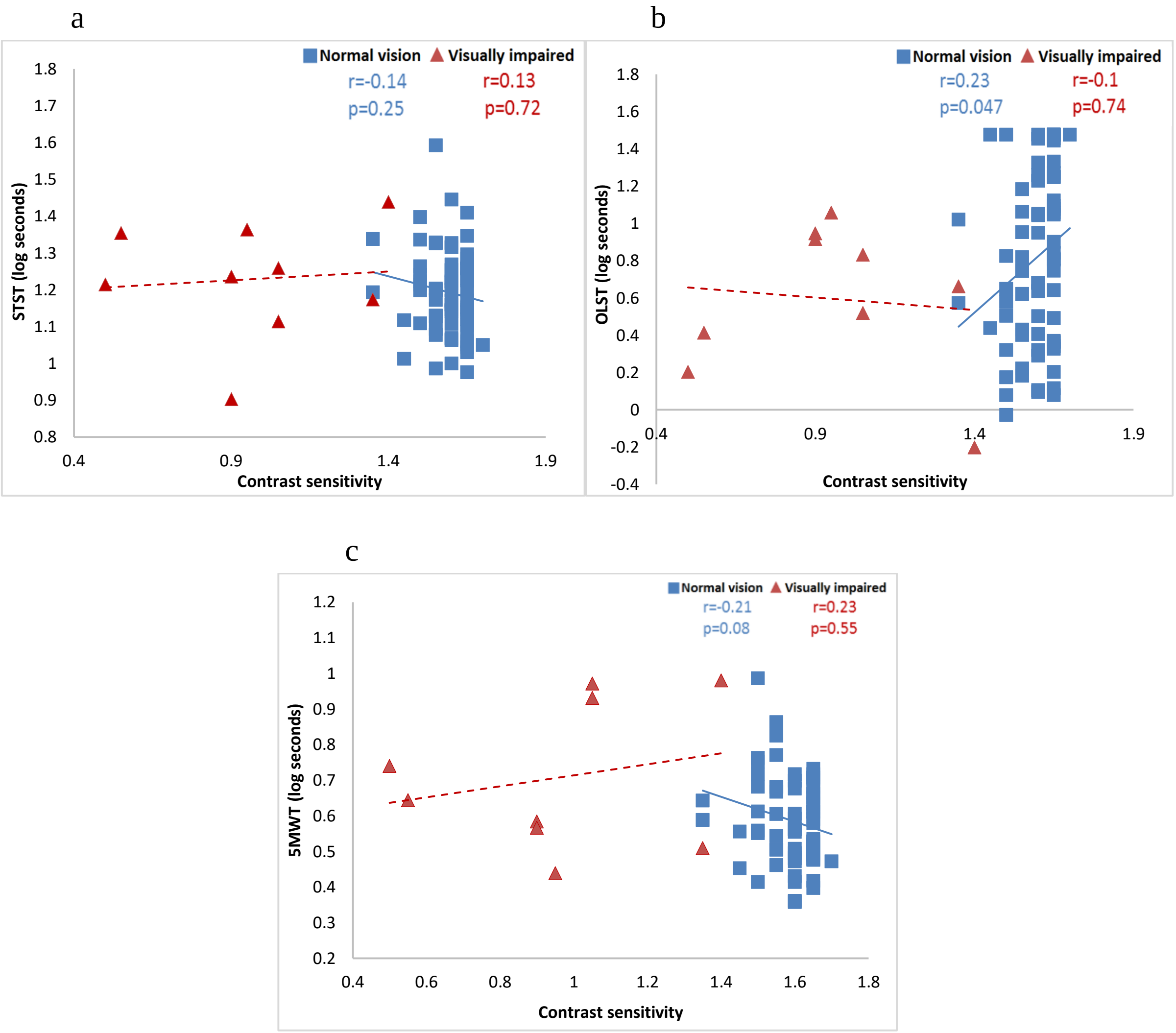

Figure 5-4: **The effect of contrast sensitivity for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test. Blue squares = normal vision, red triangles = visually impaired**

Having poorer general health in the normally sighted group was associated with the STST, and 5MWT (p=0.005 and p= 0.001 respectively) but not with the OLST (p=0.054) (Figure 5-5). On the other hand, in the group with VI none of the balance or mobility tasks were associated with poorer general health (p>0.05) (Figure 5-5). The data of the participants with VI largely lies within that of those with normal vision, with the exception of a few outliers.

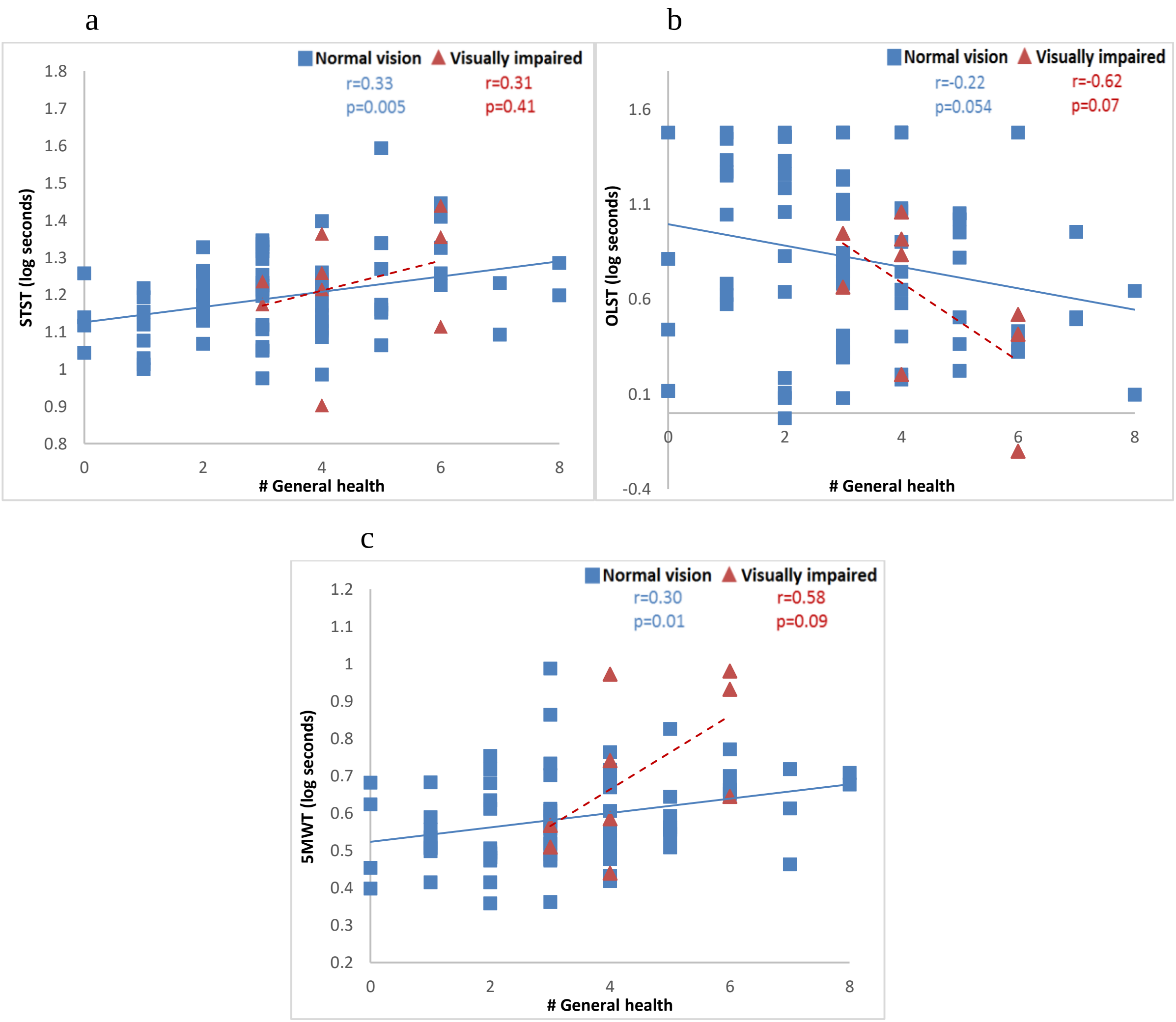

Figure 5-5: **Scattergram showing the effect of general health for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test General health. Blue squares = normal vision, red triangles = visually impaired**

Having undergone a cataract surgery in either one or both eyes was associated with the STST, OLST and the 5MWT (p=0.005, 0.02 and <0.001 respectively). Those who had had cataract surgery performed less well. In the group with VI this reached significance for the STST (p<0.01) (Figure 5-6). There was no significant correlation between the OLST and 5MWT and cataract surgery in the group with VI (p>0.05) (Figure 5-6).

Having higher fear of falling measured with the FES-I questionnaire in the normally sighted group was significantly correlated with age, intermediate VA (distance spectacles), poor general health and undergoing cataract surgery (p=0.001, 0.049, 0.01 and 0.007 respectively) (Figure 5:7). In the group with VI, fear of falling was associated with poor general health (p=0.035). All other variables were not significantly associated (p>0.05) (Figure 5-7). It should be noted that the VI group showed similar fear of falling to the normally sighted group (Table 5-1 and Figure 5-7) and both groups scored more than 23 points on the FES-I which put them on the high concern side. The data for age, the general health status and cataract surgery for the participants with VI largely lies within that of those with normal vision. By definition, the VA and CS are poorer for the VI group, but the FES-1 does not seem to be correspondingly poorer.

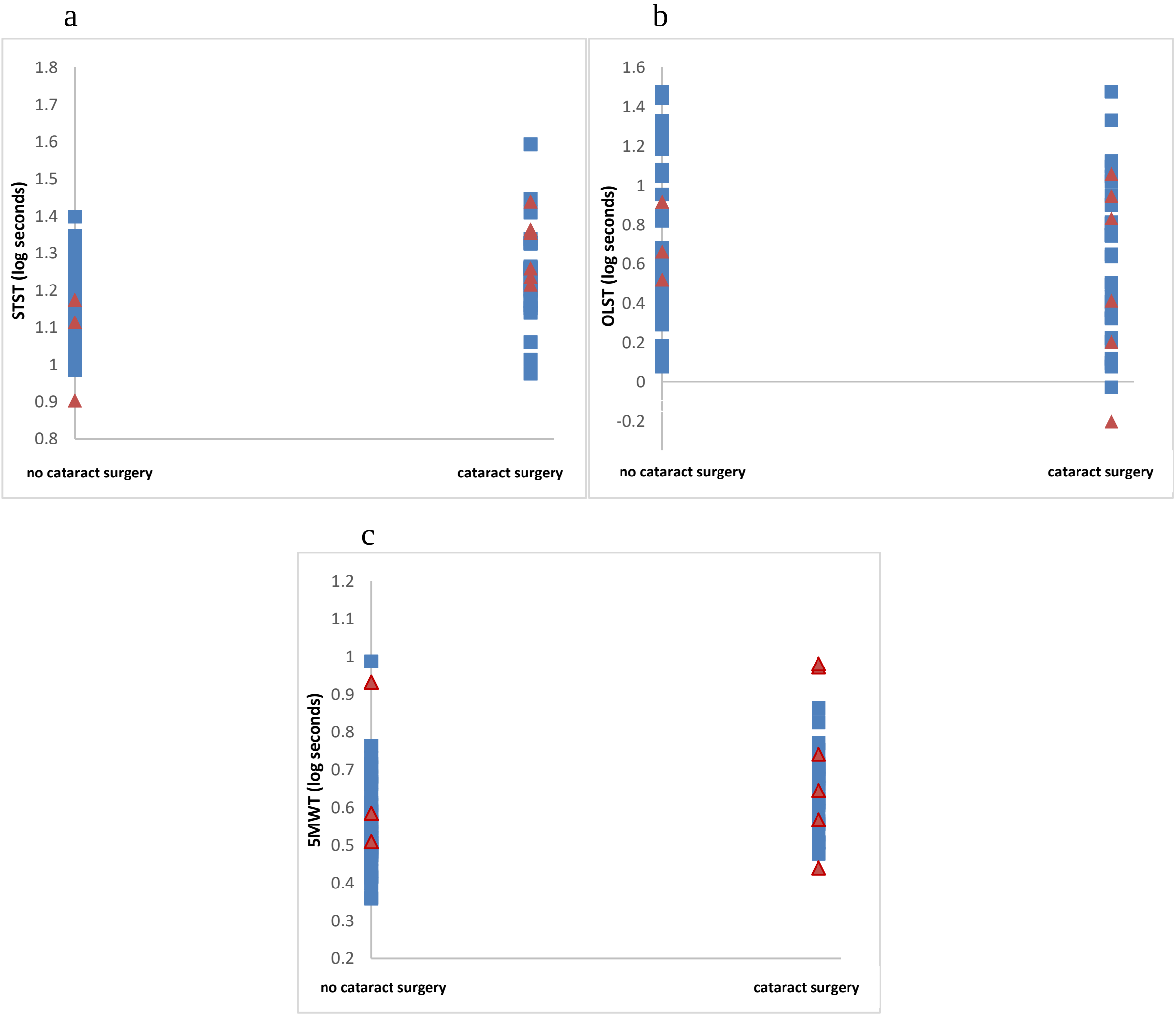

Figure 5-6: Scattergram showing the effect of undergoing cataract surgery for both groups on the performance of the a. Sit to Stand test, b. One Legged Stance test c. 5 Meter Walk test. Blue squares = normal vision, red triangles = visually impaired

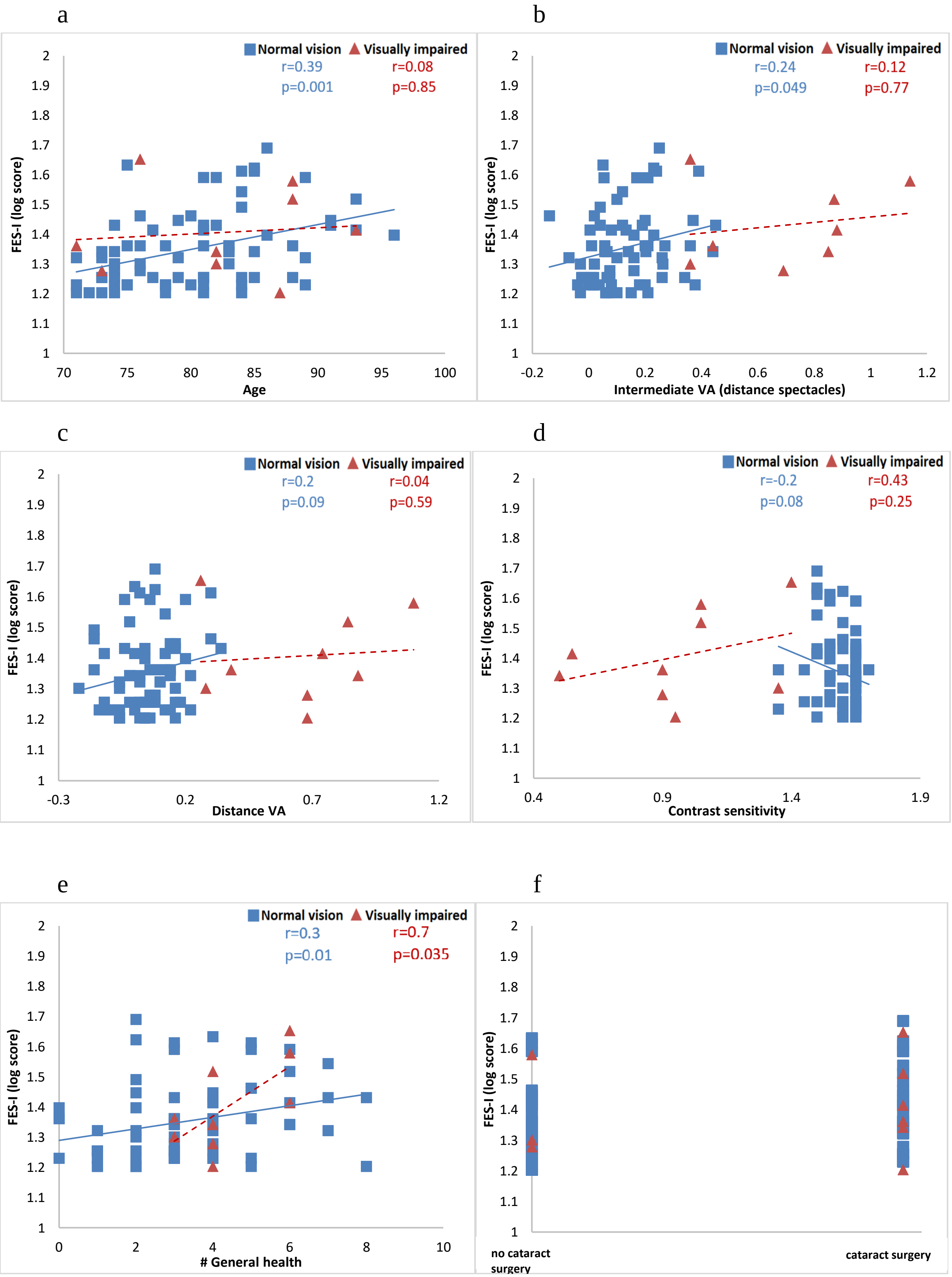
a
Normal vision
Visually impaired
r=0.39
p=0.001
r=0.08
p=0.85
FES-I (log score)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
70
75
80
85
90
95
100
Age
b
Normal vision
Visually impaired
r=0.24
p=0.049
r=0.12
p=0.77
FES-I (log score)
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
Intermediate VA (distance spectacles)
c
Normal vision
Visually impaired
r=0.2
p=0.09
r=0.04
p=0.59
FES-I (log score)
-0.3
0.2
0.7
1.2
Distance VA
d
Normal vision
Visually impaired
r=-0.2
p=0.08
r=0.43
p=0.25
FES-I (log score)
0.4
0.9
1.4
1.9
Contrast sensitivity
e
Normal vision
Visually impaired
r=0.3
p=0.01
r=0.7
p=0.035
FES-I (log score)
0
2
4
6
8
10
General health
f
FES-I (log score)
no cataract surgery
cataract surgery

Figure 5-7: **Scattergram showing the effect of a. age, b. intermediate VA (distance portion), c. distance VA, d. contrast sensitivity, e. general health, f. undergoing cataract surgery for both groups on the performance of the FES-I questionnaire. Blue squares = normal vision, red triangles = visually impaired**

5.4 Discussion

Vision is a major contributor to postural and locomotion control (Hallemans et al., 2010; W. Paulus et al., 1984; Pyykko et al., 1990). The results in chapter 4 also show this to be the case in the normally sighted individuals as various visual measures were correlated to balance and mobility. In participants with VI, however, this association was not so clear. Participants with VI demonstrated a similar range of performance in balance and mobility to those with normal vision, rather than being far poorer, as would be predicted from their much poorer visual abilities. This suggests that VI patients have adapted in some way to their visual impairment and other mechanisms are being implemented to compensate for this loss. This is interesting and agrees with previous work which showed that the lack of accurate visual input due to an ocular disease can be compensated by other balance systems (somatosensory and vestibular) to adequately maintain balance control (Anand et al., 2003; Elliot et al., 1995; Lord et al., 1991).

In regards to general health the correlation in the visually impaired individuals was borderline significant for the OLST and 5MWT (Figure 5-3), although this may have been due to having low power in this part of the study.

An unexpected result was found in regards to cataract surgery and its relation with balance and mobility in the group with normal vision (see chapter 4 for more explanation). The visually impaired group shows the same trend as those with normal vision - having had cataract surgery was a predictor for poorer performance, and this reached significance for the STST ($p<0.01$) (Figure 5-6a). This was discussed in Chapter 4 as possibly caused by pseudophakic dysphotopsias rather than the effect of adjustment post-cataract surgery, since most of our sample underwent the surgery more than two years prior to the study. It should be noted that it is unknown whether cataract surgery was performed before or after the onset of other ocular disease. The individuals who had cataract may have had another reason for poor VA at the time of the surgery or may have developed reduced VA afterwards. So perhaps undergoing cataract surgery made less improvement in their visual acuity, and they therefore, still depend on the other systems for balance control. Overall, it still seems true that cataract surgery may decrease balance and mobility performance.

Limitations

Having a low number of participants in this study is a limitation. Unfortunately, it was difficult to recruit more participants in the visually impaired group. Another limitation was that the UFV and AFOV (see chapter 4) were not designed for the visually impaired at the outset, and it was found that this group were not able to complete these tests.

5.5 Conclusion

To conclude, none of the predictors in the group with visual impairment was correlated with any of the balance or mobility tasks with the exception of an agreement between cataract surgery and STST. This might have been due to the lower number of participants with LV. But what is clear is that the group with VI exhibited similar performance in the balance and mobility tasks (Table 5-1) even though they were at a disadvantage due to their visual loss. This could indicate that VI participants have developed some adaptations and are compensating by other systems of balance to overcome their visual loss and maintain their postural balance.

Chapter 6

Are all visual attention tests the same?

6.1 Introduction

Slowing in visual processing speed is part of aging. Older adults require more time to process visual information especially in the presence of cluttered visual environment, so that more time and effort is required to process incoming visual input (Ball et al., 1988; Sekuler, Bennett, Mamelak, 2000). One way of assessing visual processing is by examining the functional field of view (FFOV). The functional field of view (FFOV) is "the region from which useful information can be acquired during a given eye fixation." (Henderson & Ferreira, 2013) Previous research described a number of tests that could be used to measure the FFOV. One common approach is the use of the Useful Field of View (UFOV®) (Ball et al., 2007; Ball & Owsley, 1993; Leat & Lovie-Kitchin, 2008; Owsley, 1994). The UFOV® is a computer based program that measures the area where useful information can be extracted in a short glance without head or eye movements (Ball et al., 1988). In the UFOV® a peripheral target is presented and localization of the target in the presence or absence of distractors or a dual task is required. The UFOV® has been shown to be a predictor of car crash involvement (Ball et al., 2006; Owsley et al., 1998), reduced balance and mobility (Althomali & Leat, 2013; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004), increased time for completing instrumental activities of daily living and visual tasks, such as, reading a can label, finding a phone number in a telephone book or finding scissors in a crowded drawer (Edwards et al., 2005; Owsley, McGwin, Sloane, & Stalvey, 2001)

Other tests that are less common in measuring the FFOV have emerged, such as, the Attended Field of View (AFOV) (Coeckelbergh et al., 2002; Coeckelbergh et al., 2004). The AFOV uses a visual search paradigm and is used to assess the area of functional and useful visual field while allowing head and eye movements during testing. The AFOV mimics everyday life viewing situations where head and eye movements occur. The AFOV is correlated to age (Coeckelbergh et al., 2004) and driving performance (Coeckelbergh et al., 2002).

Both tests seem to be valid tests of visual attention, however, to date there has no study of how correlated these measures are. The aim of this study is to investigate the correlation between different tests of visual attention. This investigation has not been considered before, and if a high correlation exists then they can be considered as measuring the same aspect of vision as being interchangeable. In experiment 1 (Chapter 4), participants undertook both the UFV and AFOV, and so their data are compared here.

6.2 Subject and methods

Participants

The participants recruited in this study were the same participants recruited in Chapter 4.

Methods

The apparatus, procedure, design and analysis were previously described in chapter 4. It should be noted, however, that for the UFV1, participants were asked to identify the location of a white triangle without the presence of any distractors while for UFV2, the same triangle target as UFV1 was used, but it was placed amongst 23 circles, which acted as distractors. A more detailed description of the methods used can be found in section 3.2.1 of this thesis.

Analysis

As described in Chapter 4, in the UFV the participants’ responses were recorded so that errors could be calculated in terms of exact location being correct (direction and eccentricity) or the direction only being correct (ignoring the eccentricity). In this chapter the data was analyzed in each of these ways. An arcsine transformation was performed on all the UFV data as in previous studies (Sekuler et al. 2000; Ball et al. 1988; Leat and Lovie-Kitchin 2008).

For the AFOV, the final threshold was determined by plotting trial duration against the trial number and taking the average of the reversals of the last section of the plot. The values included in this averaging were based on the following criteria a) at least 8 reversals, b) the minimum slope for the regression line.

In this chapter, an unadjusted univariate linear regression analysis was performed to measure the correlation between different tests of visual attention, followed by linear regression adjusting for age and then for age, sex, number of general health conditions and number of medications.

6.3 Results

In the unadjusted univariate linear regression, the UFV analyzed in different ways was significantly correlated with the AFOV (Table 6-1). These associations remained when adjusting for age, and then for age, sex, general health and number of medications.

Table 6-1: **Unadjusted and adjusted linear regression for all the visual attention tests**

	AFOV unadjusted	**AFOV adjusted for age**	**AFOV adjusted for age, sex, general health and number of medications**
	r (p)	**r (p)**	**r (p)**
UFV1 (Exact location)	0.5 (<0.001)	0.58 (<0.001)	0.56 (<0.001)
UFV1 (Correct direction)	0.4 (0.001)	0.45 (<0.001)	0.44 (0.001)
UFV2 (Exact location)	0.62 (<0.001)	0.57 (<0.001)	0.59 (<0.001)
UFV2 (Correct direction)	0.56 (<0.001)	0.51 (<0.001)	0.52 (<0.001)

6.4 Discussion

The results of this experiment show that the UFV is significantly associated with the AFOV although both these test employ different strategies for localizing the target; the AFOV uses a free viewing paradigm, which allows head and eye movements while the UFV does not. This link is independent of age, sex, general health and number of medications.

However, although these tests are significantly correlated, the correlation co-efficient is not high (ranging from 0.4 to 0.62) (Table 6:1). The amount of variance explained by this would be between 16% and 38%. This outcome suggests these two measures are not interchangeable and that there are differences in the aspect of vision that is measured. This might be explained by the considerable differences between these two measures of visual attention. To elaborate, the UFV assesses how much information can be processed in a specified time frame, whereas the AFOV assesses the time needed to locate the target and process the orientation of the Landolt C. This results in two distinct approaches to measure the integrity of the functional field of view.

Moreover, different analyses were used to determine the functional field of view, where localization errors are calculated either in terms of actual location errors (direction or direction and eccentricity) (UFV) or duration in milliseconds to detect various targets' eccentricities using a staircase (AFOV). Data transformation was also different; arcsine and logarithmic transformations were applied to the UFV and AFOV data, respectively. This was because the data was in percent correct in the UFV and milliseconds in the AFOV.

Another difference is the more complex target utilized in the AFOV compared to the UFV. The Landolt C target used in the AFOV is very similar to the distracters around it while in the UFV, the target shape is more different than the distractors. When the presented target has a unique feature from the surrounding distractors a parallel processing strategy occurs and that target “pops out”. This results in a shorter presentation time to identify the target. However, when the target shares some features with the distractors then a serial processing strategy is implemented, which requires more time to process the visual targets (Treisman & Gelade, 1980). The different strategies used in these two tests might have caused the more different UFV target to “pop out” and be detected by more parallel processing while the AFOV be a more serial task.

Chapter 7

Can older adult's balance and mobility improve with visual attention training?

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Authors' contribution

Author	Concept/Design	Acquisition of Data	Analysis	Write up/Publication
Althomali	✓	✓	✓	✓
Vallis	✓	Advised	Advised	Edited
Leat	✓	Advised	Advised	Edited

Overview

Purpose: We hypothesize that training older adults with a structured visual attention task will result in improved balance and mobility, potentially reducing their risk for falls.

Methods: Healthy older adults aged 70+ took part in the study (mean age 80.3 ± 6 yrs). In this randomized controlled trial (NCT02030743), 15 participants were randomly assigned to a visual attention training group and 15 to a control group. Visual attention training was undertaken with versions of a selective attention useful field of view test and attended field of view test. The outcome measures were postural sway using a force plate platform, the mini Balance Evaluation Systems Test, the One Legged Stance test, the 5 Meter Walk test, the Sit to Stand test, the Timed Up and Go test without and with a concurrent cognitive task.

Results: There was a greater improvement in visual attention after training in the intervention group compared to the control group ($p< 0.01$). However, a mixed ANOVA (2x group, 2x visit, 5x trials) showed no main effect of visit or group or any interaction for any of the force plate platform parameters. A mixed ANOVA (2x group, 2x visit) of the changes over time between the intervention group and the control groups for the other balance and mobility assessment tools showed no improvement after training.

Conclusion: Although visual attention itself was improved by the training, there was no improvement in mobility or balance after the visual attention training and no difference between the intervention and the control groups.

7.1 Introduction

Falls are not random events and are quite common among seniors. It is projected that one in every three seniors experience a fall every year (Choy, Brauer, & Nitz, 2003; Dolinis, Harrison, & Andrews, 1997; Lord & Clark 1996), and some experience multiple falls annually (Lord & Ward 1994; Lord & Dayhew 2001). In institutional settings the falls rate increases to 60% of all residents experiencing a fall at least once a year (Lord et al., 2003). Falls are a major cause of injury or even death among older adults in Canada (Centers for Disease Control and Prevention, 2015; Public Health Agency of Canada, 2014). The injuries sustained after a fall can cause loss of independence, immobilization, impaired daily function, reduced health status, early institutionalization and even death (Alegre-Lopez, Cordero-Guevara, Alonso-Valdivielso, & Fernandez-Melon, 2005; Cumming, Salkeld, Thomas, & Szonyi, 2000; Davidson, Merrilees, Wilkinson, McKie, & Gilchrist, 2001; Dunn, Sadkowsky, & Jelfs, 2002; Koski, Luukinen, Laippala, & Kivelä, 1998; Tinetti, Speechley, & Ginter, 1988; Tinetti, De Leon, Doucette, & Baker, 1994).

Given the epidemiological data and potential catastrophic results after a fall (Centers for Disease Control and Prevention, 2015; Public Health Agency of Canada, 2014) it is not surprising that falls are a major concern for seniors and the health care system; clearly, falls prevention is an important matter that needs to be addressed. In the past, studies on fall prevention typically included either an intervention that targets vision, exercise, environment modification, education intervention or a combination of these interventions grouped together. Many studies have found that exercise is effective for falls prevention (Barnett, Smith, Lord, Williams, & Baumand, 2003; Cadore, Rodríguez-Mañas, Sinclair, & Izquierdo, 2013; Fitzharris, Day, Lord, Gordon, & Fildes, 2010; Karlsson, Vonschewelov, Karlsson, Coster, & Rosengen, 2013; Sherrington, Whitney, Lord, Herbert, Cumming, & Close, 2008). Others report that improving vision (e. g: conducting cataract surgery) is effective in reducing falls (Brannan et al., 2003; Harwood et al., 2005; Schwartz et al., 2005), although not all studies are in agreement (McGwin, Gewant, Modjarrad, Hall, & Owsley, 2006). The current consensus is that the most effective falls prevention programs may be those that have a multi-component approach and this is the recommendation of current researchers in this area of study (Cameron et al., 2012; Clemson et al., 2004; Day et al., 2002; Fitzharris et al., 2010) and joint Geriatric Society guidelines (Kenny et al. 2011; American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopedic Surgeons Panel on Falls Prevention 2001)..

It is interesting that many studies have reported a strong association with reduced visual acuity (Lord & Dayhew, 2001), contrast sensitivity (Ivers, Cumming, Mitchell, & Attebo, 1998; Klein B, Klein R, Lee, & Cruickshanks, 1998), depth perception (Lord & Menz, 2000; Nevitt, Cummings, Kidd, & Black, 1989) and field of view (Black, Wood, & Lovie-Kitchin, 2011) and falls incidents. Collectively these findings suggest the importance of having optimum vision for safer navigation and falls reduction, however it is interesting that, to date, the impact of a purely visual attention training program aimed to improve balance and/or mobility has not been studied. The current study was designed to fill the gap in the scientific literature. Specifically we were interested in visual attention training as a modality to improve balance and/or mobility in older adults with the goal of reducing falls. Reduced visual processing speed (for example as measured with visual attention tests) is part of aging and older adults require more time than younger adults to process visual information, particularly in the presence of visual clutter (Sekuler & Ball, 1986; Sekuler, Bennett, & Mamelak, 2000). Additionally, reduced visual attention is associated with balance and mobility (Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004) and visual attention training programs have been shown to improve visual attention performance (Sekuler & Ball, 1986; Willis et al., 2006). We hypothesize, therefore, that training older adults with only a structured visual attention task will result in improved balance and mobility in this group of individuals. The study design was a randomized controlled trial, participants being randomized to either a visual attention training group or a control group who did not change any of their behaviors, but continued to undertake their normal daily activities.

7.2 Methods

Participants

The recruited participants were living independently in the community without any assistance and were healthy older adults, aged 70+ (mean age 80.3 yrs ± 6, range 70-95 yrs). The first method of recruitment was from a previous study conducted in the same laboratory (Althomali & Leat, 2013). Participants were chosen based on their falls rate, balance status and visual attention scores. We chose those with poorer balance, reduced mobility and low visual attention, so that there was room for improvement. Another source of recruitment was through the Primary Care clinic at the School of Optometry and Vision Science at the University of Waterloo. Participants were excluded from participation if their visual acuity was worse than

6/12 in either eye, unable to speak English, diagnosed with cognitive impairment or cognitive delay or not able to walk independently without a walker or a cane. This study was reviewed and received clearance through a University of Waterloo Research Ethics Committee. The study is registered with ClinicalTrials.gov, number NCT02030743.

There are no previous data of the effect of visual attention training with the UFV or AFOV on mobility and balance on which to base a sample size calculation. So sample size was based on studies which showed a significant improvement of visual attention with training. The studies of Richards et al. (2006), Ball et al. (1988) and Sekuler and Ball (1986) showed a significant improvement of visual attention with the useful field of view training with 8, 9 and 8 participants respectively. The most similar data to the visual attention training that we were planning was that of Richards et al. (2006). We estimated the mean pre and post difference and standard deviation from the data of older participants in the focused attention task. For a two sample t-test with 80% power and a significance level of 5%, a sample size of 12 participants per group was calculated. We increased the sample size to 15 participants in each group to be sure not to be underpowered.

Baseline measures

All testing and training took place at the School of Optometry and Vision Science (see Figure 7-1 for the protocol). At baseline demographic information, such as sex, age, general health and number of medications were collected. Binocular distance visual acuity was measured with the habitual spectacles using a Bailey-Lovie logMAR acuity chart and using by-letter scoring (Bailey & Lovie, 1976) at a distance of 3 meters.

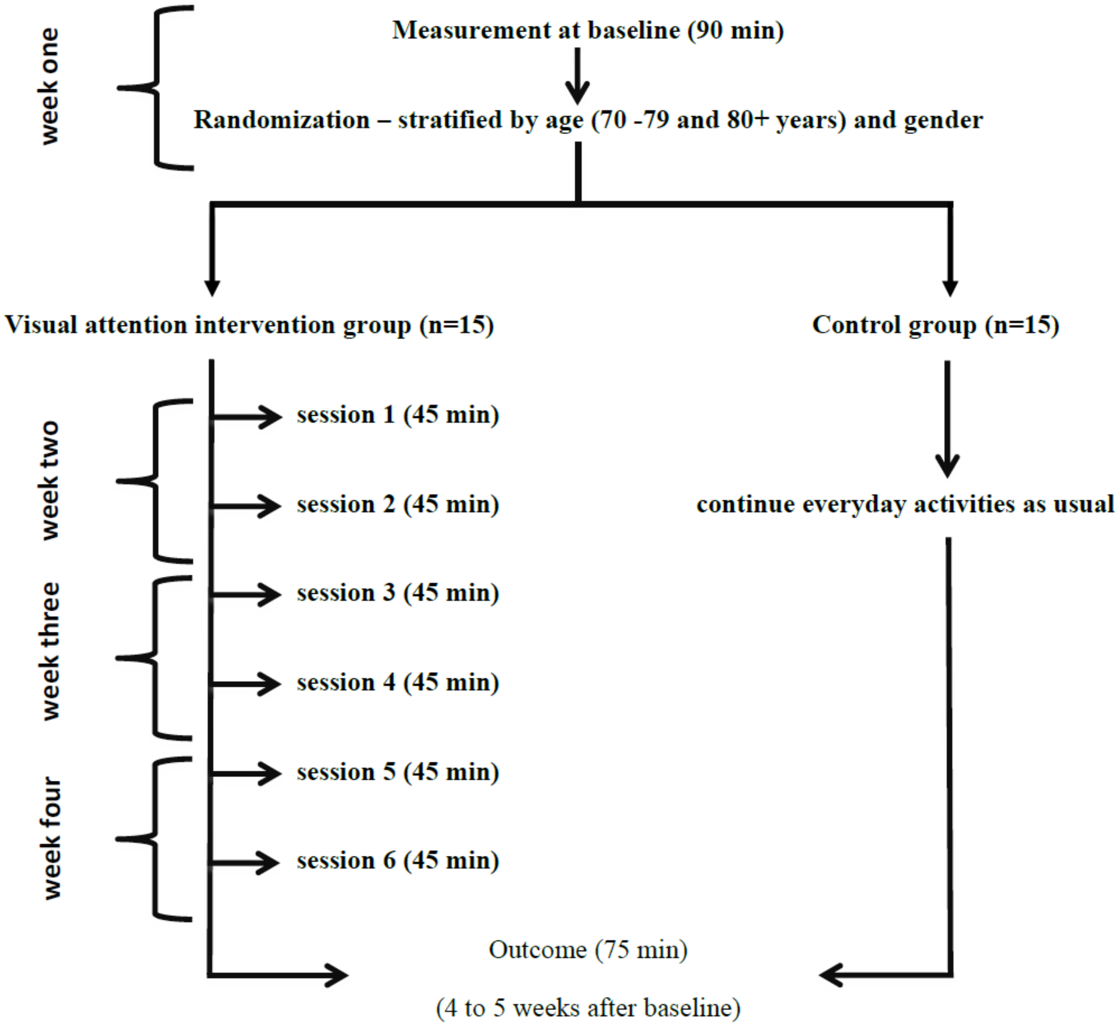


Figure 7-1: Study protocol

Visual attention

Visual attention was measured with a useful field of view test (UFV) (Ball, Beard, Roenker, Miller, & Griggs, 1988; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986) including 2 subtests (UFV1 and UFV2) and the Attended Field of View (AFOV) (Coeckelbergh, Cornelissen, Brouwer, & Kooijman, 2004).

In all the visual attention tests, the white targets and distracters (when included) were presented on a computer monitor with grey background and having 50% contrast (Weber's contrast) measured with a Minolta cs-100 photometer. The viewing distance was 50 cms and the UFV target, which was a triangle, had a total angular subtense of 1.37 x 1.2 degrees (82 minutes of arc x 72 minutes of arc) and the width of the line was 0.23 degrees (13.8 minutes of arc, equivalent to 6/83m Snellen acuity). The circular distractors subtended 1.39 degrees (83 minutes of arc) as did the Landolt C targets in the AFOV and the width of the line was 0.34 degrees (20.6 minutes of arc, equivalent to 6/124m Snellen acuity). The gap of the Landolt C target used in the AFOV was 0.23 degrees. Testing was conducted under binocular viewing conditions and participants were provided with their best near spectacle prescription required for that working distance in a trial frame.

For the UFV1 (Figure 7-2a) participants were asked to identify the location of a white triangle. The target was presented for 200 milliseconds to preclude any eye movement during the target presentation, and was followed by a visual mask. There were 24 potential locations of the target, located on three possible eccentricities 4, 8 and 12 degrees and eight possible radii oriented at 0, 45, 90, 135, 180, 225, 270, 315 degrees. The order of presentation of the target location was randomized. For the UFV2, the same triangle target as UFV1 was used, but it was placed amongst 23 circles, which acted as distractors (Figure 7-2b). Participants were asked to point to the location of the triangle on the screen and to guess if they were unsure. Their responses were recorded so that errors could be calculated in terms of exact location being correct (direction and eccentricity) or the direction only being correct (ignoring the eccentricity). An arcsine transformation was performed on all the UFV data as in previous studies (Sekuler et al., 2000; Ball et al., 1988; Leat & Lovie-Kitchin 2008).

The AFOV test was designed according to Coeckelbergh and colleagues' (2004) design (Figure 7-2c). In this test participants were asked to locate a Landolt C amongst 23 circles. The gap of the Landolt C was randomly oriented up, right, left, and down. In order to shorten the test and not to fatigue the participants, targets were only presented in 9 out of the 24 possible locations as described for the UFV (Figure 7-2d). The participants were not informed that only 9 locations were to be tested, and were not aware of this afterwards. During the test the duration of the stimulus was varied to determine a threshold in milliseconds with an interleaved "one up and one down" staircase method for the presentation time for each of the 9 locations. Each location's staircase was independent of the others and the order of presentation of the nine locations was randomized. The presentation time started at a full second, hence allowing eye and head movements and the step size was 0.1 log unit. The number of trials at each location was 30 trials, so that the total number of trials was 270 trials. These values were chosen after pilot testing with a young adult population, which showed that a threshold was approached after this number of trials and starting from this duration. The final threshold was determined by plotting trial duration against the trial number and taking the average of the reversals of the last section of the plot. The values included in this averaging were based on the following criteria a) at least 8 reversals, b) the minimum slope for the regression line.

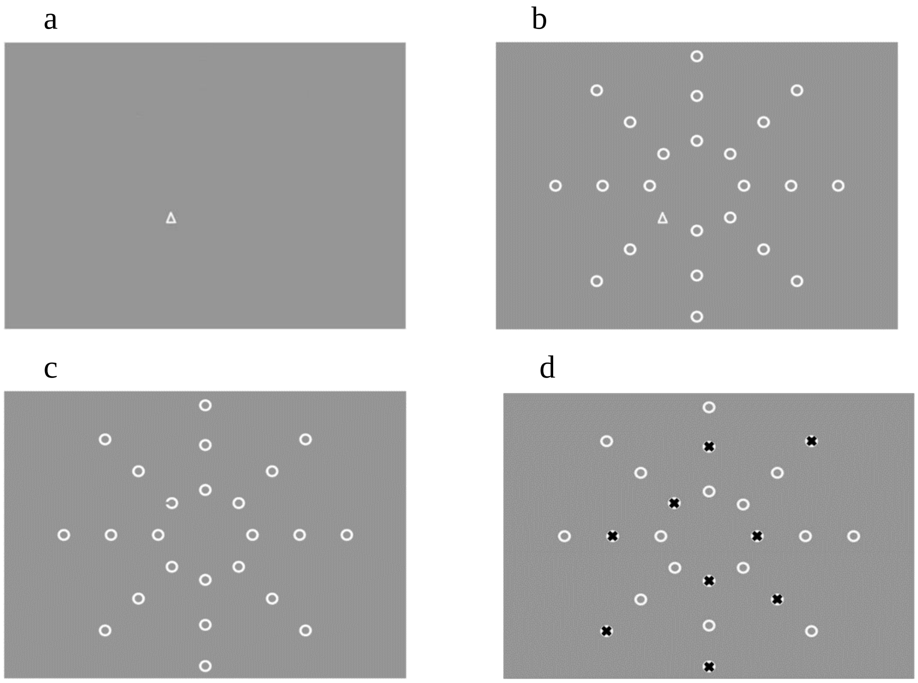


Figure 7-2: **The visual attention tests. a, UFV1: target presented with no distractors. b, UFV2: target presented with distractors. c, AFOV: target presented with distractors. d, AFOV: locations where the targets were presented are marked in crosses .**

Balance and mobility

For the balance and mobility assessment the participants removed their shoes and wore their habitual spectacle glasses throughout.

Of the balance and mobility tests, the timed Sit to Stand test (STST) was performed first. An armless standard height chair (44.5 cm) with 1 cm of padding was used. The participants were asked to start the test in the seated position with their arms next to their body and their back against the chair's backrest. They were instructed to *"Put your arms next to your body and to stand up and sit down 5 times as fast as you can, as long as you feel comfortable and safe".* They were asked to keep looking straight ahead and not to use their arms to push up from the chair. They were timed with a stopwatch from when the examiner gave the "Go" signal and stopped at the fifth repetition when the participant first touched the chair seat. The final outcome was the time taken to complete the task.

The timed One Legged Stance test (OLST) was performed next. Participants were asked to decide which leg they prefer to stand on and the test was performed on a smooth hard floor. Participants were instructed to stand on both feet in a relaxed stance and then to "*Lift one leg, it doesn't matter which leg, up in front of you with your arms next to your body*. "Participants were asked to fixate a target in front of them and to maintain their balance for up to 30 seconds. The duration they were able to maintain their balance was then recorded for one timed trial per participant.

The Mini-Balance Evaluation System's Test (Franchignoni, Horak, Godi, Nardone, & Giordano, 2010) is a composite test and was included as it is a clinical balance assessment tool that measures the integrity of four different balance control systems in the body. This tool was developed to improve and shorten the lengthy BESTest (Horak, Wrisley, & Frank, 2009). It consists of 14 short balance tests divided under four domains of balance control; 1) anticipatory body control, 2) reactive postural control, 3) sensory orientation and 4) balance during dynamic gait. The first part includes a scored version of the Sit to Stand test, Stand on One Leg test and Rise to Toes test. The third part included the following: stance with feet and arms together on a firm surface with eyes open and closed for 30 seconds and stance while standing on an inclined ramp with the participants' toes toward the top of the ramp with their eyes closed for 30 seconds. Finally, balance during dynamic gait was assessed by checking gait with changing speeds, with head and pivot turns, while stepping over obstacles and Timed up and Go test (with and without dual tasking). These tests are rated using a three level scale, where "0" means severe impairment, "1" indicates moderate impairment and "2" is normal function. The final score for the Mini-BESTest was the sum of the sub-test scores, which results in a maximum score of 28.

In the Timed Up and Go test (TUG), two conditions were performed; the TUG alone and the TUG with a cognitive task (TUGco). In the TUGco participants counted backwards from 100 by threes until the TUG was completed. The final measure recorded for both TUG test versions was the duration they were able to complete the test.

In the 5 Meter Walk test (5MWT), participants were asked to walk an 8 meter distance but only the middle 5 meter distance was timed to measure the participant's performance. The first and last 1.5 meters were to allow for acceleration and deceleration. The walking course was straight with no obstacles and was on a hard floor. The participant was instructed to "*Walk as fast as you feel comfortable and safe for 5 meters. I will tell you when to start and when to stop*". The examiner followed the participant along the course and timed the start when the leading foot crossed the first tape, which marked the beginning of the 5 meters and stopped as soon as the leading foot crossed the end of the 5 meters, although participants continued to walk to the end of the 8 meters. The time taken to complete this task was the outcome measure of interest.

These tests of balance and mobility were administered by a naive experimenter, who did not know to which group the participant was assigned.

Postural sway

Postural sway was measured using the portable AMTI AccuGAIT force plate platform (200 Hz) to record ground reaction forces and moments as participants stood in quiet stance, while barefoot, on the force plate. To ensure the consistency of the base of support throughout all the sessions and trials, each participant's preferred foot position was traced on paper that covered the surface of the plate; this foot tracing was s reused at the outcome visit to ensure that the participant was standing in the same position at baseline and outcome visits. Postural sway was recorded for two test conditions; eyes open and eyes closed. In the eyes open measurement condition, participants were asked to stand on the force plate platform with eyes open and arms next to their body. Participants were instructed to look straight ahead at a fixation target placed 1 meter away in front of them, while wearing their habitual glasses. When the test started they were asked to maintain their balance for 60 seconds, which was repeated for 5 trials. In the eyes closed condition, participants were asked to stand, to cross their arms across their chest and keep their head straight. During the stance participants were instructed to try to control their balance for 30 seconds, and this was repeated for 3 trials, if possible. The first 5 and last 5 seconds of the data were removed, and then a 6 Hz low pass (dual pass) Butterworth filter was used to remove any noise in the data. From the force and moment values center of pressure (CoP) was calculated (Winter, 1995). The outcome measures were the standard deviation of the medial lateral (ML) and anterior posterior (AP) center of pressure, ML and AP CoP maximum sway, ML and AP CoP range in each direction (range = maximum excursion – minimum excursion) and the cumulative path length in centimeters. Any trial that was 3 standard deviations away from the mean was excluded from these postural analyses.

For all the balance and mobility tasks in this study, a safety spotter stood next to the participant minimize the risk of falling and incurring an injury during test sessions.

Participants were allowed to rest in between tests to reduce the effects of tiredness or fatigue.

Intervention

After the baseline assessment participants were randomly assigned to one of the two groups in the study. Randomization was stratified by age (70-79 and 80+ years) and gender. One group received the visual attention training while the other was asked to continue their everyday activities as usual. The training sessions took place at the School of Optometry and Vision Science. The training sessions were conducted twice a week for 3 weeks to a total of 6 sessions. Each session involved 45 minutes of visual attention training similar, using UFV2 and AFOV stimuli which were similar, but not the same, as at baseline and ranged in difficulty. There were 7 different UFV2 targets and 3 different AFOV targets. The difficulty level was determined with a pilot study and the training started with the easier and moved to the harder levels. The appendix shows the different targets and conditions used in the training sessions.

Outcome visit

The outcome visit was 4 to 5 weeks after the baseline assessment. Participants performed the same battery of tests as at baseline, except for VA testing.

Data Analyses

Two sample t-tests were performed between the intervention and control group demographic data to determine if the groups were equal at the start of the study. In this randomized controlled trial, the outcome measures were sway using the force platform plate (standard deviation of ML and AP CoP, ML and AP CoP maximum sway, ML and AP CoP range and cumulative path length), the Mini-Balance Evaluation System's Test (Mini-BESTest), One Legged Stance test (OLST), the 5 Meter Walking test (5MWT) the Sit to Stand test (STST), the timed up and go test (TUG) and TUG with a cognitive task (TUGco). Statistical analyses on each dependent variable was undertaken with mixed ANOVA (2x groups, 2x visits). For the balance tests with the forced plate platform the ANOVA was 2x groups, 2x visits, 5x trials. Significance was set at $p<0.05$. Data analysis was undertaken with Systat software (Systat Software, Inc. San Jose, CA, USA). For situations where an ANOVA was repeated with the same data set (e.g. for the UFV calculated with different scoring and the force-plate platform data), a Bonferroni correction was applied to correct for multiple comparisons.

7.3 Results

Thirty older adults aged 70+ took part in the study (mean age 80.3 yrs ± 6) with females being 47% of the sample. In this randomized controlled trial study, 15 participants were assigned to each group. Table 7-1 shows a comparison between the two groups at baseline. There was no significant difference between any of the parameters.

Table 7-1: **Baseline comparison between the control and intervention groups. logMAR = log of the Minimum Angle of Resolution**

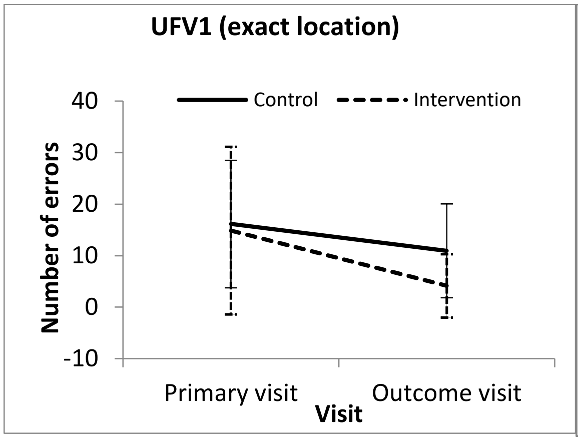
	Control Group (n=15)	**Intervention Group (n=15)**	**t-test (p value)**
Age (yrs) (mean ± SD, range)	81.7 ± 6.1, 71-95	78.7 ± 5.8, 71-91	0.15
body Weight (kg)	74.2 ± 12.9	76.7 ± 16.7	0.65
height (cm)	169 ± 6	170 ± 10.6	0.71
# of general health conditions	4.2 ± 1.6	3.4 ± 2.3	0.27
# of eye conditions	1.4 ± 0.83	1.9 ± 1.1	0.19
# of medications	3.5 ± 2.6	4 ± 4.9	0.72
visual acuity (logMAR)	0.07 ± 0.1	0.09 ± 0.09	0.55

Firstly, we considered whether the training did actually improve visual attention itself. The results of the mixed ANOVA (2x group, 2x visits) are shown in Table 7-2 and the data are plotted in Figure 7-3. The UFV results are shown with both the analysis using errors for exact location and correct direction of the target. There was no main effect of group for any of the measures indicating that there was no overall difference between the groups. There was a main effect of visit for all the measures, indicating that both groups performed better on the outcome visit. This remained significant after application of the Bonferroni adjustment (p for significance was changed to $0.05/2 = 0.025$). There was a significant interaction between visit and group for the AFOV ($p<0.001$) and a borderline interaction for UFV2 correct direction ($p=0.07$) demonstrating that the visual training itself was effective.

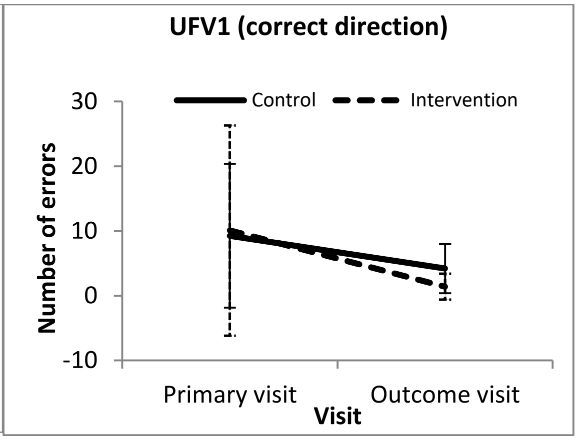
Table 7-2: **Mixed ANOVA for visual attention tests before and after training. UFV1 = useful field of view subtest 1. UFV2 = useful field of view subtest 2; AFOV = Attended Field of View.**

Test	Data used	Effect	F-ratio	p-value
UFV1	**Exact location**	group	0.68	0.42
		visit	14.24	0.001
		group x visit	1.76	0.19
	Correct direction	group	0.04	0.84
		visit	7.66	0.010
		group x visit	0.65	0.42
UFV2	**Exact location**	group	3.64	0.06
		visit	17.78	<0.001
		group x visit	1.59	0.22
	Correct direction	group	2.20	0.15
		visit	30	<0.001
		group x visit	3.48	0.07
AFOV	**Log average time (seconds)**	group	4.55	0.04
		visit	37.2	<0.001
		group x visit	22.6	<0.001

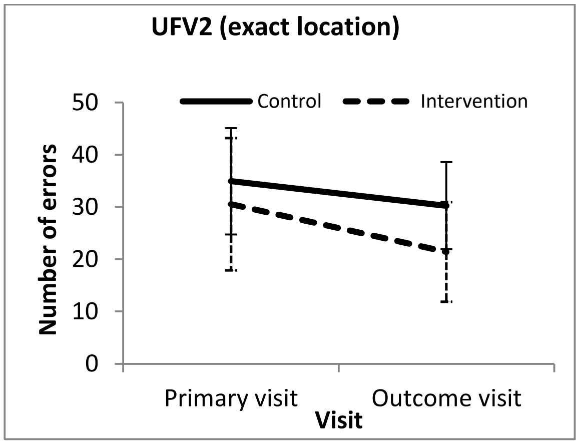
a


UFV1 (exact location)
Control
Intervention
Number of errors
40
30
20
10
0
-10
Primary visit
Outcome visit
Visit

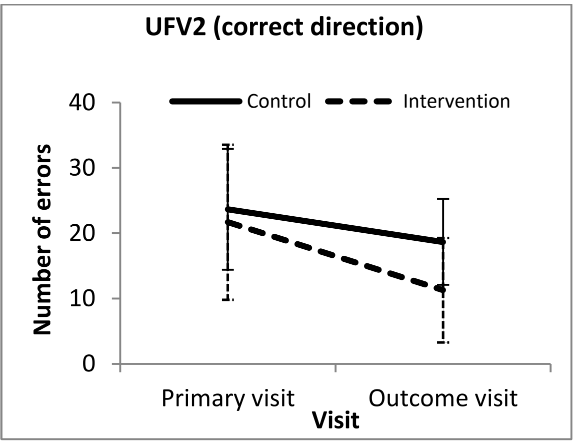
b


UFV1 (correct direction)
Control
Intervention
Number of errors
30
20
10
0
-10
Primary visit
Outcome visit
Visit

c


UFV2 (exact location)
Control
Intervention
Number of errors
50
40
30
20
10
0
Primary visit
Outcome visit
Visit

d


UFV2 (correct direction)
Control
Intervention
Number of errors
40
30
20
10
0
Primary visit
Outcome visit
Visit

e

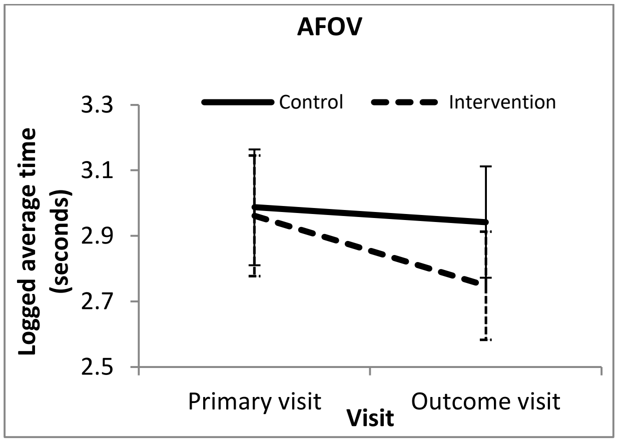

AFOV
Control
Intervention
Logged average time (seconds)
3.3
3.1
2.9
2.7
2.5
Primary visit
Outcome visit
Visit

Figure 7-3: **The effect of visit for visual attention tests (means ± SD). a. UFV1 (exact location), b. UFV1 (correct direction), c. UFV2 (exact location), d.UFV2 (correct direction), e. AFOV**

For postural sway with eyes open, mixed ANOVA (2x groups, 2x visits, 5x trials) revealed no interaction effects between group and visit for all force plate platform data including (ML) and (AP) center of pressure (CoP) standard deviation (p=0.87 and p=0.64 respectively), ML and AP CoP Max (p=0.94 and p=0.42 respectively), ML and AP CoP Range (p=0.92 and p=0.41 respectively) and cumulative path length (p=0.82). Figure 4A demonstrates the changes over time for the cumulative path length data with eyes open. A main effect of group for any of the parameters was also not observed; medial lateral (ML) and anterior posterior (AP) center of pressure (CoP) standard deviation (p=0.42 and p=0.71 respectively), ML and AP CoP maximum sway (p=0.52 and p=0.88 respectively), ML and AP CoP Range (p=0.54 and p=0.73 respectively) and the cumulative path length (p=0.29). Neither was there a main effect of visit for any of these parameters; ML and AP CoP standard deviation (p=0.33 and p=0.98 respectively), ML and AP CoP maximum sway (p=0.08 and p=0.99 respectively), ML and AP CoP Range (p=0.54 and p=0.90 respectively) and the cumulative path length (p=0.14).

For sway with the eyes closed, mixed ANOVA (2x groups, 2x visits, 3x trials) showed no significant interactions between group and visit for all the force plate platform data; (ML) and (AP) center of pressure (CoP) standard deviation (p=0.95 and p=0.85 respectively), ML and AP CoP Max (p=0.58 and p=0.53 respectively), ML and AP CoP Range (p=0.29 and p=0.11 respectively) and cumulative path length (p=0.37). Figure 4B demonstrates the changes over time for the cumulative path length data with eyes closed. Specifically, no main effects of group for any of the postural parameters were observed; medial lateral (ML) and anterior posterior (AP) center of pressure (CoP) standard deviation (p=0.81 and p=0.33 respectively), ML and AP CoP maximum sway (p=0.98 and p=0.67 respectively), ML and AP CoP Range (p=0.94 and p=0.55, respectively) and the cumulative path length (p=0.5). There was no main effect of visit; ML and AP CoP standard deviation (p=0.18 and p=0.49 respectively), ML and AP CoP Max (p=0.13 and p=0.78 respectively), ML and AP CoP Range (p=0.15 and p=0.78 respectively) and the cumulative path length (p=0.55).

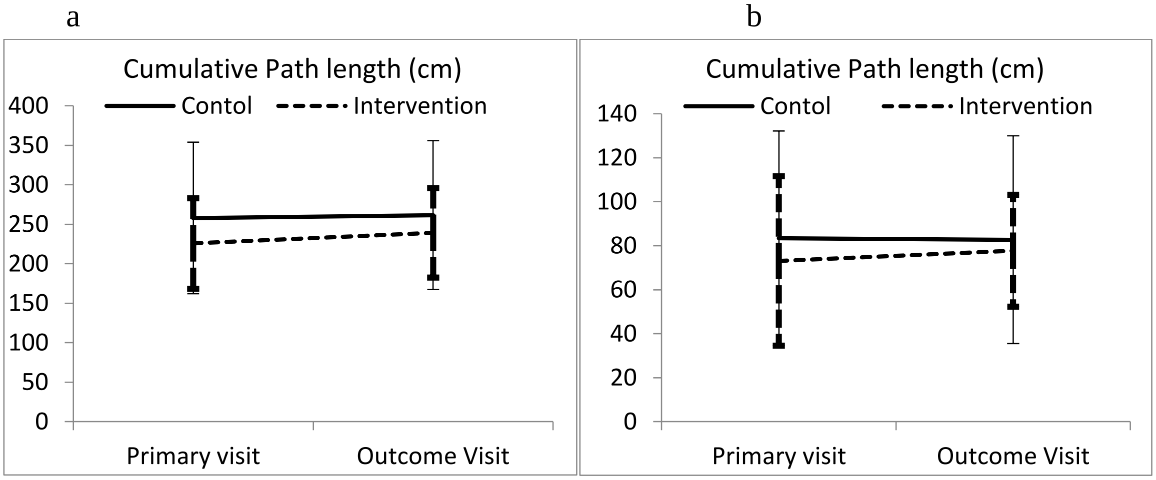


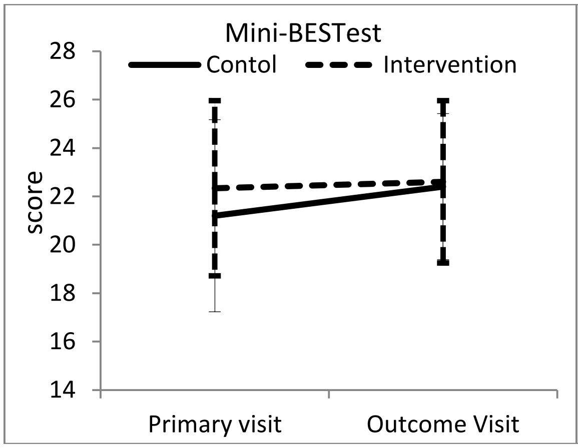
Figure 7-4: **Cumulative path length for both the control and intervention groups at baseline and outcome visits (means ± SD). Higher value = more sway a. eyes open, b. eyes closed**

For the clinical assessment tools of balance and mobility, mixed ANOVA (2x group, 2x visit) showed no significant interactions between group and visit for all the balance and mobility tasks (p>0.05) (table 7-3). There was no main effect of group (p>0.05), nor were there any effects of visit (p>0.05). Figure 7-5 demonstrates the changes over time for the all the balance and mobility tasks.

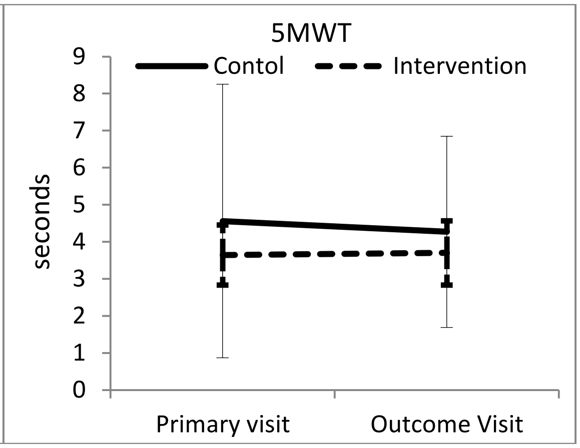
Table 7-3: **Mixed ANOVA (2x group, 2x visit) between pre and post training assessment periods for the balance and mobility clinical assessments. STST = Sit to Stand Test; OLST = One Legged StandTest; TUG = Timed Up and Go test. TUGco = Timed Up and Go test with cognitive load; 5MWT = Five Meter Walking Test.**

Test	Effect	F-ratio	p-value
STST	group	0.18	0.67
	visit	0.40	0.52
	group x visit	1.13	0.29
OLST	group	0.01	0.90
	visit	0.95	0.33
	group x visit	1.03	0.31
Mini-BESTest	group	0.30	0.58
	visit	3.33	0.078
	group x visit	1.35	0.25
TUG	group	1.11	0.3
	visit	3.41	0.07
	group x visit	3.13	0.08
TUGco	group	0.39	0.53
	visit	0.18	0.66
	group x visit	1.63	0.21
5MWT	group	0.78	0.38
	visit	0.49	0.48
	group x visit	1.20	0.28

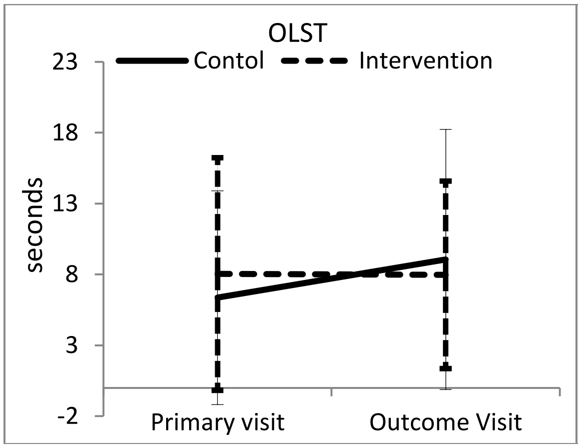
a


Mini-BESTest
Contol
Intervention
score
28
26
24
22
20
18
16
14
Primary visit
Outcome Visit

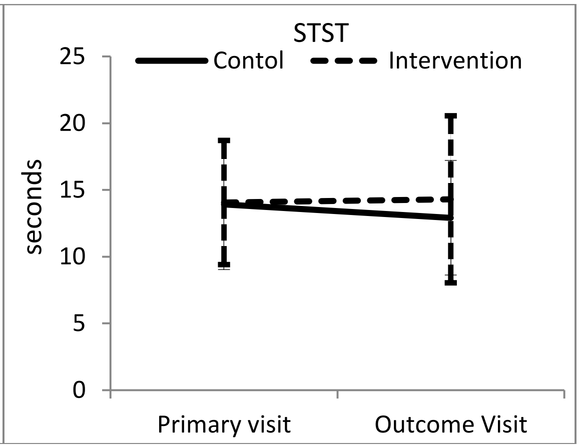
b


5MWT
Contol
Intervention
seconds
9
8
7
6
5
4
3
2
1
0
Primary visit
Outcome Visit

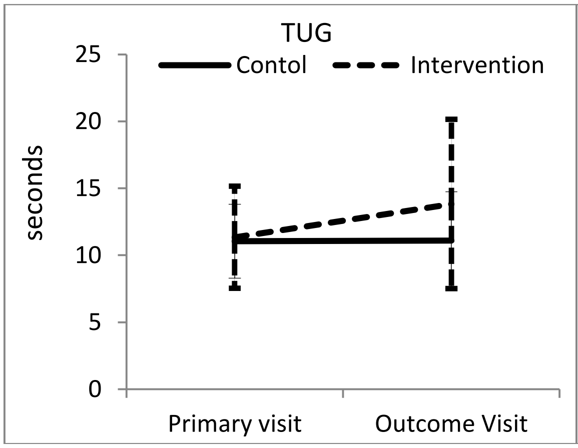
c


OLST
Contol
Intervention
seconds
23
18
13
8
3
-2
Primary visit
Outcome Visit

d


STST
Contol
Intervention
seconds
25
20
15
10
5
0
Primary visit
Outcome Visit

e


TUG
Contol
Intervention
seconds
25
20
15
10
5
0
Primary visit
Outcome Visit

f

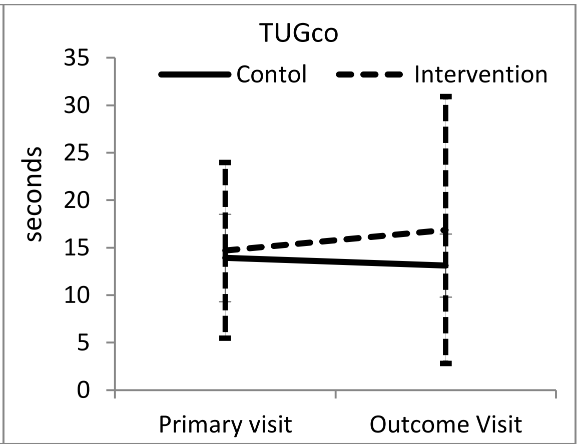

TUGco
Contol
Intervention
seconds
35
30
25
20
15
10
5
0
Primary visit
Outcome Visit

Figure 7-5: **The effect of visit for the balance and mobility tests (means ± SD). a. Mini-BESTest (maximum score of 28) (higher score = better balance), b. 5Meter Walking Test (higher score = poorer balance), c. One Legged Stance Test (higher score = better balance), d. Sit To Stand Test (higher score = poorer balance), e. Timed Up and Go test (higher score = poorer balance), f. Timed Up and Go test with a cognitive task (higher score = poorer balance).**

7.4 Discussion

Impaired visual attention has been associated with increased crash rate while driving (Ball et al., 2006), balance and mobility difficulties (Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004), and increased time for completing visual tasks (Owsley, McGwin, Sloane, & Stalvey, 2001). Some studies have shown that visual attention training is amenable to training, which is maintained for up to 2 years (Sekuler & Ball, 1986). In fact, one study suggested that the effect of training can last up to 5 years (Willis et al., 2006). In our previous study, we found that even after controlling for age, balance was significantly correlated with visual attention. (Althomali & Leat, 2013). Therefore, we expected that a visual intervention program, using a structured visual attention training, would improve balance and mobility and might reduce the incidence of falls in older adults.

We did demonstrate some improvement in visual attention with training in the AFOV ($p<0.001$) and a borderline effect in UFV2 ($p=0.07$). It is also noticeable that the intervention group was always better at the outcome visit than the control group. For UVF1, a floor effect in the visual attention training may have occurred as the number of errors was 8% before training for the exact location analysis and 7% for correct direction analysis; therefore there was little room for improvement with training. This is illustrated in Figure 7-3a, which shows that a number of participants were making zero errors at baseline.

Even though some improvement was noted in the visual attention training, there was no improvement in mobility or balance in this population. In the literature, the cut-off score in the TUG for healthy older adults to be classified as at risk for a fall is >13.5 seconds (Shumway-Cook, Brauer, & Woollacott, 2000), while the cut-off score for the STST to show any balance dysfunction is >14.2 (Whitney et al., 2005). In this study our sample average score for the TUG and the STST at baseline was 11 seconds and 14 seconds respectively for both groups. This indicates that our participants, although chosen based on their balance and falls rate, were still relatively healthy and high functioning. This means that there was less room for improvement, which may have been a reason why a significant change was not found. In the literature the most effective programs in reducing falls rate are those that include a multifactorial risk abatement approach (Cameron et al., 2012; Clemson et al., 2004; Day et al., 2002; Fitzharris et al., 2010). Our findings agree with this statement, visual attention training alone did not result in improved balance and mobility and may not be effective in reducing the falls rate in older adults. This does not preclude the possibility that visual training may be effective if implemented in conjunction with a physical training component.

Recently, the use of the Nintendo Wii has shown some benefit in physical therapy and nursing home settings. This involves a physical and visual component to training, and improvements in balance have been demonstrated (Bateni, 2012; Nicholson, McKean, Lowe, Fawcett, & Burkett, 2015; Pluchino, Lee, Asfour, Roos, & Signorile 2012; Singh et al., 2012; Toulotte, Toursel, & Olivier, 2012) and this training may reduce the risk of falls (Fu, Gao, Tung, Tsang, & Kwan, 2015).

Participants chosen in the study were recruited from our previous study and were chosen for this training intervention based on their reported falls history and poor balance data. By selecting this cohort of participants we hypothesized that there would be more room for improvement and that these participants could benefit the most from the program. Unfortunately, we saw no significant improvement in our population's balance or mobility from our isolated vision attention only training. The selection of this cohort of participants may have precluded us from either extreme of the population. For example, those who were even more frail might show more improvement while those who were less frail might show more transfer of the training.

Limitations of the study

The participant pool was small but given that this was a small pilot study it is important to note (see Figures 7-4 and 7-5) that the changes over time in the intervention group in a number of measures were not in the expected direction (e.g. cumulative path length eyes closed, TUG and TUGco). The inclusion of more participants in the future, and the inclusion of a more diverse population will increase the application of these study results to a wider group of older adults (e.g. those with mobility issues like osteoarthritis). Secondly, the control group was not given any scheduled activity for an equivalent time to the intervention group, but had this been included, it would be expected to decrease the likelihood of finding a significant effect, and therefore does not impact the current negative findings. Thirdly, only two specific types of visual attention were used. It is possible that training with a wider range of attention tasks e.g. including more sustained attention, may have been effective.

In conclusion, our findings indicate no improvement following visual attention training with UFV and AFOV for any of the mobility and/or balance measures chosen for study. We conclude that UFV and AFOV visual attention training alone is not effective for improving balance and mobility in this population. It is possible that a training program that includes physical movement in combination with visual attention may be needed to obtain significant improvements in healthy older adults. Given the change in the Canadian demographics towards an older population (Statistics Canada, 2015) and since a substantial portion of that population fall every year and many suffer from its debilitating effect it is imperative to still continue to develop intervention programs aimed at reducing falls in older adults and more research is needed on the effectiveness of such programs.

Chapter 8

Discussion

The first aim of this thesis (study 1, Chapter 4) was to investigate the associations between different visual parameters and balance and mobility in older adults. In the literature there are many studies which show a link to exist. For example, visual acuity (Lord & Dayhew, 2001), contrast sensitivity (Ivers et al., 1998; Klein et al., 1998), visual fields (Black et al., 2011) and depth perception (Lord & Menz, 2000; Nevitt et al., 1989) are related to the loss of balance and the risk of falls in older adults. The work in this thesis is novel as I included measures of visual attention, and binocular vision and eye movement disorders, which have not been considered before and to my knowledge this is the first study to discuss such measures. I also included a number of visual measures that are known to be associated. As expected, various visual parameters were found to be related to balance and mobility. What is interesting though is that measures of visual attention and binocular vison and eye movements were found to be related to balance and mobility.

There is little documentation of binocular vision and eye movement disorders (BV disorders) in older adults in the literature. In this study 69% of the sample had binocular vision and eye movement disorders. Those who had BV disorders were shown to have poorer balance (Sit to Stand Test and One Legged Stance Test) independent of the effect of age. This correlation with balance was still significant after controlling for the effect of age, sex, general health and number of medications. The results are of high importance as many binocular vision and eye movement disorders can be managed with optical correction, vision therapy or surgery.

Uncorrected refractive error may result in reduced visual acuity or differences in VA between the two eyes, resulting in a disturbance of sensory fusion which can decrease the fusional ability and stereopsis and could lead to sensory strabismus (Scheiman & Wick, 2014). Dwyer and Wick demonstrated improvement in binocular function in non-strabismic pre-presbyopic participants aged 6-34 years following refractive correction (Dwyer & Wick, 1995). In their sample, binocular disorders included basic phorias, convergence insufficiency and excess and fusional vergence dysfunction. Participants younger than 13 years were more likely to recover normal vergence function than those who were older than 14 years old. However, recovery was still seen in those between the ages of 14 and 34 years old. These results may extend to those adults who are older than this cohort. Tetelbaum, Pang and Krall (2009) reported a decrease in symptoms related to convergence insufficiency following prism correction for presbyopic adults aged 45 to 68 years old.

Another approach is vision therapy, which has been successful in treating ocular motor dysfunction and non-strabismic binocular vision disorders (Scheiman & Wick, 2014). Evidence supports vision therapy success in treating binocular vision disorders in younger (Scheiman et al., 2005) and older adults (Birnbaum, Soden, & Cohen, 1999; Wick, 1977). Wick (1977) reported a success rate of 92% in their sample for participants aged 45 to 89 years old following visual training. Cohen and Soden (1984) showed that vision therapy alleviated visual symptoms in older adults above the age of 60 years who suffered convergence insufficiency and reported a success rate that exceeded 90%. Thus there is some evidence that vision therapy is effective in older adults, but this is an area that needs more study.

Another treatment option is surgery. This route is highly unlikely to be taken in the presence of non-strabismic binocular vision dysfunction with the exception of large phorias and when vision therapy success is limited (Scheiman & Wick, 2014). A report by the American Academy of Ophthalmology showed that surgical treatment for adults with strabismus is effective and safe (Mills, Coats, Donahue, & Wheeler, 2004). Magramm and Schlossman (1991) reported that the majority of strabismus surgery conducted on patients above the age of 60 was due to an ocular disease of adult onset. In their study 71% of older adults suffered from diplopia and asthenopia and experienced visual symptoms for an average of 8 years before undergoing strabismus surgery. This indicates that little attention is given to strabismus and the resulting symptoms in the older adults' population, which would leave them suffering conditions that can impair their vision. These treatment options should not be ignored and may help reduce symptoms of asthenopia, improve stereopsis, eliminate suppression and increase accuracy in saccade and pursuit eye movements, which will transfer to better visual input resulting in improved balance and mobility.

It might be argued that these binocular vision and eye movement disorders in older adults are likely to be long standing and asymptomatic and therefore not important as a fall risk. But as noted above, many cases of strabismus are not long-standing in this population and do result in symptoms. And a similar argument could be made about poor visual acuity. This could also be long standing and asymptomatic yet, these predictors are not excluded or ignored as risk factors of loss of balance and falls. A further study would be needed to look at the different types of BV disorders and their duration, which are most closely associated with poor balance and falls, and which are more amenable to treatment.

Intermediate VA was show to correlate with balance and mobility measures in this study even after adjusting for other cofounders (age, sex, general health and medications). This predictor may seem more relevant than distance or near VA to balance and mobility because the distance used to measure intermediate VA is the critical distance for negotiating hazards (Patla & Vickers, 2003). Therefore, older adults should be re-educated and counselled about the use of their multifocal glasses and how to avoid looking through their reading segment. This could help prevent any falling incident. In fact, Haran et al. (2010) found that providing single vision glasses with tints for older adults who were already wearing multifocal glasses and were active outdoors resulted in a reduction in the falls rate and the number of injurious falls. However, this approach was not effective in those who are not involved in outdoor activities.

Another visual parameter that was included in study 1 was visual attention measured with the UFV and AFOV. The correlation between age and visual attention is well established (Coeckelbergh et al., 2004; Sekuler & Ball, 1986). My study also demonstrates this link. What is interesting is even after controlling for age, balance was significantly correlated with visual attention. Previous work has shown the link between the UFV and mobility impairment in normal sighted (Owsley & McGwin, 2004) and low vision individuals (Leat & Lovie-Kitchin, 2008). In the current study both measures of visual attention were found to be linked to balance and mobility. After control for age, the UFV was still associated with poor balance (One Legged Stance Test). It is known also that visual attention declines considerably with age (Ball et al., 1988; Coeckelbergh et al., 2004; Sekuler, Bennett, Mamelak, 2000; Sekuler & Ball, 1986). The present study provides more understanding of the wide-ranging effects of slower processing speed on older adults. Previous work has demonstrated a reduction in functional reach (Riolo, 2004), driving competency (Ball et al., 2006) and performance of instrumental activities of daily living (Owsley et al., 2002) in individuals who score poorly on visual attention tasks. Sims et al. (2000) demonstrated that a 40% reduction in the UFV score yielded a two times greater likelihood that an older adult would be involved in a vehicle crash. Further work is warranted to determine a cut-off point in visual attention performance score that would identify those who are at risk of losing their balance and falling.

Looking at the visually impaired study (low vision group, Chapter 5) none of the predictors were significantly correlated with any of the balance or mobility tasks with the exception of cataract surgery. This is most likely because of the small sample of people with visual impairment. It is interesting that the group with visual impairment exhibited similar performance in the balance and mobility task (Chapter 5) even though they were at a disadvantage due to their visual loss. This could indicate that participants with visual impairment showed some sort of adaptation or compensated by other systems of balance to overcome their visual loss and maintain their postural balance. Previous work demonstrated that when there is lack of accurate visual input due to an ocular pathology, other balance systems (somatosensory and vestibular) can adequately maintain balance control (Anand et al., 2003; Elliot et al., 1995; Lord et al., 1991).

Because of the link that I established between visual attention and balance and mobility in chapter 4, I hypothesized that an intervention program that utilizes visual attention training would help improve balance and mobility and might reduce the incidence of falls in older adults. If this approach is effective in improving older adults' balance and mobility to reduce the risk of falls, it could be recommended for those older adults who are frailer and cannot get involved in physical training or activities. In study 2 (Chapter 5) 15 participants were randomly assigned to a visual attention training group and 15 to a control group. Visual attention training was undertaken with versions of a selective attention useful field of view test and the Attended Field of View test. The outcome measures were postural sway using a force plate platform, the mini Balance Evaluation Systems Test, the One Legged Stance test, the 5 Meter Walk test, the Sit to Stand test, the Timed Up and Go test without and with a concurrent cognitive task. This is the first study that has specifically looked at visual attention training to improve balance and mobility. Despite the significant improvement in visual attention in the intervention group, there was no improvement in balance or mobility. No enhancement was seen in any of the balance or mobility outcome measures. A number of reasons could have attributed to this result. My sample was relatively healthy and high functioning at the start, and that might have prevented any measurable benefits due to there being less room for improvement i.e. a floor effect.

In the literature it seems that the most effective programs in reducing falls rate are those that include a multifactorial risk abatement approach (Cameron et al., 2012; Clemson et al., 2004; Davison et al., 2005; Day et al., 2002; Fitzharris et al., 2010; Gillespie et al., 2012). The current study was new as only visual attention training was implemented in the intervention program and that might not be sufficient to show any benefits in improving balance and mobility and falls prevention. This does not, however, rule out the possibility that different visual attention tests or more training sessions might yield in a transfer of the effect of training to gain improvement in balance and mobility. Chapter 7 documented how there was a significant, but low, correlation between the UFV and AFOV, and so they seem to be measuring somewhat different aspects of Visual attention. In addition, the combination of an exercise program with a visual attention training might be effective. For example, the use of computer-based virtual reality consoles such as the Nintendo Wii platform with physical exercise has been shown to be more effective in enhancing balance performance than Wii training only (Bateni, 2012). A more diverse population might show benefits of this approach.

Future studies

Future work in the area of study of this thesis could include:

1. The use of a quantitative assessment technique (e.g. force plate platform or accelerometer) to measure postural balance and correlate it to different visual parameters is acquired. This would provide more accurate and sensitive data and give more insight on the relationship between balance and vision.

2. Future work in the field of binocular vision and eye movement disorders in older adults may include investigating which underlying conditions are more common in older adults and which specific disorders are more related to impaired balance and mobility.
3. The application of a physical plus visual attention training could be studied to determine whether that might improve balance. In addition, the use of a wider range of attention tasks and designs, possibly including more sustained attention tasks might provide a better training modality for measurable transfer of the effect of training to balance and mobility.
4. Larger sample size in the visual impairment study to better understand the effect of visual disability on performance of the clinical assessment tools.

In conclusion, different visual measures were shown to be associated with poor balance and mobility; in particular, visual attention, binocular vision and eye movement disorders, and intermediate visual acuity. A new intervention approach (visual attention training) was described in this thesis, aimed at reducing the risk of falls in older adults. The findings, however, do not support the use of this particular intervention, although positive gains might be seen if visual attention was trained in conjunction with physical movement.

Falls can cause injuries (Alexander, Rivara, & Wolf, 1992; Lord, Ward, Williams, & Anstey, 1993), reduced mobility (Davidson, Merrilees, Wilkinson, McKie, & Gilchrist, 2001; Tinetti, De Leon, Doucette, & Baker, 1994), loss of independence (Cumming, Salkeld, Thomas, & Szonyi, 2000), institutionalization (Koski et al., 1998; Tinetti et al., 1988) and injury related fatality(Alegre-Lopez, Cordero-Guevara, Alonso-Valdivielso, & Fernandez-Melon, 2005;

Dunn et al., 2002; Tinetti et al., 1994). The latest population census (Statistics Canada) revealed that the population is ageing and, in 2015, Canadian seniors > 65 years exceeded the number of younger individuals between the ages of 0-14 years by 0.1%. Therefore, due to this shift towards an older demographic, it is imperative that eye care practitioners who work with older adults be aware of these associations, question older adults about a history of falls or walking and balance problems, and ensure that the vision of older people is optimally managed. Similarly, it is important that all health care professionals working with older adults are aware of the links with vision and efforts should still continue to develop intervention programs aimed at reducing falls in older adults. More research is needed on the effectiveness of such programs.

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Appendix A
Visual attention targets used in experiment 7

Table A1. Visual attention targets used for training listed in order of difficulty and order that they were performed. All versions had 23 distractors except for version 7, which had 33.

Order #	Type of visual attention test	Target	Target duration (milliseconds)	Number of locations used for target presentation	Response required	Number of trials
1 *(easiest)*	UFV	filled circle	200	24	location	72
2	UFV	unfilled circle	200	24	location	72
3	UFV	triangle	200	24	location	72
4	UFV	triangle	150	24	location	72
5	UFV	triangle	100	24	location	72
6	UFV	backward D	200	24	location	72
7	UFV	landolt C	200	24	peripheral orientation and location	72
8	AFOV	landolt C	500 (staircase)	9	peripheral orientation and location	270
9	AFOV	alternating smiling or frowning face location set 1	500 (staircase)	9	expression of central face and peripheral location	270
10	AFOV	alternating smiling or frowning face location set 2	500 (staircase)	9	expression of central face and peripheral location	270
11 *(most difficult)*	AFOV	two landolt C's	500 (staircase)	9	orientation of central C and peripheral location	270