The Association between Visual Attention and Body Movement-Controlled Video Games, Balance and Mobility

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Vision Science

Waterloo, Ontario, Canada, 2018

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Purpose: Interactive video virtual-reality body movement games such as Xbox Kinect may have potential for training visual attention and physical fitness concurrently in older adults in order to reduce the risk of falls. The purpose of this study was to investigate the relationships between performance in these types of games and visual attention, mobility and balance measures. This information is important before commencing any future randomised trial regarding the effectiveness of training visual attention and physical abilities with such games.

Methods: This thesis includes two cross sectional studies of healthy adults, the first with an older (aged +65, n=50) and the second with a younger group (aged 18-40, n=50). Visual attention was measured with two different tests: useful field of view (UFV) and multiple object tracking (MOT). The useful field of view included two versions: a static (UFV-S) similar to those used in previous studies and a new dynamic version (UFV-D).

For balance, body sway was measured with the Accugait portable force plate which records the center of pressure (CoP) under the feet. Body sway was measured in bi-pedal quiet stand test (QST) and one-legged stand (OLST). The medial-lateral (ML) and anterior-posterior (AP) CoP variability, ML and AP CoP maximum displacement, ML and AP CoP range and the cumulative path length were calculated. For mobility, the Five Meter Walk Test (5MWT) was used to observe the gait variability and walking speed. Stride and step lengths and widths were measured. The average and standard deviation of steps lengths (SL) and widths (SW) were calculated. Lastly, the velocity over the leg length (Vel-L) ratio was calculated to adjust participants' speed according to their leg length.

Performance in two pairs of games using the Microsoft™ Xbox® 360 Kinect™ interactive video game system was used in this study and were chosen based on the apparent visual attention demand. The first pair had apparently high visual attention demand and the second pair had apparently lower visual attention demand. All the games had a physical component (exercise games).

Results: In both experiments, measures of visual attention (UFV and MOT) showed correlations with Xbox Kinect game scores that appeared to have a high visual attention demand, while there was minimal or no significant association with the games of apparent low visual attention demand. Static useful field of view (UFV-S) was the most common visual attention test that showed correlations with the high visual demand. Dynamic useful field of view (UFV-D) had a role for the younger group, but not in the older adults. Multiple regression models showed that scores for some of the games with high visual attention demand were predicted by visual attention measures. Age was also a predictor in the older group. The games with low visual attention demand were found to be mainly predicted by balance and/or mobility measures.

There were correlations between some visual attention tests and balance and mobility in the older adult group which remained after adjustment for other factors. However, visual attention measures were not found to be predictors for any balance and mobility measures in the multiple regression models for either group. Significant correlations were found between Xbox Kinect games and some measures of balance and mobility.

Conclusion: The results in this study suggest that there are relationships between visual attention, balance, mobility and Xbox Kinect games performance. Thus, playing these games may train visual attention and improve the balance and mobility over time. However, the choice of the game is important as some are more associated with physical ability and others with attention. Playing Xbox Kinect games may have a potential for training visual attention as well as physical abilities, but the game chosen is critical and a battery of games may be most effective.

Acknowledgements

This thesis becomes a reality with the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

First of all, I would like to express my special gratitude and thanks to my supervisor, **Dr. Susan Leat**, for her guidance and constant supervision as well as providing necessary information regarding this research & also for her support in completing this research.

I would like to express my gratitude to **Dr. Lori Ann Vallis** and **Dr. Densie Hileeto** for sharing their knowledge, and expertise in this work.

I would like to thanks my sponsor, King Saud University in Riyadh, Saudi Arabia, and the Saudi Arabian Cultural Bureau in (SACB), Canada, and the Canadian Optometric Education Trust Fund (COETF) for their financial support.

My thanks and appreciation also go to my colleagues and people who have willingly helped me out with their abilities.

Nobody has been more important to me in the pursuit of this project than the members of my family. I would like to thank my parents; whose love and guidance are with me in whatever I pursue. They are my ultimate role models. Most importantly, I wish to thank my loving and supportive wife, **Eman**, and my two wonderful children, **Turki** and **Laura**, who provide unending inspiration.

Dedication

To my parents Aliya and Ahmad,

To my beloved Wife Eman,

To my wonderful children Turki and Laura,

To my brothers and sisters,

Without whom none of my success would be possible

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Chapter 1

Introduction

1.1 Aging of population

Aging describes normal changes that typically occur to each human and involve changes in their skills and ability in later life that are associated with eventual decline. The number of the adults who are 65 or over is increasing and makes up a large percentage of the population (United Nations, 2013; World Health Organization, 2011). It is estimated that by 2030 in the global population the number of older adults who are 65 or older will be higher than the number of children aged 0- 9 years. According to the World Health Organization (WHO) and Statistics Canada (SC), the percentage of older adults in the population already exceeds the child population in the developed countries such as Canada. The increase in life expectancy is accompanied with an increase in the need for investigations to enhance our understanding of the normal changes expected with aging, it is also important to explore the treatment and management options for the chronic health issues that affect older adults in order to maintain quality of life.

1.2 Normal vision changes with age

Aging processes usually impact our visual function through changes in the physiological and biological structures of the eye and visual system. This description will concentrate on the functional impacts of those changes. Studies have addressed the effect of aging on spatial vision using such measures as visual acuity (VA), contrast sensitivity (CS) and stereopsis.

(Elliot, Yang, & Whitaker, 1995; Owsley, 2016; Pitts, 1982; Rubin et al., 1997; Weale, 1975). Visual acuity is one of the most commonly used clinical measures of vision. It is best characterized as the logarithmic of the minimal angle of resolution (logMAR) that the person can resolve. Visual acuity begins to develop at birth reaching its peak in the 20's and then remains relatively stable with little change (in the absence of a disease condition) up to the end of 60th year, at which time it starts to slowly decline (Elliot et al., 1995; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Pitts, 1982; Weale, 1975). The factors that determine this decline are either organic (i.e., pupil size or retinal status) or optical (i.e., transparency of the lens and/or the cornea) (Rosenbloom & Morgan, 2007). Despite the fact that high contrast visual acuity is important and is widely used as a clinical measure, it is not the best spatial resolution measure to understand older adults' quality of vision, and changes in high contrast VA are slight compared to other visual functions (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Haegerstrom-Portnoy, 2005). For example, low contrast visual acuity is more affected by aging than high contrast visual acuity, and low contrast acuity in low light is even more diminished with age (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Haegerstrom-Portnoy, 2005).

Contrast sensitivity also changes with the aging process. This change starts at about age 40 to 50 years although there is insignificant change until 70 years, at which time there is a sharp decline (Liutkevičienė et al., 2013; Owsley, Sekuler, & Siemsen, 1983). According to Rubin and his colleagues after the age of 65 years, there is 28% decline (0.1 log unit) in contrast sensitivity for each decade of life (Rubin et al., 1997). Under photopic conditions (luminance levels that typically occur during day light hours) the change in contrast sensitivity in older adults is most apparent at intermediate to high spatial frequencies (Elliott, Whitaker, & MacVeigh, 1990; Owsley et al., 1983), rather than lower spatial frequencies. There is no consensus on the primary cause of the effect of age on contrast sensitivity, whether it is an optical or neural effect (Elliott, 1987; Elliott et al., 1990). Owsley (Owsley, 2016) and Haegerstorm-Portnoy (Haegerstrom-Portnoy, 2005) addressed these factors. Owsley (2016) suggested that, under photopic conditions, the optical characteristics of the eye has the major role. Reduction in pupil size in older people (which causes reduced retinal illumination), cataract, vitreous opacities, aberrations and light scatter are optical factors that contribute to reduced contrast sensitivity in older adults (Owsley, 2016). Neural factors also have a role in contrast sensitivity reduction (Elliott et al., 1990; Spear, 1993) but they are minimal compared to the optical factors (Owsley, 2016) for medium and high spatial frequencies. Owsley (2016) concludes that neural factors are the main cause of low frequency contrast sensitivity loss and optical factors are the main contribution to medium and high frequency loss.

Glare and glare recovery time are other common changes which impact the vision of older adults. Glare (often measured as glare disability) is thought to be optical in origin due to the effects of intraocular light scatter. It causes a reduction in visual acuity, contrast sensitivity and other visual functions (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Haegerstrom-Portnoy, 2005). Haegerstrom-Portnoy and colleagues showed that older adults are more sensitive to glare than younger people and this is associated with optical media changes as result of cataract and vitreous changes with age. Moreover, glare has a higher impact on low contrast visual acuity than high contrast visual acuity for older people (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Glare recovery time is another measure of glare and is also a challenge for older adults. Glare recovery is the time required to recover visual sensitivity after exposure to a source of glare. It is due to neural changes in the retina (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). Studies have reported that glare recovery time increases with age (Elliott & Whitaker, 1990; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999).

Scotopic conditions (low-luminance levels) have a large impact on visual functions with aging. Visual acuity and contrast sensitivity are more impacted in low luminance conditions (Jackson & Owsley, 2000). Dark adaption is reported to be delayed; there is an increase in recovery time, and a decrease in final sensitivity (Jackson, Owsley, & McGwin Jr, 1999).

There are also changes with normal aging processing in motor visual systems (Leat et al., 2013; Rosenbloom & Morgan, 2007). Leat et al., reported that 30 % of older adults above 70 years have a binocular vision and/or eye movement disorder and this increased to 38% for people above 80 years (Leat et al., 2013). Further, older people show more difficulty in fixation during scotopic conditions (Dannheim & Drance, 1971), and increased lag during pursuit eye movements which results in an increased number of catch-up saccades in order to maintain fixation (Kanayama et al., 1994; Sharpe & Sylvester, 1978).

There is an age-related decline in overall visual field sensitivity values (Jaffe, Alvarado, & Juster, 1986; Spear, 1993). The reduction in sensitivity within the visual field compared to normal age-matched norms is faster in the peripheral region than the central region. The rate of peripheral sensitivity decline at 30 degrees from the center is twice the rate of decline in the central sensitivity (Jaffe et al., 1986). It has been reported that the decreases in sensitivity in the superior field are greater than in the inferior field (Spry & Johnson, 2001). More about attentional visual fields will be discussed later in this chapter. These declines in visual field are attributed to senile miosis and the density of lens on the one hand and a decrease in the number of photoreceptors (the rods) and their sensitivity on the other (Gartner & Henkind, 1981; Jaffe et al., 1986; Rosenbloom & Morgan, 2007).

Processing speed usually slows during our lives (Salthouse, 2000). This decrease in processing information time can impact older adults' attention and delay their reaction time. Among these processing changes, visual processing time is also affected (Ball et al., 1988; Sekuler & Ball, 1986). Thorpe and his colleagues (1996) conclude that human visual system needs less than 150 ms to react for a highly visual demanding task (Thorpe, Fize, & Marlot, 1996). The speed of visual processing could increase to be significantly longer in some older adults. A study on older drivers' vision which included a sample aged in three age categories (70', 80's and 90's) measured performance with the UFOV subtest 2 which measures the processing time under divided attention conditions (Owsley, McGwin Jr, & Searcey, 2012). The authors reported that about a third to half of older adult drivers have visual processing impairment. There were more people in the 70's group who had a processing speed faster than 150 ms compared to the older groups. However, there are individual differences among older adults; some have visual processing speeds close to those of younger people (Ball et al., 1993; Owsley, McGwin, & Searcey, 2012; Rubin et al., 2007).

1.3 Visual Attention

It is not possible to equally and simultaneously process all the information which enters our sensory systems, and so a selection process is required (Rensink, O'Regan, & Clark, 1997). Visual attention is a mechanism that helps to select the information that is necessary for an ongoing event, in order to accelerate the response time (Rensink, O'Regan, & Clark, 1997). In our everyday lives, there are many activities that depend on our ability to select and process visual information from the surrounding environment. For example, the complexity of the visual task and the quantity of distractor information determine the load on processing. The ability to employ visual attention allows quicker processing and results in a quicker response.

Visual attention can be a voluntary (intentional) or involuntary (automatic) process (James, 2013). A person can voluntarily select where to attend (process visual information) in the visual field and can sustain his/her attention. This aspect of vision allows us to select which visual information is critical to analyze at a particular time. However, there is capacity-limitation in visual processing (Pashler & Sutherland, 1998) and we voluntary or involuntary direct our attention to scan the interested area of the visual field and filter the rest. Attention in general, and visual attention, has attracted scientists since the 1890s (Carrasco, 2011). The interest in visual attention has increased recently with the improvement of research tools, electronic displays, and applied experiments.

Older adults report difficulties in visual activities of everyday life which involve multi-tasking and experience an increase in the incidence of injuries resulting from mobility in cluttered environments. Hence there has been interest in the impact of aging on visual attention. In 1970 Sanders introduced the concept of the Functional Field of View (FFV) to illustrate the information in a selected area in the visual field that can be processed and recognized in a short time (Sanders, 1970). The same concept was used in the following decade by Verriest (1985), using the term Occupational Field (OF). This was taken up and developed by Ball and colleagues in 1988 who introduced the Useful Field of View (UFOV) test (Ball et al., 1988). A considerable amount of research on visual attention was conducted in the 1980s in which various aspects of visual attention were illustrated. Different aspects of visual attention have been described. Selective attention is the ability to select a stimulus of interest among others. Divided attention is the ability to divide the attention simultaneously between more than one stimulus and sustained attention is the ability to sustain attention on the selected stimuli for period of time (Posner & Petersen, 1990; Robertson et al., 1996). Pylyshyn and Storm (1988) introduced Multiple Object Tracking (MOT) which involves aspects of divided attention, selective attention, and sustained (Pylyshyn & Storm, 1988). Visual attention is the interaction between spatial distribution and temporal dynamics of attention. The UFOV aims to measure spatial visual attention (including selective and divided attention) at a fixed point in time, while the MOT captures these aspects of spatial visual attention in addition to adding a sustained component over a specific time period.

1.3.1 Useful Field of View (UFoV)

Clinical visual field testing (perimetry) is an important aspect of visual function. However, standard and automated perimetry tests cannot assess the impact of the complexity of the visual task in everyday activities. Ball and colleagues in 1988 defined the Useful Field of View (UFOV) as “the visual area in which information can be acquired within one eye fixation” (Ball et al., 1988). They pointed out that efficiently analyzing the visual environment for everyday tasks not only depends on the sensitivity of peripheral vision (as measured in clinical visual field tests). It involves a more complicated process of detecting, localizing and identifying visual information. The standard version of the UFOV has three subtests (Ball et al., 1988;

Leat & Lovie-Kitchin, 2006a; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986; Wood & Owsley, 2014). The first subtest aimed to measure the processing speed during low visual demand. The second subtest is called divided attention and aimed to measure the processing speed while presenting central (identification) and peripheral (localization) tasks. The third subtest is called selective attention and is similar to the second subtest but the peripheral target is presented among distractors (Leat & Lovie-Kitchin, 2006a; Wood & Owsley, 2014). There is a reduction in the useful field of view with increased crowding due to distractors or when there is less discriminability of the target compared to the distractors. In the useful field of view, the sub-test for processing speed test, divided attention or selective attention can be included. The test is a measure of higher cognitive and sensory function that cannot be measured with a standard visual field test (Leat & Lovie-Kitchin, 2006a; Owsley, Ball, & Keeton, 1995). The test went through a number of modifications and there are different versions that have been used in the literature. It can be scored in terms of speed or percent correct. (Edwards et al., 2006; Wood & Owsley, 2014).

The UFOV has been shown to predict driving performance and vehicle collisions and also to measure risk of failing to detect pedestrians (Ball et al., 1993; Clay et al., 2005; Owsley et al., 1998; Owsley & McGwin Jr, 2010; Rubin et al., 2007; Sims et al., 2000).

There is a commercially available version of the useful field of view (UFOV) (the UFOV®) (Visual Awareness Research Group, Punta Gorda, Fla., USA). A number of studies on the UFOV® have shown the validity, repeatability, and correlation with experimental versions (Edwards et al., 2006). This commercially available version mainly measures processing time but not the extent of the useful field of view and uses a narrower area of the field (10 degrees rather than 30 degrees) (Wood & Owsley, 2014). Other researchers have undertaken studies with their own version of the useful field of view (Althomali & Leat, 2017; Leat & Lovie-Kitchin, 2006a; Leat & Lovie-Kitchin, 2008).

Studies of visual attention measured by the useful field of view indicate a relationship with performance in several daily visual tasks which demand visual attention. Sims et al. (2000) and Roth et al. (2003) found that those who score less in the UFOV show limitations in house work and physical activities (Roth et al., 2003; Sims et al., 2000). There were also associations in performance in tasks such as reading, finding things in a crowd and using tools (Owsley et al., 2001). In studies done by Huisingh et al. (2014) and Sims et al. (1998) regarding frequent falling, more frequent falls during the past few years were associated with poorer score on the UFOV (Huisingh et al., 2014; Sims et al., 1998). Mobility and gait studies indicated a relationship with UFOV (Broman et al., 2004; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004). The preferred walking speed, avoidance of obstacles, and safe walking show associations with UFOV scores, and thus UFOV might be used to predict performance in these activities. The UFOV has been shown to predict driving performance and vehicle collisions and also to measure risk as pedestrians (Ball et al., 1993; Clay et al., 2005; Owsley et al., 1998; Owsley & McGwin Jr, 2010; Rubin et al., 2007; Sims et al., 2000).

1.3.2 Multiple Object Tracking (MOT)

Selective attention, divided attention, and processing speed, mentioned above, measure visual attention for briefly presented stimuli. However, some researchers believe that the study of attention in a static display may not transfer to, or explain, the dynamic environment which we experience every day. They believe that everyday tasks (such as driving and mobility) have a dynamic nature and we generally experience a continually changing environment. Therefore, the aspect of attention called "dynamic or sustained attention" has been studied to match real world visual experience.

Multiple object tracking (MOT) is a technique developed by Pylyshyn and Storm in 1988 that measures dynamic visual attention and cognition (Pylyshyn & Storm, 1988). They argue that the visual system must be able to simultaneously index multiple objects and maintain this tracking over time. Therefore, the test requires continuous and sustained attention over time and includes divided attention over multiple objects. Additionally, the MOT task is an active task that requires attention during all the presentation time, and it is possible to manipulate the magnitude of attention demand by increasing the tracking load (Scholl, 2009). In the paradigm of Pylyshyn et al. (1988), a number of identical objects, between 1 and 5, are tracked among similar distractors. The total items (targets plus distractors were 10 plus (+) signs. The objects to be tracked are distinguished initially before the start of the test by flashing, but once the tracking started, they are identical to the distractors. The eyes fixate at central a target with no eye movement while tracking the objects through para-foveal fixation. Then all the items begin to move in a random fashion for different periods of time and then stop. The observer's task is to track the targets and then to indicate which are the targets at the end of the time period (Pylyshyn & Storm, 1988).

There are many studies that have used MOT as a measuring tool in different populations such as different age groups (Trick, Perl, & Sethi, 2005) and among video gamers (Green & Bavelier, 2006b; Sekuler, McLaughlin, & Yotsumoto, 2008). The impact of dual-tasking (Trick, Guindon, & Vallis, 2006) and cognitive training (Legault, Allard, & Faubert, 2013) has been studied.

Bowers et al. (2011) developed a brief version of MOT, the brief MOT, which was validated by showing threshold speeds that were highly correlated with threshold speed obtained by the psychometric function version of the full MOT ($r = 0.876$, $p < 0.001$). Moreover, they showed moderate correlation between the brief MOT and driving performance (as one of daily life activities) in 15 participants. There were very similar correlations between driving error score and MOT ($r = -0.670$, $p = 0.006$); and driving error score and UFOV (divided attention version r = 0.656, p = 0.008). In addition, there was a moderate correlation between UFOV [identification of central target only] and UFOV (divided attention) with MOT (r = -0.596, p = 0.015 and r=0.656, p = 0.008 respectively).

In a later study with 47 participants, Bowers et al. (2013) explored whether the Mini-mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975), the MOT, or the UFOV could be used to give a clinical standard assessment for safe driving. They found that driving performance was correlated to these measures. They found that the UFOV is a slightly better predictor of being an at-risk driver than MOT (but it was not significantly better). They found significant correlations between both UFOV subtests and MOT; r = 0.36, p < 0.05 and r = 0.50, p < 0.01 between MOT and UFOV (identification of central target only) and UFOV (divided attention) respectively (Bowers et al., 2013).

In a study by Alberti et al. (2014), 11 visually impaired subjects with bilateral central field loss were included and the authors found that the MOT adds more information about visual attention for the driving situation than UFOV. The brief MOT test was a slightly (but not significantly) better predictor of safe reaction times during a driving performance task (r = 0.73, p = 0.01) than the UFOV (r = -0.66, p < 0.04). They concluded that the brief version of the MOT visual attention test could be an important measure for visually impaired people to understand performance for mobility tasks in crowded places (Alberti, Horowitz, Bronstad, & Bowers, 2014).

Multiple object tracking has been used as a factor in different dynamic visual attention tasks to indicate the performance of everyday life. Perhaps driving is one of the most common aspects to be studied. In modern life, visual technology has become widespread. Television, computers, video games, virtual reality, and smart phones, etc. are essential visual devices for communication, work and leisure. Researchers have reported the roll of MOT in explaining performance of video gamers (Green & Bavelier, 2006b).

An increasing amount of research has found that there are large age-related deficits in visual function and visual perception resulting in lower performance in the UFOV in older adults compare to younger groups (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler & Ball, 1986), slower tracking in MOT tasks (Sekuler, McLaughlin, & Yotsumoto, 2008) and lower of number of objects able to be tracked (Trick et al., 2005).

1.3.3 Training visual attention

Training visual attention with UFOV type paradigms is possible and has been shown to have multiple benefits on health (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler & Ball, 1986). Importantly for older adults, research has shown declines in visual attention measures are linked to functional impairments (e.g., performance in driving a car and instrumental activities of daily life) (Ball, Edwards, & Ross, 2007; Ball et al., 2010; Edwards et al., 2005). Training processing speed as one aspect of visual attention training has been undertaken in a number of studies (Ball et al., 1988; Ball et al., 2002; Ball et al., 2007; Edwards et al., 2005; Roenker et al., 2003; Vance et al., 2007; Wadley et al., 2006). In these studies, training was typically conducted for 5 to 6 weeks for a total of 10 sessions and may have included other aspects of cognitive training. Each session took 60 to 75 minutes for all cognitive training including the visual processing speed training. Depending on the targeted population, their health status, the method, and the duration of the training, the improvement of visual attention remained from 6 months to 2 years after training (Ball et al., 1988; Ball et al., 2002; Roenker et al., 2003) or even up to 5 years (Wadley et al., 2006).

Importantly, improvement in visual attention after training with useful field of view tasks has been shown to translate to improvement in some everyday activities for older adults (Ball et al., 2007; Edwards et al., 2005; Roenker et al., 2003; Willis et al., 2006). For example, Roenker and colleagues (2003) reported that driving performance (on a road test) improved for at least 18 months after training processing speed (Roenker et al., 2003). Moreover, training processing speed enhances the performance in instrumental tasks such as finding a phone number, instructions on a food package or counting correct change (Edwards et al., 2005).

Improvement of multiple object tracking (MOT) with training has also been reported. Training visual attention using the MOT in 2D and 3D showed enhancement in visual attention (Green & Bavelier, 2003; Green & Bavelier, 2006a; Green & Bavelier, 2006b; Legault, Allard, & Faubert, 2013). There are also associations with video game playing, which would demand good visual attention. According to Green and Bavelier (2006) enumeration (the number of items that can be tracked) is greater in video game players compare to non-video game players (Green & Bavelier, 2006b). They also reported that participants who practice action video games improved in multiple object tracking (Green & Bavelier, 2006b). In addition, as the video gamers improved in MOT, there was an improvement in working (short-term) memory. Visual working memory is essential for sustained visual attention on an object during eye or object movement. There is an overlap between visual attention and the visual working memory (Astle & Scerif, 2011; Awh, Vogel, & Oh, 2006) and that may explain why playing video games improves MOT performance. Visual attention contributes in the enhancement of the capacity and the precision of visual memory by facilitating the encoding of visual information.

1.4 Video games and vision

In the early 1970s video games started to become popular as an entertainment (Greenfield, Brannon, & Lohr, 1994) and are common in contemporary life (Green & Bavelier, 2003; Greenfield et al., 1994). According to Lenhart and colleagues (2008), about 97% of teenagers

(12-17 years old) in the U.S. play video games (Lenhart et al., 2008). Playing video games has high visual and attentional demands that need fast visual processing and cognitive skills. Video gamers who frequently play action games more than one hour per day increase the possibility of training visual attention which may lead to enhancing in their function in daily life in ways mentioned above. It is also apparent that the improvement in the new generation of video games consoles (e.g., PS4™ and Xbox® see figure 1.1) has increased the visual and cognitive demands. For instance, the new virtual reality accessories, Kinect™, which gives augmented reality and mixed reality make these video games more comparable to real environments.

Figure 1.1 The PlayStation®4 console with tracking sensor and the PlayStation®VR

From PlayStation®, https://www.playstation.com

Figure 1.2 Xbox One console with Kinect™ sensor

From © Microsoft Xbox, https://www.xbox.com

Studies of the impact of action video games on visual spatial and temporal resolution, show that action video gamers have better spatial attention than non-video gamers as demonstrated by better UFOV performance for selective and divided attention (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a). Also, a larger Goldman visual field size was noticed using kinetic perimetry in action video gamers (Buckley, Codina, Bhardwaj, & Pascalis, 2010). According to Li et al. (2009), the contrast sensitivity function was better in those who play action video games (Li, Polat, Makous, & Bavelier, 2009). Green et al. 2007 found that action video gamers showed improve in crowded visual acuity (Green & Bavelier, 2007). Moreover, visual processing speed (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2012) and the number of targets that can be traced in the MOT test were enhanced for those who have prolonged experience playing action video games (Green & Bavelier, 2006b). Recently, video games have been used in vision rehabilitation such as treatment for amblyopia (Gao et al., 2018; Kelly et al., 2016; Manh et al., 2018).

To summarize, visual attention can be improved via training programs by manipulating visual stimuli to increase either temporal or spatial attention. Therefore, extensive action video game playing may enhance spatial visual attention and sustained attention. This improvement in visual attention after training may be important for elderly people who usually have declines in these skills. In addition, the studies have shown that visual attention enhancement can transfer to improve activities of daily life.

1.5 Balance and mobility and changes with aging

Postural control involves an integration of visual, vestibular, and somatosensory components. The integration of these three sensory systems contributes to postural adjustments while standing and walking with respect to gravity (Massion, 1994). Numerous researchers have investigated the effect of the aging process on the steadiness of postural control. This section gives brief review about the role of the three components in balance and the normal age changes.

1.5.1 The visual system

The visual system plays a major role in balance and mobility control. The incoming information from vision is important for awareness of the body location and the surrounding environment. The visual system can detect the person’s direction of movement and the direction of a moving object. That makes the role of visual information important to maintain balance and avoid surrounding hazards while moving. It has been reported that visual information improves recovery of unexpected loss of balance during a forward fall (Hoshiyama et al., 1993). The detection of external motion is limited to the visual system while the vestibular system detects motion of the head in space, and the somatosensory detects body configuration and orientation (Guerraz & Bronstein, 2008).

Both central and peripheral visual field have been shown to play major role in postural control (Straube, Krafczyk, Paulus, & Brandt, 1994). Vision is an exteroceptive source of information, and has an integral role with other body systems in order to maintaining balance (Lee & Lishman, 1975). It has been shown that the amplitude of postural sway and its velocity is affected by visual information (Lestienne, Soechting, & Berthoz, 1977; Masson, Mestre, & Pailhous, 1995). Guerraz et al. (2008) illustrated the effect of optic flow in controlling anterior-posterior sway - the anterior-posterior body sway or adjustment occurs in the opposite direction of optic flow (Guerraz & Bronstein, 2008). Another example of how vision interacts with movement, is how the perceived parallax motion of the background and eye movements are affected by medial-lateral sway (Guerraz & Bronstein, 2008). Therefore, the increase of postural sway when the eyes are closed is expected, especially when the visual information is the favored input. Lord and colleagues reported that postural sway increases 50% when the eyes are closed in contrast to eyes open either with or without somatosensory input (Lord, Clark, & Webster, 1991; Lord et al., 1994).

It has been reported that body sway increases with decreases in visual acuity (Paulus, Straube, & Brandt, 1984). For example, Paulus et al., reported that sway increased 40% for a person with 20/200 visual acuity compared to someone with 20/20, and it increased 60% when visual acuity was 20/650 (Paulus, Straube, & Brandt, 1984). Body sway increases with reduced visual field as a result of ocular or neurological diseases. Ocular disease such as glaucoma, age related macular degeneration (AMD) and diabetic retinopathy affect either the central or peripheral visual field. These kinds of diseases are more common in the older population. The visual field defects resulting from such diseases have been shown to increase body sway, indicating the role of vision in balance (Lord & Menz, 2000; Turano, Herdman, & Dagnelie, 1993). Similar results have been shown with simulated visual field loss although the group with simulated visual field defects showed more body sway than those with visual field loss due to disease. This may be because in the case of simulated loss, the person is not adapted to the visual field loss (Black, Wood, & Lovie-Kitchin, 2011).

Spectacle type and spectacle magnification increase the risk of loss of balance and falls (Lord, 2006). For example, multifocal lenses have been shown to increase the risk of falls due to the blur in the lower visual field. Moreover, the magnification changes which occur with changes of spectacle prescription has been reported to cause stepping inaccuracies resulting in increasing the possibility of slips or trips (Elliott, 2014). The effect of general age changes on vision, as described above, may also be a factor and these changes may affect postural control.

These various research approaches speak to the important contribution of the visual system to balance control. Results indicate the existence of a link between vision and postural sway, particularly when the input from vestibular and somatosensory is interrupted.

1.5.2 The vestibular system

The vestibular system is a sensory system which contributes to awareness about head movement and orientation in space (Angelaki & Cullen, 2008). It consists of three orthogonal semicircular canals for rotational movement sensation and two otolith organs for linear movement sensation. This system works efficiently with other balance sensory systems in order to provide full conceptualization of the body orientation and movement (Angelaki & Cullen, 2008). The vestibular system has a clear role in balance and postural control (Angelaki & Cullen, 2008; Fregly, 1975; F. Horak, Nashner, & Diener, 1990; Hornbrook et al., 1994). However, some studies have illustrated that the role of vestibular system can be compensated by the visual and somatosensory systems (Diener & Dichgans, 1988; Nashner, Black, & Wall, 1982). Other studies have suggested a minor role in balance correction by the vestibular system (Dietz, Horstmann, & Berger, 1988; Macpherson & Inglis, 1993). It is suggested that the level of dependency on vestibular system for balance control is dependent on the task.

Patients with vestibular disorders have been shown to have problems with balance, frequent falls, and problems with gait (Fregly, 1975; Nashner et al., 1982). These studies suggest that balance relies on vestibular input in the case of some postural disturbances. In addition, patients with vestibular problems have difficulty standing on one foot, standing or walking in tandem (heel to toe) and standing on an inclined surface even with the eyes open (Fregly, 1975; Horak, Shupert, & Mirka, 1989; Horak & Nashner, 1986). It has been reported that, compared to healthy older adults, patients with vestibular problems fail to maintain balance (either fall or take a step to prevent a fall) when standing on a moving or short space support surface (Horak et al., 1990). Studies have also indicated that vestibular dysfunction is associated with age (Neuhauser et al., 2005; Sloane, Coeytaux, Beck, & Dallara, 2001). Up to about 35% of people above 40 years old may have vestibular impairment (Agrawal, Carey, Della Santina, Schubert, & Minor, 2009). It is suggested that there is about 40% reduction in vestibular nerve fibers and receptor cells during life (Bergström, 1973; Rosenhall, 1973).

1.5.3 The somatosensory system

The somatosensory system receives information from tactile sensation and proprioception in order to ingrate it with the information from the two other sensory systems (visual and vestibular) to control balance. Proprioception is defined as “the perception of joint and body movement as well as position of the body, or body segments in space” (Sherrington, 1907). Information is received from muscles and joints to form a sense of limb movement (Gandevia, Refshauge, & Collins, 2002). The tactile sensation (cutaneous input) gives the ability to characterize and localize objects with touch. Input information from both tactile sensation and proprioception is necessary for balance (Guerraz & Bronstein, 2008). The somatosensory system helps the body to maintain an upright position and gives alerts from any mechanical changes on the surface when there are changes (Liaw, Chen, Pei, Leong, & Lau, 2009).

Similar to other sensory and motor systems, the somatosensory system changes with age and sway increases with age either through disease or weakness (Shaffer & Harrison, 2007). Researchers have found that sway increases at a relatively young age and results in deterioration of balance which happens faster after age 60 years (Era et al., 2006). It has been found that lower limb proprioceptive decline is likely in older people (Horak et al., 1989; Lord & WARD, 1994; Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989) and is correlated with poor balance and falls (Lord, Rogers, Howland, & Fitzpatrick, 1999; Sorock & Labiner, 1992; Tinetti, Speechley, & Ginter, 1988). Further, it has been found that people with diseases that affect the peripheral nerves, such as diabetes, have increased sway compared to healthy people from the same age group. This difference becomes greater if they stand on a soft platform, which decreases further the input from proprioception (Anand, Buckley, Scally, & Elliott, 2003b; Lord & Menz, 2000). Other research has studied diabetic patients to see the effect of extra input information to their balance from another limb. They found that sway decreased when they applied even a fingertip on a solid surface, and the sway deceased even more with stronger touch (Dickstein, Shupert, & Horak, 2001). Specifically, diabetic neuropathy has been reported to have a negative impact on balance (Richardson & Ashton-Miller, 1996). Numerous studies have been done to study the effect of neurological diseases which are common in elderly people and how they increase their risk of fall. Neurological conditions such as Parkinson's disease (Conte et al., 2013) and multiple sclerosis (Jamali et al., 2017) have been reported to have a role in impairment of the somatosensory system and consequently in balance also.

1.6 Aging and Falls

For older adults, a fall is a serious health problem and can lead to decreases in quality of life and functional independence and even to death (Kenny et al., 2011). A fall is typically defined as "unintentionally coming to the ground or some lower level, other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" (Gibson, 1987) or as "unintentionally coming to rest on the ground or other lower level with or without loss of consciousness" (Bell, Talbot-Stern, & Hennessy, 2000).

Due to age related changes and age-related disease, falls are a major problem caused by poor balance in older people. Falls are frequent in older adults and it has been shown that 30 to 40 % of adults over the age of 65 fall at least once every year (Hausdorff, Rios, & Edelberg, 2001; Tinetti & Speechley, 1989). The percentage is higher for those who are over 80 (Inouye, Brown, & Tinetti, 2009). In 2014 the Public Health Agency of Canada [PHAC] reported that about 35 to 50% of older people are at risk of a fall, which is more likely in females. According to the US Centers for Disease Control and Prevention (CDC) in 2015, 25,000 older adults die annually as a result of falling (Centers for Disease Control and Prevention, 2015). Falls are the leading cause of injuries that may lead to death such as hip fractures and traumatic brain injury (TBI) (Centers for Disease Control and Prevention (CDC), 2006). Rubenstein (2006) mentioned that 40% of all deaths due to injury were as result of a fall (Rubenstein, 2006).

It should be clarified here that the problem of falls is not only the prevalence of the fall itself, as younger athletes have high prevalence of falls. Rather, it is the subsequent problems resulting from age-related diseases that may increase the severity of the injury or the slow healing processes which make even a simple fall relatively dangerous. Even if the fall itself did not cause harm, the subsequent fear of a fall and loss of confidence with balance can lead to decreased activity and an increased risk for falls in the future (Cumming et al., 2000; Fletcher et al., 2010).

Recent reports, such as the WHO Global Report on Falls Prevention in Older Age, indicate that falls and their consequence problems are often preventable through various interventions and/or reducing the risk in the home environment. Therefore, understanding and identifying the risks either from the surrounding environment or a person’s health may help in developing falls prevention programs.

1.6.1 Falls risk factors

The risk factors for falls generally have been categorized into intrinsic (of the person) or extrinsic (in the environmental) (Deandrea et al., 2010). The intrinsic factors include internal characteristics that person has such as age, gender, general health, diseases and side-effects of medications. These factors can affect sensory systems including vision, the postural control system (motor system), cognitive impairment and loss of consciousness (Lach et al., 1991). Extrinsic (environmental) factors include external hazards such as obstacles, furniture, lighting, slippery floors, etc. These factors can cause a slip or trip resulting in a shift in the center of mass. Center of mass (COM) is defines as “the point equivalent of the total body mass in the global reference system and is the weighted average of the COM of each body segment in 3D space” (Winter, 1995). The point location of the vertical ground reaction force vector is called the center of pressure (CoP). The relationship between COM and CoP is such that when the COM moves off balance in one direction, the COP moves in the other direction to compensate, in order to maintain postural steadiness (Winter, 1995). Further sub-categories have added to further our understanding and prevention of the problem (Scott et al., 2001). Scott et al (2001) mention four categories: biological factors (e.g. balance, mobility and vision), behavioural factors (e.g. history of falls, and multiple medications, risk taking behaviour), social and economic (e.g. low income, low education and transportation) and environmental (e.g. inadequate building codes, home hazards and stairs, poor lighting) (see Seniors' Falls in Canada: 2nd Report 2014 (Public Health Agency of Canada, 2014)). It should be remembered that risks for falls are multifactorial and the chance of a fall increases with age.

Gender is one of the intrinsic factors. It has been reported that women were 58% more likely to have a fall injury than men (Dunlop, Manheim, Sohn, Liu, & Chang, 2002) while men are more likely to have a fatal fall than women (Hornbrook et al., 1994). Diseases is another intrinsic factor that increases the risk of falls. Chronic diseases such as diabetes and hypertension, are associated with decrements in balance and gait measures (Hausdorff et al., 2003). Gait instability and muscle weakness have been reported to be the most influential risk factor for falls (Tinetti et al., 1988). There is evidence showing associations between using citrine medications (such as psychotropic, sedative, hypnotic, and anti-depression medications) and falls (Hartikainen, Lönnroos, & Louhivuori, 2007). Patients who take multiple medications report an increasing number of falls (Leipzig, Cumming, & Tinetti, 1999).

1.6.1.1 Vision and falls

Vision impairment is considered as one of the strongest risk factors for falls in older adults (Rubenstein, 2006). The role of visual information in maintaining balance and mobility has been discussed above. Visual information is important for balance control and obstacle avoidance by providing spatial information. With aging comes the changes in most body systems. The decreased input from the vestibular and proprioceptive systems are described above so the load of information input is increased to the visual system to compensate this deficiency. Therefore, older adults may rely more on visual information for postural control and safe mobility. Turano et al. (1994) reported that fallers have less dependence on visual information for balance than non-fallers. Specific visual functions and falls have been investigated in many studies which are described in the following sections.

1.6.1.1.1 Visual Acuity

Visual acuity (VA) is the most common test of visual function. Studies of falls and related problems show that people who have visual acuity around 20/25 to 20/30 or worse have increased risk of multiple falls to around 2 to 3 times that of people with better VA (BOptom et al., 1998; Klein et al., 1998; Klein et al., 2003). Other studies have shown that the risk increased when the visual acuity dropped to 20/40 (Coleman et al., 2004) and was more correlated to injuries when visual acuity became 20/67 or worse (Koski et al., 1998). Black and Wood (2005) report that visual acuity is an important factor for stable posture in older adults (Black & Wood, 2005). Lord and associates (1990) reported that increase in body sway was not correlated with poor visual acuity when standing on a firm surface, but it did correlate when standing on a complaint surface. In the latter case there is less input from the proprioceptive system, which suggested that the demand on vision was increased resulting in the better correlation (Lord, Clark, & Webster, 1991). However, some studies have failed to find a link between visual acuity and falls when adjusting for confounders, especially age (Lord, Smith, & Menant, 2010).

1.6.1.1.2 Contrast sensitivity

Contrast sensitivity gives more information of visual function than visual acuity as it measures sensitivity for a variety of spatial frequencies. This visual information is important for our scanning and negotiating ground-level hazards in order to move safely within the environment. It has been shown that lower spatial frequency information is importance for postural stability (Anand et al., 2003a). Therefore, it was suggested that reduction the contrast sensitivity for low and mid spatial frequencies could be considered as an important risk factor of fall (Black & Wood, 2005). Lord and colleagues demonstrated that contrast sensitivity plays a major role in postural control and it predicts fallers (Lord et al., 1994).

1.6.1.1.3 Depth perception/stereopsis

The inability to perceive depth causes inaccuracy in judging distances and the height of steps which is important for moving safely within the environment. The role of depth perception is essential in postural control (Lord & Menz, 2000). Associations have been found between poor depth perception and multiple falls in a group of older people (Lord & Dayhew, 2001).

The risk of multiple falls was double in those who had a reduction in stereoacuity compared to those who did not. Depth perception was among the visual risk factors for multiple falls in another study of community-dwelling older adults (Salonen & Kivelä, 2012). Another study illustrated that older adults who had good vision in one eye and moderate or poor in the other eye (which would also affect stereopsis) had multiple falls at a similar rate to those who had poor vision in both eyes (Lord & Dayhew, 2001).

1.6.1.1.4 Visual field

Peripheral vision is essential for locating and avoiding obstacles. Visual field is also important for the postural control - it has been shown that postural stability is worse with a simulated restriction in visual field size (Paulus, Straube, & Brandt, 1984; Turano et al., 1993). This situation is similar to glaucoma patients where reduction of sensitivity occurs in their peripheral field. Visual field impairment also affects mobility performance; slower walking speed with an increased tendency (22%) to hit obstacles was found in participants with glaucoma who have reduced visual field sensitivity (Turano et al., 1993). A number of studies have suggested that visual field loss is a risk factor of falls (BOptom et al., 1998) and multiple falls (Coleman et al., 2007; Klein et al., 2003). Specifically, inferior visual field loss has been correlated with higher rates of falls (Black et al., 2011). However, there is some debate, as there are other studies which show no relationship with falls when adjusted with confounder factors such as age or gender.

In summary, falls have been associated with different risk factors that can be internal (from the person) or external (from the surrounding environment). Falls risk factors can be classified as biological, behavioural, environmental and social/economic. Aging increases the risk of falls as it is associated with changes in cognitive, sensory and physical function. The external factors are more influential in those who are younger than 75 years old while internal factors are more influential in those who are 80 years or more (Lach et al., 1991). Falls are multifactorial and are an increasing problem. However, the incidence of falls may be reduced through intervention programs that aim to minimize the risks.

1.6.2 Falls prevention

Programs to prevent or reduce falls have been widely studied. The effectiveness of any intervention program relies on the target population who are risk of falling and the risk factor that is reduced. Studies show that multifactorial intervention programs are the best way to prevent falls (Kenny et al., 2011). A single intervention program was effective for healthy older adults in one specific case (Petridou et al., 2009). Below is an overview of fall prevention programs that aimed to enhance health and reduce the risk of falls.

1.6.2.1 Exercise intervention

Only a few percent of older adults 65 years and above meet the daily physical activity recommended requirement (Crespo et al., 1996). In Canada, it has been reported that only 11% of Canadians aged between 60-79 years attain Canada's physical activity guidelines (Public Health Agency of Canada, 2014). Physical activity can improve muscle strength which has a major role in mobility and balance (Howe, Rochester, Jackson, Banks, & Blair, 2007). Physical training has been shown to be effective for older adults who are at risk of falls (Sherrington et al., 2011; Sherrington et al., 2017). The most effective training programs seem to include exercises that improve muscle strength, balance, and coordination of gait (Faber et al., 2006). In the studies of training, training duration was variable. The limited effect of some interventions may be related to insufficient intervention intensity (Day et al., 2002). Effective exercise programs consistently have been shown to be more than 10 weeks duration and include muscle strength, balance and gait training (Lord et al., 2003; Maritz et al., 2013). The recommendations of training duration are between 12 to 25 weeks from 1 to 3 times a week (Kenny et al., 2011; Sherrington et al., 2011; Sherrington et al., 2017). Although low intensity exercise was not effective in some studies, DeVito et al. 2003 reported that even low intensity exercise can improve balance and gait especially for those who are at risk of falls (DeVito et al., 2003). Dynamic balance exercises, such as Tai-Chi, show improvement in balance and reduction in falls (Wu, 2002).

1.6.2.1.1 Exercise training with video games

Recently, numerous studies have used interactive video games for the purpose of exercise training, balance training or even as a balance assessment tool (Goble, Cone, & Fling, 2014; Padala et al., 2012; Padala et al., 2017; Reed-Jones, Dorgo, Hitchings, & Bader, 2012b; Rendon et al., 2012). Recent studies have shown that exercise with the Nintendo Wii-Fit® exergame gives a significant improvement in balance and gait in older adults (Goble et al., 2014; Padala et al., 2017). The Wii-Fit® system includes a video game console that connects to a TV and the Wii balance board (WBB) or hand controller accessory (See Figure 1.3). The exercise game is an interactive game between the player through the WBB and the game on the screen. For instance, the player conducts leg exercise while standing on the WBB following the instructions provided on the TV screen. The WBB as a controller is connected to the console and can read the transition of the central of pressure (CoP) from the player as the move and then transfer it as a motion response to the game. This exercise approach may increase the exercise engagement of older adults through direct guidance and making it fun. The studies have used the Wii-Fit system for training with either balance games (Rendon et al., 2012) or exercise games (Williams et al., 2011). Williams et al used Nintendo Wii Fit to train balance in older adults aged 74 to 94 and they found significant Improvement in the Berg balance Scale (BBS) score after training (Williams et al., 2011).

Figure 1.3 Nintendo Wii-Fit™ with sensor and balance board

From Nintendo® http://www.nintendo.com

Rendon et al., (Rendon et al., 2012) did a similar study with a control group who received no training and they reported a significant improvement in the UP & GO test and the Activities-specific balance confidence scale (ABCS) (Rendon et al., 2012). Reed- Jones and colleagues report that those who trained with Wii-Fit had the greatest improvement (22%) in the performance on obstacle course compared to two other groups which had different physical training and they suggested that the Wii-Fit could be considered for fall prevention programs (Reed-Jones et al., 2012a).

Other studies have used the Xbox® with Kinect™ to investigate the effectiveness of programs similar to those done with the Wii-Fit (See Table 1.1). One study by Vernadakis et al. (2014) studied young male adults who had experienced a sports injury. The study found improvements in balance with the Xbox® Kinect exercise games which were equal to those achieved with regular physiotherapy (Vernadakis et al., 2014). A randomised clinical trial was conducted by Su et al. (2015) on groups of healthy adults and included an intervention and control group (Su et al., 2015). The intervention group played Xbox Kinect games 3 times weekly for 6 weeks for 20 minute sessions. The authors stated that improvement in agility and dynamic balance was noted from the second week of intervention that continued at week 4 and week 6. However, they did not notice improvement in static balance (Su et al., 2015). Bieryla et al., (2016) included groups of normal healthy older adults aged 70+ years who were randomised to a control or intervention (playing Xbox Kinect) group (Bieryla, 2016). They found improvement in the Berg balance scale (BBS) and the Fullerton advanced balance (FAB) scale in the experimental group but not in the control group. No significant difference in functional reach (FR) or Timed Up and Go (TUG) was found in either group.

However, the author is not aware of any study that has measured visual attention with any Xbox Kinect™ intervention game or investigated see the potential impact of training from these types of games on both vision and balance measures. Nor are there any studies that have measured the association between visual attention and performance on Xbox games.

Table 1.1 Studies of intervention programs for balance training using the Xbox® 360 with Kinect™ games

Study	**Sample size**	**Groups**	**Intervention**	**Outcome Measure**	**Conclusion**
(Ortiz-Gutiérrez et al., 2013)	n=50 Multiple sclerosis aged (28-60) years	2 groups: 1.Control group (physical exercise) n=23 2. Xbox Kinect training n=24	10 weeks Control 2x weekly, 40 min session Experimental 4x weekly, 20 min session	1.A computerized dynamic posturography (CDP) Sensory Organization Test (SOT) 2. Visual preference and vestibular information	Improvement in visual preference and vestibular information, when there was no somatrosensory input
(Luna-Oliva et al., 2013)	n=11 Cerebral palsy	1 group	8 weeks 30 min session 2x weekly	AMPS, PRT, 10MW, GMFM, JHFT, ADL, JHFT	Significant improvements in motor assessment, balance and ADL in CP participants
(N. Vernadakis et al., 2014)	n=63 previously injured young competitive male athletes aged 16 ± 1 years.	3 groups: injured/non-injured in each 1. control group 2. Xbox Kinect training 3.Traditional physiotherapy training	10 weeks 24 min session 2x weekly 4 balance video games 8 different balance exercises	(BSS), (OSI), (LOS) 2. the Physical Activity Enjoyment Scale. 3.Self-reported compliance	Improvements in balance with the Xbox® Kinect exercise games which were equal to those achieved with regular physiotherapy
(Galna et al., 2014)	n=9 Parkinson's disease Aged 40-80 years	1 group n=6 progressed in all game levels	4 weeks 1-2x weekly	Game performance (recorded) The Flow State Scale (questionnaire)	The Kinect may be feasible and safe for PD training. Care and caution must be considered when training at home

(Beaulieu-Boire et al., 2015)	n=4 elderly people aged 65+	1 group n=3	10 weeks 30 min session 2x weekly	[BBS]), [TUG], walking speed for 5m, [STS], [ABCS], [QUEST].	Improvement in BBS, TUG, ABC and STS for two subjects. Walking speed remained same
(Su et al., 2015)	n=43 health adults aged 20-30 years	2 groups: 1. control n=21 2. intervention n=22	6 weeks 20min session 3x weekly	(GLEQ) (PAR-Q) The side step test (HELMAS II Physical Testing) Static Balance test, Dynamic Balance test (the SEBT).	Intervention group showed improvement in agility and dynamic balance from week 2 that continued improving at 4 and 6 weeks. No sig. different between groups in static balance.
(Bieryla, 2016)	n=13 healthy older adults aged 70+years	2 groups: 1.Control n=7 2.Experimental n=6	3 weeks 30min session 3x weekly	(BBS), (FAB), (FR), (TUG).	Significant improvement in BBS and FAB in experimental group No change in FR and TUG
(Türkbey, Kutlay, & Gök, 2017)	n=20 Stroke Aged 38-79 years	2 groups 1.Control n=9 2.Experimental n=10	4 weeks 60 min session 5x weekly	(BBT) (WMFT) (FIM) (BMRS) (Borg CR10)	Greater improvement in experimental group in BBT, WMFT and BMRS.

(Aşkın et al., 2018)	n=40 Stroke Aged 34-72 years	2 groups 1. physical therapy + Xbox Kinect n=18 2. physical therapy n=20	4 weeks 60 min session 5x weekly + 20 sessions of PT Second group only 20 PT sessions	(UE), (FMA). (BMRS), (MAS), (BBT), (MI), and (AROM)	Training with Xbox Kinect may contribute to the improvement of UE motor function and AROM in chronic stroke patients

10MW= the 10-meters walking test, **ABCS**= Activities-Specific Balance Confidence Scale, **ADL**= Activities of Daily Living, **AMPS**= Assessment of Motor and Process Skills, **AROM**= Active Range of Motion, **BBS**= Berg Balance Scale, **BBT**= Box and Block test, **BMRS**= Brunnstrom Motor Recovery Stage, **Borg CR10**= Borg Category-Ratio 10 scale, **BRS**= Brunnstrom Recovery Stages, **BSS**=The Biodex Stability System, **CDP**= Computerized Dynamic Posturography, **FAB**= Fullerton advanced balance scale, **FIM**= Functional Independent measure, **FMA**= Fugl-Meyer Assessment, **GLEQ** =The Godin Leisure-Time Exercise Questionnaire, **GMFM**= the Gross Motor Function Measure, **JHFT**= The Jebsen Taylor Test of Hand Function, **LOS**= limits of stability, **MAS**= Modified Ashworth Scale, **MI**= Motricity index, **OSI**= overall Stability Index, **PAR-Q**= The Physical Activity Readiness Questionnaire, **PRT**= the Pediatric Reach test, **QUEST**= Quebec User Evaluation of Satisfaction Test, **SEBT**= the Star Excursion Balance Test, **SOT**=Sensory Organization Test, **STS**= Sit-to-Stand, **TUG**= Timed Up and Go, **UE**= Upper Extremity, **WMFT**= Wolf Motor Function Test

1.6.2.2 Vision intervention

There is limited research illustrating the effectiveness of visual intervention in fall prevention. Visual assessment and prescription of new glasses has been studied as a visual intervention to reduce the risk of falls (Cumming et al., 2007). Visual acuity can be improved with visual intervention studies, however, inappropriate eyeglasses or a major change in the new prescription may increase the risk of falls particularly during the adjustment time for new eyeglasses (Cumming et al., 2007). In the Cumming et al study, the authors reported that intervention group fell more frequently than the control group. However, they also reported that about only 30% of the intervention group received new spectacles, while a large proportion (72%) of the control group visited their eye care provider during the study and possibly received new spectacles. The authors themselves stated that the study was flawed.

Haran et al. (2010) conducted a randomized clinical trial in which the intervention was the provision of single vision spectacles instead of multifocal lenses for outdoor wear. This study was performed because the use of multifocal lenses may increase the risk of falls as the near segment of the lens affects some aspect of spatial vision such as visual acuity and contrast sensitivity at the ground level (Haran et al., 2010). They found no overall effect or difference between the intervention and control groups. (Haran et al., 2010). However, a sub-analysis showed that this intervention was effective for those who were more active outdoors. Those who were not active out of doors experienced an increase in falls incidents with the new glasses. This study indicated that multifocal lenses are appropriated for people who are less active and spend more time indoors while single vision lens may be indicated for older people who are active outdoors.

There is equivocal evidence about whether cataract surgery reduces falls rates (Brannan et al., 2003; Foss et al., 2006; Harwood et al., 2005; Schwartz et al., 2005). One study showed that postural stability improves after cataract surgery (Schwartz et al., 2005). In studies of the effectivity of cataract surgery as a visual intervention for older women, researchers found significant improvement in vision, balance confidence and level of physical activity (Harwood et al., 2005). Some studies have found a reduction in falls rates after cataract surgery. For example, rates fell 32-34% during 12 months follow up (Foss et al., 2006; Harwood et al., 2005). Alternatively, there is one study which showed no change in falls after cataract surgery (McGwin et al., 2006) and one other study reported an increase in the risk of falls (Meuleners et al., 2013).

Training of aspects of vision such as visual attention has been discussed above in this chapter, and improvements in visual attention have been demonstrated after training with video games. Also, other studies of exercise video games report improvements in postural control and decreased risk of falls. This raises a fundamental question about the possibility of training both vision and balance with interactive video games that might be more effective than training either alone.

1.6.2.3 Multifactorial intervention

Since falls are multifactorial problem, combinations of several forms of intervention may result in better falls prevention than a single intervention alone. Previous research has found that the combination of more than one intervention resulted in better improvement (Day et al., 2002). It has been also indicated that the most efficient physical training intervention programs are those that include muscle strength, balance, and coordination of gait (Faber et al., 2006). Day et al reported a decrease in falls rate of 24% with exercise alone but 33% reduction with a multifactorial intervention program which included vision and home modifications (Day et al., 2002). Casteel and colleagues reported that those who participated in their multiple intervention program called “the No More Falls (NMF)” showed a 53% reduction in the risk of a fall (Casteel et al., 2004). The NMF included the following: reduction of domestic environmental hazards, management of medication and alcohol use, development of lower limb strength and balance, and identification and treatment of existing vision and hearing impairments.

There is obvious potential to reduce the risk of falls with these types of programs and finding the optimum combination of components is a topic of on-going study.

Chapter 2
Research objectives

2.1 Purpose

The aging process is known to cause deterioration in body structures and functions. These deteriorations may have impacts on older adults' quality of life. I have already discussed the natural changes that occur with age in some visual and body functions and the possibility of reducing the risk of falls by different training intervention programs. For example, physical training for older adults with muscle weakness improves their postural control and reduces their risk of falls (Skelton & Dinan, 1999). Additionally, cognitive training has a positive effect on balance control for older people (Smith-Ray et al., 2013).

Interactive video virtual-reality games such as Xbox Kinect™ and Nintendo® Wii fit games have been shown to be an effective and safe tool for training and assessment of balance (Bieryla, 2016; Chao, Scherer, & Montgomery, 2015; Goble et al., 2014; Vernadakis et al., 2014). Numerous studies have reported the effectiveness of training both older people and young people, who either have normal abilities for their age or who have physical injury or neurological impairments. Several studies have also indicated the benefits of playing video games, specifically action video games, on visual attention and other cognitive skills. However, only a few studies have investigated the effectiveness of training visual attention with video games. To our knowledge there are no studies investigating the value of training visual attention with body movement control games such as Xbox Kinect™ games. These types of games may train aspects of visual attention and the physical function concurrently.

Before starting a clinical trial of the effectiveness of Xbox game training, it is important to first find the relationships between performance in this type of games and visual attention, mobility and balance measures so as to choose the optimal type of Xbox game that can offer the strongest affect.

Therefore, this study was designed to determine the relationships between visual attention as measured by UFOV (static and dynamic attention) and MOT (sustained attention) and performance in body control movement games (Xbox Kinect™ games). Secondly, determine the type of Xbox Kinect games that have the best correlation with visual attention measures. In addition, the role of different aspects of vision, including visual attention on balance and mobility was studied. This information is important for assessing the possible methods for a future randomised clinical trial for training visual attention and physical abilities with such games.

2.2 Research hypotheses

The hypotheses of this study are:

1. **H_1:** Tests of visual attention (UFV and/or MOT) **have a stronger agreement,** as indicated with correlation and regression, with the performance in Xbox Kinect™ games which were chosen to have a strong visual attention component, compared with those that appeared to require less visual attention but only have a physical component, in older (Chapter 4) and younger adults (Chapter 5)
2. **H_1:** Tests of visual attention (UFV and/or MOT) **both have a significant association with balance** (measured with the force plate and one-legged stand test) **and mobility/gait** (assessed with the variability of steps and walking speed in the 5 Meters Walking test)

2.3 Experiment design

Two cross-sectional studies were undertaken firstly with a group of older adult participants described in Chapter 4 and then with a group of younger adults described in Chapter 5. These two studies were designed to determine the relationships as described in hypotheses 1 and 2. Measures of visual attention included two versions of the useful field of view (UFV), and the multiple object tracking (MOT). Measures of balance were obtained with a force plate platform, measures of gait were taken with the 5-metre walking test and Xbox games included two games with less apparent visual attention component and two with a higher apparent visual attention component.

Chapter 3
Research Methods

3.1 Participants

This thesis includes two cross-sectional studies. The first study consisted of relatively healthy older adults 65+ years (Experiment 1, Chapter 4) and the second study consisted of healthy adults 18-40 years (Experiment 2, Chapter 5). Participants were recruited from the Primary Care Clinic at the School of Optometry and Vision Science at the University of Waterloo, from among friends and family members, grad/undergrad students and staff at the School of Optometry and Vision Science and from snowball sampling. When recruiting participants from the School of Optometry clinics, the files of participants who had a written consent to be contacted regarding research studies, were reviewed before contact to make sure that they met the study inclusion criteria. If so, a letter of information about the study sent by mail, email or given by hand to the potential participants. The inclusion criteria for experiment 1 and experiment 2 are listed in (**Table 3.1**).

All participants in both groups underwent a phone call to determine eligibility (see Appendix A) and to answer all the questions they might have. Written consents were given by all participants who were involved in the study including specific consent for video-recording. The study was reviewed and received clearance through a University of Waterloo Research Ethics Committee.

Due to the expected differences in activities, physical activities and cognitive status between younger and older adults, the inclusion/exclusion was slightly changed for the younger group compared to the older group.

Table 3.1 Inclusion/exclusion criterion for experiment 1 and 2

	Study Inclusion characteristics
Experiment 1 Older adults group	Aged 65 and above Either gender Montreal Cognitive Assessment (MoCA) test score after correction for level of education ≥ 24 (Nasreddine et al., 2005; Rossetti et al., 2011) Not diagnosed with dementia, Parkinson's disease, history of cerebrovascular accident resulting in residual paresis, multiple sclerosis, cerebellar dysfunction, peripheral neuropathy of any etiology, or advanced arthritis such as to cause significantly reduced range of motion of the weight bearing or small joints, or significant hearing loss Not using medications which are known to increase risk of falls (antipsychotics sedatives, antidepressants, anti-histamines, anti-hypertensive and long-acting sleeping medications) Independently mobile (able to walk without a cane or walking frame) No clinical vision loss (corrected binocular visual acuity 6/12 (20/40) or better with no diagnosed glaucoma or hemianopia) No previous use of Xbox exercise gaming.
Experiment 2 Younger adult group	Aged 18-40 Either gender No significant vision loss (binocular VA 6/7.5 (20/25) or better with glasses if used) and/or no ocular diagnosis that would cause vision loss (e.g. glaucoma). Not diagnosed with dementia, Parkinson's disease, history of cerebrovascular accident resulting in residual paresis, multiple sclerosis, cerebellar dysfunction, peripheral neuropathy of any etiology, and advanced arthritis so as to cause significantly reduced range of motion of the weight bearing or small joints, or significant hearing loss Not using medications which are known to increase risk of falls (antipsychotics sedatives, antidepressants, anti-histamines, anti-hypertensive and long-acting sleeping medications) No previous concussion with residual symptoms that affect balance No previous injury that still affects balance or mobility Not a video gamer who plays action video games >3 hours 5x per week Not an athlete (defined as 4 hours of exercise per day 5x per week) Able to walk independently (without cane or walker)

On the day of the study, participants in the older adult group took part in a cognitive test, The Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). The MoCA is a brief screening cognitive tool designed to detect people who have cognitive impairment. According to Nasreddine et al., the cutoff score for the normal range [no cognitive impairment] is taken as 26. However, a study conducted by Rossetti et al (2011), which included a wider ethnic group but did not include an adjustment for education, gave rise to a lower cut point score. The mean was about 24 (depending on age group) with a standard deviation of approximately 3. From Nasreddine's study, we estimated the mean to be 27, and the lower 95% value to be 24. Therefore, so as not to exclude too many participants, it was decided to use a cutoff score of 24 or more for eligibility to take part in the first study.

The participants in the experiment 2 were asked to undertake a questionnaire instead (see Appendix B). As some people in this younger population may be very physically active or frequent gamers, this included questions about the amount of physical exercise and video gaming of various types that they typically do. This was used to control for these confounding factors. It was decided that excluding all video game players would have excluded too many potential participants. This was the only difference between the two study protocols and procedures.

3.2 Initial vision screening (Eligibility)

3.2.1 Distance Binocular Visual Acuity (BVA)

Visual acuity was measured for all participants while wearing their habitual vision correction. It was clarified with the participant that the habitual vision correction was the visual correction used for driving, walking and shopping. Visual acuity was measured with the 4 meters version of the Early Treatment Diabetic Retinopathy Study chart (the ETDRS chart), by Precision Vision, (chart R) (see Figure 3.1). The ETDRS chart is one of the most precise visual acuity measures and has become the gold standard for VA measurement. The ETDRS chart has 5 letters on each line, and it follows a logMAR progression (Ferris III et al., 1982). We scored with by-letter scoring by which each letter is given a weight of 0.02 logMAR (Bailey & Lovie, 1976; Hazel & Elliott, 2002). The average chart luminance was about 84.5 cd/m^2 as measured by a Minolta Camera Co., Ltd. Chroma meter CS-100. VA as measured at 4 meters and each participant was asked to start reading at the 4/10 (0.40 LogMar) line. The letters should be read in order and participants were not allowed to correct themselves once they read the next letter. Participants who had visual acuity worse than 6/12 (20/40) in older adults' group or worse than 6/7.5 (20/25) in adults' group were excluded from the study.

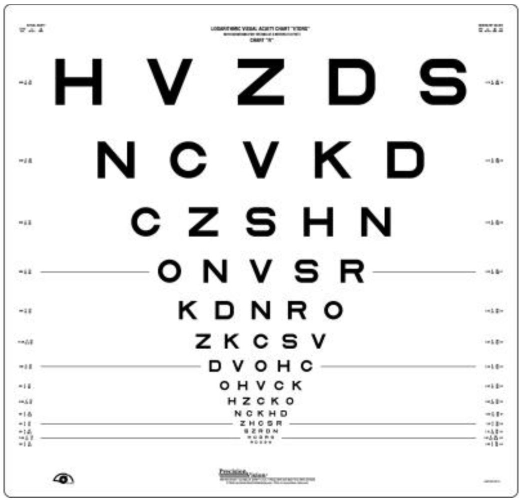


Figure 3.1 The ETDRS Visual Acuity Charts R 13ft/4m

(Image from Precision Vision, https://www.precision-vision.com/)

3.2.2 Confrontation visual field test

The confrontation visual field test is a routine clinical screening test for identifying major visual field loss. It can detect the participants with gross field defects. The test can be performed quickly with no equipment. All participants underwent the test under normal room lighting. The participant was seated in front of the examiner with his/her eyes level with the examiner’s and was asked to fixate on the opposite examiner’s eye while occluding the other eye. Then the participant was asked to count the number of stationary fingers presented in each field quadrant. The test was conducted in order to confirm that there was no field defect of which the participant was unaware. Participants who failed this test were excluded from the study.

3.3 Balance and mobility measures

3.3.1 Body sway

Many studies have addressed the relationship between body sway with balance and falls (Guerraz & Bronstein, 2008; Lestienne et al., 1977; Masson et al., 1995; Paulus, Straube, & Brandt, 1984). Body sway is commonly assessed in laboratory experiments based on the Center of Pressure (CoP) displacement over time. The central of pressure (CoP) can be measured with the force platform and is calculated from the force and moments of participant sway (Winter, 1995). In this study, body sway was measured with the Accugait portable force plate (200 Hz) (Advanced Mechanical Technology Inc, Watertown, MA, USA). This platform measures the ground reaction forces in three standardized axes Fx, Fy, and Fz and the moments Mx, My and Mz in order to record the location and movements of the Central of the Pressure (CoP). The acquisition sampling frequency was set at 200 Hz (i.e., 200 data points per second). In order to remove data noise, the first and the last five seconds of data were removed for a one-minute measurement, this left 50 seconds or 10,000 data points for analysis). Then the data were filtered using a 6Hz low pass (dual pass) Butterworth filter.

The body sway was measured in two sets of assessment: bi-pedal quiet stand test (QST) and one-legged stand (OLST) (see Figure 3.2). The QST required the participant to remain standing barefoot, with both feet placed apart from each other, on the same spot on the force plate platform. Each participant was requested to stand as stable and relaxed as possible, not moving or talking, for one minute with their eyes open, focussed on a fixation target 1 m away on front of them while both hands were placed together in front of them. For OLST the participant was asked to stand still on one preferred leg with the other leg extended in front (see Figure 3.2 B) for 30 seconds. Both hands were placed to their sides. This was performed with their eyes open, fixating on a target 1 m away in front of them. Each participant was asked to do three trials of QST and OLST.

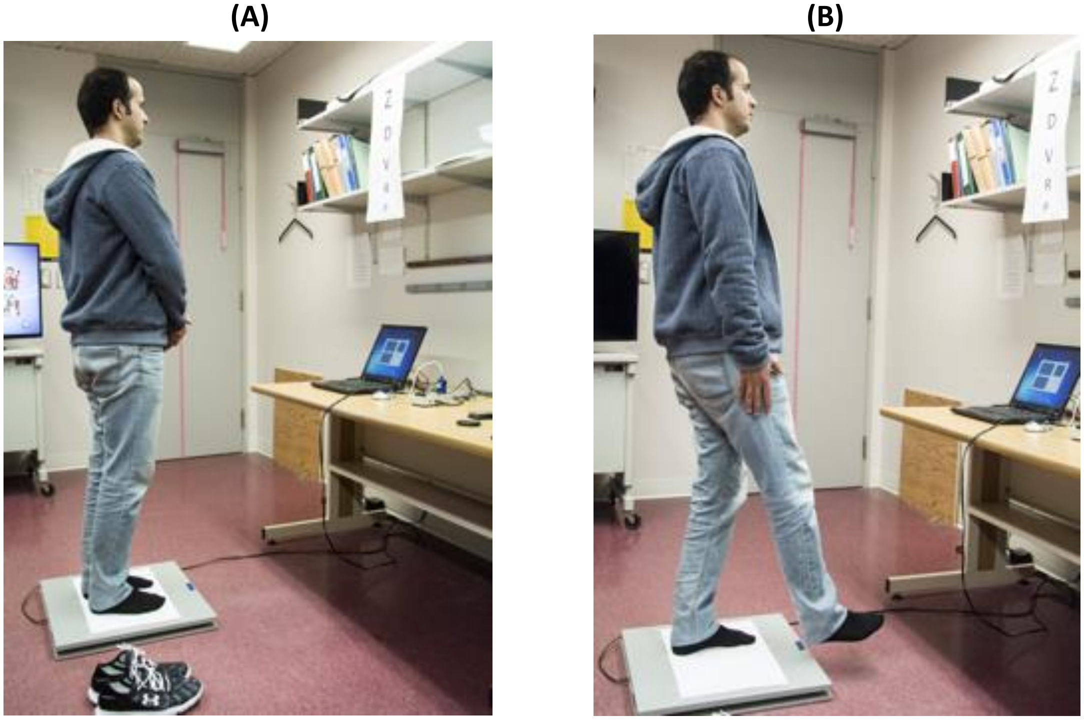


Figure 3.2 A participant engaged in balance sway measured on the force plate platform; A) bi-pedal stand test (QST). B) one-legged stand (OLST)

From the center of pressure (CoP) displacement points over the time, the displacements of the center of pressure for anterior-posterior (AP), medial-lateral (ML) (see Figure 3.3 A, B) direction and the cumulative path length (CPL) (see Figure 3.4) were calculated in cm.

After the CoP raw data for all participants were collected, the following postural sway measures were calculated for each trial: the medial-lateral (ML) and anterior-posterior (AP) center of pressure (CoP) variability (standard deviation), ML and AP CoP maximum displacement, ML and AP CoP range and the cumulative path length in cms. The mean of the three trials was calculated and data points that were more than 3 standard deviations away from the mean were excluded from the analyses (Prieto et al., 1996).

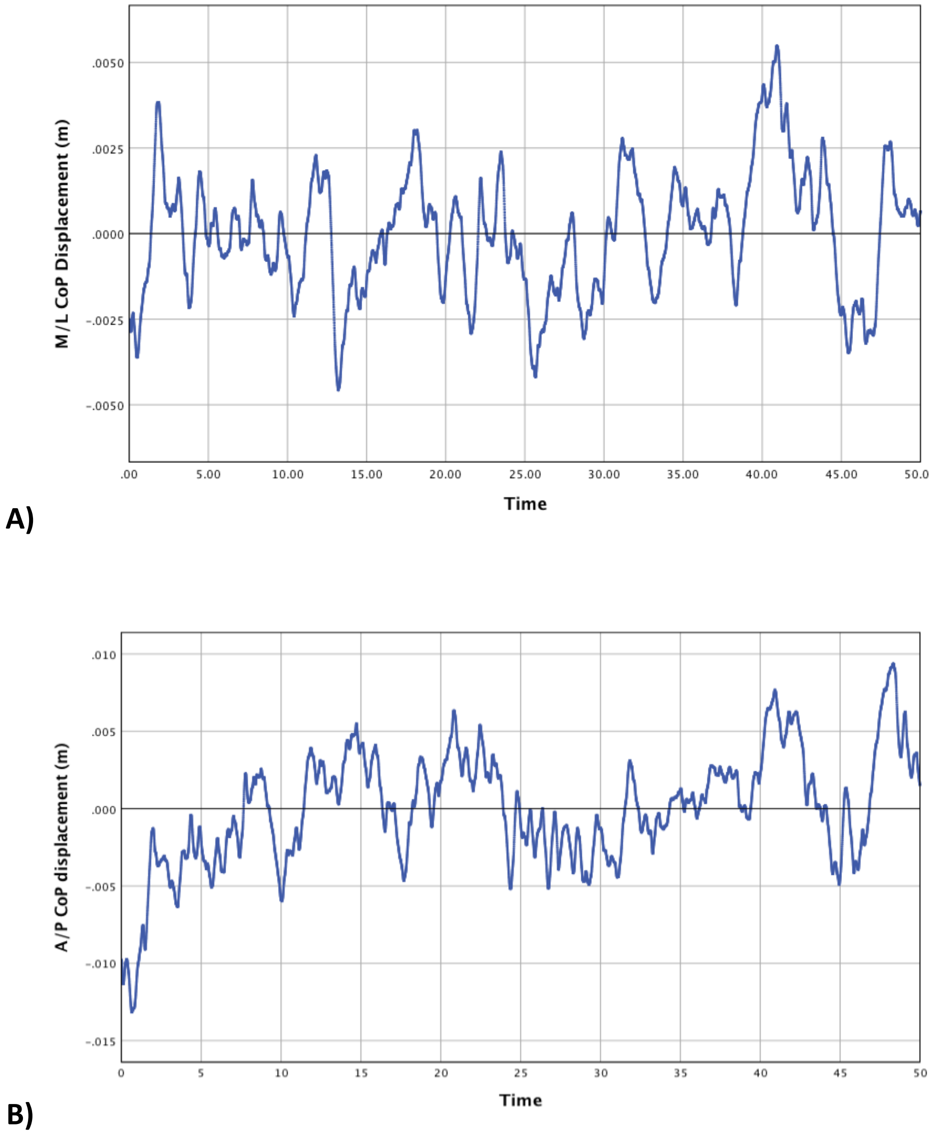


Figure 3.3 Center of Pressure (CoP) displacement (m) as a function of time (sec.) for one older participant; A) medial-lateral (ML CoP) sway. B) anterior-posterior (AP CoP) sway

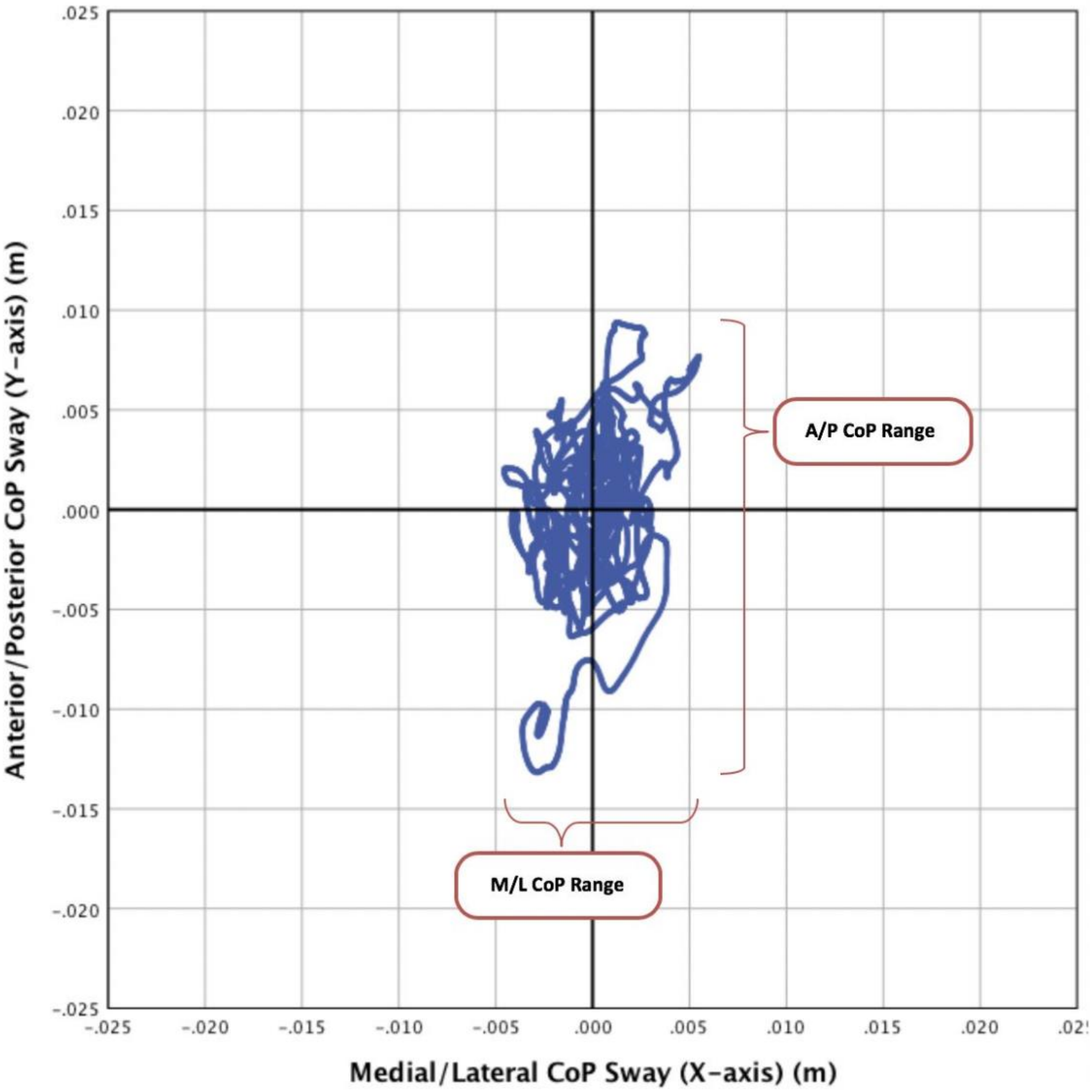


Figure 3.4 The Center of Pressure (CoP) trace over time; representative data for one older participant

3.3.2 Gait variability

Studies have shown gate variability increases with age and increases the risk of falls. The 5 Meter Walk Test (5MWT) was chosen in the present study to observe the gait variability and walking speed. All participants walked with their shoes on, forth and back on an unobstructed hard floor, covered with a strip of paper, taped on the floor (see Figure 3.5 A). Before walking, a sticker was attached on the posterior heel of their shoes and this sticker was then covered with ink to mark their steps (Wilkinson, Menz, & Raspovic, 1995). The length of the paper was 9 meters and the width 0.65 meter. Two meters was added at the beginning and at the end for acceleration (equivalent of about 3 walking steps) (see Figure 3.5 B) to allow the examination of gait parameters during only the steady state stage of gait (i.e. not during the acceleration and deceleration phase of gait initiation and termination, respectively). All participants were given the same instructions to walk at their normal pace, described as the pace that they usually adopt while walking on the side walk or for shopping.

The time was measured for the middle five meters for both forth and back walk (there was a break in between) (see Figure 3.5 B). The examiner followed the participant along the way and started the timer when the participant crossed the first marked starting point and then stopped timer when the participant crossed the second marked point.

Stride and step lengths and widths were measured from the print heel to heel perpendicularly (see Figure 3.6). The average and standard deviation of steps lengths (SL) and widths (SW) were calculated for all subjects. The average of the two walking times (forth and back) was calculated for analysis purposes. Lastly, the velocity over the leg length (Vel-L) ratio was calculated to adjust participants' speed regarding to their leg length.

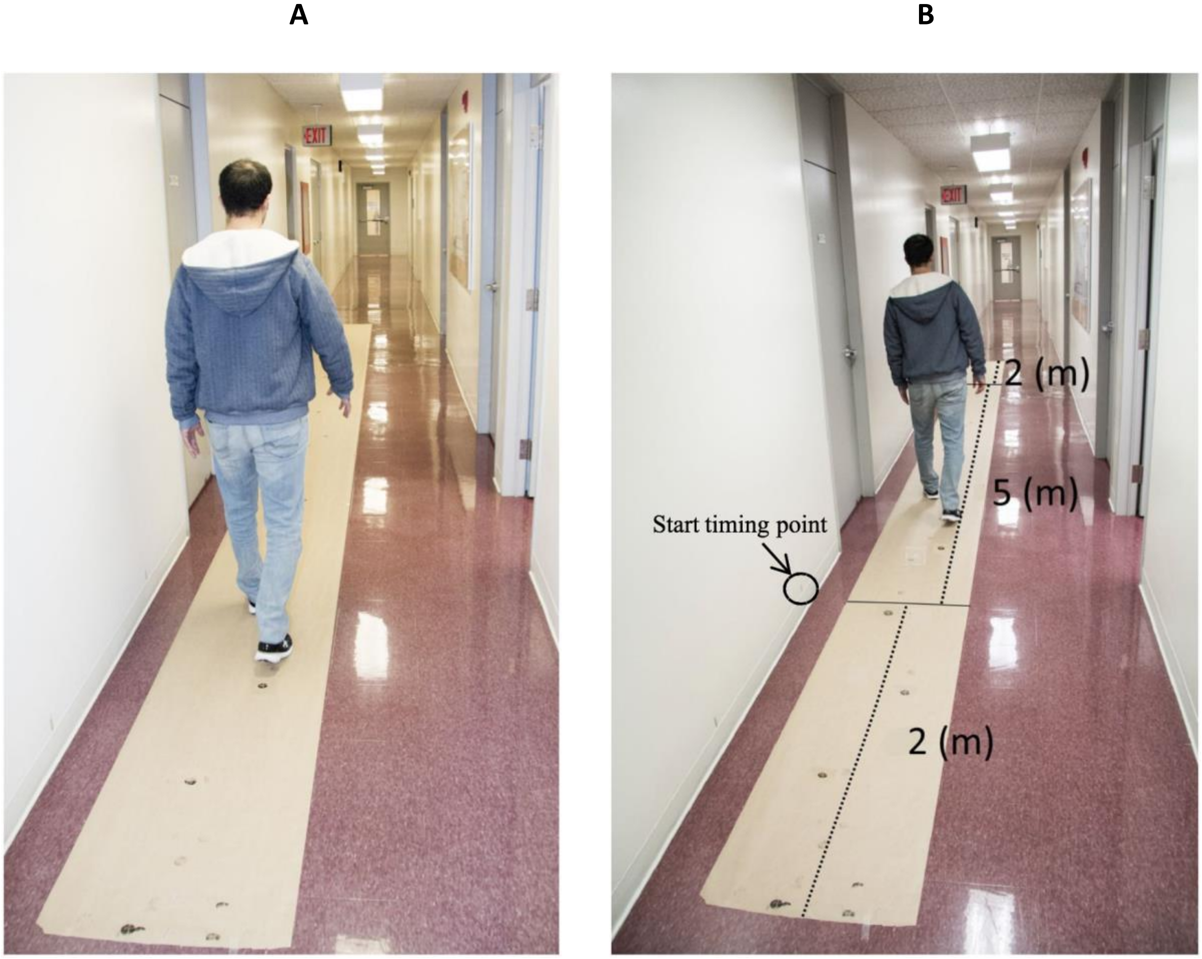


Figure 3.5 The Five-meters walking test (5MWT)

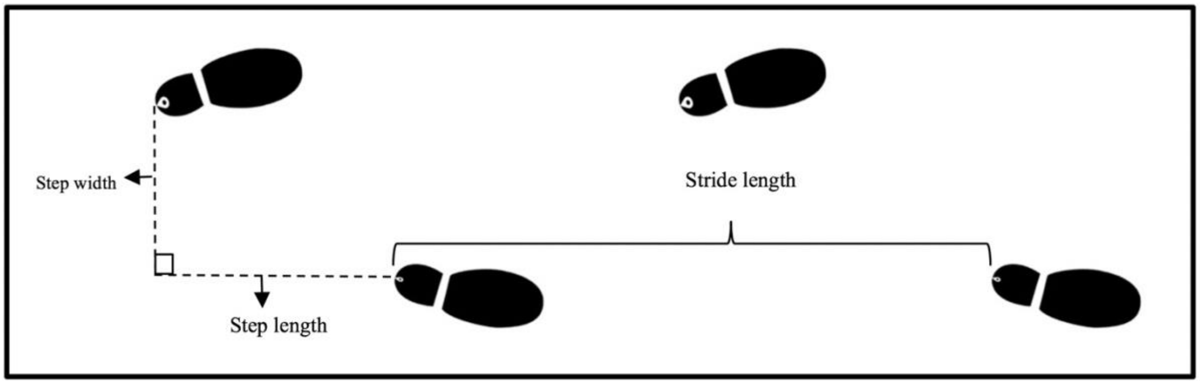


Figure 3.6 The spatial gait parameters,
adapted from (Wilkinson et al., 1995)

3.4 Visual attention

Visual attention was measured with two different tests: multiple object tracking (MOT) and the useful field of view. The useful field of view included two versions: the static version (UFV-S) similar to the version used in a previous study (Leat & Lovie-Kitchin, 2006a; Wood & Troutbeck, 1995) and a new dynamic version (UFV-D) which designed to have a dynamic peripheral stimulus. All visual attention tests were conducted binocularly the with distance habitual glasses with a +1.75 DS over their glasses for the older adult group, to correct them for the 50 cm intermediate distance.

3.4.1 Multiple object tracking (MOT)

3.4.1.1 Apparatus

The visual stimuli for this test were displayed on 24-in Samsung LED screen. Spatial resolution was set at 1600x1200 pixels with refresh rate of 60 Hz. The screen was connected to computer with Intel® Pentium® CUP G620 @ 2.60GHz Processor running on Microsoft OS Windows 10 Pro. The program ran on MATLAB version 8.3.0.532 with Psychophysics Toolbox.

3.4.1.2 Procedure

In this test, each trial consisted of six high contrast black disks presented on a white background at a 50 cm viewing distance (see Figure 3.7). Each disk subtended a visual angle of 1.5° (equivalent diameter= 1.31 cm or 90 min of arc). At the beginning of each trial, three of the six disks turned to yellow for 2 seconds and then turned to black again. These three yellow disks were considered the targets while the others were the distractors (see Figure 3.7 A). Therefore, during the trial, the targets are indistinguishable from the distractors (see Figure 3.7 B, C). In each trial, these disks will randomly and continuously move within he display area (20° by 20°, 18.2 by 18.2cm). The disks “bounce” off the edge when they hit the display area boundary or when they hit another disk (i.e., there was no overlapping between disks).

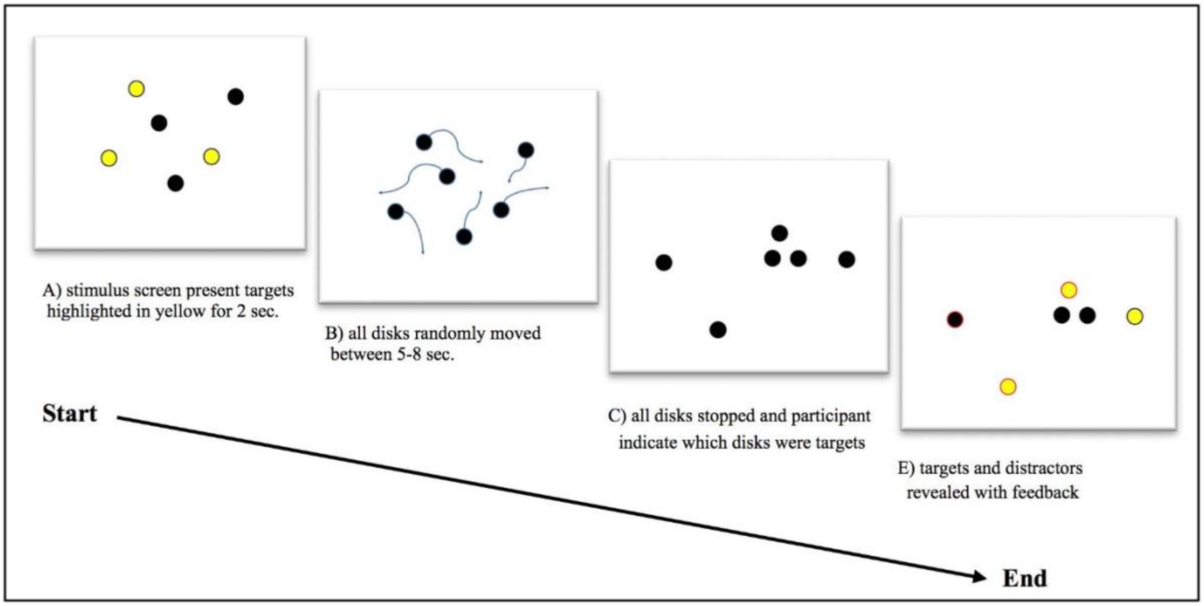


Figure 3.7 The Multiple Object Tracking (MOT) - trial sequence

The speed threshold was determined with a one up, one down staircase. The initial disk speed was set at 12°/s and increased by 40% for a correct trial or decreased by 60% for incorrect trial (Bowers et al., 2011).

In this study, participants were seated 50 cm from the display. Each participant was given an oral explanation of the task sequence and on screen written instructions. They were instructed to notice the three targets initially presented. They completed 3 practice trials prior to 40 experimental trials. The participant was instructed to keep tracking those three targets for 5-8 seconds (the total time was variable). At the end of each trial, the disks stopped moving and the participant was asked to indicate the final location of each target i.e. which were the targets. The examiner used the computer mouse to input the participant's response. Targets and distractors were revealed after the selection was inputted. The participant's selections were highlighted with a red ring (see Figure 3.7 D). The trial was considered correct only if the participant was able to choose all three correct targets. The outcome measure was the angular target speed giving 60% correct performance based on one up one down staircase method. To complete the test took about 10 minutes.

3.4.2 Useful Field of View

3.4.2.1 Apparatus

The visual stimuli for both versions of tests were displayed on 24-in Samsung LED screen. Spatial resolution was set at 1280x800 pixels with refresh rate 60 Hz. The screen was connected to computer with Intel® Pentium® CUP G620 @ 2.60GHz Processor running on Microsoft OS Windows 10 Pro. The programs ran on Experiment Builder software (SR Research) version 1.10.1241 which used the Python programming language.

3.4.2.2 Targets

In these tests, targets and distractors were presented in white on a gray background with 50% contrast (Weber's contrast) as measured with a Minolta cs-100 photometer. The size of the display area subtended 30 by 30 degrees at the 50 cm viewing distance. Targets were cartoon smiling or frowning faces at centre of the screen (see Figure 3.8). Distractors consisted of circles arranged in eight radial directions at three eccentric circles of 10°, 20° and 30° over 24 locations (see Figure 3.8). During the test, there were two targets present simultaneously: one centre and one peripheral.

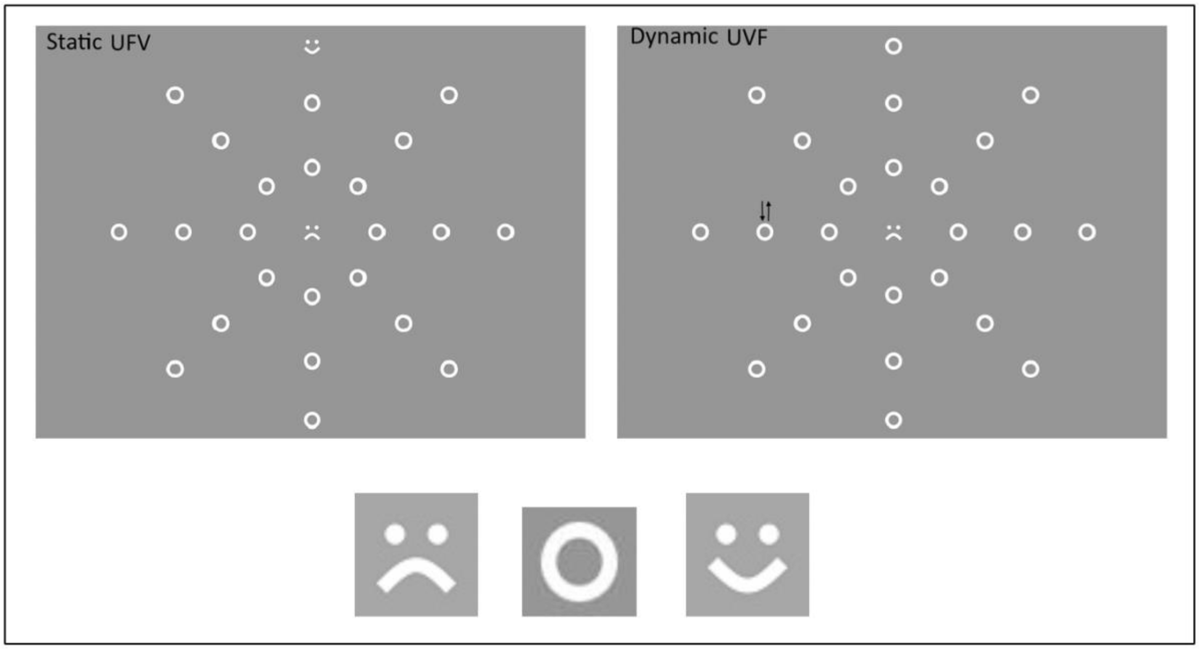
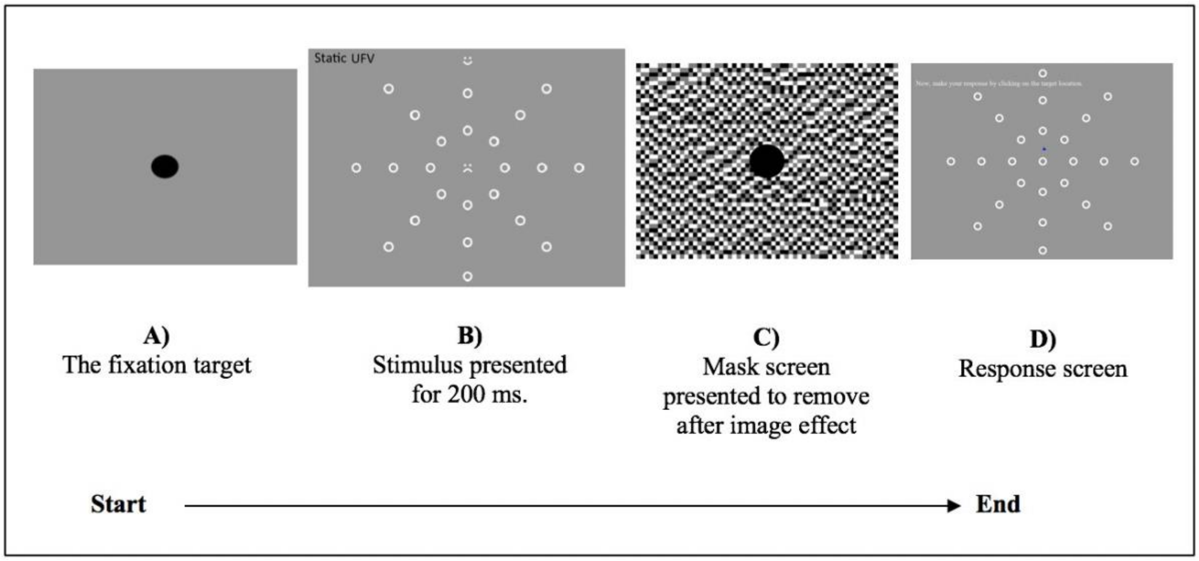


Figure 3.8 the Useful field of view stimuli targets

The presentation time was 200 ms. The peripheral target location was presented random at one of the 24 distractors location and was presented two times in each location. Therefore, there were a total of 48 trials. Each distractor circle had an angular subtense of 1.26° (75.6 min of arc, 1.1 cm in diameter). The line thickness of the targets and distractors was 0.23° (13.8 min of arc, equivalent to 6/83 visual acuity). The trial was considered correct if the participant was able to correctly identify the central target and correctly locate the peripheral target. The outcome measure of the UFV test was the percentage correct trials (accuracy = the number of correct trials as percentage of total trials). An arc sine transformation was applied to the test results similar to other studies.

3.4.2.3 The Useful Field of View-Static (UFV-S)

This test is a measure of functional visual field (search, localization and divided attention). The test involved two tasks; to identify the central target (the cartoon face either smiling or frowning) and simultaneously to locate the peripheral target (always a smiley face in this version) among the other 23 distractors (see Figure 3.8). All participants were given an oral explanation of the task sequence and had practice trials prior to starting. During the test, participant was instructed to binocularly fixate on central black disk fixation target (see Figure 3.9 A). The stimulus screen was presented for 200ms followed by the mask screen to cancel any after-image effect. Participants in the older age group verbally indicated their response for the central target and then pointed with their finger on the location of the peripheral target on the subsequent response screen (see figure 3.9 D). They received feedback for their response after each response. The next trial sequence was instantly presented after the feedback screen or, if there was no response, after 10 seconds.



A) The fixation target

B) Stimulus presented for 200 ms.

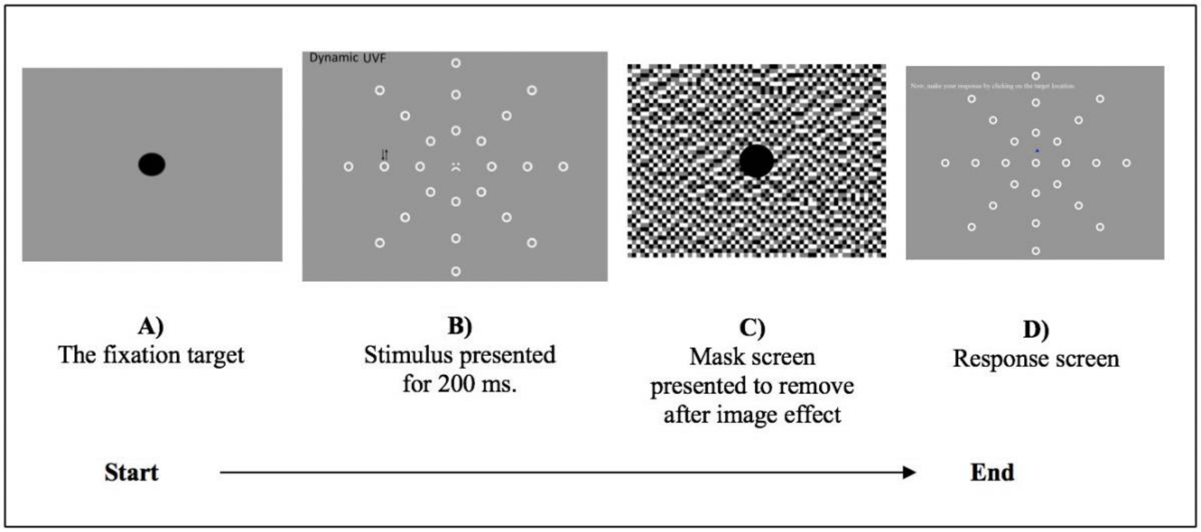
C) Mask screen presented to remove after image effect

D) Response screen

Figure 3.9 The static Useful field of View (UFV-S) trial sequence

3.4.2.4 The useful of view-dynamic (UFV-D)

The dynamic useful field of view (UFV-D) was similar to the static version except that the peripheral target moved instead of being a different shape (see Figure 3.10 B). This test used the same procedure and sequence as the UFV-S but differed in the peripheral target. One of distractors circles vibrated vertically upwards and then returned back to its original position once during each trial. The peripheral target movement distance was about same distance of the width of the distractor line (0.23 mm in each direction, about 0.46 mm movement in total) during the presentation time (200ms). All other measures and outcomes were the same as the static useful field of view UFV-S.



A) The fixation target

B) Stimulus presented for 200 ms.

C) Mask screen presented to remove after image effect

D) Response screen

Figure 3.10 Useful field of View dynamic (UFV-D) a trial sequence

Before conducting the experimental trial, each participant had practice trials on both versions of UFV tests. To reduce the practice effect, there were no more than 10 practice trials for each test. The duration of presentation for practice trails was longer (500 ms) to ensure that the participant had time to see the target and understood the test.

3.5 Xbox Kinect™ games

3.5.1 Apparatus

The Microsoft™ Xbox® 360 Kinect™ interactive video game system was used in this study (see Figure 3.11). The system was connected to a 39-in TV screen (89 by 52 cm) with a viewing distance of two meters (equivalent 24 degrees of view) (see Figure 3.12) under normal room lighting.

For consistency and to ensure that participants understood the game, each participant was given oral instructions about the game in additional to one trial being demonstrated by the examiner first and then the participant was given one practice trial. No practice trial has done for the exercise games because there is a coach that the participant has to follow. The coach gives instructions and demonstrates the movements. However, the examiner still demonstrated the exercise movement to ensure that participant was able to undertake them.

A video camera recorded from behind to capture the participant’s movements and the coach’s movements on the screen, and the score which appeared on the screen for some games. The TV screen showing the avatar was videotaped for all games and this video recording was used afterward for final scoring.

Figure 3.11 The Microsoft Xbox 360 console and the Kinect™

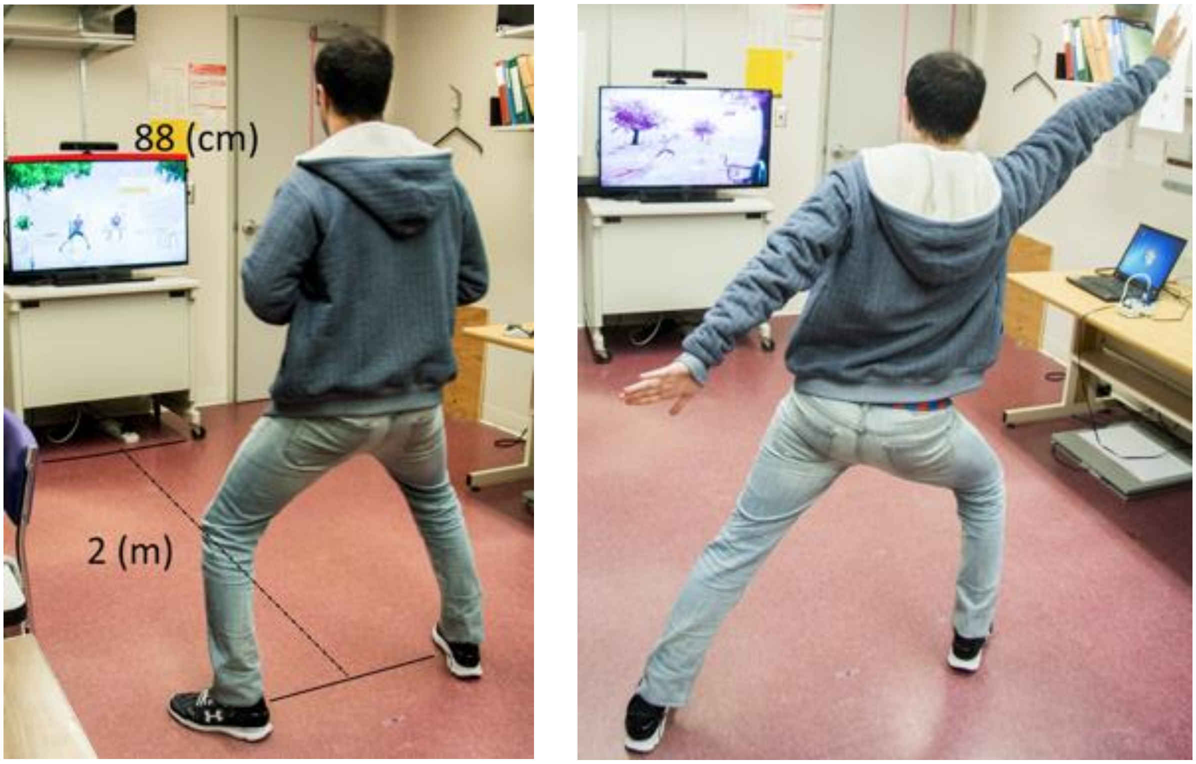


Figure 3.12 Participant plays Xbox Kinect™ Game

3.5.2 Video games

Games were chosen biased on the estimation of the visual attention demand. The selection of games was the result of a comprehensive review of a group of commercially available Kinect games. For all, we considered the type and amount of physical movement required, and the amount of change of attention/number of targets/speed of targets that appeared which had to be attended to. Two games were chosen in each set or type. The first set included games that had an apparently high visual attention demand i.e. targets that appeared suddenly in the eccentric area of vision, and which the participant would have to react to. The second set included games that had apparently lower visual attention demand – here were no newly appearing targets. All the games had a physical component (exercise games) i.e. a combination of body movement, weight transfer from one foot to another and/or front or side steps. In addition, these games were chosen to be similar to physical exercise games that help to improve balance. They were reviewed by a Kinesiologist who works in the area of aging to ensure that they would be considered good physical exercise for older adults.

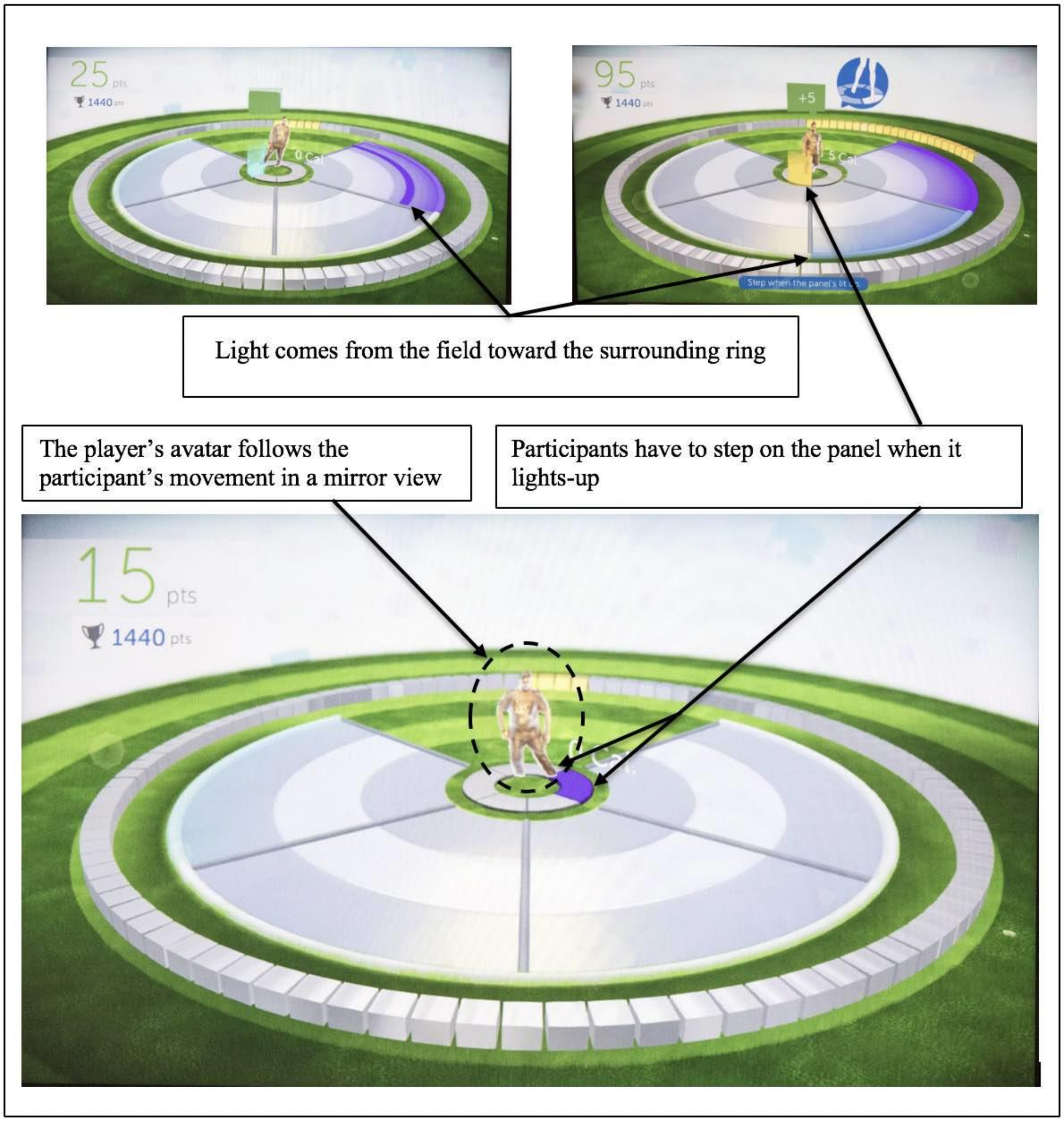
3.5.3 High visual demand games

These games were selected to be games that required high visual demand. The examiner explained the game's task to the participants and then conducted one trial while the participant watched and was allowed to ask any question that they might have. After that, the participant did one practice trial. The experimental trial came next. Two games were selected in this set of games: Stomp-it and Skiing (see Figure 3.13 & 3.14). The participant controlled the avatar on the screen.

In Stomp-it, the participant was required to track the lights that move from side or front area on the floor until it reached to the central ring, this ring had four panels around the game avatar (see Figure 3.13). When the panel lights up, the participant must “stomp” on the panel that is lit up immediately. The task required them to track the light and stomp at the exact correct time. The movement of the colored lights towards the centre increased in speed during each trial. The outcome measure was the percentage of correct steps during the trial, out of a total of 84 trials or “stomps” required.

In skiing, the participant was required to move their body from side to side, to make small jumps or lean forward to control the avatar as it went down the hill in order to negotiate the jumps and the gates. The task was to ski downhill safely avoiding the flags that made the gates. There were also three jumps which had to be negotiated correctly and at the correct time (see Figure 3.14). For older participant’s safety, it did not require them to make an actual jump, just to stretch the body upwards including both hands, which was enough to make the avatar jump. Participants conducted two experiment trials. The outcome measures were accuracy i.e. the percentage of correctly negotiated gates and jumps. If participant’s avatar hit a flag while passing the gate, it was counted as only half a point. Time for each run was also recorded.

3.5.3.1 Xbox 360 Stomp-it



Light comes from the field toward the surrounding ring

The player's avatar follows the participant's movement in a mirror view

Participants have to step on the panel when it lights-up

Figure 3.13 Screenshots of your shape™ game (Stomp-it)

3.5.3.2 Xbox 360 Skiing

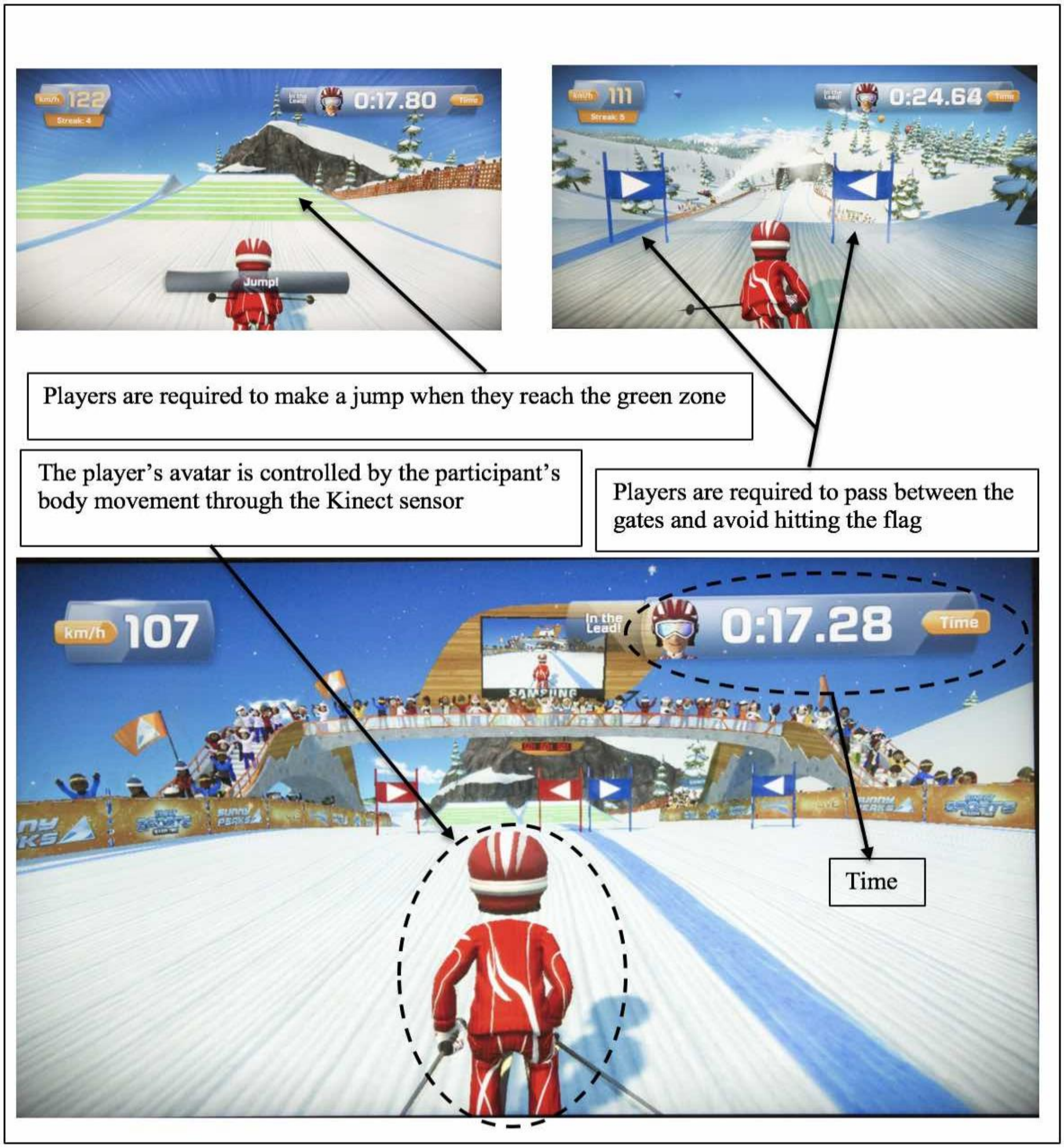


Figure 3.14 Screenshots from Kinect Sports 2 (Skiing)

3.5.4 Low visual demand games

This set included games that had mostly a physical component (exercise games), but less apparent visual attention demand. Two games were selected in this set of games: Leg exercise and Tai Chi (see Figure 3.15 & 3.16). The examiner explained the tasks to the participant and then demonstrated the movement of the exercise. The participant was then asked to try the movement with the examiner prior to doing it with the Xbox. There was no practice on the games directly because during the exercise games there was a coach demonstrating the exercise and giving the instructions. There were three exercise movements in the Leg exercise game and three movements in the Tai Chi exercise game. The three movements in Leg exercise were step squat, sumo squad and side to side lunge with and the three movements in Tai Chi were side travel, ballet movement and warrior posture. The exercise games were fairly easy and applicable for the elderly and used to the muscles important for balance. All these games were reviewed by a Kinesiologist who works in the area of aging to ensure that they would be considered good physical exercise for older adults. They were slower in motion compared to the high visual attention demand games and required a slower response to follow the task. Participants were informed to keep their eyes on the coach when they were performing the exercise. The outcome measure was provided from the game score which provided by the software in percentage correct moves at the end of each experimental trial. A score is given based on the accuracy with which they follow the coach’s movements, and the outcome measure was the final percentage score given in the software.

To control the learning and fatigue effects the order of the visual attention tests and games was balanced between the participants. They always started with one visual attention test followed by one Xbox game set, then the second visual attention test followed by the second set of Xbox games set (see Figure 3.17). In addition, participants were allowed breaks if they needed them at any time.

3.5.4.1 Xbox 360 Leg exercise

Players are required to follow the coach's movement to do three different lower limb exercises

The coach conducts the exercises movements

Participant's avatar

Figure 3.15 Screenshots of Your Shape™ game (Leg-exercise)

3.5.4.2 Xbox 360 Zen energy (Tai Chi)

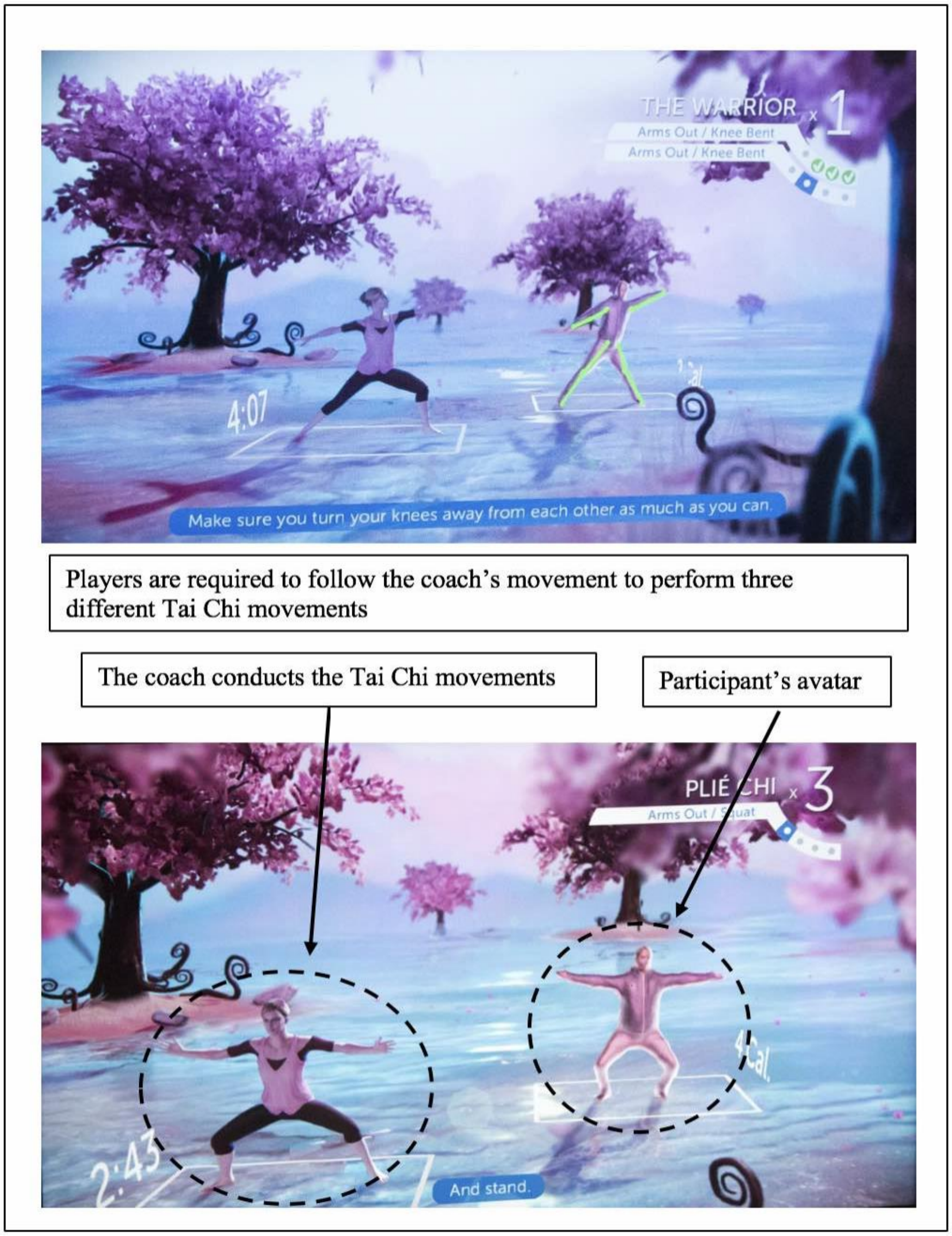


Figure 3.16 Screenshots of Your Shape™ game (Zen energy-Tai Chi)

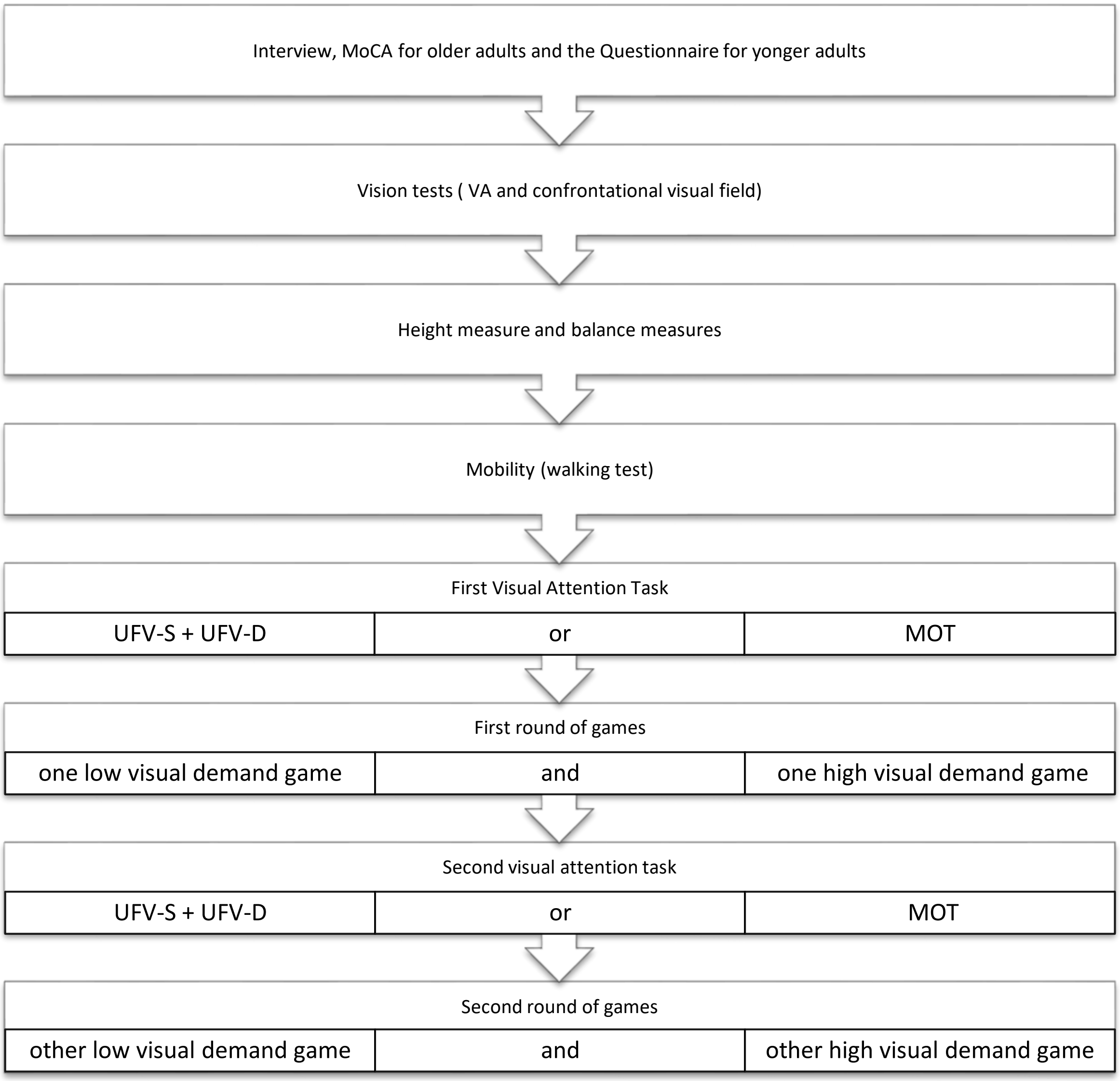


Figure 3.17 The Study Procedure Order

Chapter 4

The Association between Visual Attention and Body Movement-Controlled Video Games (Xbox Kinect^{TM}), Balance and Mobility in Older Adults

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This chapter is in preparation for submission as follows:

Alghamdi M, Vallis LA, Leat SJ. European Journal of Applied Physiology

Authors' Contributions

Author	Concept/Design	Data Collection	Data Analysis	Article Writing	Article Editing
Alghamdi	✓	✓	✓	✓	✓
Vallis	✓		Advised		Edited
Leat	✓	Advised	Advised	Advised	Edited

4.1 INTRODUCTION

Experiencing a fall can pose a serious threat to the safety and health of an older adult. Falls are the leading injury resulting in death and increase in prevalence among seniors who are 65 years or older (Public Health Agency of Canada [PHAC] 2014; (Stevens, Mack, Paulozzi, & Ballesteros, 2008) . Falls are also the leading cause of partial or total permanent disability due to injury (SMARTRISK, 2009; Stevens et al., 2008). Thirty percent of adults >65 years fall once per year (Hausdorff et al., 2001) and this rises to 50% in those who are over 80 years of age (Inouye et al., 2009). Among older adults who fall, 20 to 30% have moderate to severe injuries that lead to serious health impacts or even to death (Sterling, O'connor, & Bonadies, 2001). The impact of a falls is not confined only to the injury itself because, even with no reported physical injury there can be a loss of confidence that leads to a decrease of activities which may lead to future falls (Cumming et al., 2000; Fletcher et al., 2010).

Falls are multifactorial (Stinchcombe, Kuran, & Powell, 2014; Yoshida, 2007), the most pertinent to the current study are the biological factors, specifically vision and balance control. The control of balance is an integrative process between three sensory systems: visual, vestibular and somatosensory (Lord et al., 2010). Some studies indicate that visual input is the most salient, particularly for mobility (Guerraz & Bronstein, 2008; Lee & Lishman, 1975). The role of visual input in maintaining balance and preventing a fall has been extensively studied (Black & Wood, 2005; Lord et al., 2010). In particular, visual acuity, visual field, contrast sensitivity, glare sensitivity, and depth perception often have been studied and shown to be main aspects of vision that are associated with falls (Black & Wood, 2005; Guerraz & Bronstein, 2008; Lord et al., 2010; Lord & Menz, 2000). Recent studies have included another important aspect of vision, visual attention, and have shown a relationship with balance (Althomali & Leat, 2017) and mobility (Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004). Understanding what causes the reported delays in the processing time of the sensory information (Ball et al., 2007; Thorpe et al., 1996; Vance et al., 2007) or errors during divided attention tasks (Broman et al., 2004; Leat & Lovie-Kitchin, 2006b) is challenging. These delays and errors may result in negative effects on the postural control system, i.e. loss of balance and/or a fall. Understanding the cause of these detriments would provide fundamental and necessary information that could inform strong intervention strategies (i.e., better falls prevention programs). One well-researched test of visual attention is the useful field of view (Ball et al., 1988; Sekuler & Ball, 1986). We know that useful field of view measures improve with training (Sekuler & Ball, 1986) and are associated with mobility performance (Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004) and balance (Althomali & Leat, 2017).

Video gaming has markedly increased recently with developments in visual technology (Green & Bavelier, 2003; Greenfield et al., 1994). These games have been used recently as a tool for teaching education skills or learning new tasks (Green & Bavelier, 2012; Mitchell & Savill-Smith, 2004; Prensky, 2003; Squire, 2008) in addition to a potential tool for rehabilitation (Goble et al., 2014; Padala et al., 2012; Padala et al., 2017; Reed-Jones, Dorgo, Hitchings, & Bader et al., 2012b; Rendon et al., 2012). Various studies have shown that Nintendo Wii balance board (WBB) or Xbox Kinect^{TM} can be used to train and assess the physical performance of young people and adults (Goble et al., 2014; Padala et al., 2012; Padala et al., 2017; Reed-Jones et al., 2012b; Rendon et al., 2012). For example, performance on Nintendo Wii balance board (WBB) correlates with balance measures, and exercising with such games can improve balance (Goble et al., 2014; Padala et al., 2017). This kind of video game creates a virtual reality scene on the screen and the player interacts with it physically and visually. In the Nintendo WBB games the player's movements are detected by a balance board controller (the WBB) and this enables them to control the game. However, the size of board may limit a player's movement as the player cannot step beyond the board. This limitation is not applicable with systems that use a body motion sensor, such as Xbox 360® Kinect^{TM} which can track body postural and motion in free space (Bieryla, 2016; N. Vernadakis et al., 2014). The advantage of using motion sensors therefor is that the player can move and exercise over a more extensive space, making it possible to include a wider range of physical activities.

The relationship between video games and visual attention has been addressed in some research studies. Video game players show better performance in selective attention and divided attention as measured with UFOV. They also perform better in the number of objects tracked in MOT task (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a). Since visual attention is trainable and must be employed during video games, it may be possible to train visual attention via using video games, and this would likely be optimised with games that include a high visual demand. Simultaneous physical exercise and vision attention training may be possible when using Xbox Kinect games.

The purpose of this study is to determine the potential of this type of training to improve visual attention, balance and mobility in a group of older adults and to choose the optimal type of Xbox games to facilitate the largest gains in these areas. Xbox Kinect games were chosen that appeared to have a stronger or a weaker visual attention requirement. We hypothesise that performance on the games that appear to have high visual attention demand will be predicted by tests of visual attention in comparison to games with low apparent visual demand. We are also interested to study the associations between visual attention and measures of mobility and balance. Therefore, the present study also aimed to determine the relationships between visual attention, balance, mobility and performance in Xbox Kinect games.

4.2 METHODS

4.2.1 Subjects

In this cross-sectional study, fifty participants aged 65+ were recruited from the Optometry Clinic and from among staff and faculty, and their friends and family members at the School of Optometry and Vision Science, University of Waterloo. We also used “snowball” recruiting where participants were asked if they know of friends or family who might be eligible and willing to participant.

Inclusion criteria for all participants were: aged 65 and above, either gender, relatively good health (see below), Montreal Cognitive Assessment (MoCA) test score (Nasreddine et al., 2005; Rossetti et al., 2011)) after correction for level of education ≥ 24, not using medications which are a known the risk for falls (see below), independently mobile (able to walk without a cane or walking frame), no clinical vision loss (described below), and no previous use of

Xbox exercise gaming. Participants with a diagnosis of the following were excluded: dementia, Parkinson's disease, history of cerebrovascular accident resulting in residual paresis, multiple sclerosis, cerebellar dysfunction, peripheral neuropathy of any etiology, advanced arthritis so as to cause significantly reduced range of motion of the weight bearing or small joints, or significant hearing loss. Use of medications is expected to be high in this age group, so we only excluded participants who used medications which are known to or may increase the risk of falls or impair balance (i.e., antipsychotics, sedatives, antidepressants, anti-histamines, anti-hypertensive, and long-acting sleeping medications). For vision, all participants had binocular visual acuity 6/12 (20/40) or better, with no diagnosed glaucoma or hemianopia.

4.2.2 Procedures

4.2.2.1 Screening for inclusion criteria

A questionnaire included questions about general and ocular health, and medications, which was administered either by phone or in person. The Montreal Cognitive assessment (MoCA) (www.mocatest.org) was administered in the usual way, with the exception that the letter T was used instead of F for the Language component. Based on the results of Nasreddine et al. (2005) the exclusion criterion was chosen as <24 (Nasreddine et al., 2005).

Visual acuity was measured binocularly with the participant's habitual spectacle correction, defined as the correction that the participant used for driving, walking and shopping. Visual acuity (VA) was measured with the ETDRS visual acuity chart "R", available from Precision Vision (www.precision-vision.com), at 4 meters (Ferris III et al., 1982). The chart luminance was between 80-120 cd/m^2. Visual acuity was measured in logMAR using by-letter scoring (Bailey & Lovie, 1976; Hazel & Elliott, 2002).

Monocular visual field screening was conducted for each eye in order to confirm that there was no large field defect of which the participant was unaware. A confrontation test was used, the participant being asked to count fingers presented in each field quadrant (D. B. Elliott, North, & Flanagan, 1997).

4.2.2.2 Balance measures

Participants were asked to undertake two different sets of balance assessment: bi-pedal quiet stand (QST) and the one-legged stand test (OLST). The QST required them to stand on both feet, placed apart from each other on a portable force plate platform (AccuGAIT, AMTI, Inc) not moving or talking, for one minute (200 Hz). Participants were required to clasp their hands together in front for the duration of the trials. For OLST the participant was asked to stand still on their preferred leg with the other leg extended in front for 30 seconds; participants were asked to place their hands at their sides. Both tests were performed with the eyes open, fixating on a target in front of them and each balance assessment condition was performed three times. Calculations of the CoP used the middle 50 seconds for the quiet stand and 20 seconds of single legged of stance (i.e. omitting the first and final 5 seconds of stance time).

The portable force platform measures the ground reaction forces and moments and facilitates the calculation of the center of pressure (CoP is the weighted average of the pressure underneath the feet; (Prieto et al., 1996). For each participant, from the CoP, the path length in cms for anterior-posterior (AP) and medial-lateral (ML) sway and the cumulative path length (CPL) were calculated (average of the two trials). For both the ML and AP directions, the maximum value and CoP range were calculated. Also, the standard deviation for each person was calculated to give a measure of their postural variability. This describes the control/consistency of balance as individuals who have high variability are typically at a greater risk of falling.

4.2.2.3 Mobility/Gait test

A five-meter walking test (5MWT) was used to assess walking speed and gait variability for all participants. All participants walked shod back and forth on a hard floor, covered with a strip of paper, taped to the floor for a total of 2 walking trials. Before they walked, stickers were attached to the posterior heel of their shoes (Wilkinson et al., 1995) that were subsequently covered with ink, to mark their steps. The length of the paper was 9 meters and the width was 65 cm. Two meters (about three steps) was added at the beginning and at the end of the paper walkway to facilitate the examination of gait parameters during the steady state stage of gait only (i.e. not during the acceleration and deceleration phase of gait initiation and termination, respectively). All participants were instructed to walk at their normal pace, being the pace at which they walk when shopping.

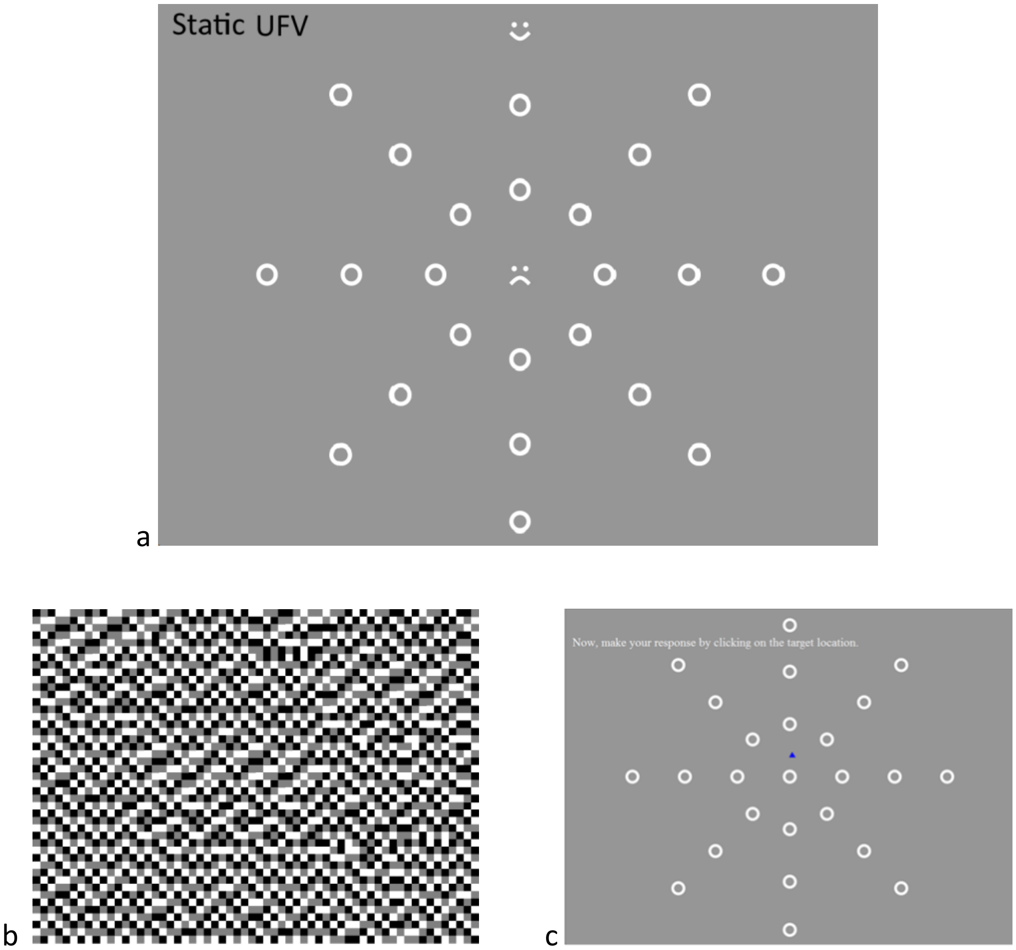
Time was measured and steps were analysed for the central 5 meters for both directions of walking. Following completion of the two walking trials, step length and width was measured from the ink marks from heel to heel in the direction of travel and perpendicular to the direction of travel, respectively. The average and standard deviation of step length and width were calculated for all subjects, in centimeters (cm). The average of the two walking trials also was calculated. Lastly, the average of the velocity for the entire 5 meters was calculated and normalized to the leg length via the calculation of a ratio (VL); this ratio adjusted participants' gait velocity for their leg length (measured from greater trochanter of the femur to the floor) to facilitate comparisons across different participants.

4.2.2.4 Visual Attention Tests

Spatial selective visual attention was measured using a useful field of view (UFV) test (Ball et al., 1988; Leat & Lovie-Kitchin, 2006a; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986; Wood & Owsley, 2014) and spatial, sustained visual attention was measured using a Multiple Object tracking test (Bowers et al., 2011). All the visual attention tests were presented on 23.6-in LED monitor at a viewing distance of 50 cm. To focus on this working distance, participants were given +1.75 DS over-the-counter reading glasses to wear (over their habitual distance glasses if they had them).

There were two versions of the useful field of view tests: static and dynamic. The static version (UFV-S) was similar to condition 4 in Leat et al. (Leat & Lovie-Kitchin, 2008) but with different targets and measures of selective attention. (Wood & Owsley, 2014) The central task was to identify if the target was either a smiling or frowning face. The peripheral target was a ‘smiley face’ located among circular distractors (Figure 1 a). The size of the whole display subtended 30 by 30 degrees for the 50 cm viewing distance. There were 24 distractors arranged in three concentric circles (10°, 20°, 30°) along eight axes. The diameter of each distractor and target was 1.26° (11 mm) in diameter and the line width was 0.23° (2 mm) The peripheral target was presented twice in each location and the order of all presentations was randomised Therefore, there was a total of 48 trials. The duration of each trial was 200 ms.

After each trial, a mask screen was shown to avoid any after-image effects (Figure 1 b). Then the participant had to verbally identify the central target and point to the location of the peripheral target on the response screen. The trial was considered correct if the participant was able to correctly identify the central target and accurately locate the peripheral target. Participants received audible feedback for each correct response. The outcome measure of this test was accuracy, in percent.



Now, make your response by clicking on the target location.

Figure 4.1 The static useful field of view (UFV-S)

a) stimulus target. b) mask screen. c) response screen.

The dynamic version of the UFV was developed as it was thought that detecting movement might be more associated with ability to detect moving objects or targets in the periphery during the Xbox games. This test used the same procedure as the UFV-S but differed in the peripheral target. Instead of a smiley face, one of distractor circles moved upwards by 0.23

degrees and then returned to its position (one cycle up and down) during the presentation of each trial (Figure 2). All other measures and outcomes were the same as the static UFV.

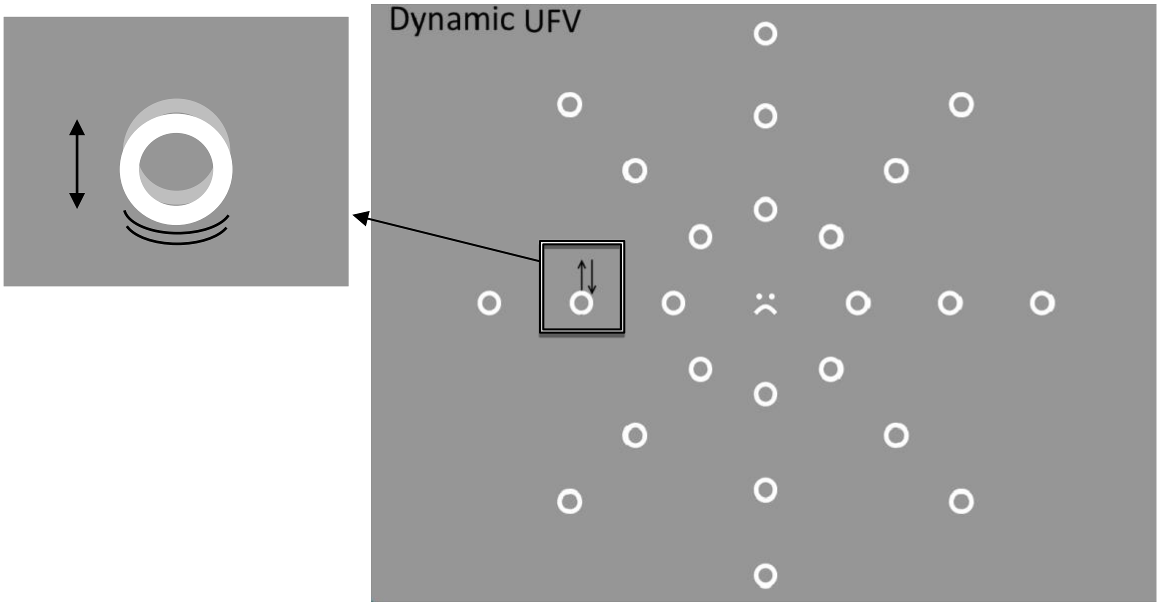


Figure 4.2 The dynamic useful field of view (UFV-D). The inset illustrates the movement. The faint circle represents the maximum extent of movement.

Before conducting the visual attention tests, each participant had practice trials on both versions of UFV tests. To reduce the practice effect, there were no more than 10 practice trials for either static or dynamic UFV and the target duration was longer (500 ms) to give the participant more time to understand the test (without giving them practice at the actual test duration).

Sustained visual attention was measured with multiple object tracking (MOT) (Pylyshyn & Storm, 1988). To reduce test duration, the brief MOT test was used (Bowers et al., 2011). The field size subtended 20° (18.2 by 18.2 cm) at the 50 cm viewing distance. The stimuli were six black circles 1.5° (1.31 cm) in diameter which moved randomly on a white background. There were three practice trials and 40 experimental trials. At the beginning of each trial three of the stimuli circles turned to yellow for 2 seconds and then turned to black again. These three yellow circles were considered as targets. The participant was required to track the three target circles for 5-8 seconds, at which point the circles stopped moving and the participant was asked to identify the targets. The trial was considered correct only if the participant was able to identify all three targets correctly. The first trial speed was always 12° per second. The speed threshold was determined with a one up, one down staircase. The speed increased by 40% after a correct response and decreased 60% after an incorrect response. The outcome measure was the angular target speed to give a 60% correct threshold (Bowers et al., 2011).

4.2.2.5 The Xbox Kinect™ Video games

The Xbox 360® console with the Kinect™ controller was used for the video games. The Kinect™ sensor can recognise and localise the physical position and motion of the player. An avatar or virtual augmented image is created by the game and is controlled by the motion of the player. For all games, participants stood in front of a 39-in TV (89 by 52 cm) at a distance of two meters. The screen subtended 24^{o} horizontally at 2 metres, which is where the participant started for each game. Four different games were chosen based on the apparent visual requirements. Two games appeared to have high visual demand (action games) and two appeared to have low visual demand (exercise games), chosen from Xbox360® Kinect™ commercially available games called “Your shape™” and “Sports season2”.

The two apparently low visual demand games were Leg exercise and Zen energy (Tai Chi). In these games, participants followed an on-screen coach. In the Leg exercise, there were three exercise movements: step squat, sumo squad and side to side lunge. The movements aim to train the thigh muscles. In Zen energy, there were three main movements: side travel, ballet movement and warrior posture. These movements are meant to stretch the thigh muscles and enhance balance control. For both games, the movements were demonstrated by the experimenter and then the participant practiced them once before they following the on-screen coach. The Kinect sensor tracked the player’s movement and assessed their ability to copy the correct position. A score is given based on the accuracy with which they follow the coach’s movements, and the outcome measure was the final percentage score given in the software.

The two high visual demand games selected for study had more visual complexity and faster motion, which required faster reactions and movement in order to attain higher game scores. The games chosen were Skiing and Stomp-it. In these games, participants saw a digital avatar which mimics their movements. Participants were asked to control the avatar's movement with their own body movements and to achieve the best possible score.

In "Skiing" the participant stood in front of the screen and mimicked skiing movements down a hill, and were asked to avoid virtual flags/gates and make jumps. As such, movements produced during the game by players require more coordinated movements of the upper and lower body; a good score requires quick reactions to the upcoming obstacles. After an explanation, the participant undertook one practice trial using the game software and was then asked to complete two different downhill runs. The outcome measure was the accuracy of performance in terms of successfully avoiding the flags and gates and making the jumps. Note that the participant did not have to actually jump (leave the ground) to make the avatar jump – they could just flex their knees to make a "sham" jump, and they were informed of this.

In "Stomp-it" colored panels start moving from right, left, front-right or front-left of the screen and move towards the avatar. The participant is required to step with one foot on each colored panel when it reaches the avatar. The number of correct steps during the trial is used to quantify the performance score of the participant. The participant was given an explanation and a practice trial before commencing the actual experimental trial.

The TV screen showing the avatar was videotaped for all games and this video recording was used afterward for final scoring. For Skiing and Stomp-It a scoring system was devised to that each error (e.g., gate hit or incorrect step) was counted equally. For the exercise games, the video was used, as the score for the game remained on the screen too briefly to record in real time.

The order of the visual attention tests and Xbox games was balanced as follows. The participant always started with one visual attention test (UFV or MOT) followed by one set of Xbox games (Tai Chi/Legs or Skiing/Stomp-It). Then the second visual attention test was followed by the second set of Xbox games set. The order of the specific attention tests and Xbox games was counter-balanced between the participants using a block design and the order of the Xbox games and UFV tests was alternated between participants (e.g., Tai Chi/Legs or Legs/Tai Chi, Static/Dynamic or Dynamic/Static UFV).

4.3 Analyses

For data analyses, the UFV scores were arcsine transformed as is usually done (Leat & Lovie-Kitchin, 2008). The data were tested for normalcy with the Kolmogorov-Smirnov test and Shapiro-Wilk test. Since a number of the measures were found not to be normally distributed, all the data was transformed by an arcsine transform (for those that were a percent correct) or a log transformation. After transformation, all the data was found to be normally distributed, except for number of medications or general health conditions. So these variables (number of medications and general health conditions) were split into a two-way score. For medications this was 0 for no medications and 1 for one or more, and for general health this was zero for up to one condition and 1 for two or more co-morbidities. For ease of understanding, the results are reported as the raw results or untransformed data. The data were plotted as histograms and there were clear outliers for some measures. Outliers that were more than 3 standard deviations from the mean were excluded (Iglewicz & Hoaglin, 1993).

The data were first analysed with unadjusted univariate linear regression analyses to describe the proposed relationships between the variables of interest. There were three groups of correlations conducted; correlations within the visual attention tests, correlations of visual attention tests with video games and correlations of visual attention tests with balance and mobility outcome measure. The univariate analysis was followed by univariate linear regression adjusting for age and then age, gender, general health condition score and medications score.

Separate forward step-wise multiple regression analyses were conducted for video games and balance and mobility measures as dependent variables. A p-value of 0.05 to enter and 0.10 to remove was used. Since there was a high correlation among measures of attention, mobility and two-legged stance balance, one independent variable was selected from each of these groups of variables to enter the model. The one chosen from each group was that which had the highest correlation with the dependent variable. Many participants were not able to stand on one leg for thirty seconds for three trials, so the outcome measure from this test used in our statistical model was the total standing time (OLST) for the three trials, i.e. so there was only one measure for OLST. For each analysis, age, gender, general health, number of medications, MoCA and OLST were also included. For example, in the model to predict performance in Xbox Skiing the following independent variables were entered; UFV-S (best visual attention measure), Velocity/Leg (best mobility measure), CoP ML-Max. (best balance measure), OLST, VA, gender, age, number of medications, general health and MoCA. A variance inflation factor (VIF) was calculated to ensure that the multiple regression models were not affected by multicollinearity. Data were analyzed with SPSS version 24 (Chicago, IL, USA) and a p value of <0.05 was used for significance.

4.4 RESULTS

Fifty participants completed this study, 22 males and 28 females with an average age of 72.4 yrs. ±5.1. Demographic data of the participants and average results for the tests of attention, gait, mobility and balance are shown in (Table 4.1).

Table 4.1 Characteristic of Study Sample (N = 50)

Characteristic	Mean Value (SD)	Range
Age	72.4 (5.1)	65-87
Male	73.1 (5.3)	65-87
Female	71.9 (5.1)	65-87
MoCA score	27.8 (1.5)	24 - 30
Visual Acuity in logMAR (VA)	-0.00 (0.06)	(-0.14) - 0.12
MOT (threshold speed, deg./sec.)	12.1 (4.1)	5.2 - 21.8
UFV-S (accuracy %)	36.8 (21.1)	2.1-83.3
UFV-D (accuracy %)	59.7 (24.4)	4.2-95.8
Low visual demand games		
Leg exercise (% correct)	52.4 (14.1)	5-78
Tai Chi (% correct)	41.4 (19.8)	8.2-79.2
High visual demand games		
Skiing (% accuracy)	70.8 (10.9)	42.2-93.8
Stomp-it (%)	36.2 (19.3)	0-94.1
Mobility		
Step length (cm)	64 ± (8.2)	39.2-86.2
Step length variability (cm)	3 ±(1.1)	1.4-6.3
Step width (cm)	9.1 ±(3.4)	1.8-23
Step width variability (cm)	3.2 ±(1)	1.9-6.1

Stride length (Right) (cm)	129.6 ±(16)	80.6-172.2
Stride length variability (R) (cm)	4.6 ±(1.8)	1.3-9.9
Stride length (left)	129.7 ±(16.1)	80.3-171.1
Stride length variability (L) (cm)	4.3± (2.2)	1.3-12.9
Five-meter walking time (secs)	4.6 ±(1)	3.2-8.3
Velocity/leg height	1.2 ± (0.2)	0.7-1.6
Balance (cm), mean ±SD		
ML COP SD	0.24 ±(0.1)	0.09-0.59
AP COP SD	0.37 ±(0.1)	0.21-0.74
ML COP MAX	0.59 ±(0.31)	0.19-1.68
AP COP MAX	0.96 ±(0.3)	0.51-2.28
ML COP Range	1.2 ±(0.6)	0.39-3.56
AP COP Range	1.94 ±(0.69)	1.04-5.41
Cumulative path-length	213.3±(80.3)	109.8 -572.3
One-legged stand time (secs), mean ±SD	73.2 ±(23.6)	0-90

In this study we found that age was correlated with all visual attention tasks ($p<0.05$) except UFV-D. For the games, one extreme outlier (>3 SD from mean) was removed from the Stomp-It data before analysis. There was a significant association with age for Stomp-it ($r=0.4$, $p=0.004$), Tai Chi ($r=-0.36$, $p=0.011$) and Leg exercise ($r=0.28$, $p=0.048$) but no significant correlation of age with Skiing. Among mobility measures, walking speed, vel./leg and step length variability showed a significant correlation with age ($r\geq 0.325$, $p=\leq0.021$). Finally, among balance measures, all the ML sway variables were significantly correlated with age ($r\geq 0.338$, $p=\leq0.007$), as was cumulative path-length ($r=0.35$, $p=0.013$). OLST was strongly correlated with age ($r=0.53$, $p<0.001$).

Table 4.2 Pearson correlation coefficient for visual attention with video games, balance and mobility. Significant correlations at the p=0.05 level are shown in bold. Note that the significant negative correlation coefficients are expected as for one of the variables, a lower number means better performance

	Unadjusted r value (p)	Adjusted for age r value (p)	Adjusted for age, no. of medications and general health r value (p)
Xbox 360® Stomp-It with MOT	**0.346** (<u>0.015</u>)	0.249 (0.074)	0.200 (0.179)
Xbox 360® Skiing with UFV-S	**0.408** (<u>0.003</u>)	**0.370** (<u>0.011</u>)	**0.383** (<u>0.015</u>)
Xbox 360® Tai Chi with UFV-S	**0.294** (<u>0.038</u>)	0.198 (0.166)	0.184 (0.235)
Step Width (SD) with MOT	**-0.402** (<u>0.004</u>)	**-0.377** (<u>0.009</u>)	**-0.367** (<u>0.017</u>)
Step Width (SD) with UFV-S	**-0.285** (<u>0.044</u>)	-0.248 (0.098)	-0.213 (0.185)
OLST with UFV-D	**0.375** (<u>0.007</u>)	**0.256** (<u>0.042</u>)	0.179 (0.175)
ML CoP (SD) with UFV-D	**-0.301** (<u>0.033</u>)	**-0.256** (<u>0.042</u>)	-0.113 (0.447)

The results of the univariate analysis of associations of the visual attention measures with mobility, balance and Xbox games are shown in Table 4.2; note that the significant correlations are included in this Table and are bolded, to show those that remained significant after adjustment. Unadjusted univariate linear regression in higher visual demand games (Skiing and Stomp-It) showed significant correlations with visual attention tests (MOT and UFV-S) (p=0.003 and p=0.015) while only one of the lower visual attention games (Tai Chi) was correlated with visual attention (p=0.038). The correlation between Skiing and UFV-S remained after adjustment for age, medications and general health. For the mobility measures, the unadjusted univariate linear regression showed a significant association between step width variability and MOT and UFV-S (p=0.004 and p=0.044 respectively) and the association with MOT remained after adjustment. In term of balance results, both one-legged total standing time (OLST) and bipedal stand (CoP medial-lateral variation) showed significant correlation with UFV-D (p=0.007 and 0.033, respectively). When adjusting for age, medications and general health score, the MOT remained significantly associated with step width variability (p=0.017).

Considering the associations between Xbox games, and mobility and balance measures, only Tai Chi showed a significant correlation with balance (cumulative path length p=0.009 and OLST p=0.23) and mobility (mean stride length p=0.03; 5MWT p=0.001; Vel./Leg p>0.001). This association with mobility remained after correction for age and age, GH score and medications. The other games did not show a significant association with any balance or mobility measure.

Table 4.3 Stepwise multiple linear regression between Xbox games, (dependent variable) with visual attention and other variables.

Dependent Variable	Predictor variable	R^2 at each step	Co-efficient B	Standardized Coefficient	t	P value
Xbox360® Skiing[1]	UFV-S	0.167	0.264	0.408	3.1	0.003
R^2 for the model= 0.17, F=9.61, p for the model =0.003 [1]predictors entered into the analysis: UFV-S, Vel/Leg, CoP ML Max, OLST, VA, gender, age, no. medications, general health and MoCA						
Xbox360® Stomp-It[2]	Age	0.146	-0.018	-0.381	-2.86	0.006
R^2 for the model= 0.15, F=8.175, p for the model =0.006 [2]predictors entered into the analysis: MOT, step width average, Cumulative path-length, OLST, VA, gender, age, no. medications, general health and MoCA						
Xbox360® Tai Chi[3]	Vel/Leg	0.238	1.240	0.487	3.87	<0.001
R^2 for the model= 0.24, F=14.96, p for the model <0.001 [3]predictors entered into the analysis: UFV-S, Vel/Leg, Cumulative path-length, OLST, VA, gender, age, no. medications, general health and MoCA						
Xbox360® Leg exercises[4]	Age	0.079	-0.009	-0.281	-2.03	0.048
R^2 for the model= 0.08, F=4.12 p for the model =0.048 [4]predictors entered into the analysis: UFV-S, 5MWT, CoP AP SD, OLST, VA, gender, age, no. medications, general health and MoCA						

Table 3 shows the multiple linear regression models for each of the Xbox games together with the independent variables that were entered into the analysis. For Skiing, the only predictor was UFV-S and performance; for Skiing this increased by 0.264% for each one percent increase in UFV-S accuracy. The model indicates that about 17% of the variability of performance in the Skiing can be explained by UFV-S. For Stomp-it, the only predictor was age and performance in Stomp-it decreased 0.016% for each year of age. This model indicates that about 15% of the variability of performance in the Stomp-it can be explained by age. Performance in Tai Chi was only predicted by velocity corrected for leg length (Vel/Leg). About 24% of the variability in Tai Chi performance can explained by the Vel/Leg. The performance in Tai Chi increased 1.24% for each unit in Velocity/leg high ratio. Finally, performance in Leg exercise was predicted by age and performance in Leg exercise decreased 0.01% for each additional year of age.

Table 4.4 Stepwise multiple linear regression for balance measures

Dependent Variable	Predictor variable	R^2 at each step	Co-efficient B	Standardized Coefficient	t	P value
OLST[1]	Age	0.283	-0.032	-0.347	-3.727	0.000
	Cumulative path-length	0.408	-0.979	-0.377	-3.144	0.003
	Step length variability	0.460	-0.78	-0.253	-2.144	0.040
[1] predictors entered into the analysis: UFV-D, stride length variability, Cumulative path-length, VA, gender, age, no. medications, general health, and MoCA *R^2 for the model= 0.46, F=13.01 p for the model <0.001*						
Cumulative path-length[2]	OLTST	0.267	-0.12	-0.517	-4.183	0.004
	Vel/leg	0.343	-0.50	-0.3	-2.322	0.025
[2] predictors entered into the analysis: UFV-D, Vel/Leg, OLST, VA, gender, age, no. medications, general health and MoCA *R^2 for the model= 0.343, F=12.25 p for the model <0.001*						

Table 4.5 Stepwise multiple linear regression for mobility measures

Dependent Variable	Predictor variable	R^2 at each step	Co-efficient B	Standardized Coefficient	t	P value
Velocity/leg height[1]	Cumulative path-length	0.211	-0.277	-0.459	-3.580	0.001
[1] predictors entered into the analysis: UFV-S, Cumulative path-length, OLST, VA, gender, age, no. medications, general health and MoCA *R^2 for the model= 0.21, F=12.82 p for the model =0.001*						
Five meters walking test[2]	Age	0.199	0.007	0.446	3.412	0.001
[2] predictors entered into the analysis: UFV-S, Cumulative path-length, OLST, VA, gender, age, no. medications, general health and MoCA *R^2 for the model= 0.20, F=11.65 p for the model =0.001*						

Table 4.4 show the step-wise multiple linear regressions for balance and mobility, respectively. The OLST and the cumulative path-length were chosen as good overall representations of one-legged stance and bipedal stance. Performance in the one-legged stand test was predicted by age ($p < 0.001$), increase cumulative path-length ($p = 0.003$) and step length variability ($p = 0.040$). Poor performance in the cumulative path-length was predicted with decreases in OLTST ($p = 0.004$) and decreases of Velocity/leg height ratio ($p = 0.025$).

For mobility (Table 4.5), velocity/leg ratio and the overall speed of walking the five meters walking test were chosen as good overall representations of mobility. Velocity/leg height ratio was predicted by cumulative path length. The five meters walking test was predicted by age alone.

The regression models were not affected by multicollinearity as the variance inflation factor analyses (VIF) was less than 2.00 for all regression models in this study (Hair, Anderson, Babin, & Black, 2010).

4.5 DISCUSSION

The participants in this study were relatively healthy, so they may not be totally representative of their whole age group. Their physical performance was similar or better than other studies that included health older participants (Helbostad & Moe-Nilssen, 2003).

The main finding in this study is that there is the expected correlation between visual attention measures and some high visual demand Xbox games such Skiing. The correlation between Skiing and UFV-S remained even after adjusting for age, number of medications and general health status. The multiple-regression model for Skiing illustrates the importance of UFV-S in predicting the game performance as it was the only predictor in that model. However, the co-efficient is low and only 17% of the variance was accounted for, which indicates that there are likely many factors which determine performance in the game.

However, performance in Stomp-it, which has the appearance of high visual demand, was not best predicted by visual attention, but by age in the multiple regression model. Although there was a simple correlation between Stomp-it and MOT, this was not significant after adjusting for age, indicating that both are determined by age and health score. Although Skiing and Stomp-it appear to both have a high visual attention component, it is likely that Stomp-it requires more physical agility, as the participant has to change step from one foot to the other quickly in response to the incoming colored targets. In Skiing, although the relative weight on each foot has to be changed, the participant does not have actually make a step. In other words, the greater physical demand in Stomp-it may overshadow the link with visual attention (it can be seen that there was an unadjusted correlation between Stomp-it and MOT, but this was not significant after adjustment for age, and age was the main predictor in the multiple regression model). Age itself is well correlated with the physical measures, such as balance and walking.

As predicted, our results demonstrate that games with apparent low visual demand such as Leg exercise or Tai Chi, show weaker or no correlation with visual attention tasks. The regression model of the low visual demand Xbox games shows that these games are predicted only with either age or physical ability.

These findings are interesting because they illustrate that there may be potential of using these games for training visual attention and mobility/balance concurrently. As visual attention can be improved with training (Ball et al., 1988; Sekuler & Ball, 1986), potential associations of visual attention with video games is important as video games might be used as a tool to train visual attention, with the expectation that this would transfer to other everyday life tasks including physical ability and cognitive status, which are also known to be associated with visual attention. However, to the authors' knowledge there are no studies showing a correlation of body movement control games with visual attention tasks. Some studies have shown that playing sedentary action video games can improve aspects of functional vision such as crowded visual acuity (Green & Bavelier, 2007), contrast sensitivity (Polat, Makous, & Bavelier, 2009) visual field sensitivity (Buckley et al., 2010), and visual attention tasks (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a).

It has also been suggested that body movement video games such as Wii fit games or Xbox Kinect games can be used useful in training physical abilities in older and younger people (Goble et al., 2014; Padala et al., 2012; Padala et al., 2017; Reed-Jones et al., 2012b; Rendon et al., 2012). Our results show that Tai Chi was well correlated with physical abilities such as balance and mobility. This was consistent with another study which reported that Tai Chi training is correlated with balance and mobility (Wu, 2002). Leg exercise, however, was not strongly correlated with either physical abilities or visual attention. Although these exercises seem similar, the Tai Chi is possibly more demanding in terms of the amount of movement/stretch required and the time to hold the pose.

Visual attention has been shown to have an association with mobility (Althomali & Leat, 2017; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004) and balance (Althomali & Leat, 2017). Our results are consistent with these previous results and show some correlation with gait and balance. Associations were observed in the current study between step width variability and MOT and UFV-S. The association with MOT remained even after adjusted for age, medications and general health status. Balance as measured by the OLST and the medial-lateral center of pressure variability was also associated with UFV-D. These correlations remain significant when adjusted with age but not when adjusted for age, number of medication and general health status. However, for balance and gait, in the multiple regressions, it was not attention, but age or other measures of physical status that were the best predictors.

To conclude, it seems that the type of game chosen to train visual attention is important, and ultimately a battery of games may be most effective (and fun). Skiing was the game that was best associated with visual attention, while Tai Chi was best associated with physical ability.

Thus, not all games that appear to be associated with visual attention are strongly associated and other factors, such as physical ability, may predominate, e.g. for Tai Chi and possibly Stomp-it because of its association with age. It also seems that the associations between visual attention and gait and mobility, while present, are weak and often explained by age or other measures of physical function.

4.6 Limitations

The study has some limitations and the results should be interpreted with caution. First, there is the cross-sectional nature of the study. This means that association, not causation, can be implied. We do not know, for example, if poor attention affects a person's gait, or whether in some way, poor gait changes attention. Only longitudinal studies can show which is the cause and which is the effect or whether there is a bi-directional effect. Second, the mobility task was a possible limitation as it was a simple measure of time and stepping parameters along an unobstructed path. Using a more challenging mobility course with obstacles and light changes similar to changes that we experience in everyday life may have shown a better correlation with attention. Third, it was not possible to analyze the one-legged stand sway with the force plate as we had originally intended, as a large percentage of the participants could not maintain the 30 seconds stand resulting in insufficient data to analyze. So, the more basic measure of the total OLST time was used. This showed a ceiling effect as many participants could reach to the maximum standing time. Finally, the age range and the health status of our sample was more limited than in some studies. There were fewer older participants, and most were relatively healthy for their age which does not reflect the average of health status expected for this age group.

4.7 CONCLUSION

This study has investigated the relationships between visual attention, balance, mobility and Xbox Kinect games performance. The results of this study indicate that some visual attention measures are associated with high visual attention demand Xbox Kinect games and can be a good predictor of the performance in this type of game. The study indicates that Xbox games may have potential for training visual attention as well as physical abilities, but the game chosen is critical. The evidence from this study also indicates that some balance and gait measures are associated with visual attention. This study has enhanced our understanding of the visual attention and its association with other systems and could be a framework for further future studies and indicates that longitudinal studies may be useful to show the potential of these games to enhance mobility and balance in order to prevent falls in older adults.

Chapter 5

The Association between Visual Attention and Body Movement-Controlled Video Games (Xbox Kinect^{TM}), Balance and Mobility in Younger Adults

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This chapter is in preparation for submission as follows:

Alghamdi M, Vallis LA, Leat SJ. European Journal of Applied Physiology

Authors' Contributions

Author	Concept/Design	Data Collection	Data Analysis	Article Writing	Article Editing
Alghamdi	✓	✓	✓	✓	✓
Vallis	✓		Advised		Edited
Leat	✓	Advised	Advised	Advised	Edited

5.1 INTRODUCTION

We live in a very visually demanding world and our interaction with many devices is fundamentally dependent on visual information. Some of the most common uses are for entertainment, such as videogames played on tablets and smart phones. There are many studies that have described the relationships between video games and vision (Buckley, Codina, Bhardwaj, & Pascalis, 2010; Green & Bavelier, 2007; Li, Polat, Makous, & Bavelier, 2009). Since these devices are popular and many applications take the form of a game, it has been suggested that training with these games may transfer to improved visual and motor skills. Vision is known to be involved in the coordination of the body with the environment. Additionally, it is known that balance is an integration process between the visual, the vestibular and the somatosensory systems (Lord, Smith, & Menant, 2010). Postural sway control requires integration of these sensory systems in addition to motor output. Vision is one key sensory input. For example, it has been shown that body sway increases when people close their eyes compared to the open eye situation (Lord & Menz, 2000).

A number of studies have considered the effectiveness of interaction games such as Xbox Kinect or Wii fit on physical training (Goble, Cone, & Fling, 2014; Su, Chang, Lin, & Chu, 2015; N. Vernadakis, Derri, Tsitskari, & Antoniou, 2014), They have been found to be effective in improving physical skills such as balance and gait in rehabilitation (Beaulieu-Boire et al., 2015; Luna-Oliva et al., 2013; Padala et al., 2012; Türkbey, Kutlay, & Gök, 2017; Vernadakis, Derri, Tsitskari, & Antoniou, 2014). Fewer studies have considered video games' impact on training visual attention (Green & Bavelier, 2003; Green & Bavelier, 2006a; Green & Bavelier, 2006b). Visual attention has been shown to be associated with mobility (Althomali & Leat, 2017; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004) and balance (Althomali & Leat, 2017) and is trainable (Ball et al., 1988; Sekuler & Ball, 1986). We are not aware of any studies that have investigated the impact of body-motion controlled (Kinect-based) games on the possibility of training visual attention; These games have the potential to provide visual attention training in combination with physical training. A system such as the Xbox combined with Kinect sensor may be effective in training both sensory and motor systems in a rehabilitation setting or in reduce the risk factors for falls in older adults. In our previous study (Chapter 4), we showed that the choice of Xbox games is critical, as some are more associated with visual attention and others with physical abilities.

There are only a few studies which have investigated the training of visual attention with video games (Green & Bavelier, 2003; Green & Bavelier, 2006a). Our earlier study with older adults (Chapter 3) is the only study of which we are aware which has investigated the applicability of training visual attention with body movement control games such as Xbox Kinect™ games.

Our knowledge of visual attention training is largely based on very limited data. The purpose of this study was therefore to determine the possibility of training visual attention concurrently with physical training, and to choose the optimal type of Xbox Kinect games. In a previous study of older adults, we chose games that had a stronger or a weaker apparent visual attention requirement. We hypothesized that performance on the games that were chosen to have high visual attention demand would be predicted by tests of visual attention in comparison to games with low apparent visual demand. For some games this was found to be true, while other games had a stronger association with physical abilities or age. In the present study, we are interested to study the same associations between visual attention and measures of mobility and balance in a younger adult population. Our research question is, since age, gait and balance may be less influential, will other predictors of performance predominate. The ultimate purpose is to determine the relationships between visual attention, balance, mobility and performance in Xbox Kinect games with the intention that this will direct the choice of games chosen for intervention studies for patients who benefit from visual attention training e.g. older adults.

5.2 METHODS

5.2.1 Subjects

In this cross-sectional study, fifty participants were recruited. The participants were healthy adults aged between 18-40 years and were recruited from the students and staff of the School of Optometry and Vision Science at the University of Waterloo, and their friends and family. Snowball recruiting was also used.

All participants underwent a phone call interview to determine eligibility. Inclusion criteria were:

aged between 18-40 years old; either gender; no significant vision loss (as described below); in good health and free from any condition that may affect their balance or mobility (as describe below); no medications (as describe below); have no previous concussion with residual symptoms that would affect balance; no previous injury that still affects balance or mobility; not a video gamer who plays action video games more than 3 hours 5 times per week; not an athlete who exercises more than 4 hours per day 5 times per week; binocular visual acuity 6/7.5 (20/25) or better; no diagnosed ocular condition that would cause vision loss such as glaucoma or hemianopia. Exclusion criteria were the same as for our previous study of older adults i.e. dementia, Parkinson’s disease, a history of cerebrovascular accident resulting in residual paresis, multiple sclerosis, cerebellar dysfunction, peripheral neuropathy of any etiology, or advanced arthritis so as to cause significantly reduced range of motion of the weight bearing or small joints, significant hearing loss; medication known to increase the risk of falls or impair balance (i.e., antipsychotics sedatives, antidepressants, anti-histamines, anti-hypertensive and long-acting sleeping medications).

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

5.2.2 Procedures

The general procedures were the same as for the previous study with older adults (Chapter 4), with the addition of a questionnaire about. sports, physical activities and video game playing. The participant completed this questionnaire at home before attending for the experimental session.

5.2.2.1 Screening test

The participants binocular visual acuity (BVA) was measured with their habitual spectacle correction, defined as the correction that the participant used for driving, walking and shopping. The ETDRS visual acuity chart "R", available from Precision Vision (www.precision-vision.com), at 4 meters (Ferris III et al., 1982) was used in this study. The chart luminance had an average of 100 cd/m^2 and was measured in logMAR using by-letter scoring (Bailey & Lovie, 1976; Hazel & Elliott, 2002).

Monocular visual field screening was conducted for each eye in order to confirm that there was no large field defect of which the participant was unaware. A confrontation test was used, the participant being asked to count fingers presented in each field quadrant (Elliott, North, & Flanagan, 1997).

5.2.2.2 Balance measures

The portable AMTI AccuGAIT force plate platform was used in this study to measure the person’s postural sway under bi-pedal quiet stance (QST) and the one-legged stand test (OLST) condition. This device measures the ground reaction forces and moments and records the location of the center of pressure (CoP). During both QST and OLST, participants were asked to stand as still as possible while focusing on a fixation target in front of their eyes. The duration was 60 seconds in QST condition and 30 seconds in OLST condition. There were three trials for each condition. The outcome measures from this test was the sway length in centimeters for anterior-posterior (AP) and medial-lateral sway and the cumulative path length (CPL) during the test time frame.

5.2.2.3 The five-meters walking test (5MWT)

The five-meter walking test was designed to assess gait speed and variability for the preferred walking speed. All participants walked forth and back on a hard floor that was covered with a 9.0x0.65-meter strip of paper taped to the floor. For acceleration and deceleration, two meters was added (equivalent to about three steps) at the beginning and at the end. Before they walked, inked stickers were attached to the posterior heel of their shoes to mark their steps (Wilkinson, Menz, & Raspovic, 1995). Participants were instructed to walk at their normal preferred pace and were timed with a stopwatch. The outcome measures included step length and width measured from the heel prints for the two walking trials (Wilkinson, Menz, & Raspovic, 1995). The average and standard deviation of lengths and widths were calculated. The time for the central 5 meters was measured for both directions of walking and the average time was calculated. The walking velocity was adjusted by the leg length, which was measured from hip joint (grater trochanter) to the floor, to determine the Velocity/Leg (VL) ratio.

5.2.2.4 Visual Attention Tests

Visual attention was assessed using a useful field of view (UFV) test (Ball, Beard, Roenker, Miller, & Griggs, 1988; Leat & Lovie-Kitchin, 2006a; Leat & Lovie-Kitchin, 2008; Sekuler & Ball, 1986) and a Multiple Object tracking test (Bowers et al., 2011) presented on 24-in LED monitor at a viewing distance of 50 cm. Participants used their habitual distance glasses if they had them.

5.2.2.5 The Useful Field of View (UFV)

The useful field of view test provides a valuable information about spatial visual attention such as ability of selective attention, divided attention and visual search. It has been used widely in research on everyday tasks such as driving (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Bowers et al., 2011; Owsley & McGwin Jr, 2010). In this study, we used two versions: static and dynamic. The static version was similar to the one used previously (Leat & Lovie-Kitchin, 2008; Wood & Owsley, 2014) The dynamic version was created for this study as it was thought that detecting movement might be more associated with the ability to detect moving targets in eccentric vision during Xbox games. The dynamic version used the same procedure as the UFV-S but differed in the peripheral target. Instead of a smiley face, one of the distractors circles vibrated upwards and then returned to its position (one cycle up and down) during the presentation of each trial (see Figure 2). All other measures and outcomes were the same as the static UFV. The details of the static and dynamic UFV can be found in Chapters 3 and 4. All the younger participants were instructed to identify the central target using the keyboard arrow (up for smiley face and down for frowning face). Then participants used the computer mouse to respond to the location of the peripheral target on the response screen.

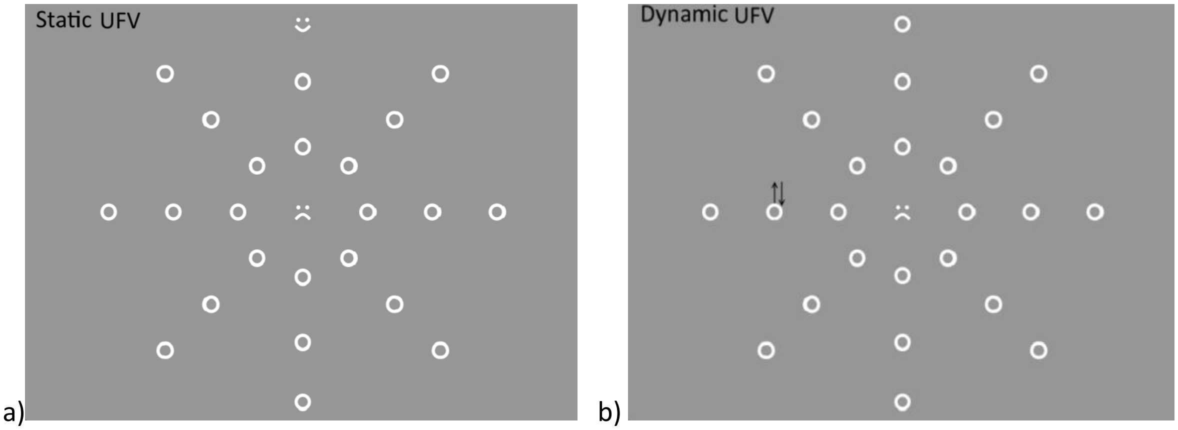

Figure 5.1 the Useful Field of View screen target a) static b) dynamic

5.2.2.6 The Multiple Object Tracking (MOT)

Sustained visual attention was measured with multiple object tracking (MOT) (Pylyshyn & Storm, 1988). To reduce test duration, the brief MOT test was used (Bowers et al., 2011). The outcome measure was the angular target speed to give a 60% correct threshold (Bowers et al., 2011). The details can be found in Chapter 3 and 4.

5.2.2.7 The Xbox Kinect™ Video games

The Xbox 360® console with the Kinect™ controller was used for the video games. Four different games were chosen based on the apparent visual requirements. Two games appeared to have high visual demand (action games) and two appeared to have low visual demand (exercise games), chosen from Xbox360® Kinect™ commercially available games called “Your shape™” and “Sports season2”.

The two apparently low visual demand games were Leg exercise and Zen energy (Tai Chi). In these games, participants followed an on-screen coach. In the Leg exercise, there were three exercise movements: step squat, sumo squad and side to side lunge. The movements aim to train the thigh muscles. In Zen energy, there were three main movements: side travel, ballet movement and warrior posture. These movements are meant to stretch the thigh muscles and enhance balance control. A score was given based on the accuracy with which they follow the coach’s movements, and the outcome measure was the final percentage score given in the software.

The two high visual demand games selected for study had more visual complexity and faster motion, which required faster reactions and movement in order to attain higher game scores. The games chosen were Skiing and Stomp-it. In these games, participants saw a digital avatar which mimics their movements. Participants were asked to control the avatar's movement with their own body movements and to achieve the best possible score. The outcome measure was the accuracy of performance in terms of successfully avoiding the flags and gates and making the jumps. In "Stomp-it" colored panels start moving from right, left, front-right or front-left of the screen and move towards the avatar. The participant was required to step with one foot on each colored panel when it reaches the avatar. The number of correct steps during the trial is used to quantify the performance score of the participant. For details of all the games, their administration and scoring, see Chapters 3 and 4.

The order of the visual attention tests and Xbox games was balanced as follows. The participant always started with one visual attention test (UFV or MOT) followed by one set of Xbox games (Tai Chi/Legs or Skiing/Stomp-It). Then the second visual attention test was followed by the second set of Xbox games set. The order of the specific attention tests and Xbox games was counter-balanced between the participants using a block design and the order of the Xbox games and UFV tests was alternated between participants (e.g., Tai Chi/Legs or Legs/Tai Chi, Static/Dynamic or Dynamic/Static UFV).

5.3 Statistical Analyses

For data analyses, the UFV scores were arcsine transformed (Leat & Lovie-Kitchin, 2008). Normality of the data was checked using the Kolmogorov-Smirnov test and Shapiro-Wilk test. If a variable was not normally distributed¸ it was transformed by an arcsine transform (for those that were a percent correct) or a log transformation. All vision data is presented in log units, as is standard. For ease of understanding, other data is reported in raw scores (untransformed), but statistical analyses were performed on the transformed data. After transformation, all the data were found to be normally distributed, except for number of number of hours spent in physical activity or number of hours spent in playing games, weekly. Therefore, these variables were split into a two-way score. For time spent in physical activity and video game playing, each was scored as 0 for undertaking physical activity not more than 2 hours and 1 for more than 2 hours. All the data were plotted as histograms and outliers that were more than 3 standard deviations from the mean were excluded (Iglewicz & Hoaglin, 1993).

An unadjusted univariate linear regression analysis was used to determine all relationships within and between visual attention, balance and mobility. The analysis was followed by univariate linear regression adjusted for age and then for age, video game playing and physical activity.

Separate forward step-wise multiple regression analyses (p-value of 0.05 to enter and 0.10 to remove) were conducted for video games and balance and mobility measures as dependent variables. Since there was a high correlation among measures of attention, mobility and two-legged stance balance, one independent variable was selected from each of these groups of variables to enter the model. The one chosen from each group was that which had the highest correlation with the dependent variable. For each analysis, VA, gender, age, physical activity score, video gaming score were also included. For example, in the model to predict performance in one of the Xbox games the following independent variables were entered; the best visual attention measure, the best mobility measure, the best balance measure, VA, gender, age, physical activity score, video gaming score. A variance inflation factor (VIF) analysis was calculated to make sure that the multiple regression models were not affected by multicollinearity. Data were analyzed with SPSS version 24 (Chicago, IL, USA) and the significance level was set at $p \leq 0.05$.

5.4 RESULTS

A total of fifty participants participated in this study, 28 males and 22 females with an average age of 26 yrs. ±4. Table 5.1 shows the demographic statistics of all participants and descriptive statistics for attention, gait, mobility and balance.

Table 5.1 Demographic data of study sample (N = 50)

Characteristic	**Mean value (SD or percent)**	**Range**
Age	26.4 (4)	18-37
Male	27.7 (4.6)	18-37
Female	25.1 (2.8)	18-29
Physical activities, > 2hr N(%)	39 (78%)	
Video gaming, >2hr N(%)	20 (40%)	
Visual Acuity in logMAR (**VA**)	-0.13 (0.06)	-0.26 to -0.04
MOT (threshold, deg/sec)	18.4 (4.3)	8.9 - 28.4
UFV-S (accuracy %)	78.7 (12.5)	33.33-100
UFV-D (accuracy %)	88.1 (14.2)	10.4-100
Low visual demand games		
Leg (% correct**)**	74.1 (11.8)	47-93
Tai Chi (% correct**)**	67.3 (14.3)	36-94.3
high visual demand games		
Skiing (% accuracy**)**	86.7 (6.2)	68.8 - 96.9
Skiing time (sec.)	48.9 (3)	46.1-66
Stomp-it (% accuracy**)**	85.6 (18.8)	46.1-100
Mobility		
Step length (cms)	72.3 (8.4)	57.8-95.8
Step length variability (cms)	2.3 (0.84)	1.1-5.1
Step width(cms)	10.5 (2.6)	6.3-16
Step width variability (cms)	2.8 (0.9)	1.2-4.7

Stride length (Right) (cms)	144.5 (15.8)	117.9-171.8
Stride length variability (Right) (cms)	5.1 (5.8)	1.7-43.5
Stride length (left) (cms)	145 (16.8)	117.7-191.7
Stride length variability (Left)	3.9 (1.7)	1.2-9.7
Five meters walking time (secs)	3.93 (0.66)	2.75-5.29
Velocity/leg height	1.4 (0.3)	0.9-2
Balance-bipedal (cms)		
ML COP SD	0.192 (0.07)	0.08-0.35
AP COP SD	0.360 (0.11)	0.22-0.74
ML COP MAX	0.49 (0.17)	0.20-0.86
AP COP MAX	0.90 (0.25)	0.56-1.65
ML COP Range	0.963 (0.31)	0.40-1.71
AP COP Range	1.74 (0.44)	1.06-3.13
Cumulative path-length	146.9 (39.22)	103.3-304.2
Balance-One leg stand (cms)		
OL ML COP SD	0.37 (0.08)	0.23 - 0.58
OL AP COP SD	0.57 (0.15)	0.34 - 1.01
OL ML COP MAX	0.99 (0.21)	0.67 - 1.54
OL AP COP MAX	1.43 (0.40)	0.83 - 2.79
OL ML COP Range	1.97 (0.40)	1.29 - 3.04
OL AP COP Range	2.94 (0.74)	1.76 - 5.04
OL Cumulative path-length	207.48 (51.46)	133.49 - 374.62

Among the visual attention tests, one extreme outlier (>3 SD from mean) was removed from the UFV-D data before analysis. Another extreme outlier was removed from Skiing time for the video games.

Table 5.2 shows significant correlations from the univariate analysis of Xbox Kinect games with visual attention measures. Significant correlations with visual attention tests (UFV-S and UFV-D) were found in the unadjusted univariate linear regression for the higher visual demand games (Skiing and Stomp-It). Unexpectedly, one lower visual attention game (Leg exercises) also showed a significant correlation with visual attention, namely in UFV-S (p=0.005) and MOT (p=0.045). Tai Chi showed no significant correlation with any measure of visual attention.

Relationships were found between performance in some of these video games and the time that participants usually spend per week playing video games or in physical activity. Stomp-it showed a significant correlation with age. Therefore, we adjusted for age and number of hours spent in video gaming and physical activity. We also found that splitting the data according to two hours or less, or more than two hours of playing video games or physical activity per week gave a balanced split of the data (for statistical validity) and the best correlation with the other variables. Therefore, we adjusted these correlations for age and playing video games > two hours and/or doing physical activity for more than two hours per week. All correlations remained significant after these adjustments except for the correlation between Leg exercise and MOT as shown in Table 5.2. There were no significant correlations between the measures of mobility and balance with visual attention tasks.

Table 5.2 Pearson correlation coefficients for visual attention with video games. Significant correlations at the p=0.05 level are shown in bold.

	Unadjusted r value (p)	Adjusted for Video Game > 2h and Physical Activity >2h r value (p)	Adjusted for Age, Video Game >2h, and r value (p)	Adjusted for Age, Video Game >2h, and Physical Activity >2h r value (p)
Stomp-it with UVF-S	**0.531** (<0.001)	**0.467** (0.001)	**0.413** (0.002)	**0.428** (0.004)
Stomp-it with UFV-D	**0.322** (0.024)	**0.248** (0.037)	**0.302** (0.020)	**0.248** (0.037)
Skiing Acc. with UFV-S	**0.395** (0.005)	**0.437** (0.004)	**0.417** (0.006)	**0.397** (0.010)
Skiing Acc. with UFV-D	**0.336** (0.018)	**0.329** (0.018)	**0.344** (0.017)	**0.326** (0.026)
Skiing Time with UFV-D *	**-0.517** (<0.001)	**-0.481** (<0.001)	**-0.511** (<0.001)	**-0.483** (<0.001)
Leg exercises with UFV-S	**0.389** (0.005)	**0.334** (0.019)	**0.386** (0.013)	**0.329** (0.028)
Leg exercises with MOT	**0.285** (0.045)	0.248 (0.078)	0.257 (0.91)	0.237 (0.100)

* negative correlation expected as less time = better performance

On the other hand, there were significant correlations between the game performance and balance as shown in Table 5.3 and 5.4. These correlations remained significant after being adjusted for age, gaming and physical activity time. For mobility, there were significant correlations between 5MWT and low visual demand games, Tai Chi and leg exercise (r=-0.597, p<0.001 and r= -0.388, p=0.005) respectively and these remained significant after being adjusted for age, gaming and physical activity time (r= -0.497, p<0.001 and r= -0.393, p=0.004) respectively.

Table 5.3 Pearson correlation coefficients for video game performance with bipedal stand balance. Significant correlations at the p=0.05 level are shown in bold. Note that the significant negative correlation coefficients are expected as for one of the variables, a lower number means better performance

Bipedal Stand					
	Cum._Path	**CoP-ML**		**CoP-AP**	
Leg exercise	**-0.35** (0.014) **-0.35** (0.009)*	Variability	**-0.41** (0.003) **-0.35** (0.013)*	Variability	**-0.39** (0.006) **-0.33** (0.023)*
		Max.	**-0.34** (0.015) **-0.32** (0.022)*	Max.	**-0.42** (0.002) **-0.36** (0.009)*
		Range	**-0.46** (0.001) **-0.41** (0.003)*	Range	**-0.43** (0.002) **-0.38** (0.006)*
Tai Chi	**-0.32** (0.022) **-0.29** (0.024)*	Variability	**-0.47** (0.001) **-0.38** (0.006)*	Variability	**-0.42** (0.003) **-0.32** (0.024)*
		Max.	**-0.46** (0.001) **-0.37** (0.008)*	Max.	**-0.41** (0.003) **-0.35** (0.008)*
		Range	**-0.51** (<0.001) **-0.43** (0.001)*	Range	**-0.49** (<0.001) **-0.42** (0.002)*
Skiing Time	n/s	Range	**-0.30** (0.037) -0.27 (0.071)*		n/s

* adjusted for age, physical activity >2h/w, video gaming>2h/w

Table 5.4 Pearson correlation coefficients for video games performance with one leg stand balance. Significant correlations at the p=0.05 level. Note that the significant negative correlation coefficients are expected as for one of the variables, a lower number means better performance

One-Legged Stand					
	Cum._Path	**CoP_ML**		**CoP_AP**	
Leg exercise	**-0.36** (0.011) **-0.35** (0.009)*	Variability	**-0.35** (0.014) **-0.37** (0.010)*	Variability	n/s
		Max.	**-0.43** (0.002) **-0.43** (0.002)*	Max.	**-0.36** (0.011) **-0.42** (0.003)*
		Range	**-0.40** (0.004) **-0.40** (0.005)*	Range	**-0.34** (0.016) **-0.39** (0.005)*
Tai Chi	**-0.46** (0.001) **-0.39** (0.003)*	Variability	**-0.61** (<0.001) **-0.52** (<0.001)*	Variability	**-0.60** (<0.001) **-0.55** (<0.001)*
		Max.	**-0.54** (<0.001) **-0.45** (<0.001)*	Max.	**-0.64** (<0.001) **-0.62** (<0.001)*
		Range	**-0.60** (<0.001) **-0.51** (<0.020)*	Range	**-0.65** (<0.001) **-0.59** (<0.001)*
Stomp-it	n/s	Variability	**-0.38** (0.006) **-0.35** (0.002)*	Variability	n/s
		Max.	**-0.32** (0.025) **-0.25** (0.030)*	Max.	n/s
		Range	**-0.33** (0.018) **-0.29** (0.011)*	Range	n/s
* adjusted for age, physical activity >2h/w, video gaming>2h/w					

The results of the step-wise multiple linear regression are given in Table 5.5, Table 5.6 and Table 5.7. The models for each of Xbox Kinect games together with the independent variables that were entered into the analysis are shown in Table 5.5. Stomp-it performance was predicted with combination of visual (UFV-S and VA) and physical (OL CoP ML SD and physical activity >2h/w) variables in addition to age and gender which eventually explained 69% of the variance. UFV-S alone explained 28% of variance in this model. Skiing accuracy performance was only predicted by UFV-S, which explained 16% of variance. Skiing-time was predicted with one visual attention test (UFV-D), 5MWT and gender, and this combination explained 42% of the variance.

Performance in Tai Chi was only predicted by balance (OL CoP AP Range) and mobility (the 5MWT), explaining 57% of the variance. Finally, performance in Leg exercise was predicted a combination of QS CoP ML Range, UFV-S and OL CoP ML Max explaining 40% of the variance.

Table 5.5 Step-wise multiple linear regression models for Xbox games.

Dependent Variable	Predictor variable	R^2 at each step	Co-efficient B	Standardized Coefficient	t	P value
Xbox360® Stomp-It[1]	UFV-S	0.282	0.696	0.453	4.792	<0.001
	Age	0.396	-0.042	-0.510	-5.330	<0.001
	Physical activity >2h/w	0.501	0.248	0.315	3.544	0.001
	OL CoP ML SD	0.560	-1.802	-0.499	-4.676	<0.001
	VA logMAR	0.612	1.806	0.349	3.571	0.001
	Gender	0.694	0.243	0.369	3.400	0.001
R^2 for the model= 0.694, F=16.284, p for the model <0.001 [1] predictors entered into the analysis: UFV-S, SW Ave., QS CoP AP Range, OL CoP ML SD, VA, gender, age, physical activity >2h/w, video gaming>2h/w						
Xbox360® Skiing Acc.[2]	UFV-S	0.156	0.228	0.395	2.976	0.005
R^2 for the model= 0.16, F=8.859, p for the model =0.005 [2] predictors entered into the analysis: UFV-S, SL SD, QS Cumulative path-length, OL CoP ML SD, VA, gender, age, physical activity >2h/w, video gaming>2h/w						
Xbox360® Skiing Time.[3]	UFV-D	0.267	-0.044	-0.519	-4.514	<0.001
	5MWT	0.334	0.073	0.325	2.756	0.008
	Gender	0.419	-0.01	-0.299	-2.540	0.015
R^2 for the model= 0.42, F=6.450, p for the model =0.015 [3] predictors entered into the analysis: UFV-D, 5MWT, QS CoP ML Range, OL CoP AP Range, VA, gender, age, physical activity >2h/w, video gaming >2h/w						
Xbox360® Tai Chi[3]	OL CoP AP Range	0.425	-1.002	-0.536	-5.343	<0.001
	5MWT	0.568	-1.075	-0.396	-3.954	<0.001
R^2 for the model= 0.568, F=15.631, p for the model <0.001 [3] predictors entered into the analysis: UFV-S, 5MWT, QS CoP ML Range, OL CoP AP Range, VA, gender, age, physical activity >2h/w, video gaming >2h/w						
Xbox360® Leg exercises[4]	QS CoP ML Range	0.213	-0.418	-0.326	-2.623	0.012
	UFV-S	0.336	0.281	0.333	2.891	0.006
	OL CoP ML Max.	0.399	-0.576	-0.273	-2.189	0.034
R^2 for the model= 0.399, F=10.162 p for the model < 0.001 [4] predictors entered into the analysis: UFV-S, 5MWT, QS CoP ML Range, OL CoP ML Max., VA, gender, age, physical activity >2h/w, video gaming >2h/w						

Table 5.6 Step-wise multiple linear regression models for balance measures

Dependent Variable	**Predictor variable**	**R^2 at each step**	**Co-efficient B**	**Standardized Coefficient**	**t**	**P value**
OL Cumulative path-length	QS Cumulative path-length	0.132	0.335	0.453	4.792	0.01
R^2 for the model= 0.132, F=7.170, p for the model =0.01 [1]predictors entered into the analysis: UFV-D, 5MWT, QS Cumulative path-length, VA, gender, age, sport>2h/w, video gaming >2h/w						
QS Cumulative path-length	OL CoP ML Max	0.265	0.6	0.515	4.157	<0.001
R^2 for the model= 0.265, F=17.282, p for the model <0.001 [2]predictors entered into the analysis: UFV-S, 5MWT, OL CoP ML Max., VA, gender, age, sport>2h/w, video gaming >2h/w						

Table 5.6 show the step-wise multiple linear regressions for balance (the one-legged stand and the bipedal stand). The cumulative path-length was chosen for both conditions as the best overall representation of one-legged stand and bipedal stand. Performance in the one-legged stand cumulative path-length was only predicted by bipedal stand cumulative path-length (p<0.001) explaining 13% of the variance. The performance in bipedal stance cumulative path-length was only predicted by OL CoP ML Max (p<0.001) which explained 27 % of the variance.

Table 5.7 Step-wise multiple linear regression for mobility measures

Dependent Variable	Predictor variable	R^2 at each step	Co-efficient B	Standardized Coefficient	t	P value
5MWT	QS CoP ML Range	0.273	0.273	0.523	4.248	<0.001
R^2 for the model= 0.273, F=18.046, p for the model <0.001 [1]predictors entered into the analysis: UFV-S, QS CoP ML Range, OL CoP ML Range, VA, gender, age, physical activity >2h/w, video gaming>2h/w						
Velocity/leg	Video gaming>2h/w	0.105	0.051	0.325	2.379	0.021
R^2 for the model= 0.021, F=5.66, p for the model =0.021 [2]predictors entered into the analysis: UFV-S, QS CoP ML Max, OL Cumulative path-length, VA, gender, age, physical activity >2h/w, video gaming>2h/w						

The five meters walking test walking speed and velocity/leg were chosen as good overall representations of mobility (Table 5.7). For the 5MWT, the walking speed was predicted only by QS CoP ML Range ($p < 0.001$) and this independent variable explained 27% of the variance in walking speed. Velocity/leg height ratio was only predicted by spending more than 2h weekly in playing video games ($p=0.021$) and that explained 10% of the variance.

Finally, in this study there was no impact of collinearity among the variables in all regression models as the variance inflation factor (VIF) was less than 2.00 for all regression models (Hair, Anderson, Babin, & Black, 2010).

5.5 DISCUSSION

We are not aware of any other study that has compared balance and mobility with these measures of visual attention tasks. This study demonstrates that Kinect video games, specifically those which appear to have high visual demand, do have associations with visual attention measures, specifically useful field of view in a young group of adults. The games chosen to have high visual demand showed stronger correlations that remained even after being adjusted for factors that may have an impact on this relationship such as age, number of hours playing video games and/or physical activity. The multiple regression models confirm that visual attention was the major predictor for the games that were chosen to be high visual demand games, although for Stomp-It and Skiing time, aspects of balance or mobility also came into the model. However, there was no significant correlation between the games with high visual demand and the MOT in this study. This may be because this visual sustained attention measure was not the same aspect of visual attention used in these games or it may be that using threshold measure was not the best measure for this correlation. Visual attention tasks which measure the sudden appearance of a stimulus or target (such as UFV) may be more relevant to games in which targets suddenly appear and have to be negotiated.

Games that were chosen to be low visual demand games (Tai Chi or Leg exercise) were more consistently correlated with balance and mobility (Table 5.4) and these types of games were predicted mostly with either balance or mobility tasks in the multiple regression models (Table 5.5). These results emphasize that the games with apparent low visual demand are predicted mainly with physical abilities followed by other factors. However, Leg exercise unexpectedly has a correlation with USV-S and MOT (Table 5.2), and UFV-S came into the multiple regression model.

This is the first study to our knowledge that demonstrates the relationship between body-motion control games and visual attention. It is well established that visual attention is trainable (Ball et al., 1988; Sekuler & Ball, 1986). The results in this study are remarkable and emphasize the possibility of including visual attention tasks with body-motion controlled games in rehabilitation intervention programs and other training programs. Previous work has shown that playing sedentary action video games can improve aspects of functional vision such as crowded visual acuity (Green & Bavelier, 2007), contrast sensitivity (Li et al., 2009) visual field sensitivity (Buckley et al., 2010); and visual attention measured with divided attention (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a), selective attention and visual speed processing speed (Dye, Green, & Bavelier, 2009). All these studies address the trainability of visual attention aspects with video games. There is also an association between visual attention and mobility (Althomali & Leat, 2017; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004) and balance (Althomali & Leat, 2017). Other rehabilitation studies have addressed the feasibility of using interactive video games in either physical rehabilitation or agility exercises (Rendon et al., 2012; Su et al., 2015; Türkbey et al., 2017; Vernadakis et al., 2014). Numerous studies have demonstrated the feasibility and effectiveness of body motion games in balance and mobility rehabilitation and exercise training (Chao, Scherer, & Montgomery, 2015; Luna-Oliva et al., 2013; Padala et al., 2017; Vernadakis et al., 2014).

The results in the current study show the potential of training visual attention and mobility/balance concurrently, and this may be a more potent rehabilitation technique than training them separately. However, the type of game chosen to train visual attention is important, as each game has different associations with visual and physical measures. Of the games that were included, Stomp-It, Leg Exercise and Skiing showed the most potential for training visual attention and mobility/balance simultaneously. Additionally, a group of games may be most effective and result in effective multi-dimensional training.

This study has a limitation due to the cross-sectional nature of the study and so we are only able to discuss associations and not causation. We are only able to suggest the training impact of these games and the long-term impact of this type of game playing on visual attention, mobility and balance. An additional limitation is that, although mobility measures shown some correlations with the games, the mobility task was simple and perhaps not sufficiently challenging. Better correlations may have occurred between the games and mobility if a more challenging mobility task had been included.

5.6 CONCLUSION

The results in this study suggest that there are relationships between visual attention, balance, mobility and Xbox Kinect games performance. Thus, playing these games may train visual attention and improve the balance and mobility over time. Further longitudinal studies are necessary to address the long-term effectiveness of these games on enhance visual attention, mobility and balance.

Chapter 6
General Discussion

The main purpose of the present research was to investigate the relationships between different visual attention measures with the performance in body control movement games (Xbox Kinect™ games) on one hand and balance and mobility on the other hand. This research consists of two main studies (Chapter 4 and Chapter 5) which include in different age groups; older adults (Chapter 4) and younger adults (Chapter 5). The study with older adults investigated these relationships with a relatively healthy sample of participants, and this may impact the findings.

Visual attention is an important aspect of vision that plays a role in mobility (Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004), balance (Althomali & Leat, 2017), and video game performance (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a). It has been shown that visual attention is trainable (Ball et al., 1988; Sekuler & Ball, 1986). Thus, the possibility of training visual attention with video games, particularly body movement control games so that physical training occurs simultaneously, could be considered as the ultimate goal of this study.

It is known that age has an impact on visual attention tasks (Ball et al., 1988; Sekuler & Ball, 1986), games performance (Dye et al., 2009), balance (Balogun et al., 1994) and mobility (Menz, Lord, & Fitzpatrick, 2003) Thus, in the present study, we included two age groups to further understand the relationships.

It is important to mention that the sample size in both these studies was considerable compared to the majority of previous studies (see Table 1.1). This indicates the importance of the current results. The results indicated that visual attention showed correlations with Kinect games that have required high visual attention demand compare to minimal or no significant associations with the games of low visual attention demand (Tables 4.2 and 5.2). These results were similar in both groups (Chapter 4 and Chapter 5) and this confirms the first hypothesis “$H_{1:}$ Tests of visual attention (UFV and/or MOT) have a stronger agreement, as indicated with correlation and regression, with the performance in Xbox Kinect™ games which were chosen to have a strong visual attention component, compared with those that appeared to require less visual attention but only have a physical component”. Of the three visual attention tests employed, it seems that useful field of view – static (UFV-S) is the most common visual attention test that showed correlations with the high visual demand games as these significant correlations remained after adjustment for factors that might affect the relationship such as age, physical and medical conditions. Useful field of view – dynamic (UFV-D) was another measure of visual attention that had a role in the younger group, but not in in the older adults (Table 5.2). On the other hand, the multiple object tracking (MOT), which is a measure of sustained visual attention did not show this correlation with video Kinect video games as it did not remain after adjusted with factors that affect these relationships. Sustained visual attention seems not to have a direct role in these games. This may be because the games chosen (Skiing and Stomp-It) require quick changes of attention to newly appearing stimuli rather than tracking stimuli that are already present, and this would be measured by UFV, rather than MOT.

Multiple regression models in this research support the first H_1 hypothesis. In both age groups, Skiing accuracy was only predicted by UFV-S and it explained a similar percentage of the variance in both groups (16.7% and 15.6% for the older and younger group respectively) (Tables 4.3 and 5.5). Skiing time was predicted by UFV-D, walking speed and gender in the younger group. Skiing time was not analysed in the older group, as participants were not encouraged to ski as fast as possible. It was analysed in the younger group as participants in that group tended to try to compete the course quickly.

However, the multiple regression model of the Stomp-it performance showed age was the only predictor for the older group (Table 4.3), which may be because this game seems to require more physical agility, where the participant has to step from one foot to the other quickly in response to the incoming targets. In addition to age, there were a number of other factors which came into the model for Stomp-It for the younger group (Table 5.5), namely UFV-S, time spent in physical activity, medial-lateral sway variability, visual acuity and gender. It is possible that age is such a predominant factor for the older group that these other factors are masked. The fact that in the younger group Stomp-it was predicted first by UFV-S and second with age followed by the amount of physical activity, supports the idea that this game requires more physical agility than the others.

Leg exercise in the younger group was predicted with UFV-S secondly after bipedal balance was added to the model (Table 5.5). One legged balance was added thirdly to the model. As with Stomp-It, In the older group, it was age alone that predicted this game and age may be such a strong factor, that other factors are masked. However, age only predicted 7.9% of the variance in the older group (Table 4.3).

Lastly, Tai Chi was predicted by walking speed for leg length (Vel/leg) in the older group and by walking time and AP balance in the younger group (Tables 4.3 and 5.5). This indicates that this game is predominantly determined by walking and balance.

In the literature, studies have reported that playing sedentary action video games can improve aspects of functional vision such as crowded visual acuity (Green & Bavelier, 2007), contrast sensitivity (Li et al., 2009) visual field sensitivity (Buckley et al., 2010), and visual attention tasks (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a). The results of this part of the current research are relevant because to the author's knowledge this is the first study showing a correlation between body movement control games and visual attention tasks. Therefore, there is a potential benefit of using these games for training visual attention and mobility/balance concurrently. The associations of visual attention with video games is important as video games might be used as a tool to train visual attention, with the expectation that this would transfer to other everyday life tasks including physical ability and cognitive status, which are also known to be associated with visual attention. It is clear, however, that the choice of game matters. The results from the younger group indicate that Stomp-It, Leg Exercise and possibly Skiing may be good choices for training both visual attention and physical skills, although Skiing does focus more on training visual attention and Tai Chi more on physical abilities. Perhaps, ultimately, a battery of games would be optimal.

In this study, visual attention measures were not found to be predictors for any balance and mobility measures in the multiple regression models for either group (Tables 4.5 and 4.5, 5.6 and 5.7). Balance was predicted by age, other balance measures or mobility. There were correlations with MOT and UFV-S with mobility (step width variability) only in the older adult group which remained only for MOT after adjustment for age, medications and general health (Table 4.2). In the older group also UFV-D was correlated with OLST and ML CoP variability (balance) which remained only after adjustment for age (Table 4.2). Therefore, the mobility and balance correlation results mean that the second hypothesis can be accepted for the older adults but not the younger adults. Hypothesis 2 was that tests of visual attention (UFV and/or MOT) both have a significant association with balance (measured with the force plate and one-legged stand test) and mobility/gait (assessed with the variability of steps and walking speed in the 5 Meters Walking test. It is possible that these associations were found for older, but not younger adults, because mobility and balance are more challenging for older adults and demand more attention.

Associations between visual attention and balance and mobility have been established in the literature (Althomali & Leat, 2017; Leat & Lovie-Kitchin, 2008; Owsley & McGwin, 2004). Furthermore, there are relationships between body movement control games and balance and mobility measures in this study. This also is consistent with literature where numerous studies have suggested that Wii fit games or Xbox Kinect games can be effectively used for training and rehabilitation of balance and mobility (Goble et al., 2014; Padala et al., 2012; Padala et al., 2017; Reed-Jones et al., 2012b; Rendon et al., 2012). As expected, the games with high physical components (Tia Chi and Leg exercise) have a stronger correlation with balance and mobility. However, in the older adults group Leg exercise was not significantly correlated with balance or mobility. The correlation with Tai Chi is possibly because it is more demanding in terms of the amount of movement/stretch required and the time to hold the pose.

6.1 Limitations

While the results in this study are promising, a number of limitations need to be considered. First, the cross-sectional natural of the data collection in this study, means that the associations, but not causations, can be studied. Thus, addressing which is the cause and which is the effect or whether there is a bi-directional relationship can only be obtained from longitudinal studies. Second, the demographic characteristic of the older adult participants limits the generalization of the study results, as a lower number of participants >75 participate in this study. Additionally, the participants in the study were relatively healthy, and different relationships might be obtained with a less healthy sample. Third, some of balance and mobility measurements in this study may be insufficiently challenging or difficult to show relationships with visual attention. However, the one-leg stand was too difficult for many of the older adults, so that the actual CoP measures of balance could not be used, and the total time of one-legged stand was instead. Alternatively, total time for the ole-leg stand could not be used for the younger group, as they all completed the whole trial time. So, this outcome measure could not be compared between the two age groups. It may be difficult to find outcomes for balance and mobility that are sufficiently challenging for the young group and not too challenging for the older group. Finally, the generalization of these relationships in this study may be limited to the types of Xbox games used in this study.

6.2 Future Research

The results of this study lead to potential future research:

1. Further investigation to support the current associations. Studies might include a more challenging mobility course with more advanced gait analysis tools and a more challenging balance test (e.g. on a foam surface or a balance measure with perturbations). These might demonstrate stronger relationships with visual attention.
2. A longitudinal study might help understand causation factors e.g. how do visual attention, mobility and balance change together over time.
3. An intervention study would be useful to indicate the potential of training with Xbox games
4. Finally, if these previous studies show positive results, a randomized clinical trial is indicated to study the possibility of developing a falls prevention intervention program that includes Xbox Kinect games for training.
5. Similar studies could also be conducted with frailer older adults frail, those with a health condition such as neurological disorders, post-stroke, injuries and fractures or in younger adults for post-concussion rehabilitation.
6. Further studies to explore the newer technology such as augmented reality in training visual attention is also warranted.

6.3 Conclusion

In conclusion, evidence from this study enhances the understanding of the role that visual attention plays in the performance of Kinect video games and addresses the associations between the visual attention, Kinect video games and measures with balance/mobility. Taken these finding together suggest that playing a selection of Kinect video games may potentially train visual attention over time as well as balance and mobility. Such training may be useful for rehabilitation in falls prevention intervention programs.

The type of game chosen to train visual attention is essential where each game has different correlations with a different range of visual and physical measures. A group of games may be most useful as previous studies have shown that multicomponent training is more effective than single component. A further longitudinal study is needed to address the effectiveness of Xbox games for preventing falls.

Appendix A

Questionnaire used with younger adults participants (Eligibility)

Name: _________________________ Study ID__________________________ Age: ________

1. Do you play video games? YES / NO

   If yes please specify which types

   ____

   Please estimate how many hours per week____

2. Do engage in physical activities or sport exercises? YES / NO

   If yes please specify____

   Please estimate how many hours per week____

3. Do experience on-gong dizziness or vertigo? YES / NO

   ____

4. Do you have any ongoing severe pain? YES / NO

   ____

5. Do you have any general health conditions that may affect your balance or ability to walk? YES / NO

   ____

6. Do you have any eye conditions apart from needing glasses? YES / NO

   ____

7. Have you had an accident or injury that is still affecting you? YES / NO

   ____

8. Do you have any other health conditions? YES / NO

   ____

Appendix B
Questionnaire for younger adults group

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UNIVERSITY OF WATERLOO

Visual Attention, balance, mobility and Xbox exercise games
(Questionnaire)

General Health Information

1. Gender: Male Female
2. Age: ________________
3. Have you ever had an accident or sports injury (e.g. concussion) that has affected how you live or your mobility? Yes No

   If yes, please specify when it happened, what part of the body was affected and if it is still affecting you:

   ____

   ____

4. Do you have any on-going general health issue? Yes No

   If yes, please specify:

   ____

   ____

5. Are you currently taking any medications Yes No

   If yes, please list:

   ____

   ____

Sports and physical activities information

6. Do you **currently** engage in active sport or physical activities? Yes No

   If no, skip to question 9

7. Please estimate the number of hours per week that you **currently** spend on each sport or physical activity

	Sport/physical activity	Average # of hours per week
1.		
2.		
3.		
4.		
5.		

8. Please estimate the number of hours per week that you spent on each sport or physical activity i**n the past 6 months**

	Sport/physical activity	Average # of hours per week
1.		
2.		
3.		
4.		
5.		

Video Game information

9. Do you play video games? Yes No

If no, skip to question 14

10. On which device do you play video games most often?
    - ☐ PC, Mac, laptop
    - ☐ Joystick controlled games (PlayStation, Xbox, Wii etc.)
    - ☐ Body movement controlled games (PlayStation camera, Xbox Kinect, or Wii camera balance board etc.)
    - ☐ Tablet or smartphone (iPhone, Blackberry, Android phone etc.)
    - ☐ Other (please specify)

11. How many hours per week on average do you spend playing each device?

	Device	Average # of hours per week
1.		
2.		
3.		
4.		
5.		

12. For how many years have you played video games? ____________________________

If you play body movement-controlled video games (i.e. the Wii Balance Board or XBox Kinect games)

Please list the games, and estimate the average number of hours per week that you spend on each one

	Game	Average # of hours per week
1.		
2.		

3.		
4.		

13. During the past 3 months, indicate the top three video game genres did you play most often (1=highest, 2=second highest, 3= third highest)
    - ☐ Adventure (Zelda, Heavy Rain, The Wolf Among Us, Broken Sword, etc.)
    - ☐ Shooting (Call of Duty, Counter-Strike, Battlefield, Medal of Honor Metal Gear Solid, Dead Space, Gears of War, Resident Evil, etc.)
    - ☐ Fighting (Street Fighter, Grand Theft Auto, Tekken, Virtual Fighter, Dead or Alive, etc.)
    - ☐ Strategies and logic (StarCraft, Command & Conquer, Age of Empires, Angry Birds, Lemmings, Solitaire, Hearthstone, etc.)
    - ☐ Racing (Need for Speed, Gran Turismo, Forza, Mario Kart, etc.)
    - ☐ Sport (EA Sports FIFA, Pro Evolution Soccer, NBA Live, Mario & Sonic at the Olympic Games, etc.)
    - ☐ Other (please specify)

Please list the three types of game you play most often, and estimate the number of hours per week that you spend on each one

	Genre of Game	Average # of hours per week
1.		
2.		
3.		

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14. If there is anything else you would like to tell us about your sport or gaming activities, please let us know below

____

____

____

____

End of questionnaire

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