RELATIONSHIP BETWEEN VISION AND BALANCE IN STATIC AND DYNAMIC MANNERS

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CERTIFICATE OF ORIGINALITY

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Abstract

Introduction

Fall is a common social problem in the elderly population. Any reduction in vision decreases the amount of visual information from external environment for maintaining balance and walking stability. Hence, improving older adults' visual function is one of the key elements to improve their balance function and reduces the corresponding risk of falls. Although many studies have examined the relationship between vision and balance functions, these studies had two major limitations. First, majority of these studies recruited mainly Caucasian populations, it is unclear how this relationship applies to Chinese population. Second, these studies focused on static visual function, largely ignoring the importance of dynamic visual function on balance performance. To address these limitations, 5 projects were included in this study.

- Project 1 investigated visual and balance performance in Chinese community-dwelling older adults using clinical screening instruments, which were developed to identify older people at high risk of falls. Age-related decline in physical fitness might affect older adults' control on body coordination.
- Project 2 investigated the effect of body locomotion in resolving visual stimuli moving at different speeds. Through recruiting subjects of different age groups, the interactive effect contributed by age and body locomotion in dynamic vision was also examined.
- Project 3 examined the relationship between vision and balance, in particular how dynamic visual (resolving moving visual stimuli) and balance systems (weight shifting or voluntary movement responding to moving stimuli) interacted.
- Project 4 investigated how newly prescribed progressive addition spectacles – one of the common aids for refractive corrections in presbyopia population, affected naïve participants' vision in which influenced gait and balance performance.

- Project 5 was a pilot study exploring the intervention effect of action video game on improving older adults' dynamic vision and balance functions.

Methods

In Project 1, 435 Chinese older adults (age ranged from 60 to 95 years, 75.5 ± 7.2 years) in the community-dwelling were recruited. Visual function and ocular health were examined by optometric screening assessments. Balance function was assessed by Physiological Profile Assessment (PPA), including peripheral sensation, lower limb strength, coordination and sway performance (eyes close and open condition; standing on firm and foam surface). Composite fall-risk index was calculated. Participants were then followed up for falls in one year period.

In Project 2, 84 healthy adults (divided into three age groups: young adults (n= 38, 25.1 ± 5.2 years), middle-aged (n= 33, 56.3 ± 6.7 years) and older-adults (n= 13, 68.9 ± 2.6 years) with normal vision were recruited to recognize visual stimuli presented at 0, 30, 60 and 90 deg/sec in 3 types of body locomotion: sitting, stepping and walking. Effects of stimuli's moving speed, type of body locomotion and age on visual acuity and contrast sensitivity were investigated.

In Project 3, 40 participants (divided into three age groups: young adults (n= 16, 24.1 ± 3.9 years), middle-aged (n= 14, 56.8 ± 6.6 years) and older-adults (n= 10, 68.7 ± 3 years)) with normal vision were recruited to examine their visual and balance functions. Methodology for measuring static and dynamic visual function was similar to that in Project 2. Static balance was assessed when participant stood on firm and foam surfaces and fixated on a central target, and viewed the randomly moving targets with and without decision making accordingly. Dynamic balance was measured by limit of stability, where participants were asked to make a voluntary body movement towards eight compass directions.

In Project 4, 10 naïve participants (aged from 50 to 70 years, 60.4 ± 5.3 years) without experience in wearing progressive spectacles or multifocal contact lenses were recruited. Each participant was prescribed a pair of single vision lens (SVL) and progressive addition spectacles (PAL). Visual, balance and gait functions were measured for participants wearing each pair of spectacles. Dynamic vision was assessed adopting the methodology in Project 2. Gait function was measured by Vicon Motion System, where participants walked along different paths with and without obstacles. Balance function was measured when participants stepped down onto a force platform at the end of the walk path.

In Project 5, 15 adults (aged from 62 to 73 years, 66.1 ± 2.6 years) were recruited to participate in a pilot quasi-experimental study which examined the intervention effect of action video game on improving dynamic vision and balance function. Participants were randomly assigned to training (receiving 30 hours action video game training) or control groups (receiving 30 hours leisure activities). Outcome measures in dynamic vision and balance function were conducted at 4 time-point with 1-month interval. .

Results

Project 1 found that only 16.5% older adults' distance acuity in the better eye was worse than 6/18, which was mainly due to cataract. Compared to the Caucasian normative database, our population had "moderate" fall-risk because of the relatively larger body sway in our balance measurements. Despite the moderately high fall-risk scores, the incidence of one plus falls in the 6-month and 1-year follow-up period was only 9.6% and 17% respectively. Participants with poor distance acuity had poorer quadriceps, slower hand reaction time and poorer balance function, while the relationships were significant. In Project 2, significant main effects of target's moving speed, body locomotion and age were found on visual function. However, impacts of these 3 factors on visual function were independent, without significant interactive effect.

Project 3 showed significant age-related decline in vision (static and dynamic) and dynamic balance functions. Similar to Project 1, significant relationship was found between vision and balance functions, however the relationship was stronger when both vision and balance functions were measured in dynamic status.

In Project 4, no significant difference in visual (static and dynamic vision) and gait performance (in terms of head angle and required time to complete each walking cycle in the task) was found in SVL and PAL wearing. However, participants wearing the PAL required significantly longer time to stabilize and had larger body sway area (with significantly more sway along the lateral direction) after negotiating one-step down.

In Project 5, no significant improvement in vision was found in both control and training groups. For balance measure, significant post-training effect was found in the postural sway along medio-lateral (M-L) and anterio-posterior (A-P) displacements when the participants fixated targets at random position or tracked a moving target. This suggested that action video-game training could potentially improve older adults' balance function in some aspects.

Conclusion

Despite relatively lower prevalence of falls in Hong Kong Chinese (~17%), they had moderate fall risk score compared to Caucasian populations. Vision was one of the factors affecting balance function in a positive correlation, in particular the dynamic natures of these measures. Wearing progressive addition spectacles did not result in significant deterioration in gait function, but significantly impaired naïve wearers' balance performance. Hence, it was important to educate new wearers about this potential fall risk due to the visual disturbance induced by this type of spectacles. The significant association between age-related decline in dynamic visual and balance functions suggested that intervention for improving visual function might also result in improving balance performance. Results from our pilot study provided some preliminary evidence to support this hypothesis, where action video game training might enhance older adults’ balance function. A large-scale study was required to confirm the effect of intervention.

<u>Publications arising from the thesis</u>

Manuscripts

1. **Siong, K.H.**, Kwan M.M., Lord, S.R., Lam K.C., Tsang, W.N. & Cheong, A.M. 2016, "Fall-Risk in Chinese Community-Dwelling Elders: A Physiological Profile Assessment Study", *Geriatrics & Gerontology International*, vol. 16, no. 2, pp. 259-265.

Posters

1. Cheong AMY, LAM HY, **Siong KH**, Ting PWK, Tsang WWN, Leat SJ, Li RW. Dynamic grating acuity in community dwelling older adults. Presented at the American Academy of Optometry, United States, October 2015.
2. Cheong AMY, LAM HY, **Siong KH**, Chan HHL, Tsang WWN, Li RW, Leat SJ. Effects of eye movements on postural sway in community dwelling older adults. Presented at the American Academy of Optometry, United States, October 2015.
3. Cheong AMY, **Siong KH,** Tsang WWN, Chan HHL. Relationship between dynamic vision and balance in community-dwelling older adults. Presented at the Association for Research in Vision and Ophthalmology, United States, May 2013.
4. Cheong AMY, **Siong KH,** Yeung F, Chen B, Wong A, Lam A. Factors associated with falls in Hong Kong Chinese community-dwelling older people. Presented at the Association for Research in Vision and Ophthalmology, United States, May 2012.
5. **Siong KH,** Chan HHL, Cheong AMY. Dynamic visual function and its aging effect. Presented at the Association for Research in Vision and Ophthalmology, United States, May 2012.
6. Cheong AMY, Chen B, Yeung F, **Siong K**, Lam A. Effect of aging on vision and postural stability in Chinese community-dwelling older people. Presented at the Association for Research in Vision and Ophthalmology, United States, May 2011.

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Abbreviations

ANOVA	Analysis of Variance
ABC Scale	Activities-specific Balance Confidence Scale
A-P	Anterio-Posterior
BCEA	Bivariate Contour Ellipse Area
BL	Both Legs
CC	Cortical Cataract
CFF	Critical Flickering Frequency
COP	Centre of Pressure
CS	Contrast Sensitivity
DC	Directional Control
Deg/sec	Degree per Second
DCS	Dynamic Contrast Sensitivity
DVA	Dynamic Visual Acuity
DL	Dominant Leg
EC	Eye Close
EO	Eye Open
ETDRS	Early Treatment of Diabetic Retinopathy Study
LBHD	Left Back Head
LE	Left Eye
LFHD	Left Front Head
LOCS III	Lens opacities Classification System III (LOCS III)
LOS	Limit Of Stability
MANOVA	Multivariate Analysis of Variance
MET	Melbourne Edge Test

M-L	**Medio-Lateral**
MMSE	**Mini-Mental State Examination**
NS	**Nuclear Sclerosis**
PAL	**Progressive Addition Lens**
PASE	**Physical Activity Scale for the Elderly**
PPA	**Physiological Profile Assessment**
PSCC	**Posterior Subcapsular Cataract**
RBHD	**Right back head**
RE	**Right Eye**
RFHD	**Right front head**
SCS	**Static contrast sensitivity**
SOT	**Sensory Organization Test**
SV	**Single Vision**
SVA	**Static Visual Acuity**
SVL	**Single Vision Lens**
TTS	**Time To Stabilization**
VA	**Visual Acuity**
VF	**Visual Field**
WC	**Walking Cycle**

Chapter 1

Literature Review

Chapter 1
Literature review

1.1 Introduction

With the improvement in medical system for early diagnosis and treatment of diseases, the mean life expectancy of the worldwide population increases. Currently, the rise of chronic non-communicable diseases such as heart disease, cancer, and diabetes imposes significant burden on global health, resulting in potential economic and societal costs to our community. To reduce these burdens, identifying those people who are at a higher risk in deterioration of functional performance is essential.

Vision and balance are two main functional performances that are mostly affected by age, where deterioration in these two aspects can lead to decrease in postural stability, effectiveness in locomotion, as well as self-independence. Coordination between vision and balance skills reflects the ability in sensory (vision) and motor (balance) systems to manage functional daily tasks. One of the common phenomena showing decrease in vision and balance coordination is "falls". In this chapter, details on falls prevalence in the worldwide population and its potential risk factors are discussed. Furthermore, the literature on dynamic vision, in which it shares similar nature of time processing information in real-life balance performance, is discussed. Similar nature in the real-time processing of information suggests the presence of mutual relationship between vision and balance performance. Spectacles wearing in vision correction are the most common approach for the elderly. Progressive addition lenses (PAL) are widely applied for people aged 40 years or above to provide clear vision for both distance and near. Discussion on how the distorted areas in peripheral lens induced by PAL affecting the wearers' functional performances is included. But not the least, the effectiveness of different types of training on improving visual functions and other functional performances is also explored. This suggests an alternative direction for rehabilitation.

1.2 Prevalence of falls

1.2.1. Overview

With the increase of age, the deterioration of health leads to decrease in functional performance such as balance control and locomotion because of the poor body coordination and decrease in physical fitness. Increase in falls is one of the most common phenomena reflecting deterioration in balance performance.

Earlier epidemiological studies showed that the risk of falls in aging population was about 30% in people aged 65 years or above (Close et al. 1999). The increase in falls in older population increased the rate of recurrent falls and decreased the quality of life and self-independence (Close et al.1999). Knowledge on more recent data on the prevalence of fall is important for future planning in falls prevention in community dwelling elderly population. As the falls incident could be caused by multiple factors, recognizing the main elements for enhancing the balance stability is crucial. In this section, the prevalence of falls in the worldwide population and the risk factors for falls incidents were reviewed.

1.2.2. Prevalence of falls

Falls is one of the most serious public health problems for older people with serious medical and economic consequences. Many population-based studies have documented the prevalence of falls in community-dwelling older adults. Because of the racial and ethnical differences in health, behavioral and lifestyle styles in different countries, it is not surprising that the prevalence of falls varied among countries. In general, the prevalence of falls is higher in Western countries, where approximately one in three people aged 65 and older have one or more falls per year (Kwan et al. 2011). Conversely, the prevalence of falls reported in Eastern countries, in particular the Chinese population is lower, where approximately one in four older adults has at least one fall per year (Kwan et al. 2011).

Large-scale cross-sectional and longitudinal epidemiological studies in Australia reported that the prevalence of falls (i.e. at least one falls per year) ranged from 18.5% to 36.4% among community-dwelling people aged 60 years or above (Lord & Ward 1994, Lord et al. 1994, Painter et al. 2009). Similar figures of falls prevalence were also reported in other Western countries, for instance, 30% in United States (Centers for Disease Control and Prevention (CDC) 2006), 12.6% to 39% in United Kingdom (Scuffham et al. 2003), 35.9% in Italy (Cesari et al. 2002), 17% in Netherland (Stalenhoef et al. 2002) and 23.3% to 67% in Caribbean region (Perracini & Ramos 2002, Rozenfeld et al. 2003, Coutinho et al. 2008, Gonçalves et al. 2008). The wide range of falls prevalence reported in different studies might be attributed to different recruitment criteria, definition of falls, ascertainment and characteristics of study population (e.g. health status and socioeconomics). Despite limited epidemiological data available in developing countries, higher prevalence of falls were found in developing countries because of the limited resources for developing and integrating falls prevention program in public health policy frameworks (Kalula et al. 2011).

In contrast to the Western countries, the falls prevalence in Eastern countries are generally lower: 21.4% in Korea (Cho et al. 2001), 14% to 30.6% in China (Tinetti et al. 1988, Li et al. 2002, Liu et al. 2004, Yu et al. 2009) and 14.1% to 26% in Hong Kong (Lau et al. 1991, Ho et al. 1996, Chu et al. 2005, Lee et al. 2006, Woo et al. 2009, Yu et al. 2009). Cultural differences in lifestyles and living habits might be one of the reasons for the lower prevalence of falls in Eastern populations (Chan et al. 1997, Chang et al. 2010). However, recent studies found that the risk factors associated with falls were similar in Eastern and Western populations (Deandrea et al. 2010, Kwan et al. 2011). Kwan and colleagues compared the physical functional measures (including physiological profile assessment, functional balance and mobility functions) in Chinese and White community-dwelling older people (Kwan et al. 2013) and found that the physical ability in Chinese group was significantly worse than that in Caucasian group. They suggested that different strategies adopted by Chinese people to cope with the physical balance in daily life might explain the lower fall rate in Chinese population. Chinese people used more conservative approach and better planning on physical activity, who shifted their attention more in falls prevention and increased their concerns on activities with high fall-risk.

1.2.3. Risk factors associated with falls

In the literature, many risk factors associated with falls have been identified (refer to Kwan et al. 2011 for a review). These factors can be categorized as extrinsic or intrinsic. Major extrinsic factors include environmental hazards (e.g. uneven or slippery surfaces, poor lighting) (Cesari et al. 2002), the use of psychoactive medications (e.g. sedative-hypnotics, antidepressants, diuretics), and improper clothing or footwear. Major intrinsic risk factors contributing to falls are advanced age, previous falls history (Berg et al. 1997, Stalenhoef et al. 2002, Pluijm et al. 2006, Stubbs et al. 2014), chronic conditions (e.g. arthritis, stroke, Parkinson's, dementia) (Arfken et al. 1994, Cesari et al. 2002), impaired sensory modalities (e.g. visual, hearing, vestibular and proprioceptive systems), deteriorated balance and gait performance, and psychological factor (Tinetti et al. 1994, Zijlstra et al. 2007). Kwan and colleagues (2011) found that similar risk factors associated with fall incidents were also recognized in Chinese population (more than 130 risk factors) (Kwan et al. 2011). People who are female, older age, with poor general health, with a strong fear of falling, poor gait stability, and eye problems are more predisposed to falls. In this chapter, our discussion focused on elucidating the impact of 3 intrinsic risk factors on falls: fear of falls, visual impairment and balance instability.

Fear of falls plays an important role in falls prevention, accounting for over 50% of falls incidence (Tinetti et al. 1994, Zijlstra et al. 2007). Fear of falls is defined as concern about falling that leads to restriction or avoidance of activity (Tinetti and Powell 1993), which might result in social isolation, depression (Chou & Chi 2005), reduced physical capabilities and decreased quality of life (Lachman et al., 1998). Although fear of falls increases with age, it is not limited to the elderly who are physically inactive and have falls history (Tinetti et al. 1994, McAuley et al. 1997, Zijlstra et al. 2007).

In the aspect of visual factors, it is well documented that older adults with vision loss due to various types of eye diseases (e.g. cataract, age-related macular degeneration, glaucoma) have a higher fear of falls (Ivers et al. 1998). For example, people with declined visual acuity (VA) have greater odds of experiencing falls (Kulmala et al. 2009), while binocular visual field loss in glaucoma patients has been suggested as the leading visual factors for falls and fractures among older community-dwelling populations (Turano et al. 1999, Coleman et al. 2007). In addition, Lord and colleagues found that impaired depth perception, lower contrast sensitivity (CS) and decreased contrast acuity were the most significant visual factors associating with falls or fall-related injuries (Lord & Dayhew 2001). Despite ample evidences showing the strong correlation between poor vision and falls (see Black and Wood (Black & Wood 2005) for review), only a few studies (Turano et al. 1994, Heasley et al. 2005) have measured visual function and evaluated the causes of visual impairment as part of the fall-risk assessment, where the deterioration of visual quality (blurred vision induced by scattered surfaces) and absence of vision lead to decrease in balance stability.

Other than vision loss, impaired balance function is another risk factor for falls in community-dwelling older people (see Deandrea et al. 2010 for a recent review). The age-related decline in sensory elements (e.g. musculoskeletal, visual and vestibular functions), and motor elements (voluntary locomotion by muscular action) explains why older adults lose their balance function. Older adults are relatively less capable of weight shifting or taking a rapid step to avoid falls when their balance is perturbed, further impairing their ability to avoid a fall after an unexpected trip or slip. In the last decades, more studies have emphasized the important relationship between impaired vision and compromised balance function. With deprived visual input, balance control and obstacle avoidance abilities become impeded because of the misinterpretation of spatial information and misjudgement of the distances. Therefore, interventions on improving older adults' vision and balance function are necessary to reduce the incidence of falls.

1.2.4. Conclusion

Falls is one of the most common and serious public health issues for older people, resulting in serious medical and economic consequences. Despite the ethnical and regional differences in the prevalence of falls between Eastern and Western countries, the overall prevalence of falls in older people is high. The reasons for falls are multifactorial, including age-related changes in physical function (e.g. reduced lean body mass, lower extremity weakness, balance disorders) and visual function (e.g. reduced visual acuity (VA), CS and visual field (VF), slower visual information processing (Rayner et al. 2009)), and psychological adverse effect (e.g. fear of falling). To minimize the health care expenditure associated with falls, many fall injury prevention programs have been implemented in the community. A recent review by McClure and colleagues found that population-based fall injury prevention programs were effective to reduce the fall-related injuries by 9 to 33% (McClure et al. 2010). These fall-prevention interventions might be more beneficial for those older people at a higher risk of falls. Hence, identifying the high risk group to receive appropriate interventions is an important strategy to reduce falls and fall-related injuries.

1.3 Dynamic vision

1.3.1. Overview

Static vision refers to the visual ability in the absence of locomotion and movement of visual targets and observers. Dynamic vision refers to the ability to detect and resolve the visual targets in motion relative to the observer, either due to the motion of the target, motion of the observer, or a combination of both. In conventional vision measures, static vision is widely assessed, including static visual acuity (SVA), static contrast sensitivity (SCS) and VF, with little emphasis made on examining an individual's dynamic vision. Although static vision gives an overview about an individual's visual function, it might not fully reflect his/her performance to resolve real-world tasks involving motions. Hence, exploring an individual's dynamic visual function is essential to obtaining a complete understanding of our visual system and its interaction with the world around us.

1.3.2. Importance of dynamic vision in clinical visual assessment

Everyday activities such as participating in sports or driving a motor vehicle involve rapidly moving stimuli. To accomplish these activities, a person requires good coordinated functioning of visual and oculomotor systems to resolve visual stimuli in motion. Throughout the years, dynamic vision has been shown to better correlate with functional activities than static vision measures (Freeman et al. 2006, Patel et al. 2006), in particular those tasks involving locomotion (e.g. driving (Retchin et al. 1988, Scialfa et al. 1988), walking (Demer & Amjadi 1993, Peters & Bloomberg 2005) and sports activity (Falkowitz & Mendel 1977, Trachtman 1973, Rouse et al. 1988).

To examine the dynamic visual function, dynamic visual acuity (DVA) is one of the most common measures. DVA is a measure of acuity factoring in time and motion, where the eye must track and focus on the moving object so that the image is presumably directed onto the fovea. The first experiment on measuring DVA was conducted by Ludvigh (1947) who asked his observers to recognize a moving Snellen letter of different speeds (0 to 120 deg/sec). They found an inverse relationship between DVA and moving speed of the target, where larger letter size (i.e. smaller DVA in decimal unit) was required as the letter's moving speed increased. After this pioneering study, more extensive basic research on DVA was conducted by Henderson and Burg (Henderson & Burg 1974) and Long and Crambert (Long & Crambert 1990). Before reviewing the factors affecting the DVA, we first discuss how DVA predicts the functional performances of 3 everyday tasks– driving, sports and balance.

Driving is a visually- and cognitively-demanding task. Many aspects of visual function and visual processing are involved for the effective control of the motor vehicle. To drive safely and efficiently, the driver needs to detect targets such as road signs, pedestrians, other motor vehicles, and potential hazards of static and dynamic nature, while managing other driving tasks (e.g. maintain safe headway). Individuals with poor dynamic vision showed poor performance in recognizing highway signs (Hulbert et al. 1958, Long & Kearns 1996) and more accident records in driving (Burg 1967, Burg 1968, Henderson & Burg 1974). The significant inverse relationship between DVA and driving performance suggests the importance of the inclusion of DVA measure in driving examination.

Nature of sports activity is dynamic, which demand a player's extraordinary capacity and precision of dynamic vision to track and resolve moving targets. For example, a soccer player must be capable of following the soccer which moves at different speeds. Because of the dynamic nature of many sports, a person with good dynamic vision is found to have better sport performance. For example, Beals and colleagues (Beals et al. 1971) reported significant correlation between DVA and basketball field shooting accuracy. Sanderson and Whiting (Sanderson & Whiting 1974, Sanderson & Whiting 1978) also found a similar relationship between DVA and performance in one-handed tennis-ball catching, where an individual with better catching performance had a higher accuracy in recognizing moving visual stimuli. Other than evaluating the relationship between DVA and sports performance, many studies have compared DVA between athletes and non-athletes to explore whether training with a dynamic task would improve a person's DVA. Rouse et al. (1988) found that the college baseball players performed significantly better on a DVA task than control group of college non-athletes.

To maintain postural control in daily environment, individuals require information from somatosensory, visual and vestibular systems. Extensive studies have investigated the relationship between vision and balance (refer to Black and Woods (Black & Woods 2005) for a review). However, most studies have focused on an individual's static visual functions rather than moving targets (dynamic visual functions), largely ignoring the relationship between dynamic vision and balance. Turano and colleagues showed that balance function in terms of postural sway was strongly associated with the ability to detect the orientation of moving dots (i.e. motion-detection threshold) (Turano et al. 1994). Similar finding was also reported by Freeman et al. (Freeman et al. 2006), where decreased ability to detect small movements was one of the factors contributing to participants with balance problems. However, both studies used motion detection rather than DVA as visual measures. In contrast to DVA, motion detection is a measure of retinal image displacement which examines an individual's ability to detect dynamic changes in motion. The relationship between DVA in resolving moving visual stimuli and balance has not been examined.

1.3.3. Methods for measuring dynamic visual acuity

Unlike SVA where standard clinical protocol is well developed and validated, no standardized protocol and instrument has been developed for measuring DVA. DVA assessments can generally be classified into 3 approaches: 1) stationary observer viewing a moving target; 2) moving observer viewing a stationary target; and 3) moving observer viewing a moving target.

1.3.3.1. Stationary observer viewing a moving target

A number of previous studies have used a mechanical system for measuring dynamic visual function. This method restricts the observer from locomotion (including head movement) who sits in front of the screen and observes a moving target which is projected by a slide projector / slide magazine (Ludvigh 1947, Ludvigh & Miller 1958, Miller 1958, Burg 1966, Nakatsuka et al. 2006, Kohmura et al. 2008, Al-Awar Smither & Kennedy 2010). Motion of the target is mechanically controlled by rotating a mirror which is mounted on a variable speed turntable and moved in the desired plane of movements. Duration of the target presented is controlled by an electronic shutter positioned in front of the projector. Visual targets of different sizes and different orientations (e.g. Landolt C or Illiterate E) are selected into the target slide and projected at different directions (e.g. left to right or vice versa), velocities and durations. This experimental design is one of the commonly used methods for measuring DVA, but this setting encounters three major drawbacks. First, using mechanical control of the rotating mirror imposes some limitation in the moving direction of target, restricting the measurement of DVA along mainly horizontal direction. In the real world, moving objects may come from different directions, so assessing the DVA in only one direction may provide limited information for a person's dynamic vision. Given that only one moving direction is available, a strong learning effect of the oculomotor system may be resulted, which might lead to an over-estimation of the DVA. To minimize the motion learning effect, the moving direction of targets should be randomized (Vaina et al. 1998), where the target randomly moves from right to left or vice versa. Second, the target is presented by a projector system, with poor contrast in a brightly illuminated environment. Hence, this setting requires dim illumination to enhance the observer’s ability to recognize the projected target. Illuminance is an important factor affecting visual acuity. It is unclear whether the dim external illuminance affects the measurement of DVA.

1.3.3.2. Moving observer viewing a stationary target

To better simulate the viewing conditions encountered in daily life during functional performance, for instance, walking and driving, methodology of DVA assessment has been changed from stationary to locomotive observer (head movement or body locomotion) resolving stationary targets. Two streams of protocol have been incorporated to measure the DVA with head motion: passive and active head movements. Passive head movement refers to the head movement triggered by the examiner, while the active head movement involves voluntary movement by the participants. Frequency of head movement of 1.5 to 2.0 Hz is commonly used (e.g. Rine & Braswell 2003, Badke et al. 2004, Dannenbaum et al. 2005) because of two reasons. First, this range of frequency is similar to that for effective bandwidth in recording and natural spectrum of head movement (Grossman et al. 1989, Lee et al. 1996). Second, frequency higher than 2.0 Hz is too demanding for experimental setting (Lee et al. 1996). This type of DVA measure is commonly applied to examine patients with vestibular deficiency who frequently complain of oscillopsia (i.e. perception of the movement of external world moving) and report difficulty in normal locomotion. Herdman and colleagues (1998) examined DVA for a group of patients with vestibular deficiency using DVA assessment task with passive horizontal head movement (Herdman et al. 1998). They found that the computer system could identify 94.5% of the patients with vestibular deficiency and the negative predictive value was 93%.

In addition, this system was effective to demonstrate different DVA for young and old patients with vestibular deficiency, suggesting the interactive effect of age and declined vestibular system on compromised dynamic visual function.

In recent years, some researchers prefer to use active and volitional head movement protocol for better control on the intra-rater variations on frequency of head movement but reduced dizzy feeling to diagnose patients with vestibular deficits (Tian et al. 2001, Schubert et al. 2002, Johnson 2002). In this measure, participants are required to move their head voluntarily to achieve the required frequency which is monitored by the magnetic coil system and rate sensor. Compared with the results for passive head movements, DVA with active volitional head movement demonstrates a better correlation with the functional performance in terms of head movement, such as tracking on moving car and people, or spotting targets in crowds. However, its sensitivity to identify patients with vestibular function is weaker than the DVA measured with passive head movement because the later condition imposes more challenging dynamic environment which further dampens the vestibulo-ocular reflex for stabilizing the image onto the retina during head movements (Vital et al. 2010).

Another spectrum of studies demonstrated how body motion in walking (i.e. vertical and lateral translations) affects an individual's ability to resolve targets. The ability to stabilize vision while walking requires the coordination of three systems - eye-head, head-trunk and lower limbs. Grossman and colleagues (1989) recruited 9 participants and compared their acuity for resolving stationary objects during standing, walking and running (Grossman et al. 1989). They found a small (< 0.1 logMAR) but statistically significant reduction in acuity during walking or running compared with standing. However, Peters and colleagues (2005) found that the declined VA with locomotion (walking or standing on an electronic treadmill) was only found in viewing near targets (40 cm), but not for distance targets (4 m) (Peters et al. 2005). They argued that the increase in the angular movement when viewing near targets was more than that in viewing distant targets, leading to a greater reduction in the ability to recognize near objects. Given that only young normally-sighted adults were recruited in these studies, it is unclear how this complicated stabilization process affects in people with poor vision due to age-related decline in visual functions or eye diseases.

Measuring static acuity with locomotion has been widely applied in vestibular (Hillman et al. 1999, Roberts et al. 2006) and spaceflight research investigations (Bloomberg & Mulavara 2003). In Hillman et al.'s study (1999), participants were asked to walk on an electronic treadmill (simulating realistic vertical volitional head movements) while reading aloud the numbers randomly presented on the screen. They found that participants with bilateral vestibular disorder exhibited significantly poor scores across all font sizes during walking. Roberts et al. (2006) compared the VA in participants with normal vestibular function and participants with impaired vestibular function (unilateral or bilateral) under 3 measuring conditions: 1) no movement; 2) walked on a treadmill; and 3) volitionally moved their head in the vertical plane but in seated position. Similar to Hillman's study, participants with impaired vestibular function performed significantly worse under dynamic conditions (i.e. walked on treadmill or moved their head) than those with normal vestibular function. Although no significant difference in acuity was found between the treadmill and head movement tasks, measuring acuity with locomotion assessed the overall ability of the gaze stabilization system to maintain gaze fixation in common everyday task- walking.

To evaluate the effects of space flight on head and gaze stability during locomotion, acuity assessment was conducted for 14 astronaut participants who were either seated (static condition – SVA) or during walking (dynamic condition – DVA) on a motorized treadmill before and after the space mission (followed up at regular intervals) (Clément & Reschke 2010). Their results showed decrement in DVA after their space mission, which might be due to the degree of oscillopsia experienced during post-flight locomotion (Bloomberg & Mulavara 2003). Although this compromised DVA showed consistent improvement during the post-flight recovery period, it remained significantly worse than their baseline measure (i.e. before their mission) 6 months after their mission, revealing that the compromised vestibular system might need longer duration to recover.

1.3.3.3. Moving observer viewing a moving target

In daily life, we always need to resolve moving obstacles or hazards when we walk or run. If we fail to identify these moving objects (e.g. a small animal moving across) and respond, we might be hit or tripped over by the obstacles and get hurt. To examine an individual's "kinetic" nature of visual system, measuring the DVA using moving objects of different sizes during head movement (either passive or active) or locomotion (e.g. standing, stepping or running) is needed. Surprisingly, no studies in the current literature have explored how our visual system responds to moving objects while we are in locomotion. It is possible that the dynamic vision measured under this natural and realistic environment (e.g. resolve moving stimuli during walking) may better reflect the observers' functional performance in daily life.

1.3.4. Factors affecting dynamic vision

Among the above-mentioned methods in DVA assessment, only the factors influencing the ability to recognize the moving stimuli will be discussed in this chapter. Similar to traditional SVA, DVA is affected by many factors broadly classified into 3 components: 1) external (e.g. stimuli variables, luminance); 2) methodological factors; and 3) human factors.

1.3.4.1. External factors

Presenting moving stimuli (via mechanical devices or computer systems) to stationary observers is a common way to assess DVA. A number of external factors such as the angular velocity of the moving stimuli, presentation duration, luminance and contrast have been confirmed to affect DVA. In general, the DVA decreases as a function of the target's angular velocity with respect to the observer (Long & Crambert 1990). In earlier studies, Ludvigh and Miller examined the relationship between angular velocity of target and DVA (Ludvigh 1947, Ludvigh & Miller 1953, Ludvigh & Miller 1958). They found that DVA was not affected at low velocities, but declined rapidly at higher velocities. This deterioration in DVA was found for horizontally-moving (Ludvigh & Miller 1953, Ludvigh & Miller 1958), vertically-moving (Miller & Ludvigh 1957, Miller 1958, Demer & Amjadi 1993), and circularly-moving targets (Ludvigh 1949, Miller 1958). Later, Burg summarized a series of research findings and concluded that DVA deteriorated markedly as the velocity of the target increased from 10 to 170 deg/sec (Burg 1966). Reading (1972) argued that human eye could resolve a target moving up to 60 deg/sec for momentary target exposure (Reading 1972). The imperfect image stabilization by pursuit had been proposed to be the main reason for the poor DVA at high velocities. This hypothesis was later supported by research findings by Brown (1972a and 1972b) and Methling and Wenicke (1968), where DVA during pursuit depended solely on retinal stabilization and was only limited by the accuracy of the eye movement.

DVA decreases with decreased exposure duration (Miller 1958, Mackworth et al. 1964). Although higher DVA achieves with longer exposure duration, it reaches an asymptote at approximately 1000 ms. Normal latency of saccades in human eye is approximately 200 to 250 ms. If the exposure duration of the moving target is longer than this saccadic latency, human eye can make an initial saccade followed by one or more smooth pursuit movements to maintain the moving target onto the fovea by matching eye movement velocity with target velocity (Ludvigh 1949, Miller 1958).

Similar to the effect of exposure duration, DVA improves with increasing luminance until it reaches the asymptote (Ludvigh 1949, Miller 1958). Depending on different angular velocities, the optimal luminance varies, but the required luminance for resolving a moving object is well above the luminance for resolving static object (Long & Crambert 1990). Approximately 10 to 20 times stronger luminance is required for achieving maximal DVA compared with SVA (Long & Crambert, 1990). In addition to luminance, increasing the target's contrast is another factor to improve DVA (Mayyasi et al. 1971, Brown 1972a, Long & Garvey 1988). Brown compared the DVA achieved in 4 levels of target / background contrast. In addition to significant contrast effects in DVA, the interaction effect on DVA by contrast levels and angular velocity was significant, where participants could only resolve large low-contrast targets, in particular when they moved very fast (Brown 1972a and 1972b). Reason for poor DVA in low contrast target was due to longer eye movement latencies to recognize targets (Brown 1972b).

1.3.4.2. Methodological factors

Applying different methodologies (e.g. different selection and manipulation of the moving stimuli, control of the head movements) provide different results of DVA. Because of the high test-retest reliability of Landolt C targets (Ludvigh 1949, Miller 1958), discriminating the orientation of target is commonly used in DVA measure. However, Methling and Wernicke (1968) argued that better DVA could be achieved if the direction of the target motion was the same as the gap orientation of the targets (e.g. vertical target motion favored the visibility of targets with vertically oriented gaps) (Methling & Wernicke 1968). To address this limitation, the gap of the target orientated in four oblique meridians were proposed (Brown 1972b) and used in later studies (Long & Garvey 1988, Long & Riggs 1991).

Other than the visual stimuli, observer's head position (e.g. making free head movement or maintaining fixed head position) also affects the results of DVA. In fixed head position, visual field subtended by the observer is approximately 90 to 100 degrees (Burg & Hulbert 1961). Previous studies have shown that DVA is better (i.e. smaller moving object) under the free-head condition (Weissman & Freeburne 1965, Long & Riggs 1991, Long & Rourke 1989). The benefit of free-head movement is more pronounced for targets of faster velocities and longer exposure duration (Weissman & Freeburne 1965). Although it is possible that the free head movement may alter the actual angular velocity of the target upon the retina, many studies continue using this approach because of its naturalistic nature of measure and potential real-world applications.

1.3.4.3. Human factors

A number of human factors have been shown to affect dynamic visual function. In this review, we will focus on four major factors: age, gender, vision and personal experiences in viewing moving objects.

1.3.4.3.1. Age

With an increase in age, the body function might deteriorate and lead to decrease in stability in body coordination and visual performance. Burg and Hulbert recruited 236 participants aged from 16 to 67 years to recognize a target moving across a screen. However, no significant age effect was identified, which was due to the bias sampling: 79% participants were within 16 to 25 years (Burg & Hulbert 1961). The skewed distribution of participants across the age range masked the impact of age on DVA. Later, he conducted another study of 17,500 California drivers (aged from 16 to 92 years) and found that DVA declined as a function of age (Burg 1966). This age-related decline was more pronounced in participants beyond age of 44 years resolving objects of higher velocities (more than 60 deg/sec). Unlike static acuity, age-related deterioration of dynamic vision started earlier when participants remained in middle-age group. Reading (1972) found that DVA in the middle-age group (median age of 44 years) were significantly worse than the young-age group (median age = 26 years) (Reading 1972). Reduced dynamic visual performance as a function of age was also found in other studies (Scialfa et al. 1988, Long & Crambert 1990, Rine & Braswell 2003). Despite the statistically significant finding, the age-related decline in dynamic acuity was not clinically significant (e.g. only 0.02 logMAR difference). Compared with SVA, DVA declined more rapidly with an increase in age.

Many studies have explored the possible reasons for the age-related deterioration in DVA. First, impairment in the oculomotor function in aging population may partly contribute to the decreased ability to track and resolve moving objects. Sharpe and Sylvester (1978) found that older adults delayed in initiating eye movements when they were asked to follow a moving target (i.e. increase in saccadic latency). Second, reduced retinal illumination due to optical degradation (e.g. smaller pupil size or aging crystalline lens) rapidly decreased retinal contrast (Long & Crambert 1990). Hence, visual performance in older adults was further impaired due to reduced retinal illumination and age-related high-order ocular aberration (Long & Crambert 1990). Recent studies in the last decades examined the development of dynamic visual function in children. Similar to other visual functions (e.g. static acuity, depth perception or stereoacuity), an improvement in dynamic visual function was observed for children aged from 5 to 15 years (Ishigaki & Miyao 1994). However, the DVA started to deteriorate since 15 years onwards, which was comparable to the study conducted by Burg (Burg 1966) (N.B. different units were applied in two studies: Burg applied the minimum angular subtend (in minute of arc) while Ishigaki and Miyao used just detectable velocity).

1.3.4.3.2. Gender

Interestingly, males are found to have slightly better DVA than females (Burg 1966, Burg & Hulbert, 1961, Long & May, 1992). Although the reason for the superiority in DVA in male is unclear, the rate of age-related decline in the rate of deterioration might be affected by physical capacity in gender difference (difference in physical and hormonal effect in males and females).

1.3.4.3.3. Clinical vision

SVA is a common clinical measure to reflect a person's visual function and a criterion to define a person with or without visual impairment (refer to WHO guidelines). Ludvigh and Miller (1954, 1958) formulated the relationship between SVA and DVA as "Y=a + bX3" (where "Y" = SVA, "X" = angular velocity, "a" and "b" = coefficients for static and dynamic VA respectively). They argued that the deteriorated DVA was caused by imperfect match between the velocities of eye movement and moving target, and this deterioration could be predicted by SVA. However, Miller conducted another similar experiment and found only a weak relationship between these 2 measures, where DVA for the participants with the same SVA was very different. Reasons for such a weak correlation between SVA and DVA might be explained by the large individual differences in DVA compared with the more homogeneous variations in SVA and the differences in visual signal processing channels for resolving static and dynamic targets (Miller 1958). To improve the relationship between SVA and DVA, lower angular velocity, increased exposure durations and free head movement can be implemented to assess DVA.

Recently, DVA has been applied as one of the outcome measures to evaluate the effectiveness of cataract surgery in visual function (Ao et al. 2014). Similar to SVA, DVA was intensively affected by cataracts and this visual disturbance was more dramatic in the fast moving targets. To further examine the effect of velocity on DVA, difference in DVA between consecutive speed levels was computed. Stronger decrease in velocity-dependent DVA was found in the cataract group. After the bilateral cataract removal, DVA significantly improved and the decreases in velocity-dependent DVA was gentler than that measured before the cataract operation. Interestingly, the improvement in DVA at all velocities was more pronounced than improvement in SVA. Because of the lack of functional measures in this study, it is unclear whether the improvement in DVA could better correlate with functional tasks than the improvement in SVA.

1.3.4.3.4. Practice/ Training

A number of studies have investigated the practice effect on DVA (Long & Riggs 1991, Long & Roarke 1989). In Miller and Ludvigh, substantial practice effect was found at targets moving at high target velocity (110 deg/sec): the first 20 trials showed the most significant training effect (Miller & Ludvigh 1957). In contrast, only weak training effect was observed at low target velocity (20 deg/sec). In addition, they found that the extent of improvement in participants with better baseline performance was smaller (i.e. ceiling effect). However, their findings were partly challenged by Long and Riggs (Long & Riggs 1991) who modified the experimental set-up by projecting the Landolt ring targets with a rotating table. Their findings agreed with Miller's study where practice effect was most significant at faster velocities, but greater improvement was found in participants with lower baseline DVA. To control the practice effect in measuring DVA, it is important to implement an initial trial protocol to improve the participant's familiarization or increase the number of trial runs to reduce the within-observer's variance.

1.3.4.4. Other measures of dynamic vision

Despite the historical and wide application of DVA in evaluating an individual's dynamic vision, other vision measures have been developed and applied to improve the understanding of our visual system in resolving moving objects.

1.3.4.4.1. Dynamic contrast sensitivity

Static visual acuity (SVA) is a standard clinical measure of the recognition of small (i.e. high spatial frequency) and high contrast target (e.g. letters or symbols). However, our "real world" is composed of objects of varying sizes and contrasts, so SVA may not fully reflect visual performance for everyday visual tasks (e.g. reading, driving and balance). CS measures allow a more complete investigation of visual function, in particular for patients complaining subtle changes in vision and functional performances. Owsley (2003) reviewed the importance of CS in clinical assessment, and its predictive ability on functional performances (e.g. reading, mobility, balance, driving) (Owsley et al. 2003). In addition to DVA, more studies have attempted to determine the effects of moving target on CS. Long and Homolka examined the contrast sensitivity function (CSF) of college students using grating targets of 3 spatial frequencies (1, 3, and 10 cycles per degree) and presenting at 4 velocities (0, 30, 60 and 90 deg/sec) (Long & Homolka 1992). They found most pronounced effects of target movement at the mid to high spatial frequencies in which the sensitivity was markedly reduced as the velocity increased. Similar to SVA, increased exposure duration (from 200 to 600 ms) decreased the adverse effect of motion on CS, but the velocity-induced reduction in CS remained significant at high spatial frequency. Recently, Long and Zavod measured dynamic contrast sensitivity (DCS) with letters of varying contrast presented at 5 target velocities (0 - 120 deg/sec) (Long & Zavod 2002). Their results showed marked decrease in CS as velocity increased. However, the magnitude decline in CS with increasing target velocity was more profound in small target than large target, demonstrating that DCS was more sensitive to target motion than the DVA of high-contrast stimuli (Long & Zavod 2002).

1.3.4.4.2. Motion contrast

In late 1990s, Wist and colleagues developed a computer program based on "form-from-motion concept" to examine a person's ability to differentiate between simple geometric forms defined by briefly presented motion gradients in a high-density static random-dot array (Wist et al. 1998, Schrauf et al.1999). In the display, “completely camouflaged Landolt rings only became visible when dots within the target area were moved briefly while those of the background remained stationary” (Wist et al. 1998). Motion contrast was manipulated by varying the percentage of moving dots within the ring (20 – 100%). Among the 1006 healthy participants aged from 20 to 85 years, a gradual decline of dynamic vision with age was found for all motion-contrast levels, reflecting that the amount of motion contrast required to discriminate the motion-defined stimuli increased with age (Wist et al. 2000). A possible explanation for the age-related decline in dynamic vision might be due to age-related decrease in sensitivity and response time in parvocellular and magnocellular pathways – two factors had been suggested for the age-related decline in other visual functions including static and dynamic vision (Giaschi & Regan 1997, Wist et al. 1998, Schrauf et al. 1999, Wist et al. 2000).

1.3.5. Conclusion

Ample evidence has supported the application of dynamic vision assessment in clinical practice for a more comprehensive evaluation of visual functions. To encounter the dynamic nature in our real world, a person with good dynamic vision is important, in particular older adults who are more prone to hazards and risks of falls. Several methods of assessing dynamic vision have been discussed. However, each method has its own advantages and limitations. To minimize the confounding factors potentially affecting the reliability of the dynamic vision assessment, special considerations must be taken. For example, a pilot test should be implemented for the participants to become familiar with the measure; otherwise, a strong practice effect might be obtained, increasing the within-participant’s variance. In addition, examining the relationship between dynamic visual functions and functional performances in common daily tasks (e.g. balance function) is essential. For example, establishing the relationship between dynamic vision and balance function allows the clinician to identify patients, in particular older adults, who might have compromised balance function if they have declined dynamic vision. Because of the strong association between balance and falls, identifying and referring these people who are high-risk fallers to fall-prevention programs is important.

1.4 Vision and balance

1.4.1. Overview

To maintain postural stability, inputs from 3 main sensory systems - visual, somatosensory and vestibular are required. Interruption to any of these sensory systems results in compromised postural stability and balance coordination, which can ultimately lead to falls. It is well documented that vision plays an important role in postural control. Diminish in visual information leads to a decrease in the amount of processing information for correct, confident and rapid locomotion.

1.4.2. Visual factors affecting balance

Numerous studies have examined the risk factors for falls. The major reasons for falls are multi-factorial (Chu et al. 2005, Chu et al. 2007), including age-related changes in physical function (e.g. reduced body mass and lower extremity weakness), diminished visual function in VA and CS (Klein et al. 1998), and environmental hazards (e.g. stumbling walking surfaces and dim walking environment). The role of vision has been widely studied in the literature. Most studies compare balance performance between eyes open and eyes close. In Schmid et al. (2007), they compared balance performance in normal vision people (under eyes open and eyes close) with that of long term visually-impaired people (which were considered as partially eye open condition). It was not surprised that the balance performance in long term visually-impaired people was worse than that in normal vision people because of two theories (Giagazoglou et al. 2009). The “general loss theory” states that the loss of visual input in helping balance cannot be fully compensated for by other afferent systems in postural control, while compensatory theory states that the supplementary effect from other afferent systems may not overcome the negative effect on postural control in the absence of vision. The emphasis on the effect of visual impairment on balance-related functional performance has been widely studied (Lee & Scudds 2003, Kulmala et al. 2009) in which better vision could lead to better postural stability. It should be noted that vision contributes to the balance stability with other sensory systems, for instance, hip stability (Woodhull-McNeal 1992, Ray et al. 2008) and upper limb reaction during stepping (Maki & McIlroy 2006).

1.4.3. Impact of progressive addition lens (PALs) wearing on balance

Presbyopia is commonly seen in people aged 40 years or above due to the decrease in accommodative ability. The decrease in accommodative ability leads to difficulty in focusing on near targets. Progressive addition lenses (PALs) are commonly used as spectacle lenses to compensate for the decline in accommodation for obtaining clear vision at different viewing distances (Charman 2014). The acceptance and satisfaction rates for PALs have been grown extensively in the past decades, in particular when more modern designs of PALs provide much easier adaptation.

1.4.3.1. Optical concerns in the PALs

Despite the convenience advantages provided by the PALs, the optical imperfections inherent in the design of these lenses become a major disadvantage. The unwanted but unavoidable aberrations in the peripheral zones of the lenses produce sensations of distortion, or apparent motion of the visual field (“swim”) when wearers move their heads. To minimize the effect of this unwanted astigmatic gradient for easier visual adaptation, modern PALs use a “softer” design, in which the unwanted astigmatic contours spread over larger areas of the front surface of the lens (Solaz et al. 2008). This design provides a wider and longer intermediate zone for mild and gradual change in power from distance to near vision. Despite substantial advancements in the PALs' design, some unwanted visual limitations such as peripheral spatial distortion in the inferior field still hinder wearers' visual perception and the corresponding functional performances in managing daily tasks, predisposing the wearers to potential hazards.

1.4.3.2. Compromised visual function in PALs in relation to balance

Studies have shown that visual function in the PAL is impaired compared with single-vision lens (SVL), including depth perception, stereoacuity (Buckley et al. 2010), contrast sensitivity (Lord et al. 2002), clearance of lower visual field (Marigold & Patla 2008, Rhea & Rietdyk 2007). Because of the diminished visual performance with PAL, the corresponding functional performances such as postural control might also be affected.

1.4.3.2.1. Inferior visual field

The distorted regions on the peripheral part of lens impose optical illusions when wearer processes the visual information collected from those regions. Studies have found a significant difference in the walking pattern and head adjustment due to the obstruction of lower VF in the PAL (Rhea & Rietdyk 2007, Marigold & Patla 2008). However, the difference in the walking pattern and head adjustment could be affected by age and viewing habit. Younger wearers could adapt to the visual distortions in the PAL better than the older wearers (Brayton-Chung et al. 2013). Age also interacted with the viewing habit of wearer in PALs wearing, where the eye or head adjustment was dominant in wearing various designs of PAL (Hutchings et al. 2007). Despite the standardization in the obstacles height in research design, various designs of PAL and how wearers changed their viewing habit make it difficult to show the actual effect of distorted lens region on visual balance performance.

Nevertheless, the importance of the visual information in spectacles wearing has been proven, where the obstruction and disturbance of lower VF increase the potential risk of balance instability, especially when there is a change in walking level (Timmis et al. 2010, Ellison 2012, Beschorner et al. 2013). Another study showed that blocking the lower VF could lead to a decrease in walking speed and step length (i.e. adopt a more conservative strategy) during locomotion (Marigold & Patla 2008). Wearers with blocked lower VF increased the head pitch angle (by 8 to 11 degrees) to view the foreseeing obstacles or ground terrain. The adjustment of the head pitch angle altered the body coordination responding to external environment, resulting in a change in the gait pattern (Rhea & Rietdyk 2007).

Although the lower VF was not blocked but disrupted in the PAL, the interference of lower VF in PAL wearing may induce potential balance instability. Because of the lack of standardization to assess the effect of distorted lens region on lower VF region in PAL, it was difficult to confirm the negative effect on balance performance with PAL wearing. Further study examining the correlation between visual information and gait pattern in PAL and SVL wearing is needed.

1.4.3.2.2. Contrast sensitivity and depth perception

To detect the obstacle and ground terrain, a person with good CS and depth perception is imperative. However, this vital visual ability substantially deteriorates when viewing through the lower lens region of the PALs (Lord et al. 2002). During descending the stairs or changing in walking level, PAL wearers might lower their eyes and view through the lower parts of PALs accidentally or involuntarily. Because of the visual disturbances and perhaps the inappropriate use of PALs, the fall-risk with PAL wearing is increased by 2.3 times compared with SVL wearing (Lord et al. 2002).

Because of the compromised depth perception, the PAL wearers increased their toe clearance when they crossed over an obstacle, compared with SVL wearers (Menant et al. 2010). The more variable and increased toe clearance above the obstacle edge might lead to more postural instability (Johnson et al. 2007). This implies that PAL wearing does not only affect the balance function, but also interferes with the walking pattern.

Buckley and colleagues (2010) reported that individuals with deficiency of stereoacuity (by occluding one eye) over-estimated their lower limb position with significant increase in toe clearance during obstacle crossing. As a result, their risk of falls might be significantly increased, especially when they had to negotiate obstacles during walking (Buckley et al. 2010). Buckley’s findings suggested that PAL wearers with compromised stereoacuity might also experience similar changes in their gait pattern. Hence, more conservative gait pattern should be recommended, especially when they are new wearers.

In the literature, the majority of previous studies examined the association between functional performances and risk of fall in experienced-PALs and non-PALs wearers (Lord et al. 2002). Very few studies examined how balance and gait functions change in naïve PALs wearers when they first experienced PALs-induced visual disturbances. Recently, Beschorner et al. (2013) revealed that the first-time PAL wearers made significant changes in their gait patterns during stepping by increasing their foot clearance over step edges and slowing their stepping time. This suggested that the new PAL wearers adopted a more conservative adaption during stepping. In contrast, these gait changes during stepping were not found in experienced PAL wearers (Johnson et al. 2007; Johnson et al. 2008; Timmis et al. 2010). However, Beschorner’s study did not examine the adjustment on head movement during walking or stepping, which might change when wearers used different parts of the PAL lenses for object viewing at different distances.

1.4.4. Conclusion

Compared with SVL, PAL wearing affects some visual functions and postural stability in overcoming obstacles (Johnson et al. 2007, Johnson et al. 2008). The deterioration in visual and balance performance is even stronger when wearers have to manage secondary tasks (Menant et al. 2009). The presence of secondary tasks stimulates the condition of attention shifting during locomotion, which is a common condition that happens in daily lives. However, it should be noted that the effect of PAL wearing on balance performance depends on the experience of lens wearing, nature of targets being viewed and the complexity of the walking pathway. For people with high falling risk, they should be recommended to wear SVL instead of PAL (Haran et al. 2009, Ellison 2012). More study examining the impact of PAL on balance and gait performance (including head adjustment) is needed when the PAL is firstly prescribed.

1.5 Can training improve a person's visual function and other functional performances in older population?

Age-related decline in visual function affects not only one's capability to recognize and integrate visual information (e.g. tracking down an object of interest) in the dynamic environment, but also one's functional performances on some activities for daily living (Freeman et al. 2006). A logical thought would be "Is there any training that can improve dynamic visual function?". A number of visual training methods for improving dynamic visual acuity and eye movement, which in turn enhance sports performance, have been researched. Some preliminary evidence shows that dynamic acuity can be improved through perceptual training (Long and Riggs 1991, Long and Rourke 1992, Herdman et al. 2003). However, the causal relationship between enhanced dynamic vision and performance in sport activity is inconclusive.

In the recent decade, a number of research studies have investigated the effect of action video game training on visual performance. Green and Bavelier (2003 & 2007) defined that action video game involved simultaneously occurring events at different locations on the screen, which required players' attention for multiple tasks. Hence, the participants were challenged in the aspects of eye-hand coordination and reaction times. Their results showed that training non-video game players for 10 hours on an action game significantly improved their visual attentional capacity. Li and colleagues (2009) reported that intensive practice on action video games significantly improves contrast sensitivity. Although it is unclear whether the enhanced visual function can be transferred to improved performance in daily activities and whether similar training effect applies to the elderly population, there is a growing body of evidence that suggests playing video games actually can improve older people's reflexes, processing speed, attention skills and spatial abilities (Clark et al. 1987, Drew and Waters 1986, Goldstein et al. 1997).

1.5.1. What is action video game?

Action video game is defined as the game genre which requires the participants to experience visual challenges on eye-hand coordination and reaction times simultaneously. The main action video game genre includes shooting, fighting and sports, either first-person or role-playing game. In the current action video game industry, there are three main action video game platforms: Nintendo Wii (Nintendo (Hong Kong) Ltd 2014), Microsoft Xbox (Microsoft 2014) and PlayStation (Sony Computer Entertainment Asia 2014).

Nintendo Wii is the most popular video game consoles, which is considered as easy-to-play and easy-to-handle. The games in Nintendo Wii can incorporate single or multiple players in the games (a maximum of 4 people). It has a maximum of 4 hand-held controllers which are connected to the Wii game with the calibration process in three-dimensional orientation. Thus the hand movement controls the character’s movement on the scene. The Wii console also connects to Wii Fit balance board (Wii Fit Plus), which requires the players to stand on board (the design principle is actually similar to a force platform), which can detect the body motion such as moving forward, backward and sideways by shifting the centre of pressure on board. The large variety of game choices are suitable to players from children to the elderly, provided that the players are physically capable to play. Game choices include shooting, racing, sport activities and body coordination, while the last two types of games require the cooperation of balance board for the simulation of body motion in real-life.

Throughout the years, three versions of Microsoft Xbox: Xbox, Xbox 360 and Xbox One have been developed. These three consoles are compatible to a wide variety of video games, including first-person shooting, third-person shooting, fighting, car racing, simulator and sports. These games require the players using a hand-held controller (with wire) to control the character’s movement on the scene. In recent years, the application of Kinect allows the player to synchronize with the character on the scene as the first-role player in the game. Through identifying and recognizing the player’s, the movement of players’ upper and lower limb can be detected without touching the screen or game controller. Because of this special function, the game choices of Xbox with Kinect include more body motion such as dancing, eye-hand coordination and fitness programs. Because of the higher demand of physical movement and excitement level in the Xbox games when compared with the ones in Nintendo Wii, the recommended age ranges of players in Xbox is “young adults to the older population”, rather than older population.

Sony PlayStation video game was the first generation of video game and it is in its eight generation. Similar to Microsoft Xbox and Nintendo Wii, the game choice of PlayStation includes racing, sport activities and shooting. Incorporating the PlayStation Eye and

PlayStation camera, the character in the scene can be controlled by the player’s body motion. The “user-face” detection mode allows the players to use their actual faces as the characters in the game, which remarkably increases the enjoyment and satisfaction in the games (Rand et al. 2004, Rand et al. 2008). Because of the game choice and hardware configuration, PlayStation focuses on the coordination and utilization of the whole body with limb movement. However, the game control mostly relies on pressing buttons on the hand-held controller rather than body motion and also there are limited choices of games suitable for older players, so it is less commonly adopted for training or rehabilitation purposes.

1.5.2. Nintendo Wii in rehabilitation

In recent years, a popular commercial action video game “Nintendo Wii” has been introduced for functional training and rehabilitation purposes. The low cost and user-friendly interface for the wide age range in Nintendo Wii attracts many rehabilitative clinicians and researchers applying this action video game in rehabilitation or training programs (Shih et al. 2010, Hsu et al. 2011). In addition to commercially available games, some researchers modify some Nintendo Wii games to suit their target populations to accomplish specific training goals (e.g. Lange et al. 2010, Billis et al. 2010, Shih et al. 2010).

Growing evidence has shown the effectiveness of Nintendo Wii games on improving older adults’ balance stability and gait performance. Examples of benefited populations include general community-dwelling elderly (e.g. Fitzgerald et al. 2008, Bateni 2012), elderly with higher falls risk (e.g. Clark and Kraemer 2009, Bainbridge et al. 2011) or neurological diseases (e.g. Lange et al. 2010, Pompeu et al. 2012). This improvement has been demonstrated using conventional balance and gait assessments, such as gait speed, gait stability, and endurance tests. Interestingly, the training effect on balance and gait functions can also transfer to advance participants' performances in managing other functional tasks in daily life (e.g. spooning, washing and phoning, Hsu et al. 2011). Other than training, Nintendo Wii Fit Plus has been widely applied in the balance assessment such as body sway measurement under eye-open and eye-close condition (Kalisch et al. 2011). The validity and reliability of the balance board to measure static balance has been confirmed (Clark et al. 2010, Shih et al. 2010, Young et al. 2011).

1.5.3. Conclusion

With the remarkable advancement in gaming industry, action video games are getting more popular across all ages. In addition to entertainment and enjoyment, action video game has been introduced for functional training and rehabilitation purposes. Recent research studies have demonstrated the effectiveness of action video game training in improving older adults' balance stability and gait performance. Our next question is whether Nintendo Wii – an easy-to-use, entertaining and affordable action video game, can effectively train older adults' on dynamic visual function – which might also decline due to aging?

1.6 Summary

Due to age-related deterioration in physical, sensory and cognitive functions, older adults' performance in instrumental tasks of daily activities gradually worsens with age, balance-control being one of the significantly impaired areas. Such deterioration can affect static and dynamic-postural control, which may ultimately lead to falls. To maintain balance, good coordination of input from multiple sensory systems including vestibular, somatosensory and visual systems is essential. Unfortunately, the age-related declines in these three sensory systems substantially impede the input and integration of the sensory information, contributing to poor balance and falls in older adults.

To minimize the incidence of falls or fall-related injuries, many fall prevention programs have been provided, which are designed to address the factors associated with falls (e.g. cataract surgery to improve visual function, muscle training to improve balance function). Given that vision plays a significant role in postural control, a person with improved vision after cataract surgery or appropriate spectacle corrections has better postural control (i.e. better balance function). Standard clinical visual assessments mainly consider the importance of static vision, largely ignoring the potential advantages of dynamic vision, which might better predict functional performances. Dynamic vision refers to the ability to detect and resolve visual targets in motion relative to the observer, either due to the motion of the target, motion of the observer, or a combination of both. Previous studies have shown some correlation between dynamic vision and functional performance. However, the relationship between vision and balance performance, in both static and dynamic aspects remains unclear. Better understanding of this relationship provides more evidence to reflect the effects of different interventions to improve older adults' vision and balance functions.

Chapter 2

Fall-Risk Assessment in Community-Dwelling Older People Using Vision and Balance Screening Tools

Chapter 2

Fall-Risk Assessment in Community-Dwelling Older People Using Vision and Balance Screening Tools

Objectives:

- To investigate the visual, physical, balance and fall-risk profiles in Hong Kong community-dwelling older population
- To establish the relationship between vision (static vision) and physical and balance functions

Hypotheses:

- Significant aging affected visual and balance performance, where performance deteriorated with increasing age
- A significant but weak correlation was expected among vision and physical and balance functions

2.1 Abstract

Introduction: Vision contributes mostly to the sensory information from external world in terms of visual sharpness, depth and spatial perception. Thus any deterioration in vision may lead to a decrease in functional performance (e.g. balance instability and higher risk for falls). Few studies measure individuals' visual function in fall-risk assessment. In this study, we examined the visual, balance and fall risk profiles in community-dwelling Chinese older adults in Hong Kong.

Methods: 435 Chinese adults aged 60 years or above were recruited from seven community centres using convenience sampling. Visual function was assessed by visual acuity (VA), contrast sensitivity (CS), visual field (VF) and ocular health. Balance function was assessed with fall risk assessment tool – Physiological Profile Assessment (PPA), where proprioception, quadriceps muscle strength in lower limb, hand reaction time and postural sway (eye close and open condition; standing on firm and foam surfaces) were measured. Fall-risk index was computed for individual participants. Participants were followed-up for 1 year for the incidence of falls.

Results: Visual function was relatively good in this sampled population with an average distant visual acuity in the better eye of 0.31 ± 0.21 logMAR. Only 16.5% participants' distant VA was 0.5 logMAR or worse, classifying as "visually impaired". Cataract remained the most common ocular problem (16.1% of all participants had significant cataract (Grade III to IV in the LOCIII system)). Quadriceps strength (30.9 ± 13.2 kg) and lower limb proprioception (1.8 ± 1.2 degrees) scores were comparable to those scores reported for Caucasian populations. However, CS (1.9 ± 0.4 log-unit), simple reaction time (372.5 ± 194.9 ms) and postural sway scores (1288.9 ± 1299 mm^2) were only classified as "fair to poor". Because of the relatively poor physical performances, the computed fall-risk score was 1.9 ± 1.6, which was classified as "moderate" fall risk.

However, the prospective incidence of one plus falls in the 6-month and 1-year follow-up period was only 9.6% and 17% respectively. Our results showed significant but weak relationships between vision and quadriceps, hand reaction time and postural sway balance ($p<0.01$), suggesting people with poorer vision loss had weaker quadriceps muscle strength, slower hand reaction time and poorer postural sway balance.

Conclusions: Although vision was significantly (but weakly) correlated with physical and balance measures, our study confirmed the importance of including vision and ocular health assessment in the fall-risk assessments.

2.2 Introduction

A fall is an event which “results in a person coming to rest inadvertently on the ground or floor or other lower level”, excluding those events such as fallings from animals, burning buildings, transport vehicles or into fire and water (World Health Organization 2010). Recent population-based cohort studies reported that one out of five Hong Kong seniors aged 65 years and above suffers from a fall at least once a year and that this proportion increased significantly with age (Chu et al. 2005; 2007). Based on the statistics from Hospital Authority, the total number of in-patient discharges and deaths associated with falls in the year 2010 to 2011 was 36,011, which was about 2.5% of the total in-patient number (The Hong Kong Hospital Authority 2011). These falls required health service utilization such as clinic visits and hospitalization. To minimize the health care expenditure associated with falls, recognizing individuals with higher risk of falls and referring them for suitable fall-injury prevention programs is essential.

Clinically, potential high-risk fallers can be recognized through different physical assessments which can be divided into objective and subjective aspects. Objective tests include gait, balance and muscular strength tests (Raîche et al. 2000, DePasquale and Toscano 2009, Verghese et al. 2009), while the subjective tests include self-report and awareness of fallings (Shorr et al. 2008, Wagner et al. 2008). In addition to physical assessment, a person’s visual function should also be considered because reduced visual function (e.g. reduced VA, CS and VF (Klein et al. 1998)) has been confirmed as one of the risk factors for falls. Despite solid evidence showing the strong correlation between poor vision and falls (see Black and Wood (2005) for review), only a few studies have measured visual function and ocular health as part of the falls-risk assessment (Abdelhafiz and Austin, 2003). We believe that a comprehensive examination on major risk factors is important to identify individuals with a high risk of falls. Therefore formal assessment of vision, physical and balance functions would improve the capacity of predicting future falls in older adults. In this project, we aimed to investigate the prevalence of visual, physical and balance problems in Hong Kong Chinese community-dwelling older adults. Further, we examined the contribution of vision in physical and balance functions.

2.3 Methodology

2.3.1. Participants

Four hundred and thirty-five older adults were recruited from seven community centres using convenience sampling. Participants, who were bed-bound, chair-bound, suffered losses of consciousness, had poor mobility skills or poor oral communication, were excluded. Informed consent was obtained in accordance with a protocol approved by The Hong Kong Polytechnic University Human Research Ethics Committee. The study followed the tenets of the Declaration of Helsinki. All assessments were conducted by optometrists, physiotherapists, and their students under supervision.

2.3.2. Visual assessments

Visual assessments included distance visual acuity (VA), contrast sensitivity (CS), visual field (VF), external and internal ocular health at community centres, where the lightings of the venue was well controlled as suggested in the literatures. Monocular distance VA was measured using the Lea number chart at 3 m with background luminance ranging from 80 to 100 cd/m^2. VA was scored to the nearest letter and recorded in logMAR (logarithm of the minimum angle of resolution) notation. CS was measured binocularly using the Melbourne Edge Test (MET) which presents 20 circular patches containing edges with reducing contrast. The MET provides a measure of contrast sensitivity in decibel units, where 1 dB = 10*log$_{10}$(contrast) (Verbaken and Jacobs 1985, Verbaken and Johnston 1986a, Verbaken and Johnston 1986b). Gross VF constriction in any of the four major quadrants was detected by confrontation. Intraocular pressure was assessed using a non-contact tonometer (CT-60 computerized tonometer). External and internal ocular health was assessed without pupil dilation using slit-lamp biomicroscopy and direct ophthalmoscopy, respectively. Criteria for defining glaucoma included cup-to-disc ratio larger than 0.5 in both vertical and horizontal measures, intraocular pressure higher than 22 mmHg in either eye or more than 3 mmHg difference between the two eyes. Criteria for defining macular anomaly included the presence of drusen and neovascularisation within 10 degrees of central fundus.

2.3.3. Physical Performances in Physiological Profile Assessment (PPA)

Physical function was measured using the Physiological Profile Assessment (PPA) protocol developed by the Falls and Balance Research Group of the Prince of Wales Medical Research Institute (Lord et al. 2003). PPA assessed (1) quadriceps muscle strength, (2) proprioception, (3) hand reaction time, and (4) postural sway (Table 2.1). Written instructions were given to experimenters for demonstrations on verbal instructions to participants in all measurements. Standardization on recordings were also given to experimenters to limit the inter-experimenters' variations.

Quadriceps muscle strength was examined in the dominant leg using a strain gauge, with the participant seated with angles of hip and knees at 90 degrees. Proprioception was measured using a lower limb position-matching task; this was performed twice, and the difference in matching the great toes was recorded using a vertical clear acrylic sheet inscribed with a protractor placed between the legs. Hand reaction time was assessed using a light as a stimulus and finger-depression of a switch as the response. Postural sway area (maximal anterior-posterior (A-P) x medio-lateral (M-L) sway in mm) was assessed using a sway-meter that measured the displacement of the body at waist level while participants were asked to maintain balance for 15 seconds for (1) eyes opened vs. eyes closed, (2) firm vs. foam surfaces, (3) standing on one vs. both legs, a total of eight testing conditions. For participants who could not maintain their balance for the entire period, time to balance failure was recorded in seconds for computing the total sway area (multiplication of displacement in A-P and M-L in mm) per second (mm^2/s). If the balance could only be maintained for <1 s, that trial was excluded from analysis. Single-leg standing performance was measured for left and right legs separately, but only the performance for the dominant leg was used for analysis. Single-leg standing performance was measured for left and right legs separately, but only the performance for the dominant leg was used for analysis.

2.3.4. Composite fall risk score

We followed the approach of Lord et al. (2003) in calculating a fall risk score. Briefly, a fall risk score expressed in standard units (z-score) was computed based on individual performance on 5 functional tasks: (1) CS, (2) quadriceps muscle strength, (3) proprioception, (4) hand reaction time, and (5) postural sway on a foam surface (double-leg standing and eyes open). A higher score is indicative of a higher fall risk.

2.3.5. Demographic information, cognitive performance and self-evaluated balance performance

Demographic information (age, gender, source of income, educational level, general health, self-reported health and vision status and history of falls in previous 3-months) was collected using a structured questionnaire. Mini-Mental State Examination (MMSE) questionnaire (Folstein et al. 1975) was used as the cognitive assessment (the Chinese version of MMSE was adopted from Chiu (Chiu 1994)). Cut-off score for individuals without and with schooling history was 18 and 20 respectively. To assess an individual's self-perceived level of confidence in performing specific activities without losing balance, a Chinese-version of the Activities-specific

Balance Confidence (ABC) Scale was employed to measure participant's fear of fall. Each participant was asked to rate their self-perceived balance confidence level from 0 (no confidence) to 100 (full confidence) for completing 16 activities of daily living (Powell and Myers 1995), Mean score of the 16 activities was calculated. Score below 50, between 50 and 80 and above 80 indicated low, medium and high level of confidence in functioning respectively. Details of questionnaire are shown in Table 2.2. The participants were followed-up for 1 year to ascertain their prospective falls history, via monthly face-to-face or phone interview.

2.4 Statistical analysis

Given that binocular VA could be reasonably predicted by acuity in the better eye alone (Rubin et al. 2000), the eye with better VA was used to compare with other functional measures. Balance function in terms of postural sway per second (mm^2/s) was log-transformed to ensure that the data were not significantly different from normal distribution ($p>0.05$). Single-leg standing performance was measured for left and right legs separately, but only the performance for the dominant leg was used for analysis. All variables were not significantly different from normal distributions (confirmed by one-sample Kolmogorov–Smirnov test, $p>0.05$).

MANOVA was employed to examine the effect of visual cues (eyes closed or eyes opened), nature of standing (single leg or double legs) and nature of standing surface (firm or foam surfaces) on postural control. If there was a significant result, univariate ANOVA was conducted for studying the individual effect. Pearson product-moment coefficient of correlation was employed to evaluate the relationship among various functional measures, including visual, physical and balance-related performances. A p-value of <0.05 was considered as significant, in which the p-value were corrected for multiple comparisons.

Table 2.1. Details of Physiological Profile Assessment. (Lord et al. 2003).

Assessment		Equipment	Testing Details	Measures
1	Quadriceps muscle strength	Spring gauge fixed at the crossbar of the chair	Maximum forward kick by the dominant lower limb (for kicking ball or same side of dominant hand). The leg was attached to spring gauge	Knee extension force (kilogram)
2	Hand reaction time	Hand reaction timer	Press the mouse button as soon as the red light appeared	Hand reaction time (millisecond)
3	Proprioception	Arcylic sheet between legs	Raise both legs together and match the position of the big toes at 2 levels (45°& 15° or 75°& 45°) with eye closed	Difference in degree between 2 legs
4	Postural sway assessment	Safety rails with firm and foam surfaces (65cm X 65cmX15cm medium density (23-130 g/cm^3)); Swaymeter	Maintain balance under conditions (eye close/open, firm/foam surfaces, and single/double leg) while wearing Swaymeter at waist	Range of movement in medio-lateral (M-L), anterior-posterior (A-P) direction

Table 2.2. Details of the questionnaires used in this project.

Questionnaire		Testing
1	Demographic questionnaire	Name, age, gender, income source, marriage status, living condition, primary source of education level, general and ocular health, living habits, history on general and ocular health, use of walking aids and fall history (pre 1-month and 3-month of assessment)
2	Activities-specific Balance Confidence (ABC) Scale	Score on the confidence level (from 0% to 100%) on task completion
3	Mini Mental State Examination (MMSE)	Cognition test with a maximum of 30 points (18 and 20 were the passing scores for the participants without and with schooling respectively)

2.5 Results

2.5.1. Demographic, health and lifestyle characteristics of the population

Ages of 435 participants ranged from 60 to 95 years (mean ± SD, 75.5 ± 7.2 years), 373 (85.7%) were female (Table 2.3). Average MMSE score was 25.5 ± 3.6, and 93.8% participants passed this cognitive screening test (i.e. MMSE score >18 or 20). On average, participants reported having 2 chronic diseases (1.9 ± 1.5); hypertension (52.1%), arthritis (32.7%) and high cholesterol level (25.3%) were the three most commonly reported chronic diseases. These participants were taking an average of 1 or 2 medications per day (1.4 ± 1.2) to manage their reported general health problem (mostly commonly for hypertension [50.2%], diabetes mellitus [16.8%] and high cholesterol level [15.7%]). Only 10.6% participants rated having poor general health. Lifestyle for majority of the participants was healthy because: 1) most did not consume alcohol

(93.6%) or smoke cigarettes (98.4%); 2) 78.4% of participants exercised on more than 3 times per week; 3) 44.8% participants walked more than 10 streets per day; and 4) 27.5% and 55.8% participants had high (>80%) or moderate levels (50-80%) of physical function (average ABC-score of 68.2 ± 19.4 (Powell et al. 1995)). Anecdotally, among those participants who reported doing regular exercise, Tai-chi and Qigong (including Baduanji, Luk Tung Kuen) were the most popular exercises (approximately 80%). Very few participants reported having had a fall in the past 1 month (5.3%) and 3 months (7.6%).

Table 2.3. Demographic information of participants.

	No. of participants (Percentage)		No. of participants (Percentage)
Age distribution			
60-69 years	93 (21.4)	**70-79 years**	211 (48.5)
80-89 years	119 (27.6)	**≥90 years**	11 (2.5)
Education level (primary source)			
Never	120 (27.6)	**Tertiary or above**	15 (3.4)
Primary School	211 (48.5)	**Professional**	2 (0.5)
Secondary School	57 (13.3)	**Others**	29 (6.7)
Self-evaluation on eye health			
Excellent	9 (2.1)	**Acceptable**	179 (41.1)
Very Good	44 (10.2)	**Poor**	75 (17.2)
Good	128 (29.4)		
Self-evaluation on general health			
Excellent	11 (2.5)	**Acceptable**	169 (38.9)
Very Good	68 (15.6)	**Poor**	46 (10.6)
Good	141 (32.4)		
Number of chronic diseases			
1	115 (26.4)	**3**	79 (18.2)
2	113 (26.0)	**4+**	20 (4.8)
Alcohol Consumption			
Never	408 (93.9)	**1 to 2 times/week**	4 (0.9)
1 to 2 times/month	15 (3.4)	**≥3 times /week**	5 (1.1)
2 to 4 times/month	3 (0.7)		
Smoking Habit (in cigarettes per day)			
Never	429 (98.6)	**11-20**	2 (0.5)
<1	1 (0.2)	**21-40**	1 (0.2)
1-10	2 (0.5)		
Exercise Habit			
Never	70 (15.7)	**Once a week**	18 (4.1)
Once per month	3 (0.7)	**>3 times per week**	341 (78.8)
<1 time per week	3 (0.7)		

Table 2.3 (Cont'd)			
Walking distance (in streets)			
Never Walk	3 (0.7)	**1 to 5**	125 (28.7)
Indoor walking	6 (1.4)	**6 – 10**	83 (19.1)
< 1 street	23 (5.3)	**Unlimited**	19 (44.8)

2.5.2 Characteristics of visual functions and ocular health

Many participants reported that they had good vision (75.4% for distance and 81.1% for near) and good eye health (41.7% rating "good to excellent". Only 17.2% of participants rated their eye health as "poor". Objective vision measures correlated to the self-reported visual functions, in which participants' distant VA ranged from -0.20 to 0.96 logMAR (0.3 ± 0.2 logMAR). Considering the eye with better distant VA, 227 (52.2%) and 363 (83.5%) participants had VA of 0.30 logMAR and 0.50 logMAR or better respectively. 371 participants (85.4%) had CS better than the age norm (1.6 to 1.7 log-unit) (Verbaken and Jacobs 1985, Verbaken and Johnston 1986a, Verbaken and Johnston 1986b), with the mean CS of 1.85 log-unit (1.9 ± 0.4 log-unit). Compared with the normative database in PPA established by Lord and colleagues (Lord, Clark and Webster 1991, Lord et al. 1994), the mean CS was only categorized as "fair". Only 6.4% and 8% of participants had a gross VF defect in the right eye (RE) and left eye (LE) respectively (10.1% had a VF defect in either eye). These VF losses were mostly attributable to cataracts or glaucoma.

In ocular health assessment, 49 (11.3%) and 51 (11.7%) participants had significant cataract in their RE and LE (Grade 3 and 4). 4.6% of participants were suspected having glaucoma, while 6.2% of participants had mild macular anomaly. Among the participants with mild (i.e. distant VA from 0.5 – 1.0 logMAR) to moderate (i.e. distant VA from 1.0 to 1.3 logMAR) subnormal acuity in the better-seeing eye, uncorrected or under-corrected refractive error was the major cause (45.9%), followed by cataract (16.1%) or macular anomaly (6.2%). Prevalence of the ocular health problems is shown in Table 2.4. Plots of visual functions (distant VA and CS) against age are shown in Figure 2.1. Distant VA in the better eye and CS in both eyes were significantly associated with age (VA: r= 0.37, $p< 0.001$; CS: r= -0.37, $p< 0.001$). Our results revealed a stronger age-related decline in CS than in VA. Compared an individual aged 60 and 85, the high contrast distant VA and CS were deteriorated by 1.8 times and 3.2 times respectively.

Table 2.4. Prevalence of the external and interal ocular health problem in the right (RE) and left eyes (LE).

[No. of participants (percentage)]					
Types of cataract (Grading*		**Mild (Grade 1)**	**Mild (Grade 2)**	**Moderate (Grade 3)**	**Severe (Grade 4)**
RE	**NS**	75 (17.3%)	104 (23.9%)	47 (10.8%)	14 (3.2%)
	CC	37 (8.5%)	90 (20.7%)	37 (8.5%)	6 (1.4%)
	PSCC	4 (0.9%)	12 (2.8%)	7 (1.6%)	1 (0.2%)
LE	**NS**	83 (19.1%)	111 (25.5%)	52 (11.9%)	11 (2.5%)
	CC	48 (11.0%)	85 (19.6%)	37 (8.5%)	5 (1.1%)
	PSCC	7 (1.6%)	11 (2.5%)	9 (2.1%)	-
Internal ocular health [No. of participants (percentage)]					
		Glaucoma		**Macula anomaly**	
RE		16 (3.7%)		20 (4.6%)	
LE		14 (3.2%)		17 (3.9%)	

* Types of cataract: NS= Nuclear sclerosis; CC= Cortical cataract; PSCC= Posterior subcapsular cataract.

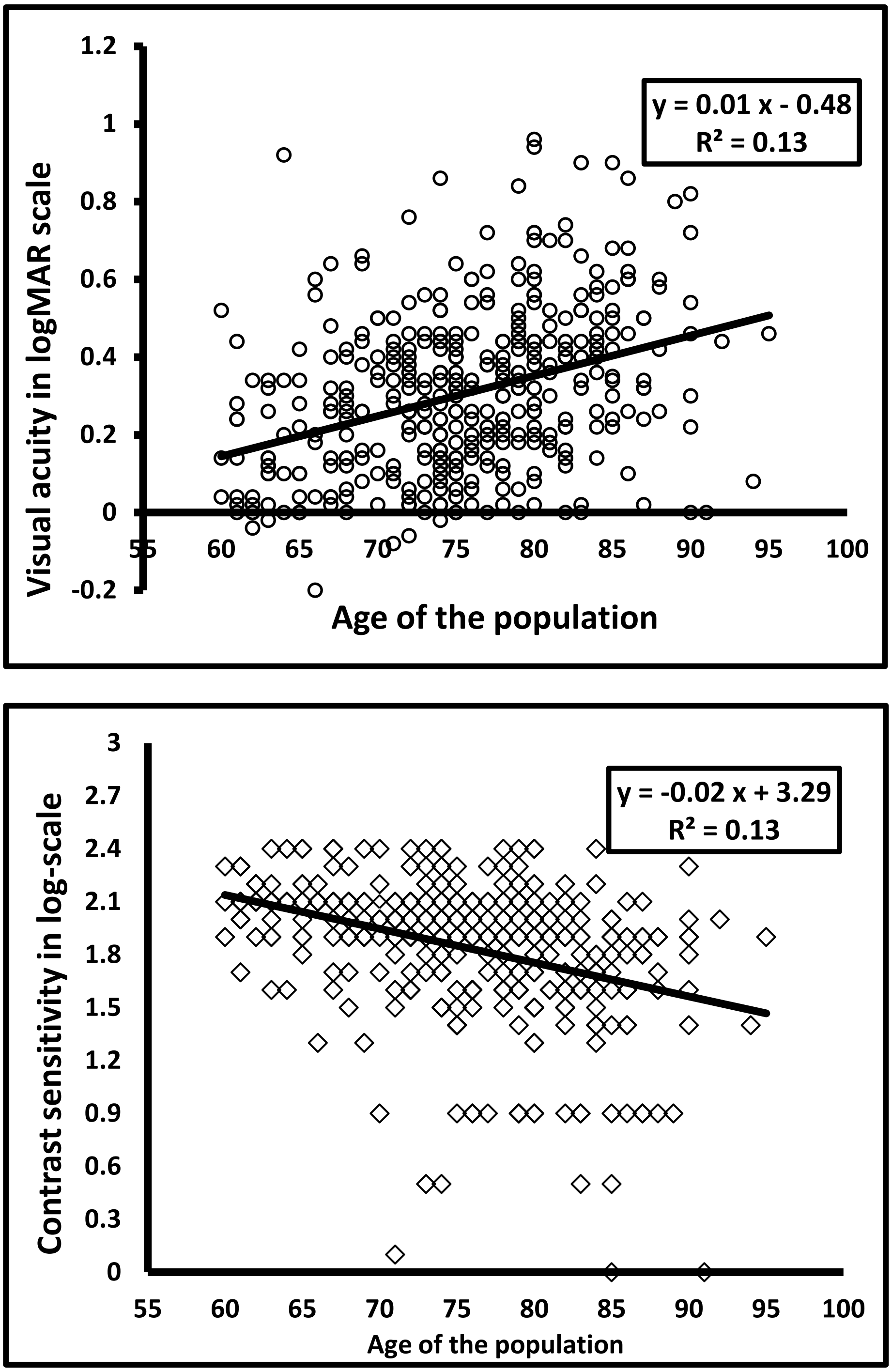


Figure 2.1. Distant VA (better eye, upper panel) and CS (lower panel) were plotted against age. Significant age-related decline was observed in both distant VA (r= 0.37, p<0.001) and CS (r= -0.37, p<0.001). Pearson product-moment coefficient of correlation is presented.

2.5.3. Characteristics of balance function in terms of postural sway

In postural sway, effects of the nature of standing (double vs. single leg) ($F(2, 4608)= 1740.18$, $p< 0.001$), standing surface (firm vs. foam surface) ($F(1, 4608)= 480.13$, $p< 0.001$) and visual cues (eyes open vs. eyes close) ($F(1, 4608)= 289.09$, $p< 0.001$) were significant. There were significant 2-way interactions between: 1) nature of standing x standing surface ($F(2, 4608)= 43.9$, $p< 0.001$); 2) nature of standing x visual cues ($F(2, 4608)= 8.2$, $p< 0.001$); and 3) standing surface x visual cues ($F(1, 4608)= 4.47$, $p< 0.001$). Our results revealed that participants swayed significantly more when they stood on the foam surface (2.2 ± 0.7 log mm^2/sec) than firm surface (1.9 ± 0.8 log mm^2/sec), in particular when they closed their eyes. Presence of visual cue (i.e. eyes open) stabilized the postural control (1.9 ± 0.7 log mm^2/sec in eyes open vs. 2.2 ± 0.8 log mm^2/sec in eyes close). Participants swayed significantly more during single-leg standing (2.4 ± 0.6 log mm^2/ sec) than double-leg standing (1.4 ± 0.6 log mm^2/sec), but the singe-leg induced postural instability was more prominent in the firm than foam surface. Further analysis showed that the postural stability of single-leg standing was not significantly different between firm and foam surfaces ($p=0.10$). Results of the correlation between balance (measured at different conditions) and age are summarized in Table 2.5. In brief, significant correlation between age and postural sway was found on foam surface and eyes open ($p< 0.01$).

Table 2.5. Relationship as shown by Pearson's correlation coefficient between balance measures in terms of sway area at different conditions and age.

Nature of standing	**Visual cues**	**Firm**	**Foam**
Double-leg	Eyes open	0.07	0.28*
	Eyes close	-0.02	0.27*
Single-leg	Eyes open	0.17**	0.19**
	Eyes close	0.06	0.11

Asterisks * and ** indicate p-value <0.05 and <0.001 respectively.

2.5.4. Characteristics of Physiological Profile Assessment (PPA)

Findings of each physical performance in the PPA were compared with the normative Caucasian database reported by Lord and colleagues (Lord et al. 1991, Lord et al. 1994) and classified into 4 scales: excellent, good, fair and poor. Combined data are presented for the two genders for the CS, proprioception, reaction time and sway tests as performances between the genders were similar. Due to large and significant gender differences for quadriceps strength ($p<0.001$), data for the two genders are compared separately.

The mean quadriceps strength [a] was 30.9 ± 13.2 kg, with a significant gender difference ($t= -6.01$, $df= 69$, $p<0.001$), where the male (42.9 ± 17.9 kg) outperformed the female (28.9 ± 11.1 kg). Quadriceps strength in both gender groups was categorized as "good". For proprioception, the average deviation between two legs while matching the great toes in lower limbs was 1.8 ± 1.2 degrees,

[a] Only 2.5% of participants (11 participants) claimed that left lower limb was their dominant leg

which was also categorized as “good”. The mean CS score and hand reaction time was 1.9 log-unit (1.9 ± 0.4 log-unit) and 372.5 ± 194.9 millisecond, which was classified as “fair” and “poor” respectively. For the sway measure on foam surface with double-leg standing and eyes open, the mean sway area was 1288.9 ± 1299 mm^2, which was regarded as “fair”. Performances in 3 PPA tests were weakly but significantly associated with age at $p <0.001$: quadriceps strength r= -0.23, reaction time r= 0.35 and postural sway r= 0.3. Proprioception was not associated with age (r= -0.03, p-0.10).

2.5.5. Computation of fall-risk score

Standardized Z score was computed for each PPA test: 1.4 ± 1.8 for quadriceps muscle strength; 0.0 ± 1.0 for proprioception; -0.8 ± 0.7 for contrast sensitivity; -1.8 ± 2.0 for hand reaction time and -0.5 ± 1.3 for postural sway (double-leg standing and eyes open on foam surface). Among these five components, only the performance of quadriceps muscle strength was better than the Caucasian populations with the standardized z score above zero (Lord et al. 1991, Lord et al. 1994). Based on the performance in these five components, a composite fall-risk score was computed for each participant using the discriminant function that comprised weighted scores from each component measure. Based on individual fall risk score, 41%, 28.7%, 21.8%, 7.8%, 0.7% of the participants were classified as marked, moderate, mild, low and very low fall-risk respectively. The average computed fall-risk score of 1.9 ± 1.6 was classified as “moderate” fall-risk (Lord and Ward 1994). Composite fall risk scores were significantly associated with age (r= 0.43, $p<0.001$). Because of the “moderate” fall-risk in this Chinese older population, we expected a relatively high number of retrospective and/or prospective falls (Table 2.6). However, only 23 (5.3%) and 33 (7.6%) participants reported at least one fall in the preceding 1-month and 3-months respectively. Among the 386 (88.8%) and 294 participants (67.6%) who had completed the 6-month and

12-month follow-up to record the prospective number of falls[b], only 9.6% and 17% reported having had at least one fall in 6-month and 12-month respectively.

2.5.6. Relationship between vision and functional measures of physical and balance

Table 2.7 summarizes the relationship between visual function and functional measures of physical and balance. Both distance VA and CS showed significant but weak relationships with the majority of the non-visual functional measures: individuals with weaker visual functions had slower hand reaction time ($p<0.001$), and swayed more under demanding conditions ($p<0.001$). This implies that individuals with worse vision might also have impairment in other functions, further contributing to a high risk of falls.

Table 2.6. Number and percentage of self-reported fall incidence in the retrospective and prospective interval.

No. of falls	**Retrospective**		**Prospective**	
	1-month	**3-month**	**6-month**	**12-month**
0	412 (94.7%)	402 (92.4%)	349 (80.2%)	244 (56.1%)
1	23 (5.3%)	28 (6.4%)	29 (6.7%)	43 (9.9%)
2	-	2 (0.5%)	5 (1.2%)	5 (1.2%)
3	-	2 (0.5%)	2 (0.5%)	1 (0.23%)
4	-	1 (0.2%)	1 (0.2%)	1 (0.23%)
	n= 435	**n= 435**	**n= 386**	**n= 294**
Number of incidence (Percent)	23 (5.3%)	33 (7.6%)	37 (9.6%)	50 (17%)

[b] The main reasons for non-completion were having moved and not able to be contacted.

Table 2.7. Relationship as shown by Pearson's correlation coefficient between visual and other functional measures.

	Distance visual acuity (logMAR)	**Contrast sensitivity (log)**
Physical		
Quadriceps strength (kg)	**-0.24 ****	**-0.18 ****
Proprioception (degree)	-0.07	0.10
Hand reaction time (log ms)	**0.33 ****	**-0.35 ****
Balance+ (log mm^2/sec)		
Double leg on foam surface	**0.19 ****	**-0.19 ****
Single leg on firm surface	**-0.11 ***	-0.09
Single leg on foam surface	**0.23 ****	**-0.19 ****
Fall risk		
Composite fall risk score	**0.39 ****	**-0.56 ****

Asterisks * and ** indicate p-value <0.05 and <0.001 respectively.
+ Only balance measures with eyes open were included in the analysis.

2.6 Discussion

To our knowledge, the current project was the first study incorporating the evaluation of vision and ocular health in the fall-risk assessment in Hong Kong community-dwelling older adults. Results of this project provided insights in 2 aspects: 1) Prevalence of vision, physical and balance deficits in Hong Kong Chinese older population; and 2) Relationship among vision, physical and balance functions.

2.6.1. Prevalence of vision problems in Hong Kong elderly

Visual function and ocular health were evaluated by standard clinical protocols and methods. Visual function was relatively good in this sampled population with an average distance VA in the better eye of 0.30 logMAR. Only 16.5% participants were classified as "visually impaired" with distance VA in the better eye worse than 0.5 logMAR[c]. Our findings were similar to the data reported in previous epidemiology studies (Wu et al. 1997, Michon et al. 2002). Wun and colleagues (1997) found that the average VA in either eye was 0.40 logMAR. Cataract remained the most common ocular problem, in which 16.1% of our participants were affected by significant cataract (Grade III to IV in the LOCIII system) in either eye (Van Newkirk 1997, Huang et al. 2009). Our results showed significant age-related decline in distant VA and CS, where distant VA and CS were deteriorated by 0.01 and 0.02 log-unit for every year increase in age (Figure 2.1). Compared the average distant VA and CS between two age groups: 60-65 vs. 90-95 years, VA and CS was deteriorated by 1.8 and 3.2 times respectively. Our findings was comparable to the results in Brabyn et al. (2001) who reported a drop of 2 and 4 times in high contrast VA and CS in the similar age groups.

2.6.2. Prevalence of physical and balance problems in Hong Kong elderly

Physical function of our participants was evaluated by the PPA together with comprehensive balance measure. Quadriceps strength and lower limb proprioception scores were comparable to those scores reported for Caucasian populations (Lord et al. 2003). However, simple reaction time and postural sway scores were relatively poor. The average composite fall-risk score was 1.9 indicating a "moderate" fall-risk when compared to the Caucasian norms. 41% and 28.7% participants were rated as "marked and moderate fallers". Despite the relatively poor physical performances and moderately high fall-risk scores, the incidence of one plus falls in the 6-month and 1-year follow-up period was only 9.6% and 17% respectively. The incidence of fall was similar to the average fall rate reported in other Hong Kong studies: 14.1% to 26% participants reported having fall in the next 12-month (Lau, Woo and Lam 1991,

[c] Distance visual acuity worse than 0.5 logMAR is defined as low vision or visual impairment by WHO.

Ho et al. 1996, Chu, Chi and Chiu 2005, Lee et al. 2006, Woo et al. 2009, Yu et al. 2009). Difference in the PPA performance between Chinese and Caucasian populations implied that the direct application of Caucasian normative data into Chinese population might not reflect the distribution of PPA performance accurately (Please refer to Chapter 1 Section 1.2.2.). Hence, it is important to establish the normative values for older Chinese people living in Hong Kong and to establish the fall-risk profile for this population in a large-scale study.

To maintain postural control in a well-lit environment, healthy individuals require information from the somatosensory (70%), visual (20%) and vestibular (10%) systems (Peterka 2002). In this study, we compared the postural sway area for participants standing on foam or firm surfaces, with eyes open or closed, with double-leg or single-leg standing to examine each factor contributing to balance control. As expected, postural control on firm surface was significantly better than that on foam surface ($p<0.001$) because of its stable supporting environment (i.e. somatosensory input), especially when participants stood with double legs. Single-leg standing is a more difficult task, requiring stronger balance mechanisms. Hence, we expected a greater detrimental effect on balance function when the somatosensory input was disturbed. Although our finding confirmed our expectation that postural control was worse in single-leg standing than double-legs standing, it only applied to the firm surface rather than foam surface. No significant difference in the somatosensory contribution to balance was found in single-leg standing. This may be because the challenge to postural control by the single (i.e. dominant) leg was too great, which may have masked any disruptive effect of reduced somatosensory input. The role of vision on balance has been widely studied, where postural sway significantly increases when visual input is removed in normally-sighted participants (Black and Wood 2005, Heasley et al. 2005, Schmid et al. 2007). Our result also agreed with previous findings where postural sway was significantly increased during eye close condition, especially when participants stood on a compliant foam surface.

Although only a small proportion of our participants (16.5%) were classified as “visually-impaired” (VI), balance function for this group was compared with the normal vision (NV) group. Further analysis showed that VI participants swayed significantly more than the NV participants, in particular when they stood on a compliant surface ($F(1,1701)= 7.1$, $p= 0.008$). To compensate for vision loss, participants should use the “non-visual” inputs for maintaining postural control, in particular when they stand under a more challenging condition. However, Giagazoglou et al. (2009) argued that the loss of visual input could not be fully compensated for other afferent systems in postural control. Hence, people with visual impairment have a higher risk of falls because of the potential impediment in balance function. Our findings further supported the importance of vision and ocular health assessment in fall-risk assessments.

2.6.3. Relationship among vision, physical and balance functions

Extensive studies have demonstrated that visual function is an important factor in balance control (Wills et al. 2003), physical and vestibular functioning (Szabo et al. 2008; Whitney et al. 2006) and the risk of falls in older adults (Lord et al. 1991). Our results showed significant but weak relationships between vision and quadriceps, hand reaction time and postural sway balance (Table 2.7). Vision could only explain 1.2 to 10% variances of the physical and balance measures. These functional tasks were relatively “dynamic” in nature when compared with vision which was measured in a sitting position. Hence, measuring a person’s vision in a dynamic setting such as resolving a moving stimulus instead of a stationary stimulus might better correlate with the functional tasks. Previous studies have revealed better association between dynamic vision and balance functions (Freeman et al. 2006, Patel et al. 2006). Hence, evaluating an individual's dynamic vision might better predict his/her balance function and the corresponding risk of falls.

Although previous studies have shown better correlation between CS and functional performances (e.g. reading, scene recognition (Angelaki and Hess 2005), orientation and mobility (Turano et al. 2004, Rietdyk and Rhea 2011) and balance (Simoneau et al. 1992)), our results only partially agreed with previous findings. Some physical measures (e.g. quadriceps, postural sway with single-leg standing on firm and foam surfaces) were better correlated with high contrast distant VA, while the other measure was better correlated with CS (e.g. hand reaction time). However, the variances of the physical and balance measures explained by distant VA and CS were similar. Owing to the potential benefits of dynamic vision, measuring dynamic VA and dynamic CS would be included in our next project.

2.7 Limitation

Participants were considered as physically healthy and active, in which the participants were recruited by voluntary enrollment. This group of participants might not represent the community-dwelling older adults in Hong Kong because of their high initiative to participate in community activities. We believed that the ones who attended the community functions by self-enrollment were more active and healthier than others. Considering the general aging population in Hong Kong, some elderly might prefer staying at home rather than engaging in group activities, organized by community centres or the government. In addition, the 33% loss to follow-up was relatively large, and it is likely that the loss was selective in nature with participants with adverse health events and possibly falls being over-represented in the group lost to follow-up. Hence, it is possible that this project might have under-estimated the fall-risk.

2.8 Conclusion

Our study provides data on the prevalence of vision, physical and balance problems, and the association among these 3 factors in Hong Kong older adults. It is important to include vision and ocular health assessment in the fall-risk evaluations because vision is significantly (although weakly) correlated with physical and balance measures. Standard clinical visual assessments mainly consider the importance of static vision, largely ignoring the potential advantages of dynamic vision, which might better predict the functional performances. In future study, assessment on dynamic vision should be included.

Chapter 3

Static and Dynamic Visual Function With and Without Body Locomotion among Three Age Groups

Chapter 3

Static and dynamic visual function with and without body locomotion among three age groups

Objective:

- To investigate the effects of moving speeds of visual stimuli, aging and body locomotion on visual performance, and its interaction effect in normally-sighted healthy people

Hypotheses:

- Dynamic visual performance was deteriorated in the aging population
- Dynamic visual performance decreased with the increase in moving speeds of visual targets
- Locomotion did not impose significant impact on visual performance

3.1 Abstract

Introduction: Dynamic vision has been shown to better correlate with functional performance, for instance, driving and walking, where there is a relative movement between observers and targets of interest. These functional performances involve the processing of visual information and other external stimulus simultaneously. Previous studies have shown stronger age-related decline in dynamic vision because of the faster rate of deterioration in processing multi-information. However, very few studies have investigated dynamic vision when both observers and visual targets are in motion.

Methods: Eighty-four healthy participants with normal vision and aged between 21 and 80 years were recruited. These participants were classified into 3 age groups: 1) young-adult group (n=38, 25.1 ± 5.2 years); 2) middle-age (n=33, 56.3 ± 6.7 years); and 3) older-age (n=13, 68.9 ± 2.6 years). Participants were required to recognize visual stimuli while they were at three different types of body locomotion - sitting, stepping and walking. Visual targets were presented at 0, 30, 60 and 90 deg/sec, moving from right to left or vice versa. Participants were required to identify the alphabets (H, O, T and V) of different sizes and orientation of gratings (horizontal, vertical, right and left tilt) with different contrast levels for measuring visual acuity and contrast sensitivity respectively.

Results: Results from MANOVA showed significant main effects of moving speeds of visual targets, body locomotion and age on visual function ($p<0.005$). Both VA and CS significantly deteriorated for resolving moving targets. Post hoc analysis revealed that the motion-induced visual deterioration was only found in targets moving at 30 deg/sec ($p<0.01$), but became plateau for target moving at 60 or 90 deg/sec ($p>0.06$). Among the 3 types of body locomotion, optimal VA was achieved in sitting position, followed by stepping and walking, with a difference of less than 0.05 logMAR at different

locomotion ($p = 0.03$). However, CS was not significantly different with different body locomotion ($p > 0.10$). Both VA and CS for participants in the older-age group were significantly worse ($p < 0.01$), but the effect of age-related decline was similar in resolving stationary and moving targets ($p = 0.26$).

Conclusion: Significant deterioration of visual performance was found in resolving moving stimuli. Visual performance in older adults was worse than young- and middle-age participants. In contrast, very little impact of body locomotion was found in resolving stationary or moving objects. The impacts of these factors on visual function were independent, without significant interaction effect.

3.2 Introduction

Measurement of static vision refers to the visual ability in the absence of locomotion of observers and movement of visual targets. In conventional vision measurement, static vision is assessed widely as in visual acuity (VA) and contrast sensitivity (CS). Although static vision gives an overview about an individual's visual functioning, it might not well correlate with many real-world tasks involving movement of both target and observer. Instead, dynamic vision (i.e. ability to resolve moving targets) better correlates with functional activities involving locomotion (Freeman et al. 2006, Patel et al. 2006), such as driving (Retchin et al. 1988, Scialfa et al. 1988), walking (Demer and Amjadi 1993, Peters and Bloomberg 2005) and sports activity (Trachtman 1973, Falkowitz and Mendel 1977, Rouse et al. 1988). These activities require people to maintain good body equilibrium between sensory (vision) and motor systems (control of muscle and executing a response). Dynamic vision is considered as the time domain processing of visual information and it is established when there is a relative movement between observers and visual targets. Such relative movement or locomotion is an essential condition frequently encountered in daily life.

Extensive studies have examined the factors affecting dynamic visual function in resolving moving objects. These factors can be broadly classified into external/ experimental and human factors. Examples of external factors include moving velocity of stimuli (Ludvigh and Miller 1958, Burg 1966, Fergenson and Suzansky 1973, Scialfa et al. 1988, Nakatsuka et al. 2006), presentation duration of the stimuli (Miller 1959, Mackworth et al. 1962)), luminance and contrast of the stimuli (Ludvigh 1949, Miller 1958, Long and Crambert, 1990, Mayyasi et al. 1971, Brown 1972a and 1972b, Long and Garvey 1988), and retinal eccentricity (Strasburger et al. 1991, Lundh and Gottvall 1995). Examples of human factors include age (Burg and Hulbert 1961, Burg 1966, Scialfa et al. 1988, Long and Crambert 1990, Rine and Braswell 2003, Ishigaki and Miyao 1994), visual (Ao et al. 2014), physical (e.g. sports practice (Beals et al. 1971, Sanderson and Whiting 1974, Sanderson and Whiting 1978, Rouse et al. 1988), and vestibular functions (Herdman et al. 1998, Tian et al. 2001, Schubert et al. 2002, Johnson 2002)). Despite a large number of studies investigating dynamic vision, these studies examined the participants' visual ability to detect a moving target when they are in stationary position, rather than in locomotion.

A number of studies have compared visual function in participants with normal and abnormal vestibular function during standing and walking on a treadmill (Roberts et al. 2006, Peters and Bloomberg 2005, Hillman et al. 1999). They found significant deterioration in visual function during self-motion in participants with vestibular dysfunction, but not in healthy individuals. Peters and colleagues (2008) also reported self-motion induced VA decline in healthy adults. However, this vision decline was only found when the participants viewed near targets (40 cm) rather than distance targets (4 m). Their findings could be attributed to the larger angular movement of near targets, imposing stronger challenge on visual recognition. Participants in the above-mentioned studies were asked to recognize static rather than dynamic visual stimuli during locomotion. In our daily life, we always need to resolve moving stimuli during walking or running (e.g. avoid a small moving animal when we walk). Surprisingly, no studies have explored how our visual system responds to moving objects while we are in locomotion. Our study was aimed to examine the effect of body locomotion in resolving visual stimuli moving at different speeds. Two types of visual functions were examined in this study – VA and CS. Further, the effect of aging on static and dynamic visual functions, together with its interaction on body locomotion was also investigated.

3.3 Methodology

3.3.1. Participants

84 normally-sighted participants were recruited from the Optometry Clinic in The Hong Kong Polytechnic University using convenient sampling. Participants were divided into 3 groups based on their age: 1) young adults (21 - 30 years, 25.1 ± 5.2 years, n=38); 2) middle-aged (31 - 60 years, 56.3 ± 6.7 years, n=33); and 3) old-aged (60 years or above, 68.9 ± 2.6 years, n=13). All participants fulfilled the following criteria were recruited: 1) No self-reported physical (e.g. using walking or mobility aids) and cognitive impairment (e.g. Parkinson's disease and Alzheimer's disease); 2) No severe medical problems (e.g. epilepsy, heart disease and pulmonary disease) and self-reported poor control on systemic diseases (if any); 3) No apparent ocular pathology such as glaucoma, diabetic retinopathy, macular degeneration, and severe cataract (grade 3 or above for all types of cataract using Lens opacities Classification System III (LOCS III) (Chylack et al. 1993); 4) Binocular habitual VA of 0.10 logMAR or better (i.e. 6/7.5 Snellen acuity) for young-adult group and 0.30 logMAR or better (i.e. 6/12 Snellen acuity) for middle- and old-age group, while the VA difference between two eyes was within 0.10 logMAR (using Early Treatment Diabetic Retinopathy Study (EDTRS) chart); 5) Absence of strabismus and eccentric fixation; 6) No self-reported vestibular-ocular reflex problem. For participants with suspected vestibular deficiency problem, dynamic gait index was conducted for screening (Wrisley et al. 2003, Wrisley et al. 2004). Only those with a score above 19 were recruited. An additional questionnaire regarding pains in the back, hip and knee in the past 1 month, their frequency (once, 2-3 times, 3-4 times, more than 5 times) and severity (mild, moderate, severe) was implemented for the old-aged participants. Participants with frequent (i.e. more than 3 times) and moderate to severe pain were excluded from the study (Woo et al. 2009). Informed consent was obtained in accordance with a protocol approved by The Hong Kong Polytechnic

University Human Research Ethics Committee and this study followed the tenets of the Declaration of Helsinki.

3.3.2. Apparatus and stimuli

The test stimuli for visual acuity (VA) consisted of 4 Sloan letters – H, O, T, V. Larger letters were constructed from proportionally larger pixel arrangement that varied in steps of 0.1 log unit. The test stimuli for contrast sensitivity (CS) were circular Gabor patches (1.4 degree radius), which consisted of sine-wave gratings of 2 cycles per degree and convolved with a 2-dimensional Gaussian profile with aspheric ratio and sigma of 1.0. The size of the Gabor patch and spatial frequency of the gratings corresponded to the angle subtended by the letter in the Pelli Robson Contrast Sensitivity chart (the Pelli and Robson 1988). The contrast of the Gabor patches was defined as Michelson contrast: $C = (L_{max} - L_{min}) / (L_{max} + L_{min})$, where L_{max} and L_{min} are the peak and minimum luminance of the stimulus respectively. Grating stimuli was rendered with a video card with 8 bit input resolution and 10.8 bits output resolution with the bit-stealing method. All test stimuli were generated by an OpenGL-based Software Package computer program, Psykinematix (Beaudot 2009) and presented on a high-resolution (1920x1080) LCD monitor of 40 inch (Sunway DI−40035D) which covered a visual angle of approximately 80 degrees (horizontal dimension) and 50 degrees (vertical dimension) when viewing at 4.8 meters, with luminance output of 700 cd/m^2 with contrast ratio of 3000:1 and refresh rate of 120Hz. The monitor was calibrated every three months to ensure the consistency of gamma correction, luminance, colorimetry and geometry.

3.3.3. Procedure

3.3.3.1. Visual acuity

Visual acuity was measured using a four-alternative forced-choice method of constant stimuli. Before the measurements, individual acuity was determined with Early Treatment Diabetic Retinoapthy

Study (ETDRS) chart at 4 meters. For static acuity, 6 acuity levels separated by 0.05 log unit and covering the range centred around the individual acuity were presented. For dynamic acuity, the range of acuity levels was shifted by a range of 0.1 to 0.4 log units, depending on the stimuli's moving speed. At each acuity level, five trials were measured and thus a total of 30 trials were accessed. Visual stimuli (one of the 4 alphabets - H, O, T and V) were presented at four moving speeds: 0, 30, 60 and 90 (deg/sec) (Hoffman et al. 1981). Visual stimulus was presented at the centre of the monitor for static VA measure, but randomly moved from either left or right of the monitor for dynamic VA measure. The exposure duration for static and dynamic stimulus was 400 ms. Shorter exposure duration was adopted because previous studies had revealed that static VA reached a plateaued for exposure duration longer than 400 ms (Baron and Westheimer 1973, Burbeck 1986). For each trial, participant was asked to verbally report the presented letter. Psychometric functions of accuracy (percent of letters read correctly) as a function of letter sizes were plotted and fitted with the cumulative Gaussian function (Wichmann and Hill, 2001a; 2001b). The criterion acuity was defined as yielding 80% of letters identified correctly. Each psychometric function was based on data from 30 trials.

3.3.3.2. Contrast sensitivity

Similar to VA, contrast sensitivity (CS) was measured by the method of constant stimuli, with the range of contrast levels covering the individual contrast sensitivity measured by Melbourne Edge Test (MET) (Verbaken and Jacobs 1985, Verbaken and Johnston 1986a, Verbaken and Johnston 1986b). After determining the range of contrast levels, six contrast levels were selected for static and dynamic CS and five trials were tested for each level using Psykinematix. For each trial, the participant was required to identify the orientation of gratings: horizontal (180 degree), vertical (90 degree), right-tilt (45 degree) and left-tilt (135 degree). The presentation and exposure duration for measuring static and dynamic CS were the same as VA measurement. Psychometric functions of accuracy (percent of orientation identified correctly) as a function of contrast levels were plotted and fitted with the cumulative Gaussian function (Wichmann and Hill, 2001a; 2001b). The criterion contrast was defined as the contrast level yielding 80% of gratings identified correctly. Each psychometric function was based on data from 30 trials.

3.3.3.3. Body locomotion for VA and CS measures

VA and CS were measured when participants wore their habitual distant spectacles under binocular viewing and free-head position at three different body locomotion: 1) steady (i.e. sitting on a high-back chair); 2) walking on a manual (for young-adult group) or electric treadmill (for middle- and old-aged groups); and 3) stepping up and down a step (forward stepping up and backward stepping down). Manual treadmill was preferable because it better simulated a person's habitual walking behavior (Mamoto et al. 2002). Participants in the young-aged group were asked to maintain a constant walking speed during the vision measures. However, some participants in the middle- and old-aged groups had difficulty in maintaining constant walking speeds or experienced too strong physical demands in manipulating the manual treadmill, so electronic treadmill was used for participants in these 2 groups with moving speed of 2 to 3 km per hour. All participants were requested to hold the handrail for safety. In the stepping task, participants were asked to walk up and down a step (257 mm x 105 mm x 45 mm, horizontal x vertical x height) in their habitual (but constant) stepping speed. The participants were given sufficient time to get familiar with the procedure of walking and stepping prior to any measures. The sequence of body postures and moving speed of visual targets were randomized. To minimize the fatigue effect, sufficient breaks were provided between measures for each condition.

3.4 Statistical analysis

All data were analyzed by IBM statistical package software version 19 (SPSS 19). Descriptive statistics was used to examine the differences in demographic and clinical data among 3 different groups. Given that all variables were not significantly different from normal distributions (one-sample Kolmogorov–Smirnov test, $p>0.05$), multivariate analysis of variance (MANOVA) was used to examine the effect of moving speeds of visual target, body locomotion and age on VA and CS (4 speeds x 3 locomotion x 2 age groups). When significant main or interaction effects existed, subsequent univariate ANOVA was conducted to ascertain the effects of each dependent variable. A p-value of < 0.05 was considered as significant, in which the p-value would be corrected in case of multiple comparison.

3.5 Results

Results from MANOVA showed that the main effects of target's moving speeds ($F(6, 1644)= 63.36$, $p<0.001$), participant's body locomotion ($F(4, 1644)= 4.02$, $p= 0.003$) and age ($F(4, 1644)= 80.71$, $p<0.001$) on visual function were significant.

3.5.1. Effect of moving speeds of visual targets on visual performance

Visual performance for VA and CS as a function of target moving speed is presented in Figure 3.1. At zero target speed, representing the static visual function, the mean VA and CS were -0.14 logMAR and 1.94 log-unit respectively. As the target moving speed increased, both VA and CS significantly declined (VA: $F(3, 823)= 116.8$, $p<0.001$); CS: $F(3, 823)= 66.2$, $p<0.001$). Post hoc analysis revealed that the motion-induced visual deterioration was only found in targets moving at 30 deg/sec, but became plateau for targets moving at 60 or 90 deg/sec ($p>0.06$). This suggested that 30 deg/sec was the critical speed imposing significant deterioration in VA and CS.

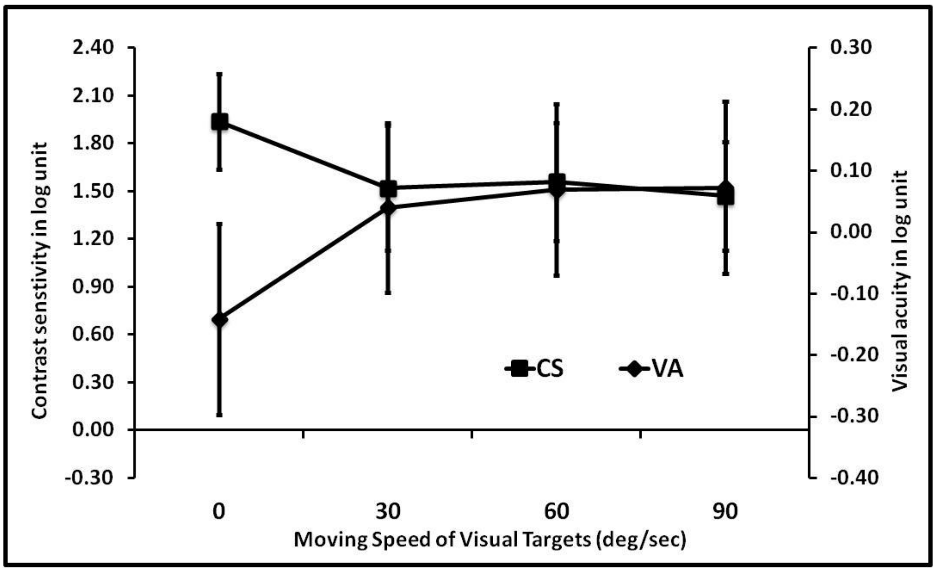


Figure 3.1. Visual acuity (VA) and contrast sensitivity (CS) measured at four moving speeds of visual targets. VA refers to the right y-axis, while CS refers to the left y-axis. Visual performance for targets at 0 deg/sec (i.e. static vision) was the best, compared with moving targets ($p<0.001$). Significant deterioration in VA and CS occurred for targets moving at 30 deg/sec, but no further decline was found for targets moving at 60 or 90 deg/sec.

3.5.2. Effect of body locomotion

Among the 3 types of body locomotion, optimal visual function was achieved in the sitting position, followed by stepping and walking. The impact of body locomotion on visual function was statistically significant ($F(4, 1644)= 4.02$, $p= 0.003$), but the difference in VA measured at different body locomotion was less than 0.05 logMAR (i.e. half of a line of VA). This difference was deemed clinically insgificant because the difference was smaller than the test-retest repeatability of VA measurements (Arditi and Cagenello, 1993). VA measured during walking (0.014±0.15 logMAR) was significantly worse than the sitting position (0.001±0.16 logMAR, $p<0.001$), but not when compared with stepping (0.007±0.16 logMAR, $p= 0.45$). However, body locomotion did not have any significant impact on CS ($p>0.10$), where the mean CS in sitting, stepping and walking was

1.62 ± 0.14, 1.65 ± 0.41 and 1.60 ± 0.15 log–unit, respectively. Since body locomotion did not significantly affect vision, the interaction effect between body locomotion and moving speed of visual targets was also insignificant ($F(12, 1644)= 0.73$, $p= 0.72$).

3.5.3. Effect of age group on visual performance

Figure 3.2 reveals the significant deterioration of vision among 3 different age groups, where both VA and CS were significantly poor in the old-aged, followed by middle-age and young-adult groups ($F(2, 823)= 159.8$, $p<0.001$ for VA; $F(2, 823)= 65.48$, $p<0.001$ for CS).

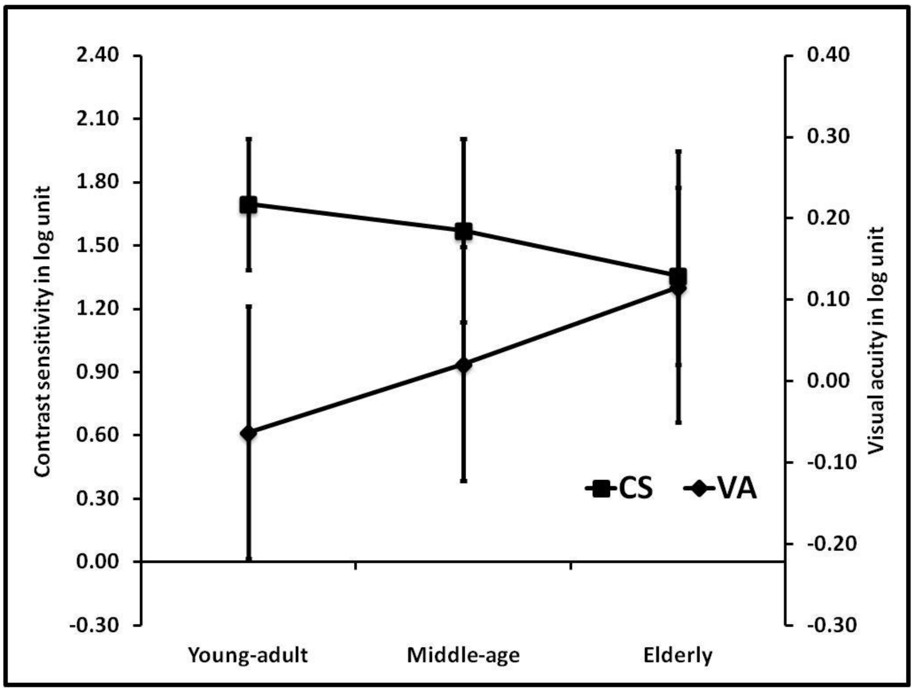


Figure 3.2. Visual acuity (VA) and contrast sensitivity (CS) in three age groups. VA refers to the right y-axis, while CS refers to the left y-axis. Significant differences were found in the visual performance among three age groups ($p<0.001$), where the performance in the young-adult group was the most superior, followed by the middle- and old-aged groups.

3.5.4. Interaction effects among age, moving speed and locomotion

No significant interaction effect in both VA and CS was found between: 1) age groups and target's moving speeds ($F(12, 1646)= 1.23$, $p= 0.26$); 2) age groups and body locomotion ($F(8,1646)= 1.25$, $p= 0.27$); and 3) age groups, target's moving speeds and body locomotion ($F(24,1646)= 1.25$, $p= 0.19$). First, the age-related decline in vision was similar for participants resolving stationary and moving targets (Figure 3.3). Further analysis using linear regression model showed that age could explain approximately 20% to 27% variance of VA and 7% to 21% variance of CS for targets moving at different speeds. Figure 3.4 illustrates the scatter plots of static and dynamic VA and CS as a function of age for participants in the sitting position. Anecdotally, stronger age-related decline was observed in the CS measured at 90 deg/sec, but the difference was not statistically significant ($p=0.06$). Second, no significant difference in age-related decline in vision was found among participants in sitting or moving locomotion ($F(12, 1644)= 1.23$, $p= 0.26$, Figure 3.5). Although visual function in the old-aged group appeared slightly better when participants were in sitting position rather than in locomotion, the difference was not statistically significant ($p>0.05$). Despite significant impacts of individual factor on visual function (target speed, body locomotion, age group), the interactive effect among these 3 factors was not significant ($F(24, 1644)= 1.25$, $p= 0.19$). Third, no significant interaction effect was found among target's moving speeds, body locomotion and age groups ($p=0.19$). This indicated that the impact of these 3 factors on visual function (VA and CS) was independent.

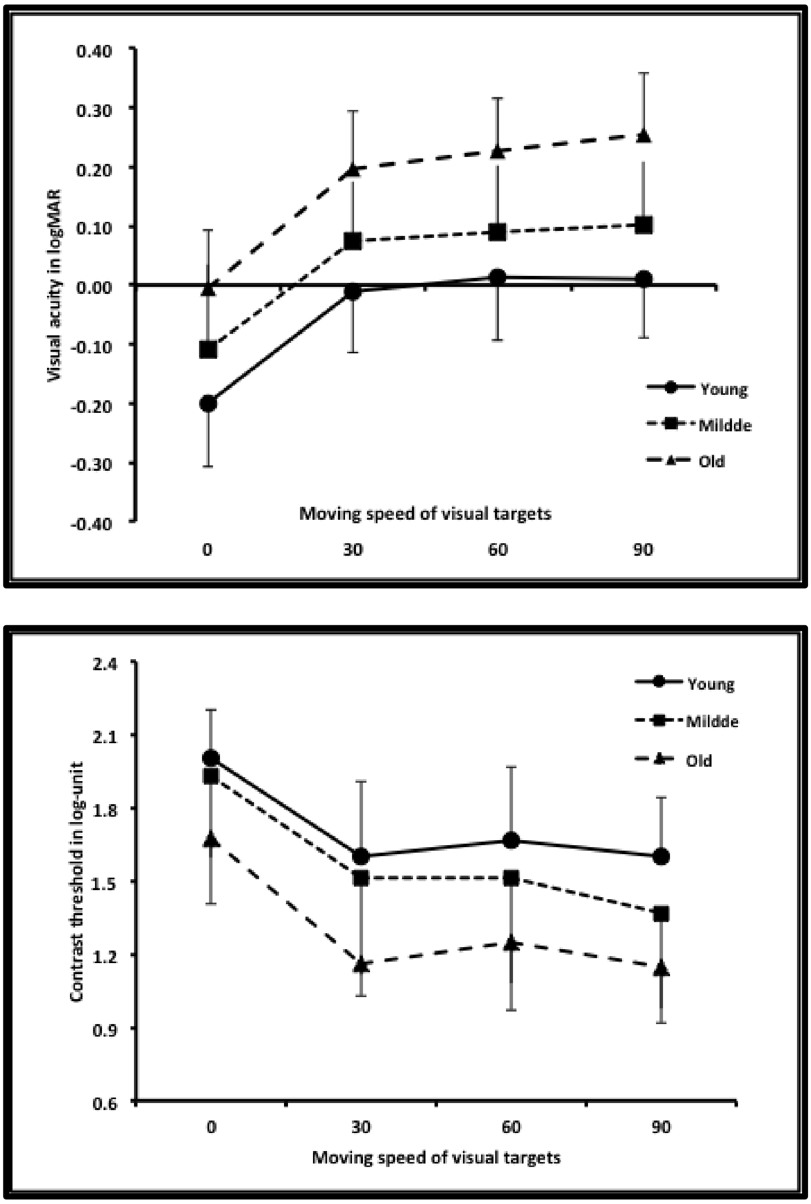


Figure 3.3. Effect of moving speeds of visual targets on visual acuity (VA, upper panel) and contrast sensitivity (CS, lower panel) among three age groups. Error bar represents the standard deviation. Age-related decline in visual function was similar for visual targets moving at different speeds.

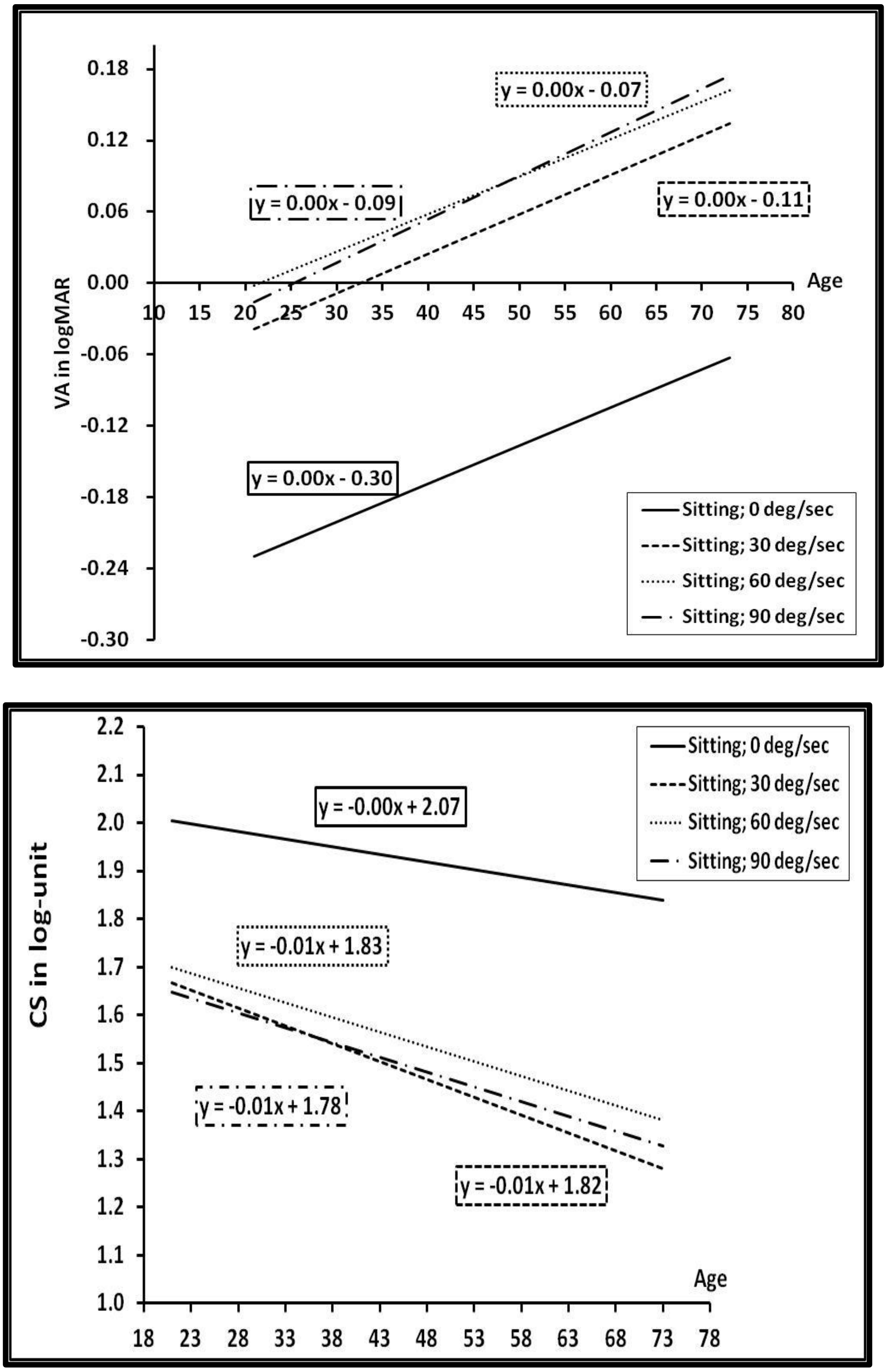


Figure 3.4 Visual acuity (VA, upper panel) and contrast sensitivity (CS, lower panel) measured at four moving speeds (0, 30, 60 and 90 deg/sec) were plotted against age (participants were in a sitting position). Given that there were too many data points in this scatter plot, only the regression lines fitted for each moving speed are illustrated.

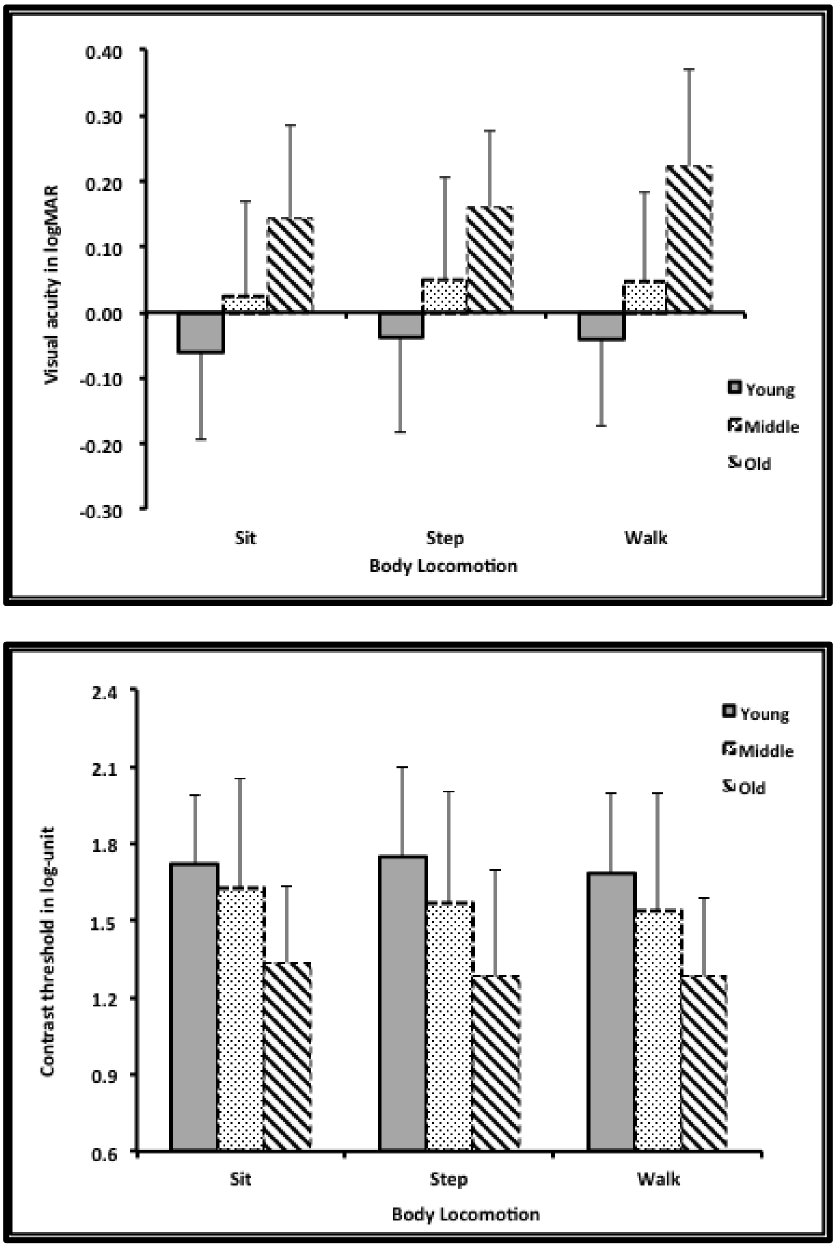


Figure 3.5. Effect of body locomotion on visual acuity (upper panel) and contrast sensitivity (lower panel) among three age groups. Error bar represents the standard deviation. The age-related changes in visual functions were similar among three types of locomotion.

3.6 Discussion

There are many factors affecting visual functions in human, which can be broadly categorized into 3 components: 1) human's optical and neural factors (e.g. refractive errors, pupil size); 2) physical and environment factors (e.g. illumination, contrast lighting); and 3) participant's physical and psychological factors (e.g. age, attentional demands). Our study investigated how the following 3 factors affect visual functions – visual stimuli's moving speed, participants' body locomotion and age.

3.6.1. Effect of stimuli's moving speed on visual function

Participants' visual ability to resolve moving objects was significantly worse than the ability to resolve stationary objects. However, the speed-induced vision deterioration was different for objects moving at different speeds, where VA and CS were substantially degraded for resolving targets moving at 30 deg/sec, but gradually reached a plateau when the moving speed increased further to 60 or 90 deg/sec. Our results were in contrast with previous findings, where visual function was not affected at relatively low velocities, but declined rapidly at higher velocities (Ludvigh and Miller, 1953, 1958, Miller and Ludvigh, 1957, Miller, 1958, Demer and Amjadi, 1993, Ludvigh, 1949, Miller, 1956). These studies revealed a more linear decrease in velocity-dependent visual function between consecutive speed levels, demonstrating that observers could resolve the target only if the size or contrast level of moving objects was sufficient. The "exponential" relationship between visual function and visual stimuli's moving speed shown in our study could be described as "velocity resistant" where vision was less susceptible to higher velocity targets (Miller and Ludvigh, 1957). Two plausible reasons might explain such discrepancy in our study.

First, there were some methodological differences in presenting moving targets. Majority of previous studies (in particular those studies published before the millennium year) used mechanical method to project a moving object onto a mirror mounting onto a variable speed turntable. The mirror then reflected the image of the target onto a screen. It is possible that the contrast level of the target presented by projector or mirror might not be optimal, but this setting facilitated the continuous motion of target stimuli. In contrast, our study presented a moving object using a computer programming on a high-resolution LCD monitor with special resolution of 1920x1080 and temporal resolution of 90Hz. In contrast with real moving objects, presenting object motion in monitor was a time-series of still shots, depending on the refresh rate of the monitor to update the information in the moving object. In our study, the refresh rate of the monitor was relatively low, rendering a new frame every 11.1 ms, in which the fine-gained changes in the alteration rate of a visual stimulus might be affected. Hence, the fast moving object (e.g. speed of 90 deg/sec) might not move smoothly through the space, resulting in motion artifacts including judder (inconsistent or jumpy rather than continuous aliasing movements) and motion blur (edge of the object getting blurred) (Johnson et al. 2014), which corresponded to the findings by Brown (Brown 1972a) and Methling and Wenicke (Methling and Wenicke 1968), in the area of image stabilization by pursuit eye movement.

Second, the free-head viewing allows the participants to create their own motion relative to the targets. Previous studies have shown that dynamic vision is better (e.g. resolve smaller moving object) under the free-head condition (Weissman and Freeburne, 1965, Long and Riggs, 1991, Long and Rourke, 1989). The benefit of free-head movement is more pronounced for targets of faster velocities and longer exposure duration. Hence, adopting the free-head movement and longer exposure duration (600 ms) at faster speeds might benefit the performance to resolve fast moving objects, resulting in less significant deterioration in dynamic VA and CS.

3.6.2. Effect of body locomotion on visual function

Effect of body locomotion had very little impact in VA but not in CS, where only 0.01 logMAR decreased for participants in locomotion (stepping and walking) compared with sitting. This suggested that vision was less susceptible to body movements (sitting, stepping or walking). Our finding was consistent with the study by Peters and Bloomberg (2005) who found no difference in distant VA when the participants were standing and walking on a treadmill with the speed of 1.79 meter/second (Peters and Bloomberg 2005). During walking and stepping, our body locomotion might interfere with the stability of the retinal image. However, our vestibular-ocular reflex (VOR) system allows us to maintain a stable retinal image by compensating for the head movement during locomotion and triggering the corresponding eye movements opposite to the direction of head movement (Grossman et al. 1989, Bloomberg et al. 1992). Thus, visual reference point can be kept at the central visual field (i.e. at macula). In our study, all participants were healthy without vestibular problem, thus it was not surprising that there were very little differences in visual performance during locomotion. In addition, the angular movement of visual stimuli observed by the participants was very small because they were presented on the monitor located at 4.8 m away. Unlike Peters and Bloomberg’s (2005), this small angular movement of retinal image had little interference on visual function.

3.6.3. Effect of age on visual function

In line with previous large-scale studies (Ishigaki and Miyao 1994, Burg 1966, Scialfa et al. 1988, Long and Crambert 1990, Rine and Braswell 2003), our results showed that visual function in the young-adult group was the most superior following by middle- and old-aged groups. Age could explain slightly more variances of dynamic vision (19 to 27% of dynamic VA; 9 to 21% of dynamic CS) than static vision (20% of static VA; 7 % of static CS). We expected stronger detrimental change in dynamic vision than static vision in the older adults because of 2 reasons: 1) reduced retinal illumination due to optical degradation in old people (e.g. smaller pupil size or aging crystalline lens) affected their dynamic visual function (Long and Crambert 1990); and 2) deterioration in oculomotor function (e.g. increase in eye movement latency, under-shooting and over-shooting) in aging population contributed to the decreased ability to track and resolve moving objects. However, our study did not agree with our hypothesis and found no differences in the detrimental change between static and dynamic vision in the older adults (i.e. no significant interactive effect between age groups and target's moving speed). Two plausible reasons might explain our findings.

First, increase in target luminance by approximately 3 folds (from 35 to 105 cd/m^2) could improve performance in dynamic vision in old-aged group, so the dynamic vision in the old-aged group was similar to that of young-aged group. Similarly, Ueda and colleagues found that increase in the luminance of environment (e.g. the luminance at working places and the lightings at highways) improved older adults' dynamic visual performance (Ueda et al. 2006, Ueda et al. 2007). In our study, the luminance of the testing environment was about 100 cd/m^2, implying that the strong luminance might optimize the dynamic vision in the old-aged group. Second, despite intensive studies revealed significant impediment in smooth eye movements of oculomotor function in aging population (Sharpe and Sylvester 1978), a recent study by Dowiasch et al. (2015) reported that the age-related oculomotor deficit was found only during tracking a spontaneously-moving target, but not tracking a pursuit-moving target when participants were asked to walk down a hallway. They proposed that additional sensory cues in real world such as head-movement or vestibular signals might partially compensate for the age-related effects in early motion processing, reducing the effect of age on oculomotor movement. Hence, it is possible that these additional sensory cues also compensated for our older participants' deteriorated dynamic vision when they were asked to recognize a horizontally moving object of different sizes or contrasts during different body locomotion.

Since older people are more vulnerable to dual-task impairments as they have more difficulty to divide their attention between tasks (Green and Bavelier 2006), we expected further deterioration in their dynamic vision during body locomotion, where participants were asked to resolve the visual stimuli while maintaining constant walking or stepping speed. Conversely, our study did not find significant interactive effect among age groups, body locomotion and target's moving speed. This implied that body locomotion did not further impede the deteriorated visual function in aging population. However, our findings might not be generalizable because of the small and perhaps biased sampling of older participants. In our study, participants were requested to perform vision recognition task in three types of body locomotion. Two of the locomotion tasks imposed significant physical challenges to older adults (continuous stepping on a step or walking on a treadmill). Hence, only a small group of participants who were active (85% participants reported regularly exercising 3 or more times per week) and relatively young (68.9 ± 2.6 years) were recruited. It is possible that their exercises (e.g. Tai Chi, regular jogging) might assist the participants developing some compensatory effect to track moving objects during body locomotion. However, further study on examining the relationship between types of exercises and dynamic visual function in large-scale older population is needed.

3.7 Conclusion

This study examined the effect of 3 factors on visual functions. We found significant effects of stimuli's moving speed and age on visual performance. The deteriorated visual performance with increasing age and moving speeds likely related to the decrease in the ability to stabilize the visual information when viewing fast moving targets. In contrast, very little impact of body locomotion was found in resolving stationary and moving objects, where visual function was only slightly better (statistically but not clinically significant) when the participants were sitting rather than in locomotion (walking or stepping). The impacts of these factors on visual function were independent, without any significant interactive effect.

Chapter 4

Relationship between Vision and Balance in Static and Dynamic Approaches

Chapter 4

Relationship between vision and balance in static and dynamic approaches

Objectives:

- To investigate the effect of age on dynamic vision and balance performance
- To establish the correlation between vision and balance in both static and dynamic approaches

Hypotheses:

- Significant aging effect was expected in dynamic visual and balance functions
- A robust relationship was established between vision and balance in the dynamic approach, where a person's dynamic vision could significantly predict his/her postural stability

4.1 Abstract

Introduction: Deteriorated visual function is one important risk factor for detrimental balance control in older adults. Most studies examined the relationship between static visual and balance functions, largely ignoring that between dynamic vision and balance. In this study, we examined dynamic visual function and its interaction with static and dynamic balance in young, middle-age and old-age people with normal vision.

Methods: Forty healthy participants with normal vision and aged between 20 and 80 years were recruited and divided into 3 age groups: 1) young-adult (n=16, 24.1 ± 3.9 years); 2) middle-aged (n=14, 56.8 ± 6.6 years); and 3) older-aged (n=10, 68.7 ± 3 years). Visual acuity (VA) was measured using Psykinematix for stimuli of different optotypes (H, O, T, V) moving at 5 different speeds (0, 15, 30, 60 and 90 deg/sec). Static balance was assessed where participants stood on firm and foam surfaces and fixated a central cross, and viewed the randomly moving targets with and without decision making accordingly. Dynamic balance was measured using limits of stability test where the participants were asked to make a corresponding weight shift as maximal as possible within their base of support to eight positions where individual stimulus representing the weight shift at a particular position was shown in the monitor.

Results: VA significantly deteriorated for recognizing stationary and moving objects as the speed increased ($p<0.001$). However, such deterioration reached a plateau when the moving speed reached 15 to 30 deg/sec, where the young group outperformed the middle-age and older-age groups ($p<0.05$). Standing on a compliant foam surface imposed significant impediment on postural control ($p<0.05$). Only dynamic balance (not static balance) was significantly impaired in the middle- and older-age groups ($p<0.05$). Multivariate analyses showed that static and dynamic vision could significantly correlate with dynamic balance ($p<0.05$), but not with static balance.

Conclusion: As a consequence of aging, visual functions in both static and dynamic were significantly deteriorated. Contrary to our hypothesis, age-related decline was only found in dynamic balance function. In addition to age, a much stronger relationship was established between dynamic vision and dynamic balance, implying that a person with poor dynamic vision has weaker dynamic balance control.

4.2 Introduction

Age-related declines in visual function may lead to functional difficulties in daily performance (Land et al. 1999), including orientation and mobility (Hassan et al. 2002, Turano et al. 2004, Rietdyk and Rhea 2011), face recognition (Lott et al. 2005, McCulloch et al. 2011), scene recognition (Angelaki and Hess 2005), balancing (Simoneau et al. 1992, Elliott et al. 1998, Marsh and Geel 2000, Anand et al. 2003, Heasley et al. 2004, Prado et al. 2007, Uchiyama and Demura 2008) and functional reach (Duncan et al. 1990, Juras et al. 2008). However, the majority of these studies focused on individual's visual functions for stationary rather than moving targets. As many real-world tasks involve relative movement between the targets and observers, exploring an individual's dynamic visual function (i.e. ability to resolve moving targets) is essential to obtain a complete picture of our visual system.

Due to age-related deterioration in physical, sensory and cognitive functions, older adults' performance in instrumental tasks of daily activities gradually deteriorates with age, balance-control being one of the significantly deteriorating areas. Balance control can be assessed in terms of postural stability. For a person with poor postural stability, he/she sways remarkably more, further impairing the postural control and may ultimately lead to falls. Studies have found that deteriorated visual function is one of the important risk factors for the detrimental balance controls in older population (refer to Black and Wood (2005) for a review). Most studies examined the relationship between static visual and balance functions, covering little on that between dynamic visual and balance functions. Freeman and colleagues (2006) revealed that elderly with poor dynamic visual functions had more difficulty with activities involving vision. Due to different underlying expectations and experiences among participants, self-reported difficulties might not agree with the measured objective findings for performance. The lack of direct comparison of visual and functional performance limits our understanding of the difficulties experienced by the elderly in their daily activities. In this study, various aspects of dynamic visual and balance performance of community-dwelling elderly were examined.

Static balance has been widely studied by asking the participants to fixate a target while measuring the postural sway on a force platform (Directions 1983). To better reflect a person's ability encountered in daily life, dynamic balance function should also be examined. In the literature, dynamic balance measures can be measured using the following methods: 1) voluntary weight shift to a designated direction: star excursion balance test (Gribble and Hertel 2003, Clark and Rose 2001) or limit of stability test (LOS, Liston and Brouwer 1996, Clark et al. 1997, Clark and Rose 2001, Girardi et al. 2001, Wallmann 2001, Juras et al. 2008, Liaw et al. 2009, Salehi et al. 2010, Rafał et al. 2011); 2) functional reach assessment (Duncan et al. 1990, Juras et al. 2008); 3) single leg support: examining the flexion-extension and abduction-adduction while stepping onto a force platform (Hill 1996, Hatzitaki et al. 2002); 4) lower limb strength and its maintenance: swaying platform (Liaw et al. 2009) and jump protocol (Wikstrom et al. 2004). Among these 4 types of dynamic postural stability measure, LOS is one of the most common tests which measures a person's maximum excursion distance (or endpoint excursion), directional control, movement velocity, reaction time, stability angle without moving the feet or losing the balance. This test has been confirmed to produce a reliable measure with excellent intraclass correlation (Liston and Brouwer 1996, Clark et al. 1997, Clark and Rose 2001, Girardi et al. 2001, Wallmann 2001, Juras et al. 2008, Liaw et al. 2009, Salehi et al. 2010, Rafał et al. 2011). In addition to static balance measure, LOS test was included in our study as a dynamic balance measure, adopting the protocol as listed in Sensory Organization Test (SOT) (NeuroCom 2012). Our study was aimed to explore the relationship between vision and balance functions, in both static and dynamic aspects.

4.3 Methodology

4.3.1. Participants

Forty participants with normal vision were recruited from The Hong Kong Polytechnic University campus and optometry clinic using convenient sampling. In accordance to their age (Spirduso et al. 2005), participants were divided into three age groups: 1) young adults (21 – 40 years, 24.1 ± 3.9 years, n=16); 2) middle-age (41 to 64 years, 56.8 ± 6.6, n=14); and 3) older-age (65 years or above, 68.7 ± 3 years, n=10). Inclusion criteria were the same as those listed in Chapter 3.3. Since this study imposed some physical challenges, only participants were reported physically fit were included. Informed consent was obtained in accordance with a protocol approved by The Hong Kong Polytechnic University Human Research Ethics Committee and this study followed the tenets of the Declaration of Helsinki. All assessments were conducted in the same day.

4.3.2. Vision measure

The test stimuli for visual acuity (VA) were similar to the experimental settings described in Chapter 3.3. Five moving speeds were adopted in this study - 0, 15, 30, 60 and 90 deg/sec. Our previous study confirmed that vision was less susceptible to body movements (sitting, stepping and walking), where less than 0.013 logMAR difference in VA was found among different types of locomotion (refer to Chapters 3.5.2 and 3.6.2). Due to such a small (clinically insignificant) difference in VA, all vision measures were conducted in a sitting position (refer to Chapter 3.3.3.3 for the procedures).

4.3.3. Balance measures

Balance function was measured in terms of postural sway assessments while participants stood on a force platform (Kristler, Type 9286AA, 400 mm (length) X 200 mm (width)). This was a standard measurement of body sway (Berg 1989, Yelnik and Bonan 2008), where the data was sampled at a frequency of 100 Hz.

Displacements of centre of pressure (COP) in the anterior-posterior (A-P) and medial-lateral (M-L) directions (Tsang and Hui-Chan 2003, Tsang and Hui-Chan 2004a, Tsang and Hui-Chan 2004b, Tsang et al. 2004) were derived in the conditions described below.

4.3.3.1. Static balance measure

Static balance performance was measured for the following parameters: a) two standing surfaces (firm and foam); and b) three types of visual tasks (central fixation, visual tracking a random moving target and a horizontally moving target with decision making). The purpose of using two standing surfaces was to compare the balance functions on normal standing (i.e. bare platform) and compliant standing (i.e. standing on a foam surface with the same dimension as the force platform and medium density of 23-130 gram/cm^3). The purpose of using three types of visual tasks was to compare the balance functions while pursuing simple fixation and visually integrated tasks (which required participants' higher level cognitive function such as visual attention). All visual stimuli were presented on a high-resolution LCD monitor (Sunway DI−40035D) at 2 m away, with luminance output of 700 cd/m^2 with contrast ratio of 3000:1 and refresh rate of 120Hz. Details of these visual tasks are provided below (Figure 4.1).

First, participants were asked to fixate a cross (subtending 2.8 deg) for 15 seconds. This task served as the baseline measurement. Second, participants were asked to visually track a randomly moving target – a letter "O" subtending 2.8 deg with very minimal head movement during balance. The rationale of using visual tracking was to simulate a person looking at a moving object while maintaining balance on an uneven street – a common dual task occurred in daily life (see Green and Bavelier 2006, Beauchet et al. 2009 for a review). The target randomly moved within a visual angle of 60 x 40 deg at two frequencies – 0.5 and 1 Hz. Third, participants were asked to visually track a horizontally moving target with decision-making requirement. This task simulated a person standing on an uneven street and looking for his/her friend who was walking into a busy street. Ten simple video sequences of 15 seconds each, containing 4 moving white cups and 1 red ring, were prepared. The ring was placed under one of the 4 cups and those cups moved around for 15 seconds. Participants were required to track the ring and determined which cup it ended up under. The cups moved within horizontal dimension of 60 deg at 2 frequencies - 0.5 and 1 Hz. Accuracy of recognition was recorded. Sequence of movie clips was randomly selected.

All static balance measures were repeated for three times and the order of trials was randomized across participants. In each measure, participants were instructed to stand barefoot on the force platform with their feet at shoulder-width and their arms along their sides, and maintain their body posture as steady as possible for 15 seconds. No interaction between the participant and examiner was allowed during measurement. Body sway in A-P and M-L (mm) and total sway area in terms of bivariate contour ellipse area (BCEA - an ellipse including 68% of the sway data, mm^2) were calculated (Steinman 1965, Duarte and Zatsiorsky 2002, Tsang and Hui-Chan 2003, Tsang and Hui-Chan 2004a, Tsang and Hui-Chan 2004b, Tsang et al. 2004, Dunbar et al. 2010).

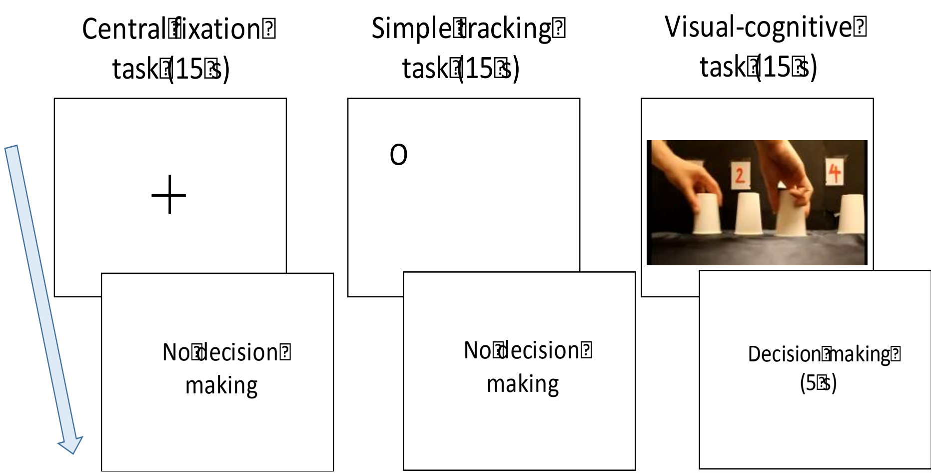


Figure 4.1. Three visual tasks in static balance measure.

4.3.3.2. Dynamic balance measure

Dynamic balance was measured in terms of limits of stability (LOS) by asking participants to make a corresponding weight shift in eight positions (front, right front, right, right back, back, left back, left and left right) whenever an individual stimulus at a particular position was shown. Participants had to shift their weight as maximally as possible without uplifting their heels and moving their foot for 100% LOS. This measure has been widely used and confirmed as a reliable test to assess the dynamic balance function in older adults (Liston and Brouwer 1996, Clark et al. 1997, Clark and Rose 2001, Girardi et al. 2001, Wallmann 2001, Juras et al. 2008, Liaw et al. 2009, Salehi et al. 2010, Rafał et al. 2011).

Dynamic balance measure was repeated for three times. In each measure, participants were instructed to keep their body in a straight line and use an ankle strategy rather than a hip strategy (i.e. use their ankle joints as the primary axis of motion) to move towards each designated target as directly and as far as possible without changing their base of support. Participants were asked to hold the lean position (at each target position) until their stability was achieved.

Four parameters were derived for each movement direction. First, “maximum excursion distance” referred to the maximum distance travelled by the COP within the trial (i.e. the maximum distance travelled by the participant without losing balance). Second, “directional control” measured the smoothness of the displacement of the COP toward the target position in terms of percentage of accuracy (DC ratio). A person who could manage more direct COP movement to the target direction obtained a higher directional control (Clark et al. 1997). Third, reaction time (in ms) referred to the duration between the presentation of a visual cue and onset of voluntary shifting of the participant’s COP towards the designated target. Fourth, stability angle (or maximum body sway angle) with respect to the normal standing position was calculated based on participant's body height and the maximum excursion point, assuming that the centre of mass was set at 55% of body height and angle of forward leaning from the vertical direction was 2.3 deg.

Stability angle = $\sin^{-1}$(0.55 x Body height) - 2.3 deg, where 2.3 deg was the forward lean contributed by the ankles from the vertical direction.

4.4 Statistical analysis

All data were analyzed by IBM statistical package software version 19 (SPSS 19). Given that all variables were not significantly different from normal distributions (confirmed by one-sample Kolmogorov–Smirnov test, $p>0.05$), MANOVA was used to examine the effect of each composite variable on visual and balance performance. First, effects of target's moving speed and age groups on visual acuity were examined (5 speeds x 3 age groups). Second, effects of standing surface, nature of visual tasks and age groups were evaluated on static balance function (2 surfaces x 3 visual tasks[d] x 3 age groups), but only effect of age groups on dynamic balance function was examined. Pearson product-moment coefficient of correlation test was conducted to study the relationship between vision and balance in static and dynamic manners. A p-value of <0.05 was considered as significant, in which the p-value would be corrected in case of multiple comparison.

4.5 Results

4.5.1. Effects of moving speed and age on visual acuity

Similar to the findings in Chapter 3 (refer to Chapter 3.5), results from MANOVA showed significant effects of target's moving speed ($F(8, 366)= 61.18$, $p<0.001$) and age groups ($F(4, 366)= 55.66$, $p<0.001$) on distance VA. Post hoc analysis revealed that the

[d] Targets of two moving speeds were adopted in the simple tracking and visual-cognitive tasks. However, balance performance while tracking the slow and fast moving targets was not significantly different ($F(3,294)= 0.61$, $p= 0.61$). Hence, the balance performance measured at 2 speeds was averaged.

significant deterioration of VA was found in targets moving at 15 deg/sec (0.07 ± 0.15 logMAR), compared with the VA for resolving a stationary target (-0.17 ± 0.12 logMAR, p<0.001). When the moving speed of the visual targets further increased from 15 deg/sec onwards, there was no significant change in the VA (0.06 ± 0.12, 0.08 ± 0.13 and 0.09 ± 0.13 logMAR for targets moving at 30, 60 and 90 deg/sec respectively, p>0.50). Among the 3 age groups, distance VA in the young-group (-0.04 ± 0.13 logMAR) outperformed the middle-age group (0.01 ± 0.14 logMAR) which was also significantly better than the older-age group (0.16 ± 0.15 logMAR, p<0.05). However, the interaction effect between target's moving speed and age groups was not significant (F(16, 366)= 1.06, p=0.39), indicating similar speed-induced deterioration in VA among three age groups (Figure 4.2).

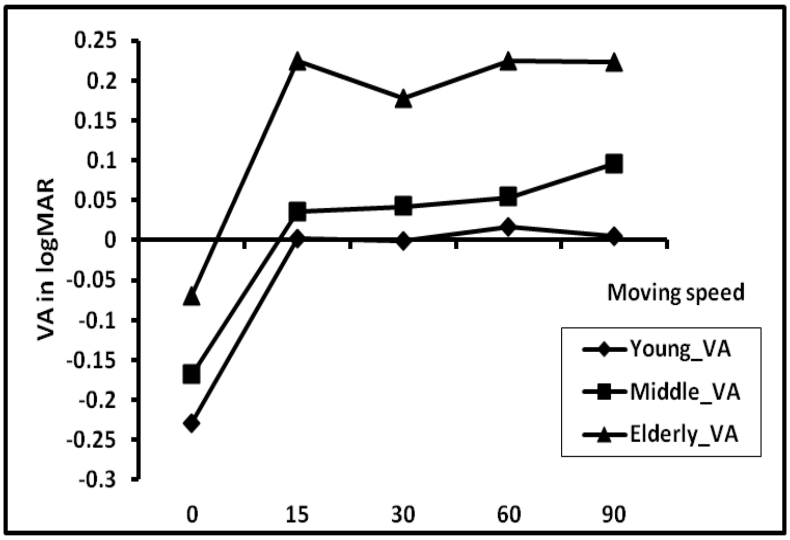


Figure 4.2. Distance visual acuity (VA) in terms of logMAR was plotted against visual targets of different moving speeds in 3 different age groups. Error bars are not shown for the ease of presentation.

4.5.2. Factors affecting static balance function

Results from MANOVA reflected significant main effects of standing surfaces (F(3, 220)= 94.5, p< 0.001), nature of visual tasks (F(6, 438)= 2.82, p= 0.01) and age groups (F(6, 438)= 4.34, p< 0.01) on static balance function. No significant interaction effect was found between: 1) standing surfaces and nature of tasks ($F(6, 438)= 1.17$, $p= 0.32$); 2) standing surfaces and age groups ($F(6, 438)= 1.78$, $p= 0.10$); 3) nature of tasks and age groups ($F(12, 656)= 0.4$, $p= 0.97$); and 4) standing surfaces, nature of tasks and age groups ($F(12, 656)= 0.38$, $p= 0.97$).

Univariate analysis was then performed to examine the impact of each effect on balance function. First, balance performance was significantly deteriorated when participants stood on foam surface, where they swayed significantly more in both A-P ($F(1, 222)=167.1$, $p< 0.001$) and M-L planes ($F(1, 222)= 185.9$, $p< 0.001$), resulting in larger sway area ($F(1, 222)= 102.1$, $p< 0.01$, Table 4.1). Second, among the three visual tasks, balance performance was the best when participants engaged in "visual-cognitive task", rather than simple fixation or simple tracking task. However, such significant difference was only found in the A-P plane ($F(2, 222)= 4.89$, $p= 0.01$), but not in the M-L plane ($F(2, 222)= 2.62$, $p= 0.08$) or total sway area ($F(2, 222)= 2.45$, $p=0.09$, Table 4.2). Third, no significant difference among the 3 age groups was found in the A-P ($F(2, 222)= 2.58$, $p= 0.08$) and M-L planes ($F(2, 222)= 1.62$, $p= 0.2$) and total sway area ($F(2, 222)= 0.19$, $p= 0.83$, Table 4.3). It was surprising that static balance function was not significantly different among 3 age groups when this factor was separately analysed using univariate analysis (compared with multivariate analysis).

Table 4.1. Effect of standing surfaces on balance performance. Mean ± Standard error.

	Firm surface	**Foam surface**
Anterio-posterior(A-P) movement (mm)	**12.1 ± 0.4**	**22 ± 0.6***
Medio-lateral (M-L) movement (mm)	**6.4 ± 0.3**	**14.2 ± 0.5***
Sway area in terms of 68% BCEA (mm^2)	**31.9 ± 2.8**	**123.3 ± 8.3***

Asterisk * indicates the significant difference of balance performance between standing surfaces.

Table 4.2. Effect of visual tasks on balance performance. Mean ± Standard error.

	Fixation	**Simple tracking**	**Visual-cognitive**
Anterio-posterior (A-P) movement (mm)	18.3 ± 1	17.4 ± 0.8	**15.4 ± 0.8***
Medial-lateral (M-L) movement (mm)	10.8 ± 0.6	10.8 ± 0.7	9.3 ± 0.6
Total sway area in terms of 68% BCEA (mm^2)	82.3 ± 9.3	87.5 ± 10.7	62.9 ± 6.9

Asterisk * indicates the significant difference of balance performance when participants engaged in a specific visual task.

Table 4.3. Effect of age groups on balance performance. Mean ± Standard error.

	Young-adult	**Middle-age**	**Older-age**
Anterio-posterior (A-P) movement (mm)	16.4 ± 0.8	18.2 ± 0.9	16.5 ± 0.8
Medio-lateral (M-L) movement (mm)	10.1 ± 0.6	9.9 ± 0.7	11.2 ± 0.7
Total sway area in terms 68% BCEA (mm^2)	76.8 ± 9.1	81.0 ± 9.7	74.1 ± 7.3

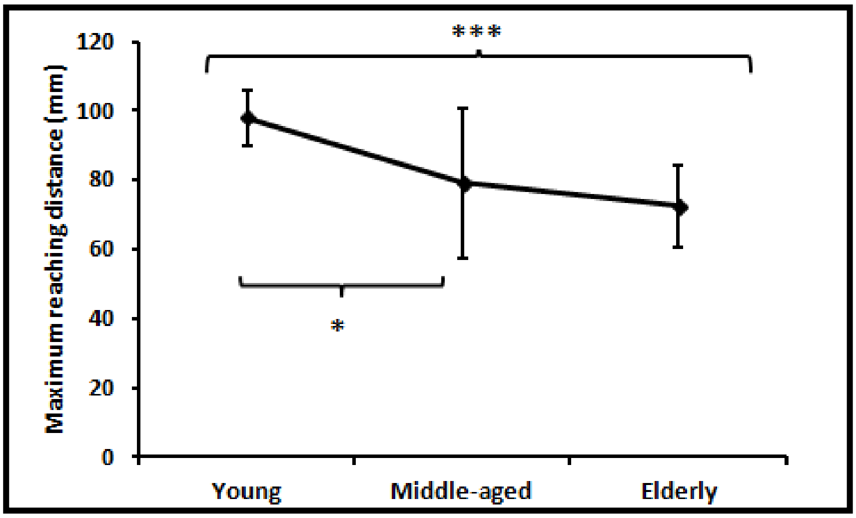
4.5.3. Factors affecting dynamic balance function

To simplify the statistical analyses, four parameters (maximum excursion distance, directional control, reaction time, stability angle) derived in the LOS measuring in eight positions (front, right front, right, right back, back, left back, left and left right) were averaged. Given that the separation between two medial malleoli was not significantly different among the 3 age groups ($F(2, 37)= 1.67$, $p= 0.2$), this variable was not considered as a covariate in the MANOVA. Results from the MANOVA showed significant effect of age on all 4 parameters in the LOS ($F(8, 66)= 4.75$, $p<0.001$). Further univariate analysis showed that the age effect for individual parameter was different. The maximum excursion distance in the young-adult group was significantly longer than the middle-age and older-age groups by an average of 18.7 mm and 25.4 mm respectively ($F(2, 37)= 10.79$, $p<0.001$, Figure 4.3a). Directional control (i.e. the accuracy in moving to specific direction) in the young-adult group was significantly better than the middle-age group by an average of 10% ($F(2, 37)= 3.41$, $p= 0.04$). Surprisingly, directional control in the older-age group was not significantly lower than the young-adult or middle-age groups ($p> 0.05$, Figure 4.3b). Reaction time for the young-adult group was longer than middle-age and older-age groups by an average of 240 and 247 ms respectively ($F(2, 37)= 13.71$, $p<0.001$, Figure 4.3c). Stability angle for the young-adult was significantly larger than for the middle-age and old-age groups by an average of 1.1 deg ($F(2, 37)= 7.9$, $p= 0.001$, Figure 4.3d).

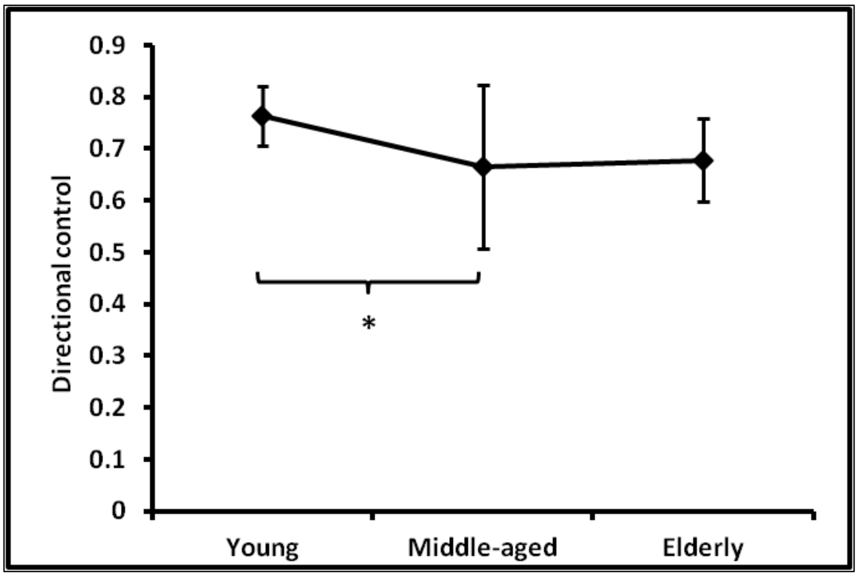
4.5.4. Relationship between vision and balance functions

Vision and balance performance was measured in both static and dynamic aspects. To simplify the statistical analyses, dynamic grating acuity (at 30 deg/sec) was selected to compare with balance function. Table 4.4a and 4.4b reveal the correlation between vision and static balance and dynamic balance function respectively. In general, very weak correlation was found between static balance and visual function ($p>0.05$, Table 4.4a). Although standing on the foam surface significantly deteriorated an individual's balance function, the relationship between vision and balance function on both standing surfaces was very weak. Engaging in different visual tasks was also another factor affecting standing, but the relationship between balance function measured with different visual tasks was insignificantly correlated with vision. Both findings suggested that vision contributed very little to our balance system in a static balance environment. Contrary to the static balance, the correlation between dynamic balance and visual function was stronger (Table 4.4b). Among the 4 parameters in dynamic balance, maximum excursion distance and reaction time it was significantly and inversely correlated with both static and dynamic vision ($p< 0.05$).

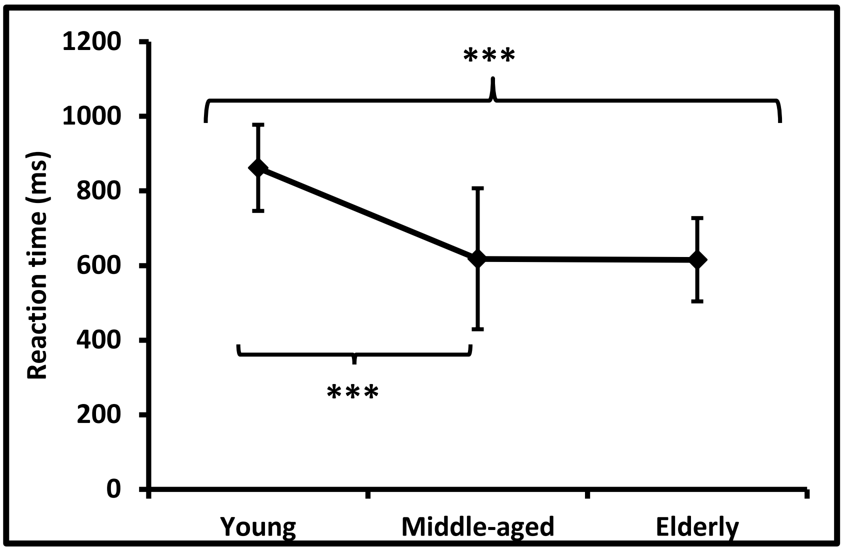
(a) Maximum excursion/reaching distance



(b) Directional control



(c) Reaction time



(d) Stability angle

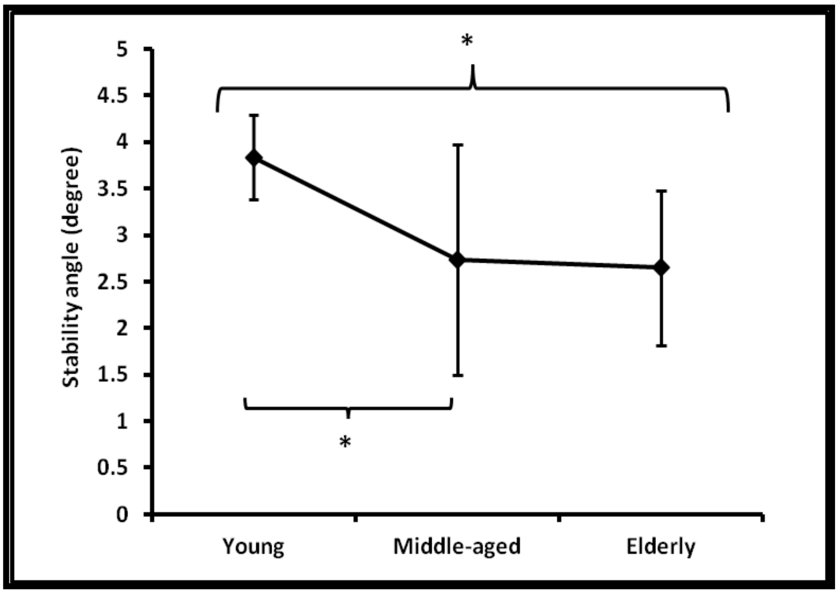


Figure 4.3. Four parameters derived in the Limit of Stability for dynamic balance measure among 3 age groups: (a) Maximum excursion/reaching distance (mm); (b) Directional control; (c) Reaction time (ms); (d) Stability angle (deg). Error bar refers to the standard deviation. Asterisk * and *** refer to the statistical significance of $p<0.05$ and $p<0.001$ respectively.

Table 4.4a. Correlation between the static balance and visual performance (for resolving a stationary target (i.e. static visual acuity (SVA) or a moving target at 30 deg/ sec (i.e. dynamic visual acuity (DVA)).

		Firm standing surface			Foam standing surface		
		M-L	**A-P**	**Total sway area**	**M-L**	**A-P**	**Total sway area**
Fixation task							
SVA	**r**	0.03	-0.02	0.07	0.01	0.00	-0.09
	p	0.84	0.90	0.65	0.97	0.98	0.59
DVA	**r**	0.07	0.16	0.16	-0.01	0.05	-0.04
	p	0.66	0.34	0.33	0.94	0.78	0.81
Simple visual tracking task							
SVA	**r**	0.00	0.04	0.00	0.20	-0.08	-0.01
	p	0.98	0.80	0.99	0.22	0.61	0.94
DVA	**r**	-0.05	-0.16	-0.08	0.19	0.06	0.14
	p	0.76	0.31	0.64	0.25	0.70	0.40
Visual-cognitive task							
SVA	**r**	0.19	**0.4***	0.26	-0.17	-0.26	-0.24
	p	0.24	**0.01***	0.10	0.30	0.11	0.14
DVA	**r**	-0.03	0.31	0.12	-0.16	-0.15	-0.17
	p	0.87	0.06	0.45	0.33	0.37	0.29

r= Pearson correlation coefficient; p= significance level.

Asterisk * indicates the significant correlation with p-value <0.05.

Table 4.4b. Correlation between the dynamic balance and visual performance (for resolving a stationary target (i.e. static visual acuity (SVA) or a moving target at 30 deg/ sec (i.e. dynamic visual acuity (DVA)).

		Max excursion distance (mm)	Directional control	Reaction time (ms)	Stability angle (deg)
SVA	**r**	**-0.33***	-0.17	-0.34	-0.26
	p	0.05	0.49	0.06	0.17
DVA	**r**	**-0.38***	-0.19	**-0.34***	-0.25
	p	**0.02**	0.25	**0.03**	0.11

3 parameters in static balance function - anterior-poster (A-P) and medial-lateral (M-L) movement and total sway area in terms of 68% BCEA were listed.

r= Pearson correlation coefficient; p= significance level.

Asterisk * indicates the significant correlation with p-value <0.05.

4.6 Discussion

4.6.1. Effect of age on visual and balance performance

As expected, age-related decline in visual function was found in both resolving stationary and dynamic visual stimuli, where young-adult outperformed the middle-age and older-age participants. In line with our previous results (refer to Chapter 3.5.4), the age-related decline in vision was similar for participants resolving stationary or moving targets. Our findings agreed with the results reporting in other epidemiology studies (Haegerstrom-Portnoy 2005), where visual function declined in the aging population. In contrast to many other aging studies in balance function (see Deandrea et al. 2010 for a recent review), our results only demonstrated significant aging effect in dynamic balance, but not in static balance function. It was surprising that the total sway area in the older-age group (74.1±9.1 mm^2) was smaller than the young-adult (76.8 ± 9.1 mm^2) and middle-age groups (81.0 ± 9.7 mm^2). Although this result was unexpected, reasons for the relatively good static balance performance in the older-age groups include the exceptionally good physical characteristics of the recruited older adults and the less challenging condition in static balance measure. First, participants (in particular the older adults) who reported physically fit were recruited. All recruited older adults reported regularly exercising three or more times per week. More importantly, 80% of them reported practicing Tai Chi on a regular basis (2 to 3 times a week) for a number of years. Tai Chi is a Chinese martial art, which has been recommended as a fitness exercise and is particularly popular among the elderly for many years. Extensive studies have shown that Tai Chi practitioners exhibit better balance control than the age-matched older adults from the general population without Tai Chi experience (Tsang and Hui-Chan 2003, Tsang and Hui-Chan 2004a, Tsang and Hui-Chan 2004b, Tsang et al. 2004). Therefore, the superior balance performance in the older-age group might be due to the high percentage of Tai Chi players. This also indicated that our findings might not be generalizable because of the small and perhaps biased sampling of the older participants. Second, in all static balance measures, the participants were required to stand barefoot on the force platform with feet at shoulder-width and their arms along their sides. This standing posture allowed the participants to stand with high confidence with better postural control.

In general, the dynamic balance function in the young-adult group was better than the other two age groups ($p< 0.001$). Our result corresponded to the literature (Liaw et al. 2009). More specifically, young participants could reach significantly farther distance with better directional control and larger extent of stability than the middle-age or older participants without losing their balance in the LOS test. Our findings partially agreed with the results in Liaw et al. (2009) where young adults had significantly better directional control than the older adults. In contrast, the young adults in our study required longer reaction time to initiate the voluntary shift in response to the visual cue. This finding was opposite to previous studies where reaction time in the older population was significantly decline (Liaw et al. 2009). The reason for the slow reaction time in the young-adult group was unclear. It is possible that the older participants' concerned more about their performance and more attentive in our study than the other age groups, reacting faster in the dynamic balance measure.

4.6.2 Establishing significant relationship between vision and dynamic balance performance

In our study, participants were asked to fixate a stationary or to track a moving object (random or horizontally moving) while maintaining balance on firm and foam surfaces. We expected a person with poor dynamic vision swayed more when he/she stood on the compliant surface and visually tracked a moving object (Schulmann et al. 1987). Contrary to our expectation, we did not find a significant relationship between static visual and static balance, and also between dynamic visual and static balance functions. This later finding was rather disappointing. Our negative finding might be attributed to the visual tasks adopted in this study. First, the tracking objects (in both simple tracking and visual-cognitive tasks) were large and moved relatively slow (i.e. small angular movement), compared with the speed of the moving gratings in the vision measure. Therefore, the visual tasks in the balance measure failed to provide a visually challenging environment, imposing a weak impact on the postural sway. Second, more attention was required to complete the visual-cognitive task. However, this increased attentive level improved an individual's balance performance (Marsh and Geel 2000). Future studies using visual tasks presenting in a random sequence or smooth movement without cognitive demand (at faster speeds) are needed to examine the relationship between dynamic vision and static balance function.

Our study found a significant correlation between vision and dynamic balance. Specifically, maximum excursion distance and reaction time were negatively correlated with both static and dynamic visual acuities. This suggests that a person with better vision (i.e. smaller acuity in terms of logMAR) can reach a farther distance and respond faster by initiating the voluntary body shift after presenting the visual cue. Vision could explain approximately 10 to 14% variances of these 2 dynamic balance functions. Although dynamic acuity could explain (12 – 15%) slightly more variances of the dynamic balance than static acuity (11%), the difference was rather small. Given that our living environment is full of dynamic visual information, measuring dynamic balance (e.g. weight shifting or voluntary movement) responding to moving visual stimuli might better reflect the balance functions in daily life and more closely relate to dynamic vision. However, participants in our study were asked to make a voluntary and corresponding weight shift to the direction of the visual cue. The visual cue in LOS was considered as a “static” rather than “dynamic” visual target. It is possible that dynamic vision might better correlate with dynamic balance if participants are required to shift their body weight to the position of a specific target which is spontaneously and randomly presented at different locations of the screen.

4.7 Limitation

As mentioned in the Discussion, the specific inclusion criteria in physical conditions applied in the older-age group might result in bias sampling. The majority of the participants in this age group were Tai Chi practitioners, a well-known exercise for improving postural control. Hence, the difference in physical characteristics of participants might be a confounding factor on balance function. During balance assessments, participants were asked to stand with their feet at shoulder-width. With increasing age, the protrusion of medial-malleoli balance became more obvious in the elderly than young adults (aging effect), affecting a person’s standing posture and region of COP. The potential difference in this standing posture might interfere the balance function in different age groups. To minimize this impact, all participants should stand with both feet together as tight as possible.

4.8 Conclusion

As a consequence of aging, visual functions in both static and dynamic were significantly deteriorated. Contrary to our hypothesis, age-related decline was only found in dynamic balance function, but not in static balance function. Several reasons had been suggested to explain the negative aging effect in the static balance function. Strong and significant relationship was established between vision and dynamic balance, implying that a person with poor vision has weaker dynamic balance control. Although more variances in dynamic balance could be explained by dynamic vision than static vision, the difference was rather small. Measuring the dynamic balance involving fixating or tracking spontaneously (randomly) presented visual stimuli might improve the relationship between dynamic vision and dynamic balance.

Chapter 5

Effect of Progressive Addition Lenses on Vision and Gait Performance in Naïve Older Adults

Chapter 5

Effect of progressive addition lenses on vision and gait performance in naïve older adults

Objectives:

- To compare static and dynamic visual performance in single vision lens (SVL) and progressive addition lenses (PAL) in older adults who had no prior experience in PAL wearing
- To investigate the differences in gait pattern and balance function in SVL and PAL wearing

Hypotheses:

- PAL significantly impaired the dynamic vision and dynamic balance, but not static vision and static balance
- More changes in the head adjustment during walking were expected in the PAL than SVL wearing
- Secondary visual task increased the cognitive demand and further impaired the gait performance in PAL wearing

5.1 Abstract

Introduction: Wearing progressive addition lens (PAL) provides clear vision for both distance and near. Despite significant improvement in modern design of PAL, peripheral distortion of lens cannot be totally eliminated. Previous studies showed that wearing PAL reduced the visual performance in depth perception and contrast aspect, further affecting accuracy of gait pattern in the presence of obstacles along the walk paths. However, little is known about the gait performance in naïve PAL wearers. In this study, we examined the effect of PAL on vision, balance and gait functions in people who were naive to PAL wearing.

Methods: Ten participants aged between 50 and 70 years were recruited, who were naïve in PAL wearing. Visual, gait and balance functions were measured for participants wearing newly prescribed single vision (SVL) and PAL. Static and dynamic visual function was assessed with visual targets presented stationary or moving in horizontal and vertical directions at 30 deg/sec. Vicon Motion System was applied to examine the gait function in 3 walking tasks. Gait functions in terms of required duration to complete the task and percentage of head angle change during the walking tasks were measured. Balance stability in terms of postural sway was measured by a force platform when participants solely stood on the platform (i.e. static balance) and completed a walking task and stepped one-step down onto the force platform (i.e. dynamic balance). Total sway area (mm^2), sway distance (mm) in A-P and M-L directions and time-to-stabilize (TTS) were computed.

Results: No significant difference in visual (static and dynamic vision) and gait performance (in terms of head angle and required time to complete each walking cycle in the task) was found in SVL and PAL ($p>0.05$ generally). However, participants wearing the PAL required significantly longer time to stabilize and had larger body sway area

(with significantly more sway along the lateral direction) after negotiating one-step down ($p<0.05$).

Conclusion: For naïve PAL wearers, their head angle adjustment and walking time during gait assessment were not significantly different from SVL wearing. However, more attention should be made to postural stability, in particular when the new PAL wearers negotiated descending stairs (i.e. step-down) or sudden change in the walking level. All new PAL wearers should be warned of the magnification changes with new spectacles and the visual disturbances induced by PAL. Educating the patients to use different parts of the PAL for stairs or obstacle negotiation and adopt a more conservative approach to maintain balance is important for the safeness of PAL wearing.

5.2 Introduction

As our population is aging, age-related decline in visual functions is inevitable. One of the common visual problems is “presbyopia” - a condition that involves a loss of accommodation capability to focus on close objects. Presbyopia is commonly seen in people starting from 40 years old (Hamasaki et al. 1956, Glasser and Campbell 1998). One of the reasons for presbyopia is due to the progressive loss of the crystalline lens’ elasticity, leading to the inability to change its shape for focusing on near objects. Progressive addition lenses (PALs) are commonly used as spectacle lenses to compensate for the decline in accommodation for obtaining clear vision at different viewing distances (Charman 2014). The acceptance and satisfaction rates for PALs have grown extensively in the past decades, in particular when more modern designs of PALs provide much easier adaptation. Despite the convenience advantages provided by the PALs, the optical imperfections inherent in the design of these lenses remain the major disadvantage. The unwanted and unavoidable aberrations in the peripheral zones of the lenses produce sensations of distortion, or apparent motion of the visual field (“swim”) when wearers move their heads. To minimize the effect of this unwanted astigmatic gradient for easier visual adaptation, modern PALs use a “softer” design, in which the unwanted astigmatic contours spread over larger areas of the front surface of the lens (Solaz et al. 2008). This design provides a wider and longer intermediate zone for mild and gradual change in power from distance to near vision. Despite substantial advancements in PALs’ design, some unwanted visual limitations such as peripheral spatial distortion in the inferior field across 225 to 315 deg (i.e. 4 to 8 o’clock region of the lens) still hinder wearers’ visual perception. Studies have shown that visual functions using PALs are impaired compared with single-vision lens (SVL), including depth perception, stereoacuity (Buckley et al. 2010), contrast sensitivity (Lord et al. 2002), interruption on lower visual field (Marigold and Patla 2008, Rhea and Rietdyk 2007). However, no studies have examined how visual disturbances induced by PALs affect our dynamic visual function (i.e. the ability to resolve moving targets). As many real-world tasks involve relative movement between the targets and observers, wearing PALs might have a stronger detrimental impact on an individual's dynamic visual function than static visual function.

Because of the diminished visual performance in PAL, the corresponding functional performances in managing daily tasks might also be affected, which predispose the wearers to potential hazards. Many PAL wearers report dizziness and visual fluctuations especially when walking (Faubert and Allard 2004). A number of studies have shown that wearing multifocal spectacles (progressive and bifocal lenses) significantly increases the risk of misjudging distances when negotiating underfoot hazards and stairs, tripping incidents and falls in older people (Lord et al. 2002). They found multifocal spectacle wearers were more than twice as likely to fall as non-multifocal spectacle wearers (Lord et al. 2002), even in long-term multifocal wearers (Timmis et al. 2010). The greater risk of falls was attributed to impaired contrast sensitivity and depth perception for detecting environmental hazards. Results from these studies highlighted the potential and important safety problems associated with wearing multifocal spectacles. However, these studies examined the association between functional performances and risk of falls in experienced-PALs and non-PALs wearers (Lord et al. 2002). Only a handful of studies have examined how functional performances change in naïve PALs wearers when they first experienced the PALs-induced visual disturbances and how these functional performances gradually change during adaptation (Hutchings et al. 2007). However, these studies only concerned about the effect of PALs on reading or computer work, which involve minimal locomotion. Recently, Beschorner et al. (2013) revealed that first-time PAL wearers made significant changes in their gait patterns during stepping by increasing their foot clearance over the step edges and slowing their stepping time. This suggested that new PAL wearers adopted a more conservative adaptation strategy during stepping. In contrast, these gait changes during stepping were not found in experienced PAL wearers (Johnson et al. 2007, Johnson et al. 2008, Timmis et al. 2010).

For the first-time (naïve) PAL wearers, clinicians always recommend their patients to “keep their head/ chin down” during ascending and descending the stairs or crossing over obstacles/ hazards along the walkway. This strategy allows patients to see stairs or obstacles through the “distance vision” of the lens, rather than the blurred and magnified lower field of the lens. To our knowledge, no studies have examined the adjustment on head movement in first-time PAL wearers during walking or stepping. Our study was aimed to investigate the effect of PAL wearing on vision, balance and gait functions in people who were naive to PAL wearing.

5.3 Methodology

5.3.1. Participants

Ten participants aged between 50 and 70 years, with a mean age of 60.4 ± 5.3 years (7 females and 3 males) were recruited. These participants had undergone comprehensive eye examination. Inclusion criteria included: 1) No history of wearing any type of multifocal spectacles or contact lenses; 2) Distance refractive errors within +2.00D to -2.00D and astigmatism of less than -1.50D[e], where the near additional powers ranged from +2.00D to +2.75D; 3) best-corrected binocular distance visual acuity of 0.1 logMAR or better; and 4) Cognitive function score of 18 or above in Cantonese-version Mini-Mental State Examination (to confirm that all participants were cognitive intact). Exclusion criteria included: 1) Presence of ocular diseases (e.g. macular degeneration, diabetic retinopathy, glaucoma); 2) Severe medical problems (e.g. stroke,

[e] PALs for higher power might have stronger distortions than those for lower power. To better control the amount of distortions induced by the PALs, subjects with a limited range of refractive errors were recruited.

Parkinson's diseases, heart disease) or self-reported neurological or cognitive disorders (e.g. dementia); 3) Physical impairments (e.g. use of orthopedic, mobility aids), or physical limitations (e.g. advanced arthritis); and 4) Self-reported vestibular functions deficiency/ diseases (or history) of vertigo. Table 5.1 shows the details of demographic information, refractive errors and clinical vision measures.

Two pairs of spectacles (SVL on distance prescription and PAL) were prescribed for each participant to examine the effect of lens type on vision and balance performance. Informed consent was obtained in accordance with a protocol approved by The Hong Kong Polytechnic University Human Research Ethics Committee. The study followed the tenets of the Declaration of Helsinki.

5.3.2 Demographic information

Demographic information including age, gender, educational level, general health, fall history in previous 12-months was collected using structured questionnaire.

			Right eye					Left eye				
Subject	**Age**	**Gender (M/F)**	**Sph**	**Cyl**	**Axis**	**Near Add**	**BCVA logMAR**	**Sph**	**Cyl**	**Axis**	**Near Add**	**BCVA logMAR**
1	57	M	PL	-0.50	85	+2.25	0.00	+0.75	-0.50	85	+2.25	0.00
2	56	F	+0.75	-	-	+2.25	0.02	+1.00	-0.50	85	+2.25	0.02
3	58	F	-0.50	-0.25	95	+2.50	0.00	-0.25	-0.25	105	+2.50	0.00
4	70	F	+0.50	-0.25	60	+2.50	0.00	+0.75	-0.75	110	+2.50	0.00
5	60	F	+1.00	-1.00	105	+2.50	0.04	+0.50	-	-	+2.50	0.04
6	60	F	PL	-0.50	20	+2.50	0.02	+0.75	-	-	+2.50	0.02
7	59	M	-1.25	-0.50	5	+2.00	-0.02	PL	-0.50	95	+2.00	-0.02
8	59	M	PL	-	-	+2.75	0.00	+2.25	-0.50	75	+2.75	0.00
9	70	F	+1.25	-0.75	110	+2.50	0.00	+2.25	-1.00	88	+2.50	0.00
10	55	F	+2.00	-0.50	78	+2.25	0.00	+0.75	-0.50	90	+2.25	0.00

Table 5.1. Demographic information.

5.3.3. Clinical measures

Monocular and binocular best-corrected distance visual acuities were measured with high contrast Early Treatment of Diabetic Retinopathy Study (ETDRS) charts at 4 m. Contrast sensitivity was measured with the MARS Numerical Contrast Sensitivity Test at 50 cm binocularly. The Humphrey 76-point suprathreshold screening visual field test was conducted to confirm that all participants had no visual field loss, which is one of the visual factors affecting balance function.

5.3.4. Prescription and dispensing of spectacles

To control the different lens designs adopted by different brands of PALs, the same type of PALs (HOYA Summit CD lens) were prescribed. This lens had clear and broad fields of distance and near vision, but short intermediate vision, offering a relative short progressive corridor for power transition, and was commonly prescribed in optometry clinic. PAL was dispensed with appropriate frame adjustment and clinical instructions on proper use, following the protocol suggested by Jalie (2008) (Appendix 1). As all participants did not have experience in PAL wearing, they were allowed to adapt to the prescription for at least 15 minutes before vision and balance measurement.

5.3.5. Static and dynamic vision

Binocular distance visual acuity (VA) and contrast sensitivity (CS) were measured when a participant sat in front of the stimuli and maintained contact with back of the chair to minimize the body and head movements. Participants were asked to verbally report presented stimuli, while the experimenter entered the responses into the computer.

5.3.5.1. Presentation of visual stimuli

Visual stimuli were generated by an OpenGL-based Software Package computer programme, Psykinematix (Beaudot 2009) and presented on a high-resolution LCD monitor of 40” (Samsung HD Monitor at resolution of 1920 (Width) x 1080 (Height) with a refresh rate of 120 Hz, contrast level of 3000:1 and luminance of 800 cd/m^2), covering visual angle of approximately 10 degrees (horizontal) and 8 degrees (vertical) when viewed at 7.0 meters. The monitor was calibrated every three months to ensure the consistency of gamma correction, luminance, colorimetry and geometry. All vision measures were performed in dim environment (about 30 cd/m^2) to minimize the light reflection or glare from the monitor, while participants were sitting on a high-chair.

5.3.5.2. Visual acuity measure

Visual acuity (VA) was measured by randomly presenting one of the four alphabets (H, O, T and V) of different sizes and two moving speeds (0 and 30 deg/sec (Hoffman et al. 1981)) using 4-alternative forced-choice interleaved staircase procedure and a 2-down 1-up protocol. The choice of moving speed of 30 deg/sec was based on our findings in previous experiments (Chapter 3 and 4), where vision was significantly impaired for resolving a moving stimulus. All test sessions began with a low spatial frequency (0.4 cycles/deg), with approximate 0.25 steps between successive stimuli, thus difficulty level was increased gradually (starting from easier level). Thresholds for each measure were based on the last six of the eight reversals, corresponding to a 70.7% probability of recognition. To measure the static and dynamic VA, alphabet of a particular size was presented at the centre of the monitor (i.e. stationary) or moved either horizontally or vertically with exposure duration of 400 ms respectively.

5.3.5.3. Contrast sensitivity measure

Circular Gabor patch of 1.4 degrees radius with sinusoidal gratings of 1 cycle/deg and different contrast levels was generated, corresponding to the same angle subtended by letters in the Pelli Robson Contrast Sensitivity chart (Pelli and Robson 1988). Stimulus contrast is expressed as Michelson contrast, which is defined as the ratio: C = (Lmax – Lmin)/ (Lmax + Lmin), where Lmax and Lmin are the peak and minimum luminance of the stimulus respectively. Same algorithm of stimuli presentation used in VA measure was adopted for contrast sensitivity (CS) measure. Static and dynamic CS (in terms of log unit) were measured by presenting the Gabor patch of a particular contrast at the centre of the monitor or moving at 30 deg/sec for an exposure duration of 400 ms, while participant was required to identify the orientation of gratings: horizontal (180 degree), vertical (90 degree), right-tilt (45 degree) and left-tilt (135 degree).

5.3.6. Gait and balance measures

5.3.6.1 Gait measure by Vicon Motion System

Gait function was measured by a 3-dimensional video-base motion analysis system with 6 cameras of infrared light source (Vicon Motion System 2013) while participants performed different walking, stepping and standing tasks (see below). Movement data was collected at a sample rate of 100 Hz. Given that our study was aimed to examine how different lens type affected the head angle during walking, reflective markers were attached to the front and back of the head on right and left sides (Figure 5.1): left front head (LFHD), left back head (LBHD), right front head (RFHD) and right back head (RBHD). Reflection from the markers were recorded by the video camera. Left head angle was chosen as default unless the data was missing (right head angle was used instead). Participants were required to wear tight clothes and pants (without reflective materials) for comfortable and smooth walk under barefoot condition to complete one standing and four walking tasks. Written instructions were given to experimenters for demonstrations on verbal instructions to participants in all measurements. Standardization on recordings were also given to experimenters to limit the inter-experimenters’ variations.

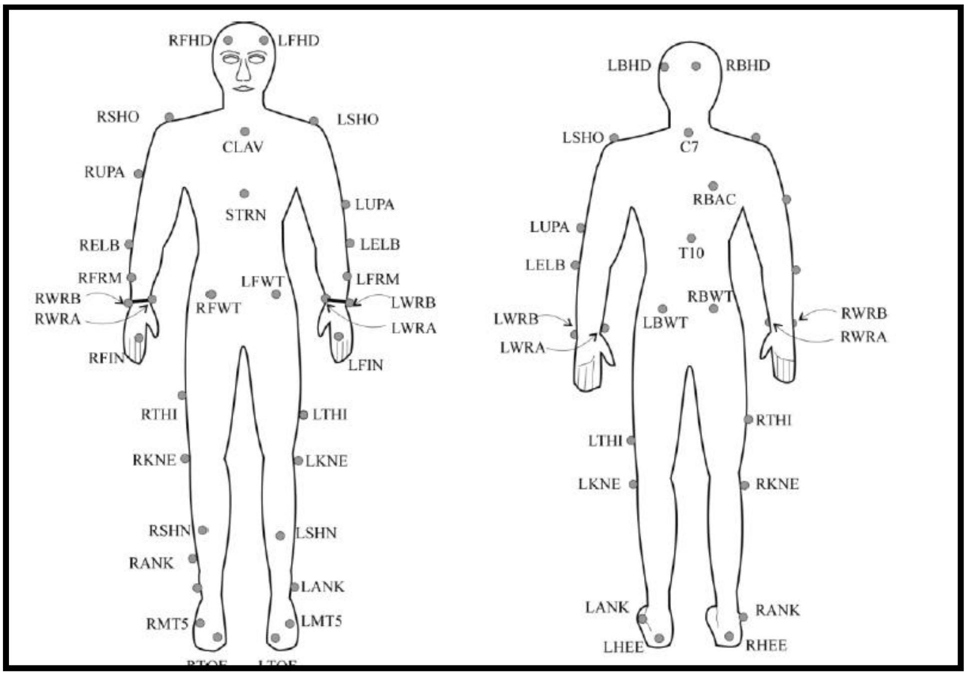


Figure 5.1. Reflective markers located at different body landmarks to examine the postural change. In this study, only four markers on the head were used to examine the change in head angle. Left front head (LFHD) and left back head (LBHD) were located approximately over the left temple and on the back of the head in a horizontal plane of the front head marker. Similar location was applied for right front head (RFHD) and right back head (RBHD).

Head angle was calculated from the tangent angle formed by the front and back markers, in which each marker represented an x, z coordinate. Coordination x and z indicated the horizontal and vertical meridian respectively when the head was in sagittal plane, thus the angle subtended by front and back marker equaled to ArcTangent$((Z_2-Z_1)/(X_2-X_1))$, where (X_2,Z_2) and (X_1,Z_1) was the coordination of back and front head marker respectively.

5.3.6.2. Balance measured by a force platform

Balance function was measured by in terms of postural sway while participants stood on a force platform (Kristler, Type 9286AA). Displacements of centre of pressure in the anterior-posterior (A-P) and medial-lateral (M-L) directions were derived. For static balance, total sway area (mm^2) and sway distance (mm) in A-P and M-L directions were calculated. For dynamic standing, time-to-stabilize (TTS), total sway area and sway distance after stabilized were computed.

5.3.6.3. Standing and walking tasks

5.3.6.3.1. Static standing

Participants were asked to stand on a force platform (Kristler, Type 9286AA) for 20 seconds, where the leg separation was about the participant's shoulder-width and eye fixated at a fixation cross at eye level. Three trials were conducted to measure participants' head angle position during static standing position.

5.3.6.3.2. Walking with and without a secondary visual task (Walking Task 1)

Baseline walking performance was measured when participants were asked to walk at their comfortable walking speed along a 5 m straight line. Six trials were performed. To evaluate whether the lens imposed a stronger interference in a more challenging walking task, participants were asked to conduct a secondary visual task by verbally reporting the presenting stimuli at the end of the pathway during walking. Visual stimuli comprised black Arabic numbers (0 to 9) of 205 mm height was randomly presented at 1 Hz on a computer screen positioned at eye level and 2 m away from the end of the walkway. Six trials were performed. The accuracy of verbal reporting was recorded.

5.3.6.3.3. Crossing over a rail obstacle of high and low contrast (Walking Task 2)

Participant was instructed to walk at his/her comfortable pace, cross over an obstacle using the dominant leg (i.e. the leg used for kicking a ball or the same side of dominant hand), step down onto the force platform (150 millimeters below the walking level) using the non-dominant leg and stand with both legs for 20 seconds. Obstacle height of 150 mm[6] with two contrast levels - yellow (high contrast) and light-grey (low contrast) were used. Six trials were performed for each contrast obstacle.

5.3.6.3.4. Crossing over two "real-world" obstacles with and without a secondary visual task (Walking Task 3)

To better simulate the obstacles in the real-world, 4 low-contrast obstacles in a box-shape of the same width and depth (400 x 600 mm) but different height[7] (35, 75, 150 mm above the ground and 35 mm below the walking level) were used. In each trial, two obstacles of different height were randomly selected and positioned along the 6-m walk path (Table 5.2), where the separation of these two obstacles must be long enough (~1200 mm) to accommodate two walking cycles (WCs) for individual participant. Each participant was required to walk along a 5 m-long level walkway and step over two obstacles. A total of 12 trials were conducted with 3 trials for each obstacle height (i.e. second obstacle,). To investigate the impact of dual task on walking with different lens types, this measure was repeated when participants were asked to perform a secondary visual task using the same methodology described above. The accuracy of verbal reporting was recorded.

[6] In Hong Kong, the maximum height of each staircase is 150 mm. Hence, this height was chosen for the obstacles used in this study (Division 7- Steps and Staircases).

[7] The sizes of the obstacles (length x width x height) were based on the guidelines for designing curb and step of escalator in Hong Kong (Electrical and Mechanical Services Department for the regulation on steps of escalator, Hong Kong).

Table 5.2. Characteristics of obstacles and walking pathways in the crossing over two “real-world” obstacles with and without a secondary visual task

Obstacles	**Length (mm)**	**Width (mm)**	**Height (mm)**
1	400	600	+150 above the ground
2	400	600	+75 above the ground
3	400	600	+35 above the ground
4	400	600	-35 below the ground
Path	**Obstacles***		
1	1		2
2	2		3
3	3		1
4	1		4
*Choice of parameters of 75, 150, 400 and 600 mm obstacles were based on the design of curb and step of escalator in Hong Kong (by Electrical and Mechanical Services Department for the regulation on steps of escalator, Hong Kong).			

5.4 Data analysis

5.4.1. Gait measure

Given that each participant had different stride length, data analysis for the percentage change of the head angle and walking time was conducted in reference to participants’ walking cycles (WC) and nature of the following walking tasks:

1) Normal walking: Gait function for the last 3 consecutive WC (WC2 vs. WC3; WC3 vs. WC4) with and without a secondary visual task;
2) Crossing over a rail obstacle with high and low contrast levels: Gait function for 2 WC before the obstacle (WC1 vs. WC2) and stepping over the obstacle (WC2 vs. Obstacle) was examined;

3) Crossing over two real-world obstacles: Gait function for 2 WC between the first and second obstacles (WC1 vs. WC2) with and without a secondary visual task was examined. The reason for choosing two WC before the obstacles was to ensure enough data points during locomotion was collected by the Vicon Motion System.

5.4.2. Balance measure

Total sway area (mm^2) and sway distance (mm) in A-P and M-L directions were calculated for the following task:

1) Static standing on a force platform
2) One-step down onto a force platform after crossing over a rail obstacle of high/low contrast

Additionally, time-to-stabilize (TTS) was computed for the “one-stepping down” task.

5.5 Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 19. All data were not significantly different from normal distributions (confirmed by Kolmogorov–Smirnov Goodness of Fit test, $p>0.05$), so parametric statistics was used for the statistical analysis. Independent t-test and MANOVA were applied to examine the effect of lens type (SVL and PAL) and natures of the task (e.g. single vs. dual tasks in Walking Task 1 and 3; high vs. low contrast obstacle in Walking Task 2) on vision, balance and gait functions. Pearson’s correlation was established between the percentage change of head angle and postural stability. A p-value of <0.05 was considered as significant, in which the p-value would be corrected in case of multiple comparison.

5.6 Results

5.6.1. Visual performance

Since the visual performance for resolving stimuli moving horizontally or vertically were not significantly different ($F(2,18)=0.54$, p=0.59), dynamic visual function for recognizing stimuli moving horizontally was used in the following analyses. In general, distance VA and CS were not significantly different for wearing SVL and PAL ($F(2,35)=1.68$, $p=0.20$). Participants performed significantly worse when resolving a moving stimuli than stationary stimuli ($F(2,35)=26.34$, $p<0.001$). An average of 0.23 logMAR and 0.76 log contrast was required for participants to resolve a moving target at 30 deg/sec. However, no significant interaction effect was found between types of lens and visual stimuli ($F(2,35)=0.65$, $p=0.53$, Figure 5.2).

5.6.2. Balance performance

Postural sway was measured for static standing and dynamic standing after stepping over a high/low contrast obstacle. In static standing, no significant differences were found in sway area ($t= -0.98$, $df= 18$, $p= 0.34$), A-P sway movement ($t= 0.22$, $df= 18$, $p= 0.83$) and M-L sway movement ($t= 1.03$, $df= 18$, $p= 0.32$, Table 5.3) between the two types of lenses. In dynamic standing, significant differences in postural sway were found between the two lens groups when participants stepped onto the force platform after crossing over either a high or low contrast obstacle ($p< 0.05$, Table 5.3). Participants wearing SVL required shorter time stabilizing ($F(1, 36)= 4.1$, $p= 0.05$), had smaller sway area ($F(1, 36)= 5.91$, $p= 0.02$), smaller A-P sway movement ($F(1, 36)= 5.51$, $p= 0.02$) and smaller M-L sway movement after stabilization ($F(1, 36)= 9.67$, $p= 0.004$). This indicated that participants wearing PAL had more difficulty stabilizing themselves after overcoming obstacles, which was a commonly encountered condition in daily life. However, effect of task natures (i.e. crossing over a high or low contrast obstacle, $F(1, 36)<0.50$, $p> 0.10$) and interaction effect of lens types and task natures were not significant ($F(1, 36)<0.10$, $p> 0.70$) in all sway parameters.

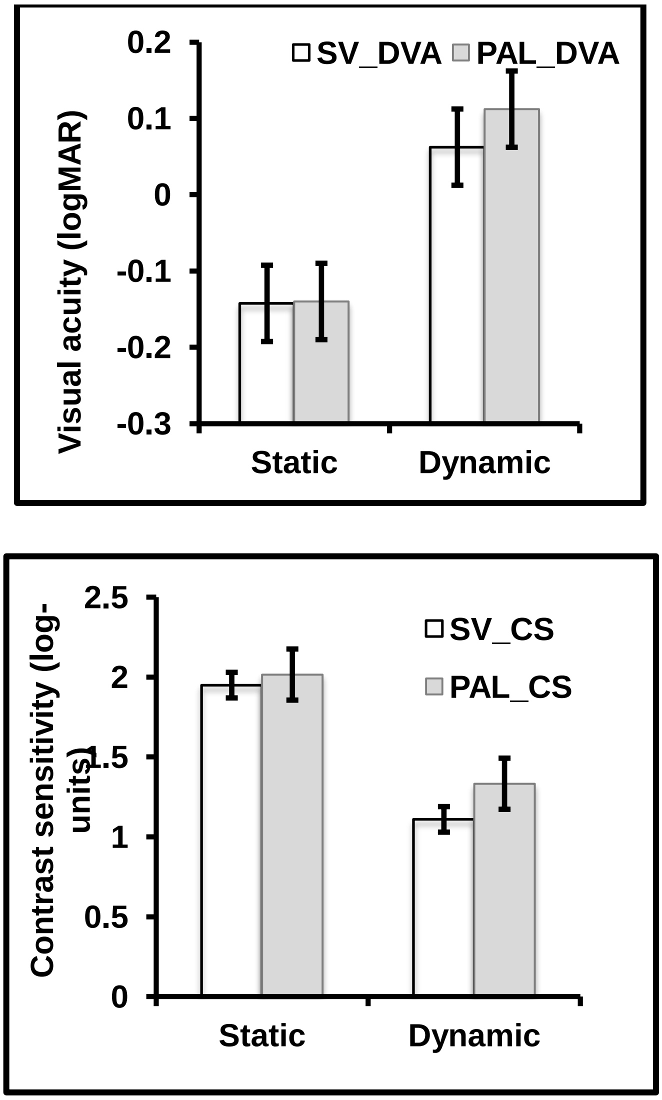


Figure 5.2. Visual performance in terms of static and dynamic visual acuity (VA in logMAR – upper panel) and contrast sensitivity (CS, in log-unit – lower panel) for participants wearing single vision lens (SVL) and progressive addition lens (PAL). Mean ± standard error is presented.

Table 5.3. Sway performance (mean ± standard error) in static and dynamic standing for two types of lenses – single vision lens (SVL) and progressive addition lens (PAL).

	Types of lens		Statistical results
	SV	PAL	
Static balance			
Sway area (mm^2)	205.9 ± 43.8	243.8 ± 52	t= -0.98, df= 18, p= 0.34
A-P sway movement (mm)	15 ± 7.5	13.4 ± 2.6	t= 0.22, df= 18, p= 0.83
M-L sway movement (mm)	41.9 ± 6.3	40 ± 5.9	t= 1.03, df= 18, p= 0.32
Dynamic balance*			
Time-to-stabilize (sec)	1.6 ± 0.1	2.6 ± 0.5	F(1, 36)= 4.13, p= 0.05
Sway area (mm2)	541.6 ± 61.9	1651.1 ± 442.2	F(1, 36)= 5.91, p= 0.002
A-P sway movement (mm)	15.9 ± 0.9	38.6 ± 9.4	F(1, 36)= 5.51, p= 0.02
M-L sway movement (mm)	67.4 ± 5	103.8 ± 10.4	F(1, 36)= 9.67, p= 0.004

* In dynamic standing, the sway parameters were captured after the participants crossed over either a high-contrast or low-contrast obstacle, stepped one-step down onto the force platform and stabilized.

5.6.3. Percentage changes in head angle during standing and walking tasks

5.6.3.1. Static and dynamic standing

Head angle in static standing when participants wore SVL (35.0 ± 3.0 deg) was not significantly different from PAL (35.1 ± 4.9 deg, t= -0.02, df= 18, p= 0.98). No significant changes in the head angle was found in both static and dynamic standing (i.e. stepping down onto a force platform after completing an obstacle-crossing walking task (p>0.05, Table 5.4).

5.6.3.2. Walking with and without a secondary visual task (Walking Task 1)

MANOVA was conducted to examine the effect of lens types (SVL and PAL) and task natures (with or without visual task). Neither lens types nor task natures significantly affected participants' variation of head angle (p>0.05, Table 5.4). Accuracy of verbal reporting was 100% among all participants, this implied that the participants must view the visual task at the end of walkway as the secondary visual task.

5.6.3.3. Crossing over a rail obstacle of high or low contrast (Walking Task 2)

Results from MANOVA showed that the effect of lens types and task natures (overcoming a high or low contrast obstacle) did not significantly affect head angle variation when participants walked and crossed over a rail obstacle (p>0.05, Table 5.4).

5.6.3.4. Crossing over real-world obstacles with and without secondary visual task (Walking Task 3)

Similar to the results reported in Section 5.6.3.3, the effect of lens types and task natures (with or without a secondary visual task) did not impose significant effect on the percentage change in head angle when the participants crossed the second real-world obstacle (p>0.05, Table 5.4). While performing the secondary visual task (i.e.

recognized the numbers presented on the monitor at the eye level), participants made less head angle when they wore PAL to cross over the obstacle, but the result was not statistically significant ($F(1, 144)= 2.39$, $p= 0.87$). Accuracy of verbal reporting was 100% among all participants, this implied that the participants must view the visual task at the end of walkway as the secondary visual task.

5.6.4. Required duration for each walking cycle in the walking tasks

MANOVA was conducted to examine the effect of lens types (SVL vs. PAL) and natures of tasks on the required duration in reference to an individual's walking cycles to complete each of the following walking task.

5.6.4.1. Normal walking with or without secondary visual task

In normal walking, the required duration to complete each of the last 3 WC before the completion of the walking task was compared for participants wearing SVL and PAL, and performing single and dual tasks (visual and walking). For all 3 WC, no significant effect on lens types and natures of tasks was found on the required duration ($p>0.10$, Table 5.5).

5.6.4.2. Crossing over a rail obstacle of high and low contrast

The required duration to complete each of the 2 WC before crossing over a rail obstacle together with the duration required for crossing over that obstacle were not significantly different for participants wearing SVL and PAL ($p>0.10$, Table 5.5). The contrast of the obstacles (high vs. low) did not affect the required duration to complete the task ($p>0.10$, Table 5.5).

5.6.4.3. Crossing over two real-world obstacles with and without a secondary visual task

Only the duration required to complete the two WC between first and second obstacles was analyzed. Results from MANOVA showed that the effect of lens type (SVL vs. PAL) and nature of tasks (single vs. dual tasks) did not significantly interfere the required duration for both WC (p>0.10, Table 5.5)

Table 5.4. Percentage change of head angle variation (mean ± standard error) for two types of lenses (SVL and PAL) in all tasks.

1) Standing				
	Static standing		**Dynamic standing***	
	SVL	**PAL**	**SVL**	**PAL**
	0.2 ± 4.4	0.3 ± 4.3	-1.4 ± 4.4	-7.2 ± 4.3
	F(1,36)= 0.07, p= 0.89		F(1, 36)= 0.88, p= 0.36	
2) Normal walking with and without secondary visual task				
	SVL	**PAL**	**Single task**	**Dual tasks**
From 2nd to 3rd WC	13.4 ± 5.7	19.0 ± 7.6	9.4 ± 4.6	23.1 ± 8.1
	F(1, 36)= 0.35, p= 0.56		F(1, 36)= 2.08, p= 0.16	
From 3rd to 4th WC	8.9 ± 4.6	10.3 ± 3.0	4.4 ± 3.3	14.8 ± 4.0
	F(1, 36)= 0.08, p= 0.79		F(1, 36)= 3.94, **p= 0.06**	
3) Crossing over a rail obstacle of high and low contrast				
	SVL	**PAL**	**High contrast**	**Low contrast**
From 1st to 2nd WC	20 ± 5.2	19.7 ± 7.3	19.3 ± 7.7	20.3 ± 4.7
	F(1, 36)= 0.001, p= 0.97		F(1, 36)= 0.01, p= 0.92	
From 2nd WC to obstacle-crossing	22.3 ± 7.3	21.4 ± 6.3	17.8 ± 6.0	25.9 ± 7.4
	F(1, 36)= 0.01, p= 0.93		F(1, 36)= 0.69, p= 0.41	
4) Crossing over two real-world obstacles with and without secondary visual task				
	SVL	**PAL**	**Single task**	**Dual tasks**
From 1st to 2nd WC	11.2 ± 2.1	9.3 ± 3.3	13.3 ± 3.4	7.2 ± 1.7
	F(1, 144)= 0.23, p= 0.63		F(1, 144)= 2.36, p= 0.13	

* In dynamic standing, the head angle was compared after the participants crossed over either a high-contrast or low-contrast obstacle and stepped one-step down onto the force platform.

5.6.5. Relationship between percentage of head angle and postural stability in dynamic balance and obstacle negotiation during walking

It is possible that the significant change in the dynamic postural stability in PAL wearing was due to a longer time allocated for the preparation for landing (crossed over a rail obstacle and negotiated one-step down) with more changes in the head position. To address this issue, we examined the relationship between TTS and percentage change of head angle when stepping down for participants wearing SVL and PAL. We found a significant correlation between these 2 measures in participants wearing PAL (r= 0.65, p= 0.04), but not wearing SVL (r= -0.07, p= 0.86).

Table 5.5. Required duration (mean ± standard error in milliseconds) to complete each walking cycle (WC) for two types of lenses (SVL and PAL) in all walking tasks.

Walking cycles	**Types of lens**		**Nature of tasks**	
1) Normal walking with and without secondary visual task				
	SVL	**PAL**	**Single task**	**Dual tasks**
2nd WC	108.6 ± 2.3	107.4 ± 2.6	108.2 ± 3	107.8 ± 1.8
	F(1, 36)= 0.1, p= 0.75		F(1, 36)= 0.01, p= 0.91	
3rd WC	108.3 ± 1.8	111.5 ± 2.3	109.6 ± 2	110.2 ± 2.2
	F(1, 36)= 1.13, p= 0.3		F(1, 36)= 0.04, p= 0.84	
4th WC	112.8 ± 1.7	117.4 ± 3.7	113.3 ± 3.1	116.9 ± 2.8
	F(1, 40)= 1.22, p= 0.28		F(1, 40)= 0.75, p= 0.39	
2) Crossing over a rail obstacle of high and low contrast				
	SVL	**PAL**	**High contrast**	**Low contrast**
1st WC	106.9 ± 1.3	106.7 ± 2.3	107.5 ± 1.6	106.2 ± 2.1
	F(1, 36)= 0.004, p= 0.95		F(1, 36)= 0.23, p= 0.63	
2nd WC	112.3 ± 1.4	113.8 ± 2.5	113.4 ± 1.8	112.5 ± 2.3
	F(1, 36)= 0.26, p= 0.61		F(1, 36)= 0.14, p= 0.71	
Obstacle crossing	85.6 ± 1.9	86.9 ± 2.5	87.5 ± 2.3	85 ± 2.2
	F(1, 36)= 0.18, p= 0.68		F(1, 36)= 0.6, p= 0.45	
3) Crossing over two real-world obstacles with and without secondary visual task				
	SVL	**PAL**	**Single task**	**Dual tasks**
1st WC	116.6 ± 1.8	113.1 ± 2.1	115.1 ± 1.9	114.6 ± 2
	F(1, 144)= 1.61, p= 0.21		F(1, 144)= 0.03, p= 0.86	
2nd WC	110.4 ± 1.4	111.8 ± 1.6	110.7 ± 1.5	111.6 ± 1.4
	F(1, 144)= 0.47, p= 0.49		F(1, 144)= 0.2, p= 0.66	

5.7 Discussion

Previous studies have reported that patients wearing PAL might increase the risk of falls and tripping, or decrease the ability in obstacles detection due to the change in gait patterns (Beschorner et al. 2013, Legters et al. 2005, Marchetti et al. 2008). However, it should be noted that the reasons for the increased fall risk in wearing PAL are multi-factorial (Reed-Jones et al. 2013), such as the history of lens wear, types of refractive errors (e.g. hyperopia, astigmatism), the history of previous falls, wearers' physical functions and age (refer to Elliott (2014) for a review). Our study investigated the effect of lens wear (SVL and PAL) on visual, head angle adjustment in different walking tasks and balance performance.

5.7.1. Effect of PAL on visual function

Due to the peripheral distortion of PAL, we expected participants having difficulty to recognize a moving target along the horizontal and vertical directions since participants might view the target through the distorted regions of the PAL (Sullivan and Fowler 1988, Atchison 1992). Contrary to our expectation, both static and dynamic distance VA and CS with the PAL were not significantly different from those with SVL. One possible reason for the non-significant finding might be the location of the distorted regions of the lens, which were concentrated at 4 o'clock and 8'clock regions (i.e. 225 and 315 deg), rather than along the horizontal (i.e. 180 deg) dimension. In other words, participants did not need to view through the distorted zones of the PAL to recognize the horizontally moving target. The monitor for target presentation was located at 7 m away from the participant's eye level, covering a visual angle of approximately 1 degree. Due to the relatively small visual angle of the moving target, participants remained using the "distant" part of the PAL to recognize the vertically moving target, rather than using the "intermediate or near" zones. However, if the vertical visual angle covered by the moving target is larger (e.g. use a monitor with larger vertical dimension) and the monitor is located at participant's knee- or foot-level, it is possible that the participant uses the "intermediate or near zone" of the PAL for recognition. The impact of visual disturbances on recognizing moving objects might be better demonstrated. Another possible reason might be due to the compensation of visual stability by the head movement and vestibular-ocular reflex (Hillman et al. 1999, Roberts et al. 2006). As all participants were physically healthy (without vestibular deficiency or mobility problem), the difference in visual performance between SVL and PAL might be trivial.

Visual performance in recognizing a moving target was significantly worse than recognizing a stationary target. It was noted that the speed-induced visual deterioration in CS (mean difference of 0.76 log unit) was greater than in VA (mean difference of 0.23 logMAR, Figure 5.2). This suggested dynamic CS was more sensitive to target motion than the DVA of high-contrast stimuli (Long and Zavod 2002).

5.7.2. Effect of PAL on static and dynamic balance

It is well established that the visual input contributes to balance stability (Lee and Scudds 2003, Giagazoglou et al. 2009, Kulmala et al. 2009). Although contribution by other sensory systems such as proprioception from lower limb and vestibular system can partially compensate for the interference on balance due to visual deprivation (Manchester et al. 1989, Giagazoglou et al. 2009), the impact of visual loss on balance function remains significant. In this study, the interference of visual input due to PAL significantly affected the participant's dynamic balance, but not their static balance (i.e. standing on a firm surface). Participants wearing PAL required longer time to stabilize after stepping one-step down onto the firm surface (i.e. the force platform) and swayed significantly more after standing on the surface.

Two reasons might explain our findings. First, compared with static balance, dynamic balance was more challenging, as it required more body coordination. For example, participants had to recognize the stair edges, estimate the stair height (which might require some head/neck adjustment), prepare the motor function for stepping down, and stand on the force platform steadily. Hence, it was not surprising that the interference of afferent visual information in the PAL greatly impaired individuals' dynamic balance (Hassan et al. 2002). Second, the blurred and magnified view of the lower visual field of the PAL affected the peripheral optic flow – one of the important visual elements for postural control (Mohapatra and Aruin 2013). Hence, our participants with PAL required longer time to stabilize and swayed significantly more (especially the M-L-direction) after stepping down. Although we did not find any significant difference in the percentage changes in head angle between SVL and PAL ($p>0.05$, Table 5.4), there was a significant correlation between time-to-stabilize and percentage change in head angle in the PAL ($r= 0.65$, $p= 0.04$). This indicated that more head adjustment was made to stabilize when the participants were inexperienced to PAL wearing. The increase in postural sway and longer time for stabilization after stepping down might impose higher risk of falls to naïve PAL wearers (Timmis et al. 2010, Ellison 2012, Beschorner et al. 2013).

5.7.3. Effect of PAL on head angle in walking

Although Beschorner et al. (2013) reported significant changes in the gait pattern in first-time PAL wearers, our findings did not find any significant change in the percentage change in the head angles and the required duration to complete each walking cycle in PAL wearing, compared with SVL wearing. Our finding was a little surprising because participants were always recommended to "keep their head/ chin down" and to use the "distance or intermediate part" of the PAL to recognize any obstacles along the walkway (depending on the location of the obstacles). If the participants followed our instruction, we expected a much greater change in head angle when participants pursued the obstacle crossing tasks. However, our result did neither find significant head adjustment (i.e. significant change in head angle) when participants crossed over a rail or real-world obstacle, nor the participants spent longer time to negotiate the obstacle during PAL wearing.

Our negative results might be explained by two possible reasons. First, given that we did not measure the gait pattern (e.g. step size/ placement and foot clearance over the obstacle), it is possible that changes in the gait patterns had compensated for the visual disturbances induced by the PAL. Therefore, participants did not need to make too much head adjustment in the walking tasks. Second, the entire walking path was 5 m and participants might have aware of the position of the obstacles at the beginning of the trial. Therefore, it is likely that the participants started to prepare the obstacle negotiation by making the necessary head adjustment and perhaps the gait changes (e.g. adjusting the lower limb coordination (Patla 1998, Patla et al. 2004) at the beginning of the trial rather than during the last moment before obstacle crossing. Menant et al. (2009) argued that earlier preparation for target detection and recognition reduced the number of obstacle contacts (i.e. safer strategy in walking). Due to the limited viewing angle captured by the Vicon Motion System, data on the head adjustment could only be captured from a couple of walking cycles before the obstacle negotiation.

To increase the challenge of the walking tasks, participants were asked to recognize the numbers presented on the monitor during normal walking (Task 1) or negotiating the obstacles (Task 3). In normal walking, secondary visual tasks marginally increased the percentage change in head angle, with the p-value close to reach statistical significance ($p = 0.06$). In the obstacle negotiation task (Task 3), more head adjustments were expected because the participants were supposed to view the visual target (which was located at their eye level) and obstacles using the “distance” part of the PAL. Contrary to our expectation, natures of tasks (single vs.

dual tasks) did not impose any significant differences in the percentage of head angle (p= 0.13). It is possible that the visual demand of this secondary task was very small because the presented numbers on the monitor were very large. Therefore, participants might not need to use the “distance” part of the PAL to recognize these numbers. Instead, they might use the “upper edge part” of the PAL for the visual recognition task and the “distance part” of the PAL for the obstacle negotiation by making more vertical eye movements rather than head adjustment.

5.8 Limitation

We acknowledge the study has certain limitations. First, participants recruited in this project aged 50 to 70 years (mean 60.4 years). They were considered as relatively young and physically healthy (compared with age group which is more prone to fall risk). Only participants with mild refractive errors were recruited. Many of them might only have minimal experience wearing spectacles for distance. Although some adaptation time was provided, participants might have difficulty adapting to the new spectacles, regardless of whether it was SVL or PAL. However, if the participant was given one week to adapt to the new SVL before the data collection, the adaptation effect to wearing “new spectacles” on balance and gait performance might be minimized. Perhaps, our data could better examine the effect of PAL on the functional performances. Second, no eye tracker was applied in this study to examine the eye position in reference to the lens. It is possible that the participants made more eye movements data (rather than head adjustment) to compensate for the visual disturbances in the PAL. However, the lack of the eye movement data did not allow us to establish the correlation between eye position and head adjustment. Third, to minimize the variability of the data, the gait and balance measures for each task were repeated for 6 trials. Therefore, the learning and practice effect might have helped. This practice effect might have under-estimated the effect of lens wearing in balance and gait performances. Last, same lens design of the PAL was adopted in this study for all participants to minimize the potential confounding effect (e.g. different lens design might induce different peripheral distortion). However, this lens design might not be the optimal for individual participant. The negative effect induced by the PAL on postural instability might be minimized if other lens designs were provided.

5.9 Conclusion

For naïve PAL wearers, visual functions (in both static and dynamic), head angle adjustment and walking time during gait assessment were not significantly different from SVL wearing. However, more attention should be made to postural stability, in particular when the new PAL wearers negotiated descending stairs (i.e. step-down) or a sudden change in the walking level. All new PAL wearers should be warned of the magnification changes with new spectacles and the visual disturbances induced by PAL. Educating patients to use different parts of the PAL for stairs or obstacle negotiation and adopt a more conservative approach to maintain balance is important for the safety of PAL wearers.

Chapter 6

Can Entertaining Action-Video Games Enhance Dynamic Visual Function and Improve Balance? – A Pilot Study

Chapter 6

Can entertaining action-video games enhance dynamic visual function and improve balance? – A pilot study

Objective:

- To investigate the training effect by playing action video game on dynamic visual and balance performances

Hypotheses:

- Significant improvement in both vision and balance performance after the intervention of action video game
- The improvement effect in balance function was stronger for dynamic vision

6.1 Abstract

Introduction: Action video game becomes a popular training tool to improve a person's visual, cognitive and balance functions. However, the effectiveness of action video game training on dynamic vision is unclear. A previous study has shown correlation between dynamic vision and balance. We hypothesized that training improved dynamic vision and the improved dynamic vision after training led to better balance performance. This pilot study investigated the training effect of playing action-video games on dynamic vision and balance function in a small group of older adults.

Methods: Fifteen normally-sighted participants aged 60 or above (66.1 ± 2.6 years) were recruited and randomly assigned into control (n=6) and training group (n=9). Only participants with no or very little video-game experience, best-corrected distance acuity of 6/9.5 or better, absence of ocular diseases, cognitive impairment and vestibular deficiency were recruited. Participants in the training group received 30 hours action video-game training for 2 to 3 sessions per week (1-hour each), while participants in the control group were kept tracked and required to keep their daily activities as usual (30 hours leisure activities as usual). Visual and balance functions were measured at 4 time points with 1-month intervals. Vision in terms of grating acuity was measured for stimuli moving at 3 different speeds (0, 2 and 4 deg/sec). Balance in terms of postural sway on firm and foam surfaces fixating at 3 different visual tasks was assessed.

Results: For vision measure, there was no training effect among 4 measurements during the 4 follow-ups and between control and training groups ($p > 0.10$). For balance measure, significant post-training effect was found in the postural sway along M-L and A-P displacements when the participants fixated at a randomly presenting or tracked a smoothly moving target in the training group ($p < 0.05$).

Conclusions: Our preliminary results showed that action video game training did not alter older adult's visual function, but significantly improved their postural sway along M-L and A-P displacements when they fixated a randomly presenting or tracked a smooth moving target. This suggested that action video-game training could potentially improve older adults' balance function in some aspects. However, the training effect in the sway path length was inconsistent. Further investigation using a randomized clinical trial approach on a larger sample size is needed to confirm the effectiveness of action video game training on vision and balance.

6.2 Introduction

Implementation of rehabilitation targeted on the muscle strength and body coordination can lead to improvement in balance stability and self-control on sway performance (Badke et al. 2004, Meli et al. 2006, Cakit et al. 2007). Improvement in self-independence and control on body sway were in line with the improvement in muscle strength. Global trend on the increase in aging population suggested the increase in fall incidence and it might lead to an increase of fall-related hospitalization (Yu et al. 2009), as well as the allocation of medical resources (Hempel et al. 2013, Staggs et al. 2014). Prevention was better than cure and thus there was an increase in cooperation between government and welfare parties for the introduction of fall prevention program (Fairhall et al. 2013, Kaskutas et al. 2013, Lee et al. 2013, Tousignant et al. 2013): promotion of health care exercises, house safety and awareness towards fall prevention.

For patients who were bed-bound, chair-bound and with difficulties in travelling to training centres for balance rehabilitation, this might restrict their progress of improvement and monitoring on rehabilitation. It was suggested that there should be alternative measures for easy-to-setup and home-based training which did not require large-scale training equipment. Action video game playing was one of the choices. With the increase in the popularity in action video game, the graphic and scene designs of the games simulate to real-life experience (please refer to literature review for further details on three main game platforms). Players were required to control the virtual reality character in the games, such as sports, adventure, shooting and driving. Players were allowed to sit or stand for controlling the remote in the games, while the hand movement was the major controlling input. This makes the challenge to the eye-hand coordination and reaction time in giving responses according to the scene. Games were also adopted into the rehabilitation for patients who were suffered from neurological and muscle disorder (e.g. Flynn et al. 2007, Yavuzer et al. 2008, Lange et al. 2010, Pompeu et al. 2012). Application of the video game acts as the supplementary element in the conventional balance program for the patients, more interactive and visually stimulated scene attract the patients during training and thus there will be an increase in compliance (Rand et al. 2004, Rand et al. 2008, Shih et al. 2010, Hsu et al. 2011).

Previous video-game training studies showed that there was corresponding improvement in the visual performance in terms of multiple objects tracking ability (Green and Bavelier 2006), spatial resolution (Green and Bavelier 2007) and CS (Li et al. 2009), and the improvement could be observed in both amblyopes and normals, where the later only required shorter time to show a significant improvement (Levi 2008, Chen et al. 2008). The process of improvement could be explained by perceptual learning, in which there was a relatively permanent and consistent change in the perception of a stimulus array following practice or experience (Goldstone 1998). With the mutual relationship established between vision and balance (as shown in Project 1, 2 and 3), this suggested that the implication of action video game as a visual training task could alter balance performance in people, provided that there was no physical locomotion was allowed for the confirmation on the utilization of vision as the sole sensory input. In the current project, the effectiveness of training program by action video game on the alternation on vision and balance performance was observed.

6.3 Methodology

6.3.1. Participants

Fifteen normally-sighted participants aged 60 years or above were recruited from elderly community centre using convenience sampling (4 males and 11 females; mean age of 66.1 ± 2.6 years). These participants were randomly assigned into two groups: 1) control group (n=6) and 2) training group (n=9). Only participants fulfilling the following inclusion criteria were recruited.

1) Habitual binocular distance acuity of 0.2 logMAR or better (equivalent to 6/9.5 or better)
2) Absence of ocular diseases (e.g. macular degeneration, diabetic retinopathy, glaucoma, severe cataract (grade 3 or above for all types of cataract using Lens opacities Classification System III (LOCS III) (Chylack et al. 1993)), ocular-motor abnormalities (e.g. nystagmus, restricted gaze movements), severe medical problems (e.g. stroke, Parkinson's diseases, Alzheimer's disease, heart disease), self-reported neurological or cognitive disorders (e.g. dementia), physical impairments (e.g. use of orthopedic, mobility aids), physical limitations restricting them from training, or self-reported vestibular or cerebellar dysfunction, history of vertigo or severe hearing loss
3) Received no formal training or regular practice of balance function (e.g. Tai-Chi) and had little and preferably no video-game experience
4) Cognitive functional score of 26 or above in the Cantonese version of The Montreal Cognitive Assessment (1 additional point was added if the participants received 12 years or less of education (Nasreddine et al. 2005))
5) Dynamic Gait Index score above 19 (to confirm for not having Ménière's disease - a disorder of the inner ear that could affect hearing and balance) (Wrisley et al. 2003, Wrisley et al. 2004)
6) No history of falls in the previous 3 months

6.3.2. Clinical measures

Binocular habitual high contrast and low contrast visual acuities were measured with high contrast (90%) and low contrast (10%) ETDRS charts. Binocular contrast sensitivity (CS) was measured by MARS contrast sensitivity chart (Arditi 2005, Dougherty et al. 2005, Haymes et al. 2006). Visual field was measured by Humphrey Field Analyzer screening test (central-40). Demographic and clinical visual information of the participants is summarized in Table 6.1.

6.3.3. Vision measures

Vision measures in terms of static and dynamic grating acuities were examined.

6.3.3.1 Apparatus and stimuli

Stimuli were sinusoidal gratings of 100% contrast and different spatial frequencies generated by a computer program - Psykinematix (Beaudot 2009) and displayed on a flat cathode-ray-tube (CRT) monitor screen (357.4 mm (width) x 268.1 mm (height)) which was placed at 6 m way from participants. Stimulus size was constrained to co-vary with the carrier spatial frequency (diameter = 2.5λ), providing the same level of cortical magnification for resolving gratings of low and high spatial frequencies (Campbell and Robson 1968, Rovamo 1979). Orientation of the grating was vertical (90 degree), 45 degrees to the left or right. For static grating acuity, the grating stimuli were displayed on the CRT monitor with a resolution of 1400 x 1050 and a refresh rate of 75 Hz. However, the resolution and refresh rate of the monitor changed to 1024 x 768 and a refresh rate of 120 Hz for measuring dynamic grating acuity.

6.3.3.2 Procedure

Static and dynamic grating acuities were measured using a three-alternative forced-choice staircase (3-down, 1-up) protocol and a block design. Participants were asked to fixate the midway between the two horizontal lines and pressed on a button to initiate a trial (with an auditory cue) whenever they were ready. A grating stimulus was presented (with a random delay in onset time between

0 to 200 ms[8], followed by a random-noise mask for 500 ms to minimize the after-image effect (Figure 6.1). Participants were required to identify the orientation of the grating – vertical or 45 degrees to the left or right. Grating acuity for each speed was calculated as the mean of the last 6 reversals of the staircase (8 reversal points were captured). For measuring the dynamic VA, stimuli moving at 2 speeds (2 deg/sec and 4 deg/sec) were randomly presented in one block. The order of measuring static or dynamic VA was randomized across participants.

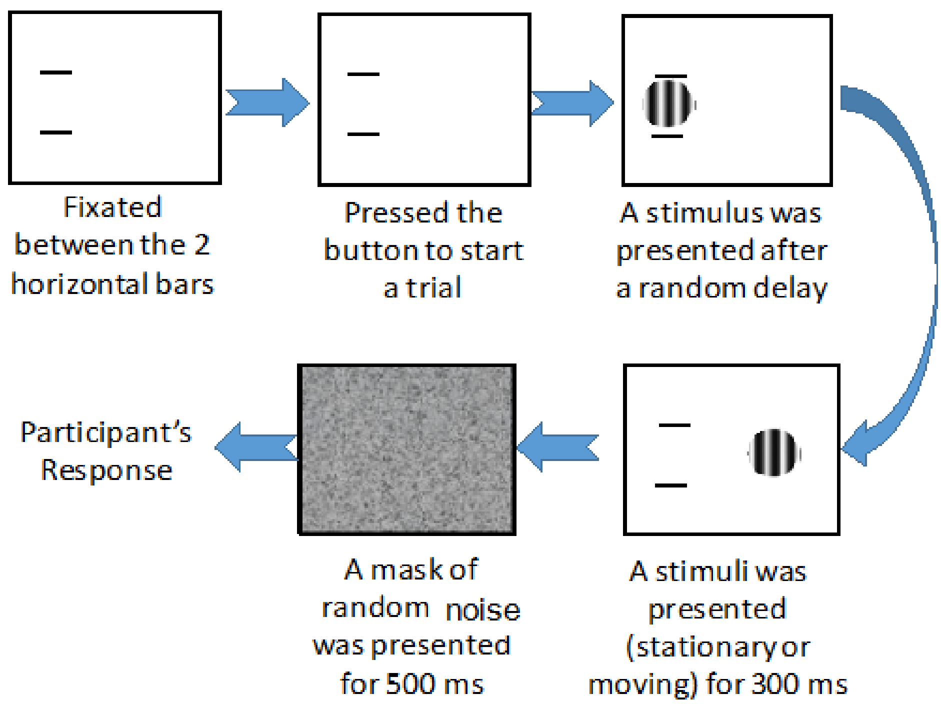


Figure 6.1. Sequence of stimulus presentation in vision measure.

6.3.4. Static balance measures

Static balance function was measured in terms of postural sway assessments while participants stood on a force platform to complete different tasks using similar methodology described in Chapter 4.3.

[8] The random delay for presenting the stimulus was aimed to maintain participants' attention level since they could not predict when the stimulus was presented.

Parti-cipant	Age/ Gender	Group	Binocular habitual VA (logMAR)		Binocular CS (log)	Subjective refraction		Monocular best-corrected VA (logMAR)	
			High contrast	Low contrast		RE	LE	RE	LE
1	67/M	Control	-0.02	0.10	1.56	+0.25/-0.50 x 85	+0.50/-0.75 x 90	0.00	0.00
2	62/F	Control	-0.02	0.20	1.60	+1.25/-0.25 x 85	+1.50/-0.75 x 85	0.00	0.00
3	68/F	Control	-0.06	0.14	1.60	+2.50/-1.00 x 95	+2.00	0.06	0.00
4	66/F	Training	0.00	0.12	1.68	+3.00/-0.75 x 95	+2.75/-0.50 x 95	-0.06	-0.06
5	66/F	Training	-0.04	0.16	1.76	Plano/-1.25 x 95	+0.50/-1.00 x 90	0.00	0.00
6	66/F	Training	0.10	0.20	1.64	+1.50/-1.00 x 100	+1.50/-0.50 x 90	0.00	0.00
7	63/F	Training	0.08	0.24	1.56	+0.75/-0.50 x 80	+0.50	-0.02	0.08
8	65/F	Training	0.04	0.16	1.48	+1.25/-0.50 x35	+1.00	0.10	0.10
9	65/F	Training	-0.12	0.10	1.52	+0.50/-0.50 x 180	+0.50/-0.50x 140	0.10	0.10
10	64/F	Control	-0.06	0.00	1.60	+2.00/-0.25 x 65	+1.75/-0.50 x 130	-0.10	-0.10
11	67/M	Training	0.00	0.14	1.60	-0.25	+0.25	0.00	0.00
12	73/F	Training	0.00	0.14	1.68	-4.25/-1.25 x 100	-2.00/-1.75 x 80	0.20	0.00
13	68/F	Control	0.10	0.40	1.60	+1.50/-0.50 x 75	+2.25/-0.50 x 105	0.00	0.00
14	64/F	Training	0.00	0.16	1.64	+0.25/-1.50 x 100	+0.75/-1.50 x 90	0.06	0.06
15	67/M	Control	-0.10	0.00	1.68	2.25/-1.00 x 110	Plano	0.00	0.00

Table 6.1. Demographic and clinical visual information of participants.

Balance performance was examined for the following parameters: a) two surfaces (firm and foam) and b) three types of visual tasks (central fixation, fixating at a randomly presenting target (saccadic eye movement) and visual tracking on a moving target (pursuit eye movement)). The purpose of using three types of visual tasks was to compare the balance functions with (i.e. saccadic and pursuit) and without eye movements (i.e. fixation). A cross of 1 deg and 100% contrast was presented at: 1) the centre of the monitor for fixation; 2) any random positions of the monitor (within the field of view of 30 deg) at a frequency of 0.5 Hz (i.e. position was changed every 2 sec)[i]; and 3) a random trajectory across the monitor in the field of view of 30 deg at 2 deg/sec.

All balance measures were repeated three times and the order of trials was randomized across participants. In each measure, participants were instructed to stand barefoot on the force platform with their feet at shoulder-width and their arms along their sides, and maintain their body posture as steadily as possible for 30 seconds. To confirm that only eye movement (with minimal head movement) was made during the balance measures, participants' head and eye movements were monitored by a live external video camera. Body sway in A-P and M-L (mm) and total length of sway path (mm) were calculated.

6.3.5. Interventions

Participants in the training group received 30-hours action video game training at the community centre using the Nintendo Wii video game - Chicken Riot (a sample of the game could be found in http://www.youtube.com/watch?v=L6lzcI9hbXw). This game required players to shoot the targets (either static or dynamic) which

[i] To ensure adequate time was allocated for the participate to trigger an eye movement towards the designated position, a duration of 2 second was selected (Rayner 1998).

were randomly displayed at different positions in the scene at different times.

To achieve a good score in this game (i.e. shooting as many chicken as possible), players had to make appropriate and efficient eye movements to spot and search for the targets and took the correspondence shooting action. Nintendo Wii game was chosen because of limited movement and locomotion required during the game playing. To ensure that minimal movement training (e.g. muscle training on lower limb) was provided, participants were required to sit at 1.5 m away from a large-screen monitor (40-inch) to play the game, where physical locomotion and lower limb movements were kept as minimal as possible. The training session was arranged for 2 to 3 sessions per week (1-hour each), thus 10-hour training could be achieved within 1-month period. Participants in the control group were also asked to come to the community centre, where their activities were recorded by a log sheet (i.e. 30-hours' leisure activities by attending non-video based activities, such as painting and calligraphy). During the whole experimental period, participants in both groups were asked to maintain their frequency of recreational and leisure activities and patterns of exercise as usual (i.e. no additional exercise or video game playing).

6.3.6. Outcome assessments

All outcome measures in vision and balance functions were conducted at 4 time-points. For the intervention group, measures were conducted before training (i.e. baseline), after 10-hour, 20-hour, and 30-hour training. For the control group, measures were conducted 4 times with 1-month interval.

6.4 Statistical analysis

All data were analyzed by IBM statistical package software version 19 (SPSS 19). Given that all variables were not significantly different from normal distributions (confirmed by one sample Kolmogorov–Smirnov test, p>0.05), independent t-test was used to confirm no significant difference in the outcome measures between groups at baseline. Multiple-ways repeated measure ANOVA was conducted to investigate the effect of time and intervention on the grating acuity (4 time points x 2 groups x 4 moving speeds) and balance functions (4 time points x 2 groups x 2 standing surfaces x 3 visual tasks). If significant main effects were found, univariate ANOVA was conducted for studying the effects individually, followed by post-hoc tests. A p-value of <0.05 was considered as significant, in which the p-value would be corrected in case of multiple comparison.

6.5 Results

The results for action video game for intervention group were recorded. All participants in the intervention group showed improvement in games, in which the performance was evaluated as 5-star scale (1-star indicates the basic performance, which 5-star indicates the best performance) (Table 6.2).

Table 6.2. Average number of star-collected at 4 time-point in the intervention group.

	Time (month)+			
Participants	**0**	**1**	**2**	**3**
4	2.3	3.7	4.6	4.5
5	1.3	2.3	3.7	3.7
6	2	3.7	4.2	4.6
7	3.4	3.7	3.8	4.5
8	4.3	4.3	4.6	4.7
9	3.8	4	4.5	4.7
11	2.3	3.7	3.8	4
12	2.3	3.8	4	4.2
14	3.7	3.8	4.2	4.3

6.5.1. Effect of action-video game training on vision

In the baseline, no significant difference in the grating acuity measured at 3 different speeds was found between the control and training groups (independent t-test, $p>0.10$). Table 6.3 shows the mean grating acuities of different moving speeds measured at different time points in the control and training groups. Results from repeated measures ANOVA revealed no significant main effects in grating acuity across time ($p>0.10$) and between groups ($p>0.70$) and measured at different moving speeds ($p>0.05$). This indicated that the intervention of action video-game training had no significant impact on grating acuity presenting in static or dynamic nature.

Table 6.3. Grating acuity (minute of arc) measured at 4 time points for the control and training groups. (Mean ± standard deviation).

Speed of grating and group		**Time (months)+**			
Groups	**Speed (deg/sec)**	**0**	**1**	**2**	**3**
Control (n= 6)	**0**	2.6 ± 0.5	2.4 ± 0.5	2.3 ± 0.4	2.5 ± 0.7
	2	2.9 ± 0.5	2.8 ± 0.4	2.8 ± 0.4	2.9 ± 0.5
	4	3.6 ± 0.3	3.4 ± 0.4	3.5 ± 0.4	3.7 ± 0.5
Training (n= 9)	**0**	2.5 ± 0.5	2.3 ± 0.3	2.3 ± 0.4	2.3 ± 0.7
	2	3.2 ± 0.6	2.9 ± 0.4	3.0 ± 0.5	3.2 ± 0.9
	4	3.8 ± 0.7	3.5 ± 0.4	3.6 ± 0.6	3.7 ± 0.9

+ In the control group, outcome measures were conducted at baseline and every 1-month interval afterwards for 3 times. In the training group, outcome measures were conducted at baseline and after every 10-hours' training (~1-month period) for a total of 30 hours.

6.5.2. Effect of action-video game training on static balance

Similar to vision measures, no significant difference in balance performance was found between the control and training groups in the baseline (independent t-test, $p>0.10$). Balance performance in terms of postural displacement in M-L and A-P planes and sway path length in the control and training groups across time is summarized in Table 6.4 (for two standing surfaces – firm and foam) and 6.5 (for three visual tasks – fixating a static central target, a randomly presented target, tracking a moving target).

6.5.2.1. Sway path length

Results from repeated measures ANOVA revealed significant time effects in sway path length ($F(3, 78) = 34$, $p<0.001$). Sway path length in the 1-month (107.9 ± 49.1 cm), 2-month (101.6 ± 49.8 cm) and 3-month (101.4 ± 54.2 cm) were significantly less compared with that in the baseline (Month-0, 155.5 ± 86.5 cm). Post-hoc analysis showed that the significant decreases in sway path length were found at the first 2 visits (Month 0 to 1, $p<0.001$), but not at the later visits (Month-2 and 3 ($p>0.10$)). There was no significant differences in sway path length between the control and training groups ($F(3, 78) = 1.82$, $p = 0.15$). This indicates that the decrease in sway path length across time was similar for both groups. In this study, balance functions were conducted on both firm and foam surfaces. Although standing surfaces imposed significant impairment on balance ($p<0.001$), there was no significant interaction effect between: 1) repeated measures (i.e. time) and standing surfaces ($F(3, 78) = 1.45$, $p = 0.23$); and 2) repeated measures, standing surfaces and groups ($F(3, 78) = 0.47$, $p = 0.71$).

In addition to standing surfaces, balance functions were measured by asking participants to complete 3 different visual tasks. Compared with fixating a central target, the sway path length significantly decreased when participants fixated a randomly presented target, but significantly increased when they visually tracked a moving target ($p<0.001$, Table 6.5). There was a significant interaction effect between visual tasks and standing surfaces ($F(1, 26) = 6.55$, $p = 0.02$), where larger sway path length was found when participants stood on the foam surface to track a moving target (but not in fixating at a central target or randomly presented target). Across time, the total sway path length for fixating a central target or a randomly presented target did not significantly change ($p>0.10$). However, the total sway path for tracking a moving object significantly increased over time ($F(3,78)= 4.73$, $p= 0.004$). Participants in the control group had mild but significantly more total sway path across time while fixating a moving target, compared with non-significant changes in the training group ($F(3, 78)= 2.82$, $p= 0.04$, Figure 6.2).

Table 6.4. Balance performance in terms of medial-lateral (M-L) displacement, anterior-posterior (A-P) displacement and sway path length (sway length) measured at 4 time points for the control and training groups. (Unit: cm, mean ± standard deviation).

Standing surface and group			**Time (months)+**			
			0	**1**	**2**	**3**
Firm	**Control**	**M-L**	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
		A-P	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
		Sway length	91.1 ± 22.2	**81.0 ± 24.4***	**64.8 ± 9.1***	**60.9 ± 7.5***
	Training	**M-L**	0.5 ± 0.3	0.5 ± 0.2	0.5 ± 0.2	0.4 ± 0.1
		A-P	0.5 ± 0.2	0.4 ± 0.1	0.5 ± 0.2	0.5 ± 0.2
		Sway length	106.6 ± 34.9	**61.1 ± 11.6***	**63.4 ±16.0***	**58.9 ± 11.3***
Foam	**Control**	**M-L**	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.1
		A-P	0.6 ± 0.1	0.6 ± 0.2	0.5 ± 0.1	0.5 ± 0.1
		Sway length	143.0 ± 54.4	**101.3 ± 22.6***	**90.4 ± 13.7***	**90.5 ±10.7***
	Training	**M-L**	0.7 ± 0.3	0.6 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
		A-P	0.8 ± 0.3	0.6 ± 0.1	0.6 ± 0.2	0.6 ± 0.1
		Sway length	137.6 ± 46.9	**83.6 ± 24.1***	**86.4 ± 30.2***	**83.5 ± 27.3***

Asterisk (*) indicates the measure at that time-point was significantly different from baseline ($p<0.05$). + In the control group, outcome measures were conducted at baseline (Month-0) and every 1-month interval afterwards for 3 times. In the training group, outcome measures were conducted at baseline and after every 10-hours' training (~1-month period) for a total of 30 hours.

Table 6.5. Balance performance in terms of medial-lateral (M-L) displacement, anterior-posterior (A-P) displacement and sway path length (sway length) measured at 4 time points for three visual tasks for the intervention group. (Unit: cm, mean ± standard deviation).

Visual tasks during standing		Time (months)			
		Baseline	1	2	3
Fixation	M-L	0.6 ± 0.3	0.6 ± 0.2	0.6 ± 0.2	0.5 ± 0.2
	A-P	0.6 ± 0.3	0.5 ± 0.1	0.5 ± 0.2	0.5 ± 0.1
	Sway length	120 ± 44.4	79.9 ± 24.4	75.9 ± 22.8	72.9 ± 21.4
Saccadic	M-L	1.6 ± 0.8	**0.7 ± 0.8***	**0.4 ± 0.1*†**	**0.4 ± 0.1*†**
	A-P	1.9 ± 0.9	**0.7 ± 0.8***	**0.4 ± 0.1*†**	**0.4 ± 0.1*†**
	Sway length	60.2 ± 27.3	61.8 ± 22.6	62.0 ± 14.9	62.3 ± 13.1
Pursuit	M-L	1.8 ± 0.8	0.9 ± 0.9*	0.6 ± 0.2*†	0.5 ± 0.2*†
	A-P	2.1 ± 0.9	**0.8 ± 0.7***	0.5 ± 0.2*†	**0.5 ± 0.2*†**
	Sway length	66.3 ± 25.2	76.9 ± 30.6	80.0 ± 26.4	**80.9 ± 25.1***

Asterisk (*) and cross (†) indicate the measure at that time-point was significantly different from baseline and 1-month measure ($p<0.05$) respectively.

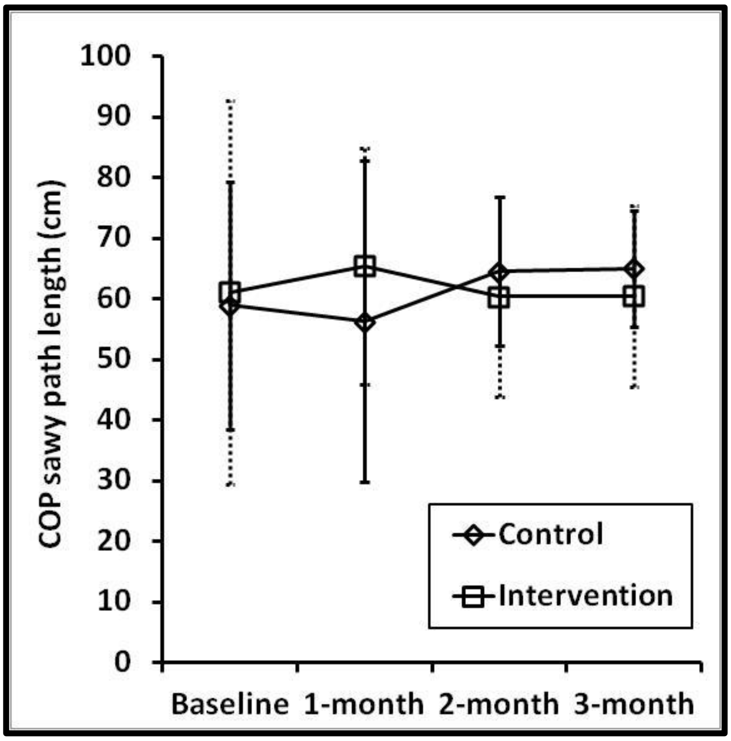


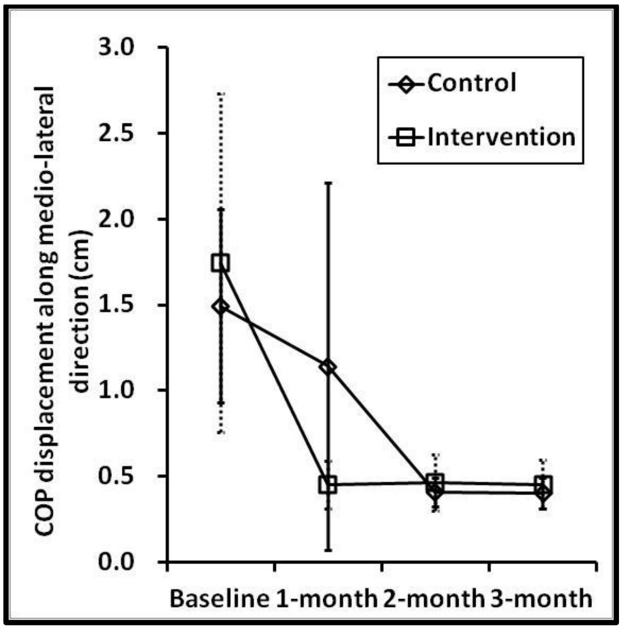
Figure 6.2. Sway path length (cm) across time for the control and training (intervention) groups when participants visually tracked a smooth moving target during standing. Error bar refers to standard deviation.

6.5.2.2. Medial-lateral (M-L) and Anterior-posterior (A-P) displacements

Contrary to sway path length, there was no significant time effect on the displacements in M-L ($F(3, 78)= 0.84$, $p= 0.48$) and A-P ($F(3, 78)= 1.21$, $p= 0.31$). There were no significant differences in M-L ($F(3, 78)= 0.15$, $p= 0.93$) and A-P ($F(3,78)= 2.66$, $p= 0.05$) between the control and training groups. Figure 6.3 shows that the M-L displacements decrease in the training group after action-video game training. Similar to sway path length, significantly larger sway along M-L and A-P planes were found when participants stood on the foam surface (M-L: $F(1, 26)= 8.78$, $p= 0.006$); A-P: $F(1, 26)= 14.09$, $p= 0.001$). There was no significant interaction effect between: 1) repeated measures (i.e. time) and standing surfaces (M-L: $F(3,78)= 1.45$, $p= 0.23$); A-P: ($F(3, 78)= 1.34$, $p= 0.27$)); and 2) repeated measures, standing surfaces and groups (M-L: $F(3, 78)= 0.26$, $p= 0.86$; A-P: $F(3, 78)= 0.16$, $p= 0.92$).

Participants swayed significantly less along both M-L and A-P planes when they fixated at a randomly presented target than tracking a moving target ($p< 0.001$, Table 6.4). When participants stood on a foam surface, they made significantly larger sway in the A-P direction ($F(1, 26)= 8.77$, $p= 0.01$), but only marginally significantly more sway in the M-L direction ($F(1, 26)= 3.97$, $p=0.05$), compared with standing on a firm surface. Contrary to the findings in sway path length, postural sway in the M-L and A-L while fixating at a randomly presented object (M-L: $F(3, 78)= 5.05$, $p= 0.003$; A-P: $F(3, 78)= 4.93$, $p= 0.01$)) or tracking a moving object (M-L: $F(3, 78)= 7.95$, $p<0.001$); A-P: $F(3, 78)= 3.93$, $p= 0.01$)) significantly and gradually decreased across time. Participants in the training group demonstrated significantly less sway along both planes after 10-hours training when they fixated at a randomly presented target or a moving target (Figure 6.3 and 6.4).

(a) Fixating at a randomly presenting target



(b) Visually tracking at a moving target

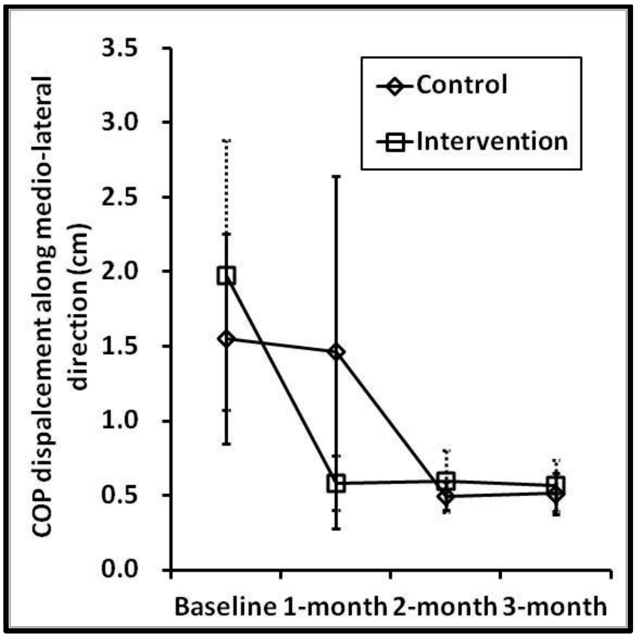
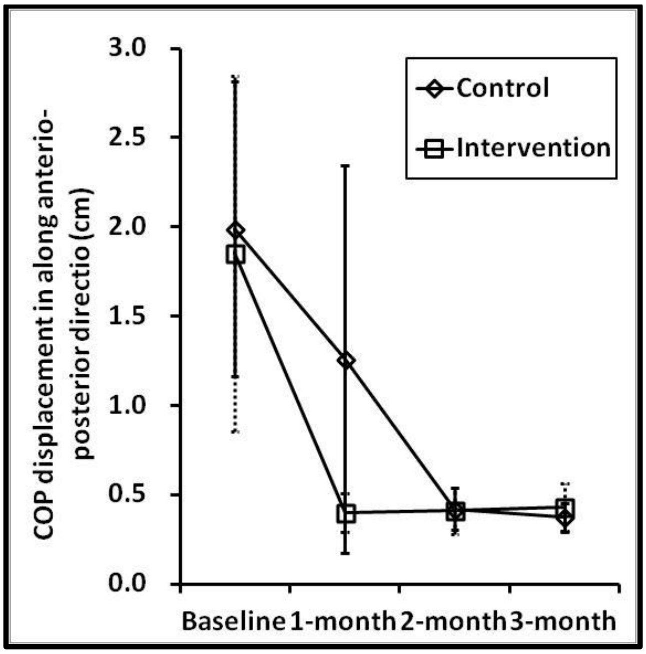


Figure 6.3. Postural sway along medial-lateral (M-L) plane (cm) across time for the control and training (intervention) groups when participants fixated at a random moving object (panel a) or visually tracked a smooth moving target (panel b) during standing. Error bar refers to standard deviation.

(a) Fixating at a randomly presenting target



(b) Visually tracking at a moving target

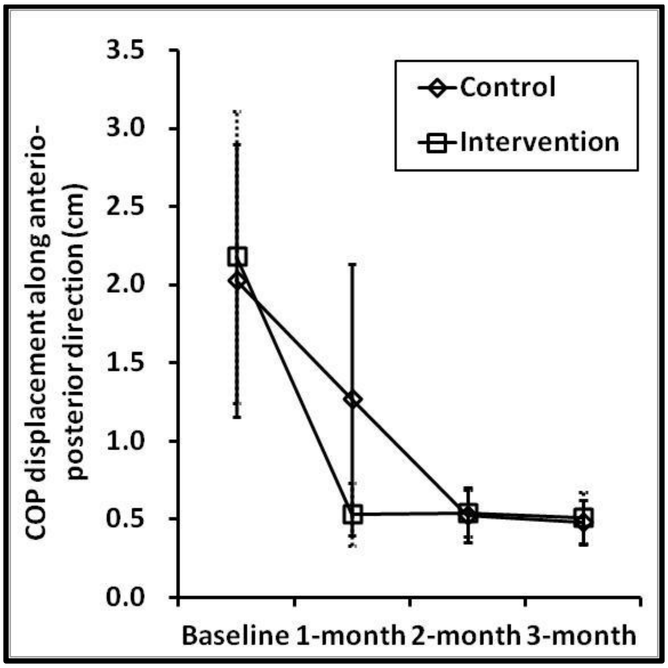


Figure 6.4. Postural sway along anterior-posterior (A-P) plane (cm) across time for the control and training (intervention) groups when participants fixated at a random moving object (panel a) or visually tracked a smooth moving target (panel b) during standing. Error bar refers to standard deviation.

6.6 Discussion

Evidence has shown the ability of action video games to improve processing speed, attention and spatial abilities (refer to Green and Bavelier (2003) for a review). Results from recent studies supported the training effect of action video games (e.g. Nintendo Wii-board) on dynamic balance and coordination in community-dwelling elderly participants (Pompeu et al. 2012). Our pilot study which was aimed to investigate the effect of action video games training on altering older adults' vision and balance performance, failed to support the benefits of action video-game training on vision and some of the balance functions.

6.6.1. Non-significant training effect on grating acuity

Previous studies have shown that action video game training significantly improves visual function in visual acuity, contrast sensitivity and positional awareness (Achtman et al. 2008, Li et al. 2009, Li et al. 2011). However, our study found no significant improvement in static and dynamic grating acuities after 30-hours' action video game training (Table 6.2). Two plausible reasons might explain the non-significant finding in our study. First, a small sample of 15 participants was recruited in our study. These participants were then randomly assigned into control (n=6) and training groups (n=9). In addition to small sample size, the uneven sampling between groups might limit the training effect. Second, most studies demonstrated the effectiveness of action video-game training on different aspects of visual function (e.g. visual selective attention (Greenfield et al. 1994, Green and Bavelier 2003, Mishra et al. 2011), multiple objects tracking ability (Green, Bavelier 2006), spatial resolution (Green and Bavelier 2007), speed of processing (Dye et al. 2009) and contrast sensitivity (Li et al. 2009)) recruited participants of young age (7 to 30 years). It is possible that the effect of video-game training, which has proven to be effective in young participants, might provide less benefit in older adults. However, ample evidence has suggested that aging brain retains some neuroplasticity (Wick et al. 1992, Wu and Hunter 2006) in which intensive training is still possible to ameliorate the aging visual function.

6.6.2. Potential training effect on balance function

In general, action video-game training did not significantly improve the older adults' balance function in terms of postural displacement in M-L and A-P directions and sway path length. However, the training effect on balance function became more obvious if the results were analyzed separately for participants engaging in different visual tasks while maintaining their balance. Participants in the training group swayed significantly less along the M-L and A-P planes after 10-hours' training when they fixated at a randomly presented target or a moving target. This indicates that the training could significantly improve participants' balance function when they made saccadic and pursuit eye movements simultaneously (Figure 6.5 and 6.6). One plausible reason for improved balance function could be due to the improved eye-hand coordination through action video game training (refer to Table 6.2 for improved game performance after training). Surprisingly, no similar training effect was found in the sway path length (Figure 6.4). Sway path length refers to the total distance travelled by the participants in the 30-seconds standing. It is possible that the participants made much "small sway" (rather than large sway along M-L or A-P directions), resulting in large sway path length, but relatively less M-L or A-P displacements. Instead of using sway path length, compared the sway area by fitting an ellipse including 68% sway data might better demonstrate the effectiveness of training on balance.

6.6.3. Effect of eye movements on balance function

Compared with fixating at a stationary object, older participants swayed significantly less when they fixated on randomly moving targets (i.e. making pursuit eye movements) than smoothly moving targets (i.e. making saccadic eye movements). However, our results were somewhat different from previous findings in younger adults, where both saccadic and smooth pursuit eye movements significantly decreased postural sway in similar contexts (Rodrigues et al. 2015, Stoffregen et al. 2006).

While fixating a randomly presenting object, the fast moving retinal image might suppress the visual perception during retinal slip (Sommer and Wurtz 2002). This visual suppression during saccadic eye movement results in less postural sway when fixating the target randomly presenting at right or left (horizontal) or up or down (vertical) directions (Schulmann et al. 1987, Rey et al. 2008). The robust and rich contribution of the proprioceptive input from extra-ocular muscle further stabilizes our postural control when we view a saccadic moving object (Buttner-Ennever and Buttner 1992). Furthermore, the higher attention level when viewing a saccadic target benefits the postural control (Uchida et al. 1979).

To track and hold a continuously and smoothly moving target on the fovea, we need to make smooth continuous eye movements by sending continuous proprioceptive input to the extra-ocular muscle (Buttner-Ennever and Buttner 1992). As we getting old, eye movement parameters are altered (Morgan 1993), such as increased saccadic latency (Abel et al 1983, Klein et al. 1996) and decreased smooth-pursuit gain (Ross et al. 1999). It is possible that the age-related decline in the eye movement characteristics further interfered a person’s balance function when they visually tracked a moving object because of the dissociation between eye movements and postural sway. However, no simultaneous eye tracking measures were included in our study to confirm this anticipation. The negative effect on balance with tracking eye movements, compared with visual fixation and saccadic eye movements is important. Older adults, in particular those who are at high risk of falls should be strongly recommended not to track moving objects when they stood on uneven surfaces or challenging environment. Further investigation on the synchronization of eye movements during postural sway is needed.

6.6.4. Potential application of action video-game training to improve older adults' functional performance

Currently, there are many training programs (e.g. lower body resistance-training program (Rezmovitz et al. 2003), exercises (Tsang and Hui-Chan 2004a, Voukelatos et al. 2007), Tai Chi (Tsang and Hui-Chan 2003, Tsang and Hui-Chan 2004a, Tsang and Hui-Chan 2004b, Tsang et al. 2004), Pilates (de Oliveira et al. 2015)) which are aimed to improve healthy older adults' balance function. However, most of these programs require a personal/ sport trainer or physiotherapist, resulting in some burden in finance and human resources. Instead, action video game training at home or community centres might solve this problem, by providing an interacted and entertaining training environment. Therefore, in recent years, action video game training has been applied in balance rehabilitation in patients with neurological diseases (e.g. Parkinson's disease, spinal cord dysfunction and stroke), or deficiency in limb coordination (e.g. Betker et al. 2007, Flynn et al. 2007, Yavuzer et al. 2008, Lange et al. 2010, Pompeu et al. 2012). Results from our pilot study provides some preliminary evidence to demonstrate the potential training effect on older adults' balance function when they fixated at a randomly moving target or followed a moving target.

6.7 Limitation

This pilot study had several limitations. First, our study had a small sample size and an uneven number of participants in the control and training groups, limiting the possible effectiveness of the action video game training on vision and balance. Second, prolonged outcome measures might inevitably impose more variabilities in the balance measures because of the fatigue effect. It is well known that standing on a compliant surface (i.e. foam surface) significantly deteriorate an individual's postural control (Teasdale et al. 1991). However, the interaction effect between standing surfaces and visual tasks; standing surfaces and time; and standing surfaces and group revealed no significant difference. To minimize the potential fatigue due to too many outcome measures, postural balance should only be conducted on foam surface. Third, a quasi-experimental design was adopted in this study, where the researchers for outcome measures were not masked for the type of intervention (control or training). A better study design using a randomized clinical trial on a larger sample would provide more solid evidence on the effectiveness of action video game training on vision and balance.

6.8 Conclusion

Our preliminary results showed that action video game training did not alter older adult's visual function, but significantly improved their postural sway along M-L and A-P displacements when they fixated at a randomly presenting or tracked a smooth moving target. However, the training effect in the sway path length was inconsistent. Further investigation using a randomized clinical trial approach on a larger sample size is needed to confirm the effectiveness of action video game training on vision and balance.

Chapter 7

Summary of Projects

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Summary of Projects

Fall is a common social problem in the elderly population. The reasons for falls are multifactorial, including age-related changes in physical function (e.g. reduced lean body mass, lower extremity weakness, balance disorders), visual function (e.g. reduced acuity, contrast sensitivity and visual field, slower visual information processing (Rayner et al. 2009)), and psychological adverse effect (e.g. fear of falling). Evidence has shown that any reduction in vision decreases the amount of visual information from external environment for maintaining balance and walking stability. Hence, improving older adults' visual function is one of the key elements to improve their balance function and reduces the corresponding risk of falls. Although many studies have examined the relationship between visual and balance functions, these studies have three major limitations. First, the majority of these studies recruited Caucasian populations, it is unclear how this relationship applies to Chinese population. Second, these studies focus on a person's static visual function, largely ignoring the importance of dynamic visual function on balance performance. Third, very few studies have examined the relationship between vision and balance in the dynamic aspects. To address the research gaps in these areas, 5 projects were included in this study.

In Project 1, we examined the visual, balance and fall-risk profiles in 435 Chinese community-dwelling older adults aged 60 years or above. Visual function and ocular health were examined by optometric screening assessments. Balance function was assessed with Physiological Profile Assessment (PPA), including peripheral sensation, lower limb strength, eye hand coordination and sway performance. Individual composite fall-risk index was calculated. Given that this recruited sampled population was physically healthy (with less than 10% participants consumed alcohol or cigarettes and about 80% participants had regular exercises for more than 3 times per week), only 7.6% participants reported having a fall in the previous 3 months. Our results found that 16.5% participants' distance acuity in the better eye was was worse than 0.5 logMAR, classifying as "mild visually impaired" by World Health Organization. Cataract was the main cause of visual impairment. Compared with the Caucasian normative database, our sampled participants had "moderate" fall-risk because of their "fair to poor" physical performance. Their performance in contrast sensitivity, simple reaction time and postural sway were inferior to Caucasian populations. Despite the poor physical performance and moderately high fall-risk scores, only low incidence of falls was found in the follow up period, where 9.6% and 17% participants reported fall in the prospective 6 and 12 months. Vigilant/ attentive behaviors and high levels of planned activities might explain the lower fall rates in Chinese older people (Kwan et al. 2013). Because of the substantial difference in physical performance between these populations, it might not be appropriate to directly apply the Caucasian normative data into Chinese population. Further, our results showed significant but weak correlation between visual, quadriceps, hand reaction time and balance performance, suggesting that a person with vision loss had weaker quadriceps muscle strength, slower hand reaction time and poorer postural sway. The very weak correlation between vision and balance might be due to the nature of vision measures, where participants were asked to resolve stationary objects (i.e. static vision) rather than moving objects (i.e. dynamic vision). As many real-world tasks involve movement of both the target and the observer, vision measure which captures a person's ability to resolve moving targets (i.e. dynamic vision) might better correlate with functional activities involving locomotion (Freeman et al. 2006, Patel et al. 2006). Prior to further investigating the relationship between vision and balance in the dynamic approach, it is essential to examine the characteristics of dynamic vision and examine the factors affecting dynamic vision in our population.

Dynamic vision can be defined as an observer's visual ability to detect a moving target, utilizing high-speed eye movements in order to place it on the highest resolution region of the retina, the fovea, so as to resolve and recognise the critical details within it. In real life, we always need to resolve moving stimuli during walking or running (e.g. avoid an obstacle when we walk). Hence, it is important to examine how observers' locomotion affects their dynamic visual performance.

In Project 2, we investigated the effect of body locomotion on dynamic vision in 84 normally-sighted adults aged between 21 and 80 years (classifying into 3 age groups: young, middle and old). Participants were asked to recognize visual stimuli while they were in three types of body locomotion - sitting, stepping and walking. Visual targets were presented at 0, 30, 60 and 90 deg/sec moving from either right or left randomly. Participants were required to identify the alphabets (H, O, T and V) of different sizes and orientation of gratings of different contrast levels for measuring visual acuity and contrast sensitivity task respectively. Our results showed that visual functions in terms of visual acuity and contrast sensitivity were significantly deteriorated for resolving moving targets. Among the 3 types of body locomotion, vision was optimal when participants were in the stationary sitting position, followed by stepping and walking. However the locomotion-induced vision decline was very small, which was considered as clinically insignificant. Vision in the old-age group was significantly poor, but the effect of age-related decline was similar in resolving stationary and moving targets. Given no significant difference in vision measured for different types of body locomotion, vision measure in the "sitting position" was adopted in future projects. Deteriorated visual function is an important risk factor for the detrimental balance control in older adults. However, our recent findings in Project 1 only demonstrated very weak relationship between vision and balance function.

In Project 3, we further examined the relationship between vision and balance, in particular how dynamic vision affected an individual's balance function. In this project, 40 participants with normal vision and aged between 20 and 80 years were recruited to examine their visual and balance functions. Visual acuity was measured by presenting stimuli of different optotypes (H, O, T, V) moving at 5 different speeds (0, 15, 30, 60 and 90 deg/sec). Static balance was measured by a force platform when the participant stood on a firm or foam compliant surface while fixating at different targets. Dynamic balance was measured by limits of stability test where participants were asked to make a voluntary and corresponding weight shift as maximally as possible within their base of support to eight positions whenever a stimulus representing the weight shift at a particular position was shown on the monitor. Our results showed significant age-related decline in vision for recognizing stationary or moving objects. However, we only found significant age-related decline in dynamic balance, but not in static balance. Several reasons had been suggested to explain the negative aging effect in the static balance function (e.g. biased sampling of older adults with exceptionally good physical characteristics; high proportion of Tai Chi practitioners in the sampled population). Because of the unexpected finding in static balance, we only found significant correlation between vision and dynamic balance, but not static balance. A stronger relationship was established between dynamic vision and dynamic balance, implying that a person with poorer dynamic vision might have weaker dynamic balance control and more prone to fall. To identify patients with comprised balance function, we should include the assessment of dynamic vision in our clinical setting.

Starting from 40 years old, many patients complain of difficulty reading or focusing. To enable patients having clear vision at different viewing distances, prescribing progressive addition lenses (PALs) is a common approach. Despite significant improvement in modern design of the PAL, peripheral distortion of lenses cannot be totally eliminated, reducing wearers' visual performance (e.g. depth perception and contrast sensitivity) and their accuracy of gait pattern in the presence of obstacles along walking paths, which might ultimately increase their risk of falls.

In Project 4, we investigated how a pair of new PAL affected a naïve wearer's visual, balance and gait performance. Ten participants who were naïve in spectacles or contact lens wearing (in particular PAL or multifocal) and aged between 50 and 70 years were recruited. Each participant was prescribed a pair of single vision lenses (SVL) and progressive addition spectacles (PAL). Visual, balance and gait functions were measured for participants wearing each pair of spectacles. Static and dynamic visual function was assessed with the visual targets presented stationary (i.e. 0 deg/sec) or moving in the horizontal and vertical directions at 30 deg/sec. Gait function was measured by Vicon Motion System, where participants walked along different paths with and without obstacles. Balance function was measured when participants stepped down onto a force platform at the end of the walk path. Our results showed no significant difference in visual (static and dynamic vision) and gait performance (in terms of head angle and required time to complete each walking cycle in the walking task) between SVL and PAL wearing. However, participants wearing PAL required a significantly longer time to stabilize and had a larger body sway area (with significantly more sway along the lateral direction) after negotiating one-step down. This suggests that new PAL wearers should pay more attention to postural stability, in particular negotiating descending stairs (i.e. step-down) or a sudden change in the walking level. All new PAL wearers should be warned of the magnification changes with new spectacles and the visual disturbances induced by the PAL. Educating the patients using different parts of the PAL for stairs or obstacle negotiation and adopting a more conservative approach to maintain balance is important for the safety of PAL wearing.

Our recent findings demonstrated significant age-related decline in visual and dynamic balance functions, in particular when both functions were measured in a dynamic environment. A logical thought would be “can training improve dynamic visual function?” and also “can such training be transferred to enhance balance? To address this question, in Project 5, we investigated the training effect of action-video games training - a popular training tool to improve a person’s visual, cognitive and balance functions, on dynamic vision and balance function in a small sample of older adults. Fifteen healthy and normally-sighted older adults aged 60 or above were recruited and randomly assigned into control and training group. Participants in the training group received 30-hours’ action video-game training for 2 to 3 sessions per week (1-hour each), while participants in the control group were required to keep their daily activities (with at least 1-hour leisure activity each day) as usual. Visual and balance functions were measured at 4 time points with 1-month interval. Vision in terms of grating acuity was measured for stimuli moving at 3 different speeds (0, 2 and 4 deg/sec). Balance in terms of postural sway on firm and foam surfaces fixating at 3 different visual tasks was assessed. Our results did not show any significant improvement in vision after receiving 30-hours’ action video game training. In contrast, significant post-training effect was found in the postural sway along M-L and A-P displacements when participants were asked to fixate at a randomly presented or track a smoothly moving target in the training group. This suggests that action video-game training could potentially improve older adults’ balance function in some aspects. Our results provide some preliminary evidence on the potential effectiveness of action video game training. Further investigation on a larger sample size using randomized clinical trial design is needed to confirm the effectiveness of action video game training on improving balance function.

Chapter 8

Conclusion and Future Investigation

Chapter 8

Conclusion and future investigation

8.1. Conclusion

Among the Hong Kong Chinese elderly with cognitively intact and physically healthy, their fall-risk was considered as “moderate” because their physical performances measured by Physiological Profile Assessment were worse than the age-matched Caucasian population. The low incidence of fall in the prospective follow up period suggests that it might not be appropriate to directly apply the Caucasian normative data into Chinese population.

Although the reasons for falls are multifactorial, reduced visual and balance functions are two essential factors. Our results demonstrated a significant relationship between vision and balance, in particular the dynamic aspect. This implies that a person with poor dynamic vision might have weaker dynamic balance control and is more prone to fall. Identifying people with compromised vision and balance functions is imperative to reduce the incidence of falls or fall related injuries. Hence, fall prevention programs should include vision measures in both static and dynamic aspects. Other than an individual’s visual function, the visual disturbance induced by spectacle wearing should not be neglected because of its potential interference on a person’s balance and gait performance. For example, a person with no experience in using progressive addition lenses (PALs) had larger body sway which requires significantly longer time to stabilize. To minimize the potential incidence of falls, all new PAL-wearers are recommended to use different parts of the PAL for stairs or obstacle negotiation and adopt a more conservative approach to maintain balance, in particular, when negotiating descending stairs or a sudden change in the walking level. Currently, many fall prevention programs are available to help older people to prevent falls and fall-related injuries. However, training with more engagement is expected to maximize the participants’ motivation, and achieve a greater intervention effect. Action video-game training (using fast-pace cartoon-type shooting games) might provide additoinal training effects to improve older adults’ balance function, in particular when they were asked to fixate a randomly presented or smoothly moving object.

8.2. Future investigation

Our pilot study provided some preliminary evidence to show the effectiveness of action video game training on balance function. To confirm the effectiveness of action video game training, a randomized clinical trial (RCT) with a larger sample size is needed. Additionally, the study design of this RCT study can be improved as follows.

This fast-pace shooting game adopted in the pilot study was aimed at training participants’ reaction time, dynamic vision and perhaps oculomotor functions responding to the randomly presented or moving stimuli. To examine the training effect on each aspect, measures on visual attention (e.g. Useful field of view) and oculomotor characteristics should be included.

In addition to fast-pace shooting game, another action game which is aimed to improve the participants’ balance should be considered (third-arm of the RCT). Nintendo Wii Fit Plus is a video game exercise game containing balance games, yoga poses, strength training and aerobics, which has been widely applied in balance assessment and rehabilitation program (Shih et al. 2010, Hsu et al. 2011). Participants are asked to stand on a Wii Balance Board to conduct the exercises by controlling their centre of balance. The reliability and validity of the Wii Balance Board has been confirmed (Clark et al. 2010, Shih et al. 2010, Young et al. 2011). It is possible that the combined training effect on dynamic vision and balance may be the optimal protocol to improve the older adults’ balance function.

To obtain a full picture of the action video game training effects, our future study should be a 4-arm RCT: 1) control without any intervention; 2) control with physical exercises; 3) fast-pace action video game training; 4) balance action video game training; and 5) combined fast-pace and balance action video game training. Results from this RCT provide evidence to confirm the most effective action video game in improving older adults' balance function.

Appendix 1

Checklist for the delivery of progressive addition lenses (PAL)

Fundamental instruction

□ Confirm the frame's setting to the original position at the time of dispensing

□ Verify the fitting cross coinciding with the participant's pupil centre.

Clean all the marking on the lens

Distant

□ Instruct the client to look at distance object in front of him/her and measure the distance VA monocularly and binocularly.

□ Guide the client to look at the laterally displaced object at the same height as the distance target. Remind the client that s/he may need to turn the head for maximum acuity for peripheral object.

Near

□ Direct the client to look at a near reading chart (habitual working distance) and measure the near VA monocularly and binocularly.

□ Instruct the client to move the near chart to one side and remind the client that s/he may need to turn/ raise the head for maximum acuity.

□ Remind the client that some visual tasks cannot be viewed clearly with the PAL, e.g. reading a memo on a notice board directly above his/her eye level.

Walking

□ Direct the client to lower the head slightly down to look at the position about one step away from his/her current location during walking.

□ Practice x 1 time

Stair/Tandem walk

□ Direct the client to tip the head completely down to see his/her shoes clearly. Remind him/her to use the upper (distant) portion of the lens when walking up and down stairs.

□ Practice x 1 time

Chapter 9

References

Chapter 9

References

1. Achtman, R., Green, C. & Bavelier, D. 2008, "Video games as a tool to train visual skills", *Restorative Neurology and Neuroscience,* vol. 26, no. 4, pp. 435-446.
2. Al-Awar Smither, J. & Kennedy, R.S. 2010, "A portable device for the assessment of dynamic visual acuity", *Applied Ergonomics,* vol. 41, no. 2, pp. 266-273.
3. Anand, V., Buckley, J.G., Scally, A. & Elliott, D.B. 2003, "Postural stability changes in the elderly with cataract simulation and refractive blur", *Investigative Ophthalmology & Visual Science,* vol. 44, no. 11, pp. 4670-4675.
4. Angelaki, D.E. & Hess, B.J. 2005, "Self-motion-induced eye movements: effects on visual acuity and navigation", *Nature Reviews Neuroscience,* vol. 6, no. 12, pp. 966-976.
5. Ao, M., Li, X., Huang, C., Hou, Z., Qiu, W. & Wang, W. 2014, "Significant Improvement in Dynamic Visual Acuity after Cataract Surgery: A Promising Potential Parameter for Functional Vision", *PloS one*, vol. 9, no. 12, pp. e115812.
6. Arditi, A. 2005, "Improving the design of the letter contrast sensitivity test", *Investigative Ophthalmology & Visual Science,* vol. 46, no. 6, pp. 2225-2229.
7. Arfken, C.L., Lach, H.W., Birge, S.J. & Miller, J.P. 1994, "The prevalence and correlates of fear of falling in elderly persons living in the community", *American Journal of Public Health,* vol. 84, no. 4, pp. 565-570.
8. Atchison, D.A. 1992, "Spectacle lens design: a review", *Applied Optics,* vol. 31, no. 19, pp. 3579-3585.
9. Badke, M.B., Shea, T.A., Miedaner, J.A. & Grove, C.R. 2004, "Outcomes after rehabilitation for adults with balance dysfunction", *Archives of Physical Medicine and Rehabilitation,* vol. 85, no. 2, pp. 227-233.
10. Bainbridge, E., Bevans, S., Keeley, B. & Oriel, K. 2011, "The effects of the Nintendo Wii Fit on community-dwelling older adults with perceived balance deficits: A pilot study", *Physical & Occupational Therapy in Geriatrics,* vol. 29, no. 2, pp. 126-135.

11. Baron, W.S. & Westheimer, G. 1973, "Visual acuity as a function of exposure duration", *Journal of the Optical Society of America,* vol. 63, no. 2, pp. 212-219.

12. Bateni, H. 2012, "Changes in balance in older adults based on use of physical therapy vs the Wii Fit gaming system: a preliminary study", *Physiotherapy,* vol. 98, no. 3, pp. 211-216.

13. Beals, R.P., Mayyasi, A.M., Templeton, A.E. & Johnston, W.L. 1971, "The relationship between basketball shooting performance and certain visual attributes", *American Journal of Optometry and Archives of American Academy of Optometry,* vol. 48, no. 7, pp. 585-590.

14. Beauchet, O., Annweiler, C., Dubost, V., Allali, G., Kressig, R.W. Bridenbaugh, S., Berrut, G., Assal, F. and Herrmann, F.R., 2009, "Stops walking when talking: a predictor of falls in older adults?". *European Journal of Neurology*, vol. 16, no. 7, pp.786-795.

15. Beaudot, W.H. 2009, "Psykinematix: A new psychophysical tool for investigating visual impairment due to neural dysfunctions", *Vision: The Journal of the Vision Society of Japan,* vol. 21, no. 1, pp. 19-32.

16. Berg, K. 1989, "Balance and its measure in the elderly: a review", *Physiotherapy Canada,* vol. 41, no. 5, pp. 240-246.

17. Berg, W.P., Alessio, H.M., Mills, E.M. & Tong, C. 1997, "Circumstances and consequences of falls in independent community-dwelling older adults", *Age and Aging,* vol. 26, no. 4, pp. 261-268.

18. Beschorner, K.E., Milanowski, A., Tomashek, D. & Smith, R.O. 2013, "Effect of multifocal lens glasses on the stepping patterns of novice wearers", *Gait & Posture,* vol. 34, no. 4, pp. 1015-1020.

19. Betker, A.L., Desai, A., Nett, C., Kapadia, N. & Szturm, T. 2007, "Game-based exercises for dynamic short-sitting balance rehabilitation of people with chronic spinal cord and traumatic brain injuries", *Physical Therapy,* vol. 87, no. 10, pp. 1389-1398.

20. Billis, A., Konstantinidis, E., Mouzakidis, C., Tsolaki, M., Pappas, C. & Bamidis, P. 2010, "A game-like interface for training seniors' dynamic balance and coordination", *XII Mediterranean Conference on Medical and Biological Engineering and Computing,* vol. 29, pp. 691-694.

21. Black, A. & Wood, J. 2005, "Vision and falls", *Clinical and Experimental Optometry,* vol. 88, no. 4, pp. 212-222.

22. Bloomberg, J.J. & Mulavara, A.P. 2003, "Changes in walking strategies after spaceflight", *Engineering in Medicine and Biology Magazine, IEEE*, vol. 22, no. 2, pp. 58-62.

23. Bloomberg, J., Reschke, M., Huebner, W. & Peters, B. 1992, "The effects of target distance on eye and head movement during locomotion", *Annals of the New York Academy of Sciences,* vol. 656, no. 1, pp. 699-707.

24. Brabyn, J., Schneck, M., Haegerstrom-Portnoy, G. & Lott, L. 2001, "The Smith-Kettlewell Institute (SKI) longitudinal study of vision function and its impact among the elderly: an overview", *Optometry & Vision Science,* vol. 78, no. 5, pp. 264-269.

25. Brayton-Chung, A., Tomashek, D. & Smith, R.O. 2013, "Fall risk assessment: development of a paradigm to measure multifocal eyeglass effects", *Physical & Occupational Therapy in Geriatrics,* vol. 31, no. 1, pp. 47-60.

26. Brown, B. 1972a, "Dynamic visual acuity, eye movements and peripheral acuity for moving targets", *Vision Research,* vol. 12, no. 2, pp. 305-321.

27. Brown, B. 1972b, "The effect of target contrast variation on dynamic visual acuity and eye movements", *Vision Research,* vol. 12, no. 7, pp. 1213-1224.

28. Buckley, J.G., Panesar, G.K., MacLellan, M.J., Pacey, I.E. & Barrett, B.T. 2010, "Changes to control of adaptive gait in individuals with long-standing reduced stereoacuity", *Investigative Ophthalmology & Visual Science,* vol. 51, no. 5, pp. 2487-2495.

29. Burbeck, C.A. 1986, "Exposure-duration effects in localization judgments", *Journal of the Optical Society of America A,* vol. 3, no. 11, pp. 1983-1988.

30. Burg, A. & Hulbert, S. 1961, "Dynamic visual acuity as related to age, sex, and static acuity", *Journal of Applied Psychology,* vol. 45, no. 2, pp. 111-116.

31. Burg, A. 1966, "Visual acuity as measured by dynamic and static tests: a comparative evaluation", *Journal of Applied Psychology,* vol. 50, no. 6, pp. 460-466.

32. Burg, A. 1967, "The relationship between vision test scores and driving record; general findings", Los Angeles: Department of Engineering, University of California, Report NO. 67-24.

33. Burg, A. 1968, "Vision test scores and driving record: Additional findings", Los Angeles: Department of Engineering, University of California, Report NO. 67-27.

34. Butler, D.P. & Willett, K. 2010, "Wii-habilitation: Is there a role in trauma?", *Injury,* vol. 41, no. 9, pp. 883-885.

35. Buttner-Ennever, J.A. & Buttner, U. 1992, "Neuroanatomy of the ocular motor pathways", *Bailliere's Clinical Neurology,* vol. 1, no. 2, pp. 263-287.

36. Cakit, B.D., Saracoglu, M., Genc, H., Erdem, H.R. & Inan, L. 2007, "The effects of incremental speed-dependent treadmill training on postural instability and fear of falling in Parkinson's disease", *Clinical Rehabilitation,* vol. 21, no. 8, pp. 698-705.

37. Campbell, F.W. & Robson, J.G. 1968, "Application of Fourier analysis to the visibility of gratings", *The Journal of Physiology,* vol. 197, no. 3, pp. 551-566.

38. Centers for Disease Control and Prevention (CDC) 2006, "Fatalities and injuries from falls among older adults--United States, 1993-2003 and 2001-2005", MMWR.Morbidity and Mortality weekly report,vol. 55, no. 45, pp. 1221-1224.

39. Cesari, M., Landi, F., Torre, S., Onder, G., Lattanzio, F. & Bernabei, R. 2002, "Prevalence and risk factors for falls in an older community-dwelling population", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 57, no. 11, pp. M722-M726.

40. Chan, K., Pang, W., Ee, C., Ding, Y. & Choo, P. 1997, "Epidemiology of falls among the elderly community dwellers in Singapore", *Singapore Medical Journal,* vol. 38, no. 10, pp. 427-431.

41. Chang, N.T., Yang, N.P. & Chou, P. 2010, "Incidence, risk factors and consequences of falling injuries among the community-dwelling elderly in Shihpai, Taiwan", *Aging Clinical and Experimental Research,* vol. 22, no. 1, pp. 70-77.

42. Charman, W.N. 2014, "Developments in the correction of presbyopia I: spectacle and contact lenses", *Ophthalmic and Physiological Optics,* vol. 34, no. 1, pp. 8-29.

43. Chen, P., Chen, J., Fu, J., Chien, K. & Lu, D. 2008, "A pilot study of anisometropic amblyopia improved in adults and children by perceptual learning: an alternative treatment to patching", *Ophthalmic and Physiological Optics,* vol. 28, no. 5, pp. 422-428.

44. Chiang, I., Tsai, J. & Chen, S. 2012, "Using Xbox 360 kinect games on enhancing visual performance skills on institutionalized older adults with wheelchairs", *Digital Game and Intelligent Toy Enhanced Learning (DIGITEL), IEEE Fourth International Conference 2012*, pp. 263-267.

45. Chiu, F.K. 1994, "Reliability and validity of the Cantonese version of mini-mental state examination-preliminary study", *Journal of Hong Kong College of Psychiatry,* vol. 4, pp. 25-28.

46. Cho, J.P., Paek, K.W., Song, H.J., Jung, Y.S. & Moon, H.W. 2001, "Prevalence and associated factors of falls in the elderly community", *Korean Journal of Preventive Medicine,* vol. 34, no. 1, pp. 47-54.

47. Chou, K. & Chi, I. 2005, "Prevalence and correlates of depression in Chinese oldest-old", I*nternational journal of geriatric psychiatry*, vol. 20, no. 1, pp. 41-50.

48. Chu, L., Chi, I. & Chiu, A. 2005, "Incidence and predictors of falls in the Chinese elderly", *Annals of the Academy of Medicine, Singapore,* vol. 34, no. 1, pp. 60-72.

49. Chu, L., Chi, I. & Chiu, A. 2007, "Falls and fall-related injuries in community-dwelling elderly persons in Hong Kong: a study on risk factors, functional decline, and health services utilization after falls",*Hong Kong Med J,* vol. 13, no. Suppl 1, pp. 8-12.

50. Chylack, L.T., Wolfe, J.K., Singer, D.M., Leske, M.C., Bullimore, M.A., Bailey, I.L., Friend, J., McCarthy, D. & Wu,

S. 1993, "The lens opacities classification system III", *Archives of Ophthalmology,* vol. 111, pp. 1506-1506.

51. Clark, R. & Kraemer, T. 2009, "Clinical use of Nintendo Wii bowling simulation to decrease fall risk in an elderly resident of a nursing home: a case report", *Journal of Geriatric Physical Therapy (2001),* vol. 32, no. 4, pp. 174-180.

52. Clark, R.A., Bryant, A.L., Pua, Y., McCrory, P., Bennell, K. & Hunt, M. 2010, "Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance", *Gait & Posture,* vol. 31, no. 3, pp. 307-310.

53. Clark, S. & Rose, D.J. 2001, "Evaluation of dynamic balance among community-dwelling older adult fallers: a generalizability study of the limits of stability test", *Archives of Physical Medicine and Rehabilitation,* vol. 82, no. 4, pp. 468-474.

54. Clark, S., Rose, D.J. & Fujimoto, K. 1997, "Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults", *Archives of Physical Medicine and Rehabilitation,* vol. 78, no. 10, pp. 1078-1084.

55. Clément, G. & Reschke, M.F. 2010, *Neuroscience in space,* Springer.

56. Close, J., Ellis, M., Hooper, R., Glucksman, E., Jackson, S. & Swift, C. 1999, "Prevention of falls in the elderly trial (PROFET): a randomised controlled trial", *The Lancet,* vol. 353, no. 9147, pp. 93-97.

57. Coleman, A.L., Cummings, S.R., Yu, F., Kodjebacheva, G., Ensrud, K.E., Gutierrez, P., Stone, K.L., Cauley, J.A., Pedula, K.L. & Hochberg, M.C. 2007, "Binocular Visual-Field Loss Increases the Risk of Future Falls in Older White Women", *Journal of the American Geriatrics Society,* vol. 55, no. 3, pp. 357-364.

58. Coutinho, E.S., Fletcher, A., Bloch, K.V. & Rodrigues, L.C. 2008, "Risk factors for falls with severe fracture in elderly people living in a middle-income country: a case control study", *BMC Geriatrics,* vol. 8, no. 1, pp. 21.

59. Dannenbaum, E., Paquet, N., Hakim-Zadeh, R. & Feldman, A.G. 2005, "Optimal parameters for the clinical test of dynamic visual acuity in patients with a unilateral vestibular deficit", *Journal of Otolaryngology,* vol. 34, no. 1, pp. 13-19.

60. Deandrea, S., Lucenteforte, E., Bravi, F., Foschi, R., La Vecchia, C. & Negri, E. 2010, "Risk factors for falls in community-dwelling older people: a systematic review and meta-analysis", *Epidemiology,* vol. 21, no. 5, pp. 658-668.

61. Demer, J. & Amjadi, F. 1993, "Dynamic visual acuity of normal subjects during vertical optotype and head motion", *Investigative Ophthalmology & Visual Science,* vol. 34, no. 6, pp. 1894-1906.

62. Demer, J.L., Crane, B.T., Tian, J. & Wiest, G. 2001, "New tests of vestibular function", *Annals of the New York Academy of Sciences,* vol. 942, no. 1, pp. 428-445.

63. DePasquale, L. & Toscano, L. 2009, "The Spring Scale Test: a reliable and valid tool for explaining fall history", *Journal of Geriatric Physical Therapy,* vol. 32, no. 4, pp. 159-167.

64. Deutsch, J., Robbins, D., Morrison, J. & Bowlby, P.G. 2, "Wii-based compared to standard of care balance and mobility rehabilitation for two individuals post-stroke", *Virtual Rehabilitation International Conference 2*, pp. 117-120.

65. Directions, I.O. 1983, "Standardization in platform stabilometry being a part of posturography", *Agressologie,* vol. 24, no. 7, pp. 321-326.

66. Dougherty, B.E., Flom, R.E. & Bullimore, M.A. 2005, "An evaluation of the Mars letter contrast sensitivity test", *Optometry & Vision Science,* vol. 82, no. 11, pp. 970-975.

67. Dowiasch, S., Marx, S., Einhäuser, W. & Bremmer, F., 2015, "Effects of aging on eye movements in the real world", *Frontiers in human neuroscienc*e, vol. 9, no. 46, pp. 1-12.

68. Duarte, M. & Zatsiorsky, V.M. 2002, "Effects of body lean and visual information on the equilibrium maintenance during stance", *Experimental Brain Research,* vol. 146, no. 1, pp. 60-69.

69. Dunbar, H.M., Crossland, M.D. & Rubin, G.S. 2010, "Fixation stability: a comparison between the Nidek MP-1 and the Rodenstock scanning laser ophthalmoscope in persons with and without diabetic maculopathy", *Investigative Ophthalmology & Visual Science,* vol. 51, no. 8, pp.

4346-4350.

70. Duncan, P.W., Weiner, D.K., Chandler, J. & Studenski, S. 1990, "Functional reach: a new clinical measure of balance", *Journal of Gerontology,* vol. 45, no. 6, pp. M192-M197.

71. Dye, M.W., Green, C.S. & Bavelier, D. 2009, "Increasing Speed of Processing With Action Video Games", *Current directions in psychological science,* vol. 18, no. 6, pp. 321-326.

72. Elliott, C., FitzGerald, J.E. & Murray, A. 1998, "Postural stability of normal subjects measured by sway magnetometry: path length and area for the age range 15 to 64 years", *Physiological Measurement,* vol. 19, no. 1, pp. 103-109.

73. Ellison, A. 2012, "Prismatic displacement effect of progressive multifocal glasses on fall risk in elderly people", [Online]. (Thesis, Bachelor of Medical Science with Honours). University of Otago. Retrieved from http://hdl.handle.net/10523/2475.

74. Enchen, L., Jianfeng, S., Young, C. & Linhong, J. 2011, "Double visual feedback in the rehabilitation of upper limb" in *Universal Access in Human-Computer Interaction. Applications and Services* Springer, pp. 384-388.

75. Fairhall, N., Sherrington, C., Lord, S.R., Kurrle, S.E., Langron, C., Lockwood, K., Monaghan, N., Aggar, C. & Cameron, I.D. 2013, "Effect of a multifactorial, interdisciplinary intervention on risk factors for falls and fall rate in frail older people: a randomised controlled trial", *Age and Aging,* vol. 0, pp. 1-7.

76. Falkowitz, C. & Mendel, H. 1977, "The role of visual skills in batting averages", *Optometric Weekly,* vol. 68, no. 20, pp. 33-36.

77. Faubert, J. & Allard, R. 2004, "Effect of visual distortion on postural balance in a full immersion stereoscopic environment", *Electronic Imaging*, vol. 529, pp. 491-500.

78. Fergenson, P. & Suzansky, J. 1973, "An investigation of dynamic and static visual acuity", *Perception,* vol. 2, no. 3, pp. 343-356.

79. Fitzgerald, D., Trakarnratanakul, N., Dunne, L., Smyth, B. &

Caulfield, B. 2008, "Development and user evaluation of a virtual rehabilitation system for wobble board balance training", *Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE*, pp. 4194-4198.

80. Flynn, S., Palma, P. & Bender, A. 2007, "Feasibility of using the Sony PlayStation 2 gaming platform for an individual poststroke: a case report", *Journal of neurologic physical therapy,* vol. 31, no. 4, pp. 180-189.

81. Folstein, M.F., Folstein, S.E. & McHugh, P.R. 1975, "“Mini-mental state”: a practical method for grading the cognitive state of patients for the clinician", *Journal of Psychiatric Research,* vol. 12, no. 3, pp. 189-198.

82. Freeman, E.E., Muñoz, B., Turano, K.A. & West, S.K. 2006, "Dynamic measures of visual function and their relationship to self-report of visual functioning", *Investigative Ophthalmology & Visual Science,* vol. 47, no. 11, pp. 4762-4766.

83. Giagazoglou, P., Amiridis, I.G., Zafeiridis, A., Thimara, M., Kouvelioti, V. & Kellis, E. 2009, "Static balance control and lower limb strength in blind and sighted women", *European Journal Of Applied Physiology,* vol. 107, no. 5, pp. 571-579.

84. Giaschi, D. & Regan, D. 1997, "Development of motion-defined figure-ground segregation in preschool and older children, using a letter-identification task", *Optometry & Vision Science,* vol. 74, no. 9, pp. 761-767.

85. Girardi, M., Konrad, H.R., Amin, M. & Hughes, L.F. 2001, "Predicting fall risks in an elderly population: computer dynamic posturography versus electronystagmography test results", *The Laryngoscope,* vol. 111, no. 9, pp. 1528-1532.

86. Glasser, A. & Campbell, M.C. 1998, "Presbyopia and the optical changes in the human crystalline lens with age", *Vision Research,* vol. 38, no. 2, pp. 209-229.

87. Goldstone, R.L. 1998, "Perceptual learning", *Annual Review of Psychology,* vol. 49, no. 1, pp. 585-612.

88. Gonçalves, L.G., Vieira, S.T., Siqueira, F.V. & Hallal, P.C. 2008, "Prevalence of falls in institutionalized elderly in Rio Grande, Southern Brazil", *Revista de Saúde Pública,* vol. 42, no. 5, pp. 938-945.

89. Graves, L.E., Ridgers, N.D., Williams, K., Stratton, G., Atkinson, G. & Cable, N.T. 2010, "The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults", *Journal of Physical Activity & Health,* vol. 7, no. 3, pp. 393-401.

90. Green, C.S. & Bavelier, D. 2003, "Action video game modifies visual selective attention", *Nature,* vol. 423, no. 6939, pp. 534-537.

91. Green, C.S. & Bavelier, D. 2006, "Enumeration versus multiple object tracking: The case of action video game players", *Cognition,* vol. 101, no. 1, pp. 217-245.

92. Green, C.S. & Bavelier, D. 2007, "Action-video-game experience alters the spatial resolution of vision", *Psychological science,* vol. 18, no. 1, pp. 88-94.

93. Greenfield, P.M., DeWinstanley, P., Kilpatrick, H. & Kaye, D. 1994, "Action video games and informal education: Effects on strategies for dividing visual attention", *Journal of Applied Developmental Psychology,* vol. 15, no. 1, pp. 105-123.

94. Gribble, P.A. & Hertel, J. 2003, "Considerations for normalizing measures of the Star Excursion Balance Test", *Measurement in Physical Education and Exercise Science,* vol. 7, no. 2, pp. 89-100.

95. Grossman, G.E., Leigh, R.J., Bruce, E.N., Huebner, W.P. & Lanska, D.J. 1989, "Performance of the human vestibuloocular reflex during locomotion", *Journal of Neurophysiology,* vol. 62, no. 1, pp. 264-272.

96. Haegerstrom-Portnoy, G. 2005, "The Glenn A. Fry Award Lecture 2003: Vision in elders-summary of findings of the SKI study", *Optometry & Vision Science,* vol. 82, no. 2, pp. 87-93.

97. Hamasaki, D., Ong, J. & Marg, E. 1956, "The amplitude of accommodation in presbyopia", *American journal of optometry and archives of American Academy of Optometry,* vol. 33, no. 1, pp. 3-14.

98. Haran, M.J., Lord, S.R., Cameron, I.D., Ivers, R.Q., Simpson, J.M., Lee, B.B., Porwal, M., Kwan, M.M. & Severino, C. 2009, "Preventing falls in older multifocal glasses wearers by providing single-lens distance glasses: the protocol for the

VISIBLE randomised controlled trial", *BMC Geriatrics,* vol. 9, no. 1, pp. 10-17.

99. Hassan, S.E., Lovie-Kitchin, J.E. & Woods, R.L. 2002, "Vision and mobility performance of subjects with age-related macular degeneration", *Optometry & Vision Science,* vol. 79, no. 11, pp. 697-707.

100. Hatzitaki, V., Zlsi, V., Kollias, I. & Kioumourtzoglou, E. 2002, "Perceptual-motor contributions to static and dynamic balance control in children", *Journal of Motor Behavior,* vol. 34, no. 2, pp. 161-170.

101. Haymes, S.A., Roberts, K.F., Cruess, A.F., Nicolela, M.T., LeBlanc, R.P., Ramsey, M.S., Chauhan, B.C. & Artes, P.H. 2006, "The letter contrast sensitivity test: clinical evaluation of a new design", *Investigative Ophthalmology & Visual Science,* vol. 47, no. 6, pp. 2739-2745.

102. Heasley, K., Buckley, J.G., Scally, A., Twigg, P. & Elliott, D.B. 2004, "Stepping up to a new level: effects of blurring vision in the elderly", *Investigative Ophthalmology & Visual Science,* vol. 45, no. 7, pp. 2122-2128.

103. Hempel, S., Newberry, S., Wang, Z., Booth, M., Shanman, R., Johnsen, B., Shier, V., Saliba, D., Spector, W.D. & Ganz, D.A. 2013, "Hospital fall prevention: a systematic review of implementation, components, adherence, and effectiveness", *Journal of the American Geriatrics Society,* vol. 61, no. 4, pp. 483-494.

104. Henderson, R.L. & Burg, A. 1974, Vision and audition in driving, System Development Corporation.

105. Herdman, S.J., Blatt, P.J. & Schubert, M.C. 2000, "Vestibular rehabilitation of patients with vestibular hypofunction or with benign paroxysmal positional vertigo", *Current opinion in neurology,* vol. 13, no. 1, pp. 39-43.

106. Herdman, S.J., Tusa, R.J., Blatt, P., Suzuki, A., Venuto, P.J. & Roberts, D. 1998, "Computerized dynamic visual acuity test in the assessment of vestibular deficits", *Otology & Neurotology,* vol. 19, no. 6, pp. 790-796.

107. Hill, K.D. 1996, "A new test of dynamic standing balance for stroke patients: reliability, validity and comparison with healthy elderly", *Physiotherapy Canada,* vol. 48, no. 4, pp.

257-262.

108. Hillman, E.J., Bloomberg, J.J., McDonald, P.V. & Cohen, H.S. 1999, "Dynamic visual acuity while walking in normals and labyrinthine-deficient patients", *Journal of Vestibular Research,* vol. 9, no. 1, pp. 49-57.

109. Ho, S.C., Woo, J., Chan, S.S., Yuen, Y. & Sham, A. 1996, "Risk factors for falls in the Chinese elderly population", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 51, no. 5, pp. M195-M198.

110. Hoffman, L., Rouse, M. & Ryan, J. 1981, "Dynamic visual acuity: A review", *Journal of the American Optometric Association,* vol. 52, no. 11, pp. 883-887.

111. Holmes, H., Wood, J., Jenkins, S., Winship, P., Lunt, D., Bostock, S. & Hill, K. 2013, "Xbox Kinect™ represents high intensity exercise for adults with cystic fibrosis", *Journal of Cystic Fibrosis,* vol. 12, no. 6, pp. 604-608.

112. Hsu, J.K., Thibodeau, R., Wong, S.J., Zukiwsky, D., Cecile, S. & Walton, D.M. 2011, "A “Wii” bit of fun: The effects of adding Nintendo Wii® Bowling to a standard exercise regimen for residents of long-term care with upper extremity dysfunction", *Physiotherapy Theory and Practice,* vol. 27, no. 3, pp. 185-193.

113. Hsu, P.C. & Miller, W.C. 2006, "Reliability of the Chinese version of the Activities-specific Balance Confidence Scale", *Disability & Rehabilitation,* vol. 28, no. 20, pp. 1287-1292.

114. Huang, S., Zheng, Y., Foster, P.J., Huang, W. & He, M. 2009, "Prevalence and causes of visual impairment in Chinese adults in urban southern China: the Liwan Eye Study", *Archives of Ophthalmology,* vol. 127, no. 10, pp. 1362.

115. Hulbert, S.F., Burg, A., Knoll, H.A. & Mathewson, J.H. 1958, "A preliminary study of dynamic visual acuity and its effects in motorists ‘vision", *The Australasian Journal of Optometry,* vol. 41, no. 3, pp. 116-130.

116. Hurkmans, H.L., van den Berg-Emons, Rita J & Stam, H.J. 2010, "Energy expenditure in adults with cerebral palsy playing Wii Sports", *Archives of Physical Medicine and Rehabilitation,* vol. 91, no. 10, pp. 1577-1581.

117. Hutchings, N., Irving, E.L., Jung, N., Dowling, L.M. & Wells, K.A. 2007, "Eye and head movement alterations in naive progressive addition lens wearers", *Ophthalmic and Physiological Optics,* vol. 27, no. 2, pp. 142-153.

118. Ishigaki, H. & Miyao, M. 1994, "A new dynamic visual acuity device: aging and sex difference in dynamic visual acuity", *Sangyo Igaku,* vol. 36, no. 3, pp. 181-182.

119. Ivers, R.Q., Cumming, R.G., Mitchell, P. & Attebo, K. 1998, "Visual impairment and falls in older adults: the Blue Mountains Eye Study", *Journal of the American Geriatrics Society,* vol. 46, no. 1, pp. 58-64.

120. Jalie, M. 2008, *Ophthalmic lenses and dispensing,* 3rd edn, Elsevier/Butterworth Heinemann, Edinburgh; New York.

121. Johnson, E.L. 2002, "Computerized dynamic visual acuity with volitional head movement in patients with vestibular dysfunction", Graduate Theses and Dissertations. [http://scholarcommons.usf.edu/etd/152].

122. Johnson, L., Buckley, J.G., Harley, C. & Elliott, D.B. 2008, "Use of single-vision eyeglasses improves stepping precision and safety when elderly habitual multifocal wearers negotiate a raised surface", *Journal of the American Geriatrics Society*, vol. 56, no. 1, pp. 178-180.

123. Johnson, L., Buckley, J.G., Scally, A.J. & Elliott, D.B. 2007, "Multifocal spectacles increase variability in toe clearance and risk of tripping in the elderly", *Investigative Ophthalmology & Visual Science,* vol. 48, no. 4, pp. 1466-1471.

124. Johnson, P.V., Kim, J., Hoffman, D.M., Vargas, A.D. & Banks, M.S. 2014, "Motion artifacts on 240 - Hz OLED stereoscopic 3D displays", *Journal of the Society for Information Display*, vol. 22, no. 8, pp.393-403.

125. Juras, G., Słomka, K., Fredyk, A., Sobota, G. & Bacik, B. 2008, "Evaluation of the limits of stability (LOS) balance test", *Journal of Human Kinetics,* vol. 19, no. 1, pp. 39-52.

126. Kalisch, T., Kattenstroth, J.C., Noth, S., Tegenthoff, M. & Dinse, H.R. 2011, "Rapid assessment of age-related differences in standing balance", *Journal of Aging Research,* 2011:160490 10.4061/2011/160490.

127. Kalula, S.Z., Scott, V., Dowd, A. & Brodrick, K. 2011, "Falls and fall prevention programmes in developing countries: environmental scan for the adaptation of the Canadian Falls prevention curriculum for developing countries", *Journal of Safety Research,* vol. 42, no. 6, pp. 461-472.

128. Kaskutas, V., Dale, A.M., Lipscomb, H. & Evanoff, B. 2013, "Fall prevention and safety communication training for foremen: Report of a pilot project designed to improve residential construction safety", *Journal of Safety Research,* vol. 44, pp. 111-118.

129. Klein, B.E., Klein, R., Lee, K.E. & Cruickshanks, K.J. 1998, "Performance-based and self-assessed measures of visual function as related to history of falls, hip fractures, and measured gait time: the Beaver Dam Eye Study", *Ophthalmology,* vol. 105, no. 1, pp. 160-164.

130. Klein, R., Klein, B. & Lee, K.E. 1996, "Changes in visual acuity in a population. The Beaver Dam Eye Study", *Ophthalmology,* vol. 103, no. 8, pp. 1169-1178.

131. Kohmura, Y., Aoki, K., Honda, K., Yoshigi, H. & Sakuraba, K. 2008, "The relationship between dynamic visual acuity and saccadic eye movement", *Human Performance Measurement,* vol. 5, pp. 23-30.

132. Kulmala, J., Viljanen, A., Sipila, S., Pajala, S., Parssinen, O., Kauppinen, M., Koskenvuo, M., Kaprio, J. & Rantanen, T. 2009, "Poor vision accompanied with other sensory impairments as a predictor of falls in older women", *Age and Aging,* vol. 38, no. 2, pp. 162-167.

133. Kwan, M.M., Close, J.C., Wong, A.K.W. & Lord, S.R. 2011, "Falls incidence, risk factors, and consequences in Chinese older people: a systematic review", *Journal of the American Geriatrics Society,* vol. 59, no. 3, pp. 536-543.

134. Kwan, M.M., Tsang, W.W., Lin, S., Greenaway, M., Close, J.C. & Lord, S.R. 2013, "Increased concern is protective for falls in Chinese older people: the Chopstix Fall Risk Study", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 68, no. 8, pp. 946-953.

135. Lachman, M.E., Howland, J., Tennstedt, S., Jette, A., Assmann, S. & Peterson, E.W. 1998, "Fear of falling and activity restriction: the survey of activities and fear of falling in the elderly (SAFE)", *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences,* vol. 53, no. 1, pp. P43-P50.

136. Land, M., Mennie, N. & Rusted, J. 1999, "The roles of vision and eye movements in the control of activities of daily living", *Perception,* vol. 28, no. 11, pp. 1311-1328.

137. Lange, B., Flynn, S., Chang, C., Ahmed, A., Geng, Y., Utsav, K., Xu, M., Seok, D., Cheng, S. & Rizzo, A. 2010, "Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury", *Proceedings of ICDVRAT, Chile,* vol. 17, no. 5, pp. 249-254.

138. Lau, E., Woo, J. & Lam, D. 1991, "Neuromuscular impairment: a major cause of non-syncopal falls in elderly Chinese", *Public Health,* vol. 105, no. 5, pp. 369-372.

139. Lee, H., Chang, K., Tsauo, J., Hung, J., Huang, Y. & Lin, S. 2013, "Effects of a multifactorial fall prevention program on fall incidence and physical function in community-dwelling older adults with risk of falls", *Archives of Physical Medicine and Rehabilitation,* vol. 94, no. 4, pp. 606-615.

140. Lee, H.K. & Scudds, R.J. 2003, "Comparison of balance in older people with and without visual impairment", *Age and Aging,* vol. 32, no. 6, pp. 643-649.

141. Lee, J.S., Kwok, T., Leung, P.C. & Woo, J. 2006, "Medical illnesses are more important than medications as risk factors of falls in older community dwellers? A cross-sectional study", *Age and Aging,* vol. 35, no. 3, pp. 246-251.

142. Lee, M.H., Durnford, S., Crowley, J. & Rupert, A. 1996, “Visual vestibular interaction in the dynamic visual acuity test during voluntary head rotation”, *Aviation, Space, and Environmental Medicine,* vol. 68, no. 2, pp. 111-117.

143. Legters, K., Whitney, S.L., Porter, R. & Buczek, F. 2005, "The relationship between the activities-specific Balance Confidence Scale and the Dynamic Gait Index in peripheral vestibular dysfunction", *Physiotherapy Research International*, vol. 10, no. 1, pp. 10-22.

144. Levac, D., Rivard, L. & Missiuna, C. 2012, "Defining the active ingredients of interactive computer play interventions for children with neuromotor impairments: a scoping review", *Research in developmental disabilities,* vol. 33, no. 1, pp. 214-223.

145. Levi, D.M. 2008, "Crowding—An essential bottleneck for object recognition: A mini-review", *Vision Research,* vol. 48, no. 5, pp. 635-654.

146. Li, L., Wang, S. & Yang, Z. 2002, "A study on risk factors for falling down in elderly people of rural areas in Laizhou City", *Chinese Journal of Geriatric,* vol. 21, pp. 370-372.

147. Li, R., Polat, U., Makous, W. & Bavelier, D. 2009, "Enhancing the contrast sensitivity function through action video game training", *Nature Neuroscience,* vol. 12, no. 5, pp. 549-551.

148. Li, R.W. & Levi, D.M. 2004, "Characterizing the mechanisms of improvement for position discrimination in adult amblyopia", *Journal of Vision,* vol. 4, no. 6, pp. 476-487.

149. Li, R.W., Ngo, C., Nguyen, J. & Levi, D.M. 2011, "Video-game play induces plasticity in the visual system of adults with amblyopia", *PLoS Biology,* vol. 9, no. 8, pp. e1001135.

150. Li, R.W., Provost, A. & Levi, D.M. 2007, "Extended perceptual learning results in substantial recovery of positional acuity and visual acuity in juvenile amblyopia", *Investigative Ophthalmology & Visual Science,* vol. 48, no. 11, pp. 5046-5051.

151. Liaw, M., Chen, C., Pei, Y., Leong, C. & Lau, Y. 2009, "Comparison of the static and dynamic balance performance in young, middle-aged, and elderly healthy people", *Chang Gung Medical Journal,* vol. 32, no. 3, pp. 297-304.

152. Liston, R.A. & Brouwer, B.J. 1996, "Reliability and validity of measures obtained from stroke patients using the Balance Master", *Archives of Physical Medicine and Rehabilitation,* vol. 77, no. 5, pp. 425-430.

153. Liu, S., Li, J., Cheng, Y., Mao, A., Hu, X. & Shi, H. 2004, "Body function and fall related factors of the elderly in community", *Journal of Nursing Science,* vol. 19, no. 6, pp. 5-7.

154. Long, G.M. & Crambert, R.F. 1990, "The nature and basis of age-related changes in dynamic visual acuity", *Psychology and Aging,* vol. 5, no. 1, pp. 138-143.

155. Long, G.M. & Garvey, P.M. 1988, "The effects of target borders on dynamic visual acuity: practical and theoretical implications", *Perception,* vol. 17, no. 74, pp. 5-751.

156. Long, G.M. & Homolka, J.L. 1992, "Contrast sensitivity during horizontal visual pursuit: dynamic sensitivity functions", *Perception,* vol. 21, no. 6, pp. 753-753.

157. Long, G.M. & Kearns, D.F. 1996, "Visibility of text and icon highway signs under dynamic viewing conditions", *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 38, no. 4, pp. 690-701.

158. Long, G.M. & May, P.A. 1992, "Dynamic visual acuity and contrast sensitivity for static and flickered gratings in a college sample", *Optometry & Vision Science,* vol. 69, no. 12, pp. 915-922.

159. Long, G.M. & Riggs, C.A. 1991, "Training effects on dynamic visual acuity with free-head viewing", *Perception,* vol. 20, no. 3, pp. 363-371.

160. Long, G.M. & Rourke, D.A. 1989, "Training effects on the resolution of moving targets—dynamic visual acuity", *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 31, no. 4, pp. 443-451.

161. Long, G.M. & Zavod, M.J. 2002, "Contrast sensitivity in a dynamic environment: effects of target conditions and visual impairment", *Human Factors*, vol. 44, no. 1, pp. 120-132.

162. Lord, S.R. & Ward, J.A. 1994, "Age-associated differences in sensori-motor function and balance in community dwelling women", *Age and Aging,* vol. 23, no. 6, pp. 452-460.

163. Lord, S.R., Clark, R.D. & Webster, I.W. 1991, "Physiological factors associated with falls in an elderly population", *Journal of the American Geriatrics Society,* vol. 39, no. 12, pp. 1194-1200.

164. Lord, S.R., Dayhew, J. & Howland, A. 2002, "Multifocal glasses impair edge-contrast sensitivity and depth perception and increase the risk of falls in older people", *Journal of the American Geriatrics Society*, vol. 50, no. 11, pp. 1760-1766.

165. Lord, S.R., Menz, H.B. & Tiedemann, A. 2003, "A physiological profile approach to falls risk assessment and prevention", *Physical Therapy,* vol. 83, no. 3, pp. 237-252.

166. Lord, S.R., Ward, J.A., Williams, P. & Anstey, K.J. 1994, "Physiological factors associated with falls in older community-dwelling women", *Journal of the American Geriatrics Society,* vol. 42, no. 10, pp. 1110-1117.

167. Lott, L.A., Haegerstrom-Portnoy, G., Schneck, M.E. & Brabyn, J.A. 2005, "Face recognition in the elderly", *Optometry & Vision Science,* vol. 82, no. 10, pp. 874-881.

168. Ludvigh, E. & Miller, J.W. 1953, "A study of dynamic visual acuity", No. JPR1. Pensacola: Kresge Eye Institute and United States School of Aviation Medicine.

169. Ludvigh, E. & Miller, J.W. 1954, "Some effects of training on dynamic visual acuity", No. JPR6. Pensacola: Kresge Eye Institute and United States School of Aviation Medicine.

170. Ludvigh, E. & Miller, J.W. 1958, "Study of visual acuity during the ocular pursuit of moving test objects. I. Introduction", *Journal of the Optical Society of America,* vol. 48, no. 11, pp. 799-802.

171. Ludvigh, E. 1947, "Visibility of the deer fly in flight", *Science,* vol. 105, pp. 176-177.

172. Ludvigh, E.J. 1949, "Visual acuity while one is viewing a moving object", *Archives of Ophthalmology,* vol. 42, no. 1, pp. 14-22.

173. Lundh, B.L. & Gottvall, E. 1995, "Peripheral contrast sensitivity for dynamic sinusoidal gratings in early glaucoma", *Acta Ophthalmologica Scandinavica,* vol. 73, no. 3, pp. 202-206.

174. Mackworth, N., Kaplan, I. & Metlay, W. 1964, "Eye movements during vigilance", *Perceptual And Motor Skills,* vol. 18, no. 2, pp. 397-402.

175. Maki, B.E. & McIlroy, W.E. 2006, "Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention", *Age and Aging,* vol. 35, no. suppl 2, pp. ii12-ii18.

176. Mamoto, Y., Yamamoto, K., Imai, T., Tamura, M. & Kubo, T. 2002, "Three-dimensional analysis of human locomotion in normal subjects and patients with vestibular deficiency", *Acta*

Oto-Laryngologica, vol. 122, no. 5, pp. 495-500.

177. Manchester, D., Woollacott, M., Zederbauer-Hylton, N. & Marin, O. 1989, "Visual, vestibular and somatosensory contributions to balance control in the older adult", *Journal of Gerontology,* vol. 44, no. 4, pp. M118-M127.

178. Marchetti, G.F., Whitney, S.L., Blatt, P.J., Morris, L.O. & Vance, J.M. 2008, "Temporal and spatial characteristics of gait during performance of the Dynamic Gait Index in people with and people without balance or vestibular disorders", *Physical Therapy,* vol. 88, no. 5, pp. 640-651.

179. Marigold, D.S. & Patla, A.E. 2008, "Visual information from the lower visual field is important for walking across multi-surface terrain", *Experimental Brain Research,* vol. 188, no. 1, pp. 23-31.

180. Marsh, A.P. & Geel, S.E. 2000, "The effect of age on the attentional demands of postural control", *Gait & Posture,* vol. 12, no. 2, pp. 105-113.

181. Mayyasi, A., Beals, R., Templeton, A. & Hale, P. 1971, "The effects of ambient illumination and contrast on dynamic visual acuity.", *American Journal of Optometry & Archives of American Academy of Optometry,* .

182. McAuley, E., Mihalko, S.L. & Rosengren, K. 1997, "Self-efficacy and balance correlates of fear of falling in the elderly", *Journal of Aging and Physical Activity,* vol. 5, pp. 329-340.

183. McCulloch, D.L., Loffler, G., Colquhoun, K., Bruce, N., Dutton, G.N. & Bach, M. 2011, "The effects of visual degradation on face discrimination", *Ophthalmic and Physiological Optics,* vol. 31, no. 3, pp. 240-248.

184. McClure, R.J., Hughes, K., Ren, C., McKenzie, K., Dietrich, U., Vardon, P., Davis, E. & Newman, B. 2010, "The population approach to falls injury prevention in older people: findings of a two community trial", *BMC public health*, vol. 10, pp. 79-87.

185. Meldrum, D., Glennon, A., Herdman, S., Murray, D. & McConn-Walsh, R. 2012, "Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii® Fit Plus", *Disability and Rehabilitation: Assistive Technology,* vol. 7, no. 3, pp. 205-210.

186. Meli, A., Zimatore, G., Badaracco, C., De Angelis, E. & Tufarelli, D. 2006, "Vestibular rehabilitation and 6-month follow-up using objective and subjective measures", *Acta Oto-Laryngologica,* vol. 126, no. 3, pp. 259-266.

187. Menant, J.C., St George, R.J., Fitzpatrick, R.C. & Lord, S.R. 2010, "Impaired depth perception and restricted pitch head movement increase obstacle contacts when dual-tasking in older people", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 65, no. 7, pp. 751-757.

188. Menant, J.C., St George, R.J., Sandery, B., Fitzpatrick, R.C. & Lord, S.R. 2009, "Older people contact more obstacles when wearing multifocal glasses and performing a secondary visual task", *Journal of the American Geriatrics Society,* vol. 57, no. 10, pp. 1833-1838.

189. Methling, D. & Wernicke, J. 1968, "Visual acuity in horizontal tracking movements of the eye", *Vision research,* vol. 8, no. 5, pp. 554-565.

190. Michon, J.J., Lau, J., Chan, W.S. & Ellwein, L.B. 2002, "Prevalence of visual impairment, blindness, and cataract surgery in the Hong Kong elderly", *B146*, vol. 86, no. 2, pp.133-139.

191. Microsoft, 2014-last update, Xbox [Homepage Xbox, Microsoft], [Online]. Available: http://www.xbox.com/en-hk/#fbid=nU6nmnhTJK1 [2014, 01/01].

192. Miller, J.W. 1958, "Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination", *Journal of the Optical Society of America,* vol. 48, no. 11, pp. 803-806.

193. Miller, J.W. & Ludvigh, E. 1957, An analysis of certain factors involved in the learning process of dynamic visual acuity for 1000 naval aviation cadets. NSAM-574, Naval School of Aviation Medicine, Pensacola FL, USA.

194. Mishra, J., Zinni, M., Bavelier, D. & Hillyard, S.A. 2011, "Neural basis of superior performance of action videogame players in an attention-demanding task", *The Journal of* *neuroscience: the official journal of the Society for Neuroscience,* vol. 31, no. 3, pp. 992-998.

195. Mohapatra, S. & Aruin, A.S. 2013, "Static and dynamic visual cues in feed-forward postural control", *Experimental Brain Research,* vol. 224, no. 1, pp. 25-34.

196. Nakatsuka, M., Ueda, T., Nawa, Y., Yukawa, E., Hara, T. & Hara, Y. 2006, "Effect of static visual acuity on dynamic visual acuity: a pilot study", *Perceptual and Motor Skills,* vol. 103, no. 1, pp. 160-164.

197. Nasreddine, Z.S., Phillips, N.A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L. & Chertkow, H. 2005, "The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment", *Journal of the American Geriatrics Society,* vol. 53, no. 4, pp. 695-699.

198. NeuroCom, a division of Natus, 2012-last update, Limits of stability (LOS) [Homepage of NeuroCom, a division of Natus], [Online]. Available: http://www.resourcesonbalance.com/neurocom/protocols/motorimpairment/los.aspx [2014, 01/01].

199. Nintendo (Hong Kong) Ltd., 2014-last update, Wii console [Homepage Wii console, Nintendo (Hong Kong) Ltd.], [Online]. Available: http://www.nintendo.com.hk/wii/wii_index.htm [2014, 01/01].

200. O'Donovan, C., Hirsch, E., Holohan, E., McBride, I., McManus, R. & Hussey, J. 2012, "Energy expended playing Xbox Kinect™ and Wii™ games: a preliminary study comparing single and multiplayer modes", *Physiotherapy,* vol. 98, no. 3, pp. 224-229.

201. Owsley, C., Sekuler, R. & Siemsen, D. 1983, "Contrast sensitivity throughout adulthood", *Vision Research*, vol. 23, no. 7, pp. 689-699.

202. Painter, J.A., Elliott, S.J. & Hudson, S. 2009, "Falls in community-dwelling adults aged 50 years and older prevalence and contributing factors", *Journal Of Allied Health,* vol. 38, no. 4, pp. 201-207.

203. Patel, I., Turano, K.A., Broman, A.T., Bandeen-Roche, K., Muñoz, B. & West, S.K. 2006, "Measures of visual function and percentage of preferred walking speed in older adults:

the Salisbury Eye Evaluation Project", *Investigative Ophthalmology & Visual Science,* vol. 47, no. 1, pp. 65-71.

204. Patla, A.E. 1998, "How is human gait controlled by vision", *Ecological Psychology,* vol. 10, no. 3-4, pp. 287-302.

205. Patla, A.E., Davies, T.C. & Niechwiej, E. 2004, "Obstacle avoidance during locomotion using haptic information in normally sighted humans", *Experimental Brain Research,* vol. 155, no. 2, pp. 173-185.

206. Pelli, D. & Robson, J. 1988, "The design of a new letter chart for measuring contrast sensitivity", Clinical Vision Sciences, vol. 2, no. 3, pp. 187-199.

207. Perracini, M.R. & Ramos, L.R. 2002, "Fall-related factors in a cohort of elderly community residents", *Revista de Saúde Pública,* vol. 36, no. 6, pp. 709-716.

208. Peters, B.T. & Bloomberg, J.J. 2005, "Dynamic visual acuity using “far” and “near” targets", *Acta Oto-Laryngologica,* vol. 125, no. 4, pp. 353-357.

209. Pluijm, S.M., Smit, J.H., Tromp, E., Stel, V., Deeg, D.J., Bouter, L. & Lips, P. 2006, "A risk profile for identifying community-dwelling elderly with a high risk of recurrent falling: results of a 3-year prospective study", *Osteoporosis International,* vol. 17, no. 3, pp. 417-425.

210. Pompeu, J.E., Mendes, Felipe Augusto dos Santos, Silva, K.G.d., Lobo, A.M., Oliveira, T.d.P., Zomignani, A.P. & Piemonte, M.E.P. 2012, "Effect of Nintendo Wii™-based motor and cognitive training on activities of daily living in patients with Parkinson's disease: A randomised clinical trial", *Physiotherapy,* vol. 98, no. 3, pp. 196-204.

211. Powell, L.E. & Myers, A.M. 1995, "The activities-specific balance confidence (ABC) scale", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 50, no. 1, pp. M28-M34.

212. Prado, J.M., Stoffregen, T.A. & Duarte, M. 2007, "Postural sway during dual tasks in young and elderly adults", *Gerontology,* vol. 53, no. 5, pp. 274-281.

213. Primack, B.A., Carroll, M.V., McNamara, M., Klem, M.L., King, B., Rich, M., Chan, C.W. & Nayak, S. 2012, "Role of video games in improving health-related outcomes: a systematic review", *American Journal of Preventive Medicine,* vol. 42, no. 6, pp. 630-638.

214. Rafał, S., Janusz, M., Wiesław, O. & Robert, S. 2011, "Test-retest reliability of measurements of the center of pressure displacement in quiet standing and during maximal voluntary body leaning among healthy elderly men", *Journal of Human Kinetics,* vol. 28, no. 1, pp. 15-23.

215. Raîche, M., Hébert, R., Prince, F. & Corriveau, H. 2000, "Screening older adults at risk of falling with the Tinetti balance scale", *The Lancet,* vol. 356, no. 9234, pp. 1001-1002.

216. Rand, D., Kizony, R. & Weiss, P. 2004, "Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy", *5th Intl. Conf. On Disability, Virtual Environments and Assoc. Technologies*, pp. 87-94.

217. Rand, D., Kizony, R. & Weiss, P.T. 2008, "The Sony PlayStation II EyeToy: low-cost virtual reality for use in rehabilitation", *Journal of Neurologic Physical Therapy,* vol. 32, no. 4, pp. 155-163.

218. Ray, C.T., Horvat, M., Croce, R., Christopher Mason, R. & Wolf, S.L. 2008, "The impact of vision loss on postural stability and balance strategies in individuals with profound vision loss", *Gait & Posture,* vol. 28, no. 1, pp. 58-61.

219. Rayner, K. 1998, "Eye movements in reading and information processing: 20 years of research.", *Psychological Bulletin,* vol. 124, no. 3, pp. 372-422.

220. Rayner, K., Castelhano, M.S. & Yang, J. 2009, "Eye movements and the perceptual span in older and younger readers.", *Psychology and Aging*, vol. 24, no. 3, pp. 755.

221. Reading, V.M. 1972, "Visual resolution as measured by dynamic and static tests", *Pflügers Archiv European Journal of Physiology,* vol. 333, no. 1, pp. 17-26.

222. Reed-Jones, R.J., Solis, G.R., Lawson, K.A., Loya, A.M., Cude-Islas, D. & Berger, C.S. 2013, "Vision and falls: A multidisciplinary review of the contributions of visual impairment to falls among older adults", *Maturitas,* vol. 75, no. 1, pp. 22-28.

223. Retchin, S.M., Cox, J., Fox, M. & Irwin, L. 1988, "Performance-based measurements among elderly drivers and nondrivers", *Journal of the American Geriatrics Society,* vol. 36, no. 9, pp. 813-819.

224. Rey, F., Lê, T., Bertin, R. & Kapoula, Z. 2008, "Saccades horizontal or vertical at near or at far do not deteriorate postural control", *Auris Nasus Larynx,* vol. 35, no. 2, pp. 185-191.

225. Rhea, C.K. & Rietdyk, S. 2007, "Visual exteroceptive information provided during obstacle crossing did not modify the lower limb trajectory", *Neuroscience Letters,* vol. 418, no. 1, pp. 60-65.

226. Rietdyk, S. & Rhea, C.K. 2011, "The effect of the visual characteristics of obstacles on risk of tripping and gait parameters during locomotion", *Ophthalmic and Physiological Optics,* vol. 31, no. 3, pp. 302-310.

227. Rine, R.M. & Braswell, J. 2003, "A clinical test of dynamic visual acuity for children", *International Journal Of Pediatric Otorhinolaryngology,* vol. 67, no. 11, pp. 1195-1201.

228. Roberts, R.A., Gans, R.E., Johnson, E.L. & Chisolm, T.H. 2006, "Computerized dynamic visual acuity with volitional head movement in patients with vestibular dysfunction", *Annals of Otology Rhinology and Laryngology,* vol. 115, no. 9, pp. 658-666.

229. Rouse, M.W., DeLand, P., Christian, R. & Hawley, J. 1988, "A comparison study of dynamic visual acuity between athletes and nonathletes", *Journal of the American Optometric Association,* vol. 59, no. 12, pp. 946-950.

230. Rovamo, J. 1979, "Visual resolution, contrast sensitivity, and the cortical magnification factor", *Experimental Brain Research,* vol. 37, no. 3, pp. 475-494.

231. Rozenfeld, S., Camacho, L.A.B. & Veras, R.P. 2003, "Medication as a risk factor for falls in older women in Brazil", *Revista Panamericana de Salud Pública,* vol. 13, no. 6, pp. 369-375.

232. Rubin, G.S., Muñoz, B., Bandeen–Roche, K. & West, S.K. 2000, "Monocular versus binocular visual acuity as measures of vision impairment and predictors of visual disability", *Investigative Ophthalmology & Visual Science,* vol. 41, no.

11, pp. 3327-3334.

233. Salehi, R., Ebrahimi-Takamjani, I., Esteki, A., Maroufi, N. & Parnianpour, M. 2010, "Test-retest reliability and minimal detectable change for center of pressure measures of postural stability in elderly subjects", *Medical Journal of The Islamic Republic of Iran,* vol. 23, no. 4, pp. 224-232.

234. Sanderson, F. & Whiting, H. 1974, "Dynamic visual acuity and performance in a catching task", *Journal of Motor Behavior,* vol. 6, no. 2, pp. 87-94.

235. Sanderson, F. & Whiting, H. 1978, "Dynamic visual acuity: a possible factor in catching performance", *Journal of Motor Behavior,* vol. 10, no. 1, pp. 7-14.

236. Schmid, M., Nardone, A., De Nunzio, A.M., Schmid, M. & Schieppati, M. 2007, "Equilibrium during static and dynamic tasks in blind subjects: no evidence of cross-modal plasticity", *Brain,* vol. 130, no. 8, pp. 2097-2107.

237. Schrauf, M., Wist, E.R. & Ehrenstein, W.H. 1999, "Development of dynamic vision based on motion contrast", *Experimental Brain Research,* vol. 124, no. 4, pp. 469-473.

238. Schubert, M.C., Herdman, S.J. & Tusa, R.J. 2002, "Vertical dynamic visual acuity in normal subjects and patients with vestibular hypofunction", *Otology & Neurotology,* vol. 23, no. 3, pp. 372-377.

239. Schulmann, D.L., Godfrey, B. & Fisher, A.G. 1987, "Effect of eye movements on dynamic equilibrium", *Physical Therapy,* vol. 67, no. 7, pp. 1054-1059.

240. Scialfa, C.T., Garvey, P.M., Gish, K.W., Deering, L.M., Leibowitz, H.W. & Goebel, C.C. 1988, "Relationships among measures of static and dynamic visual sensitivity", *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 30, no. 6, pp. 689-702.

241. Scuffham, P., Chaplin, S. & Legood, R. 2003, "Incidence and costs of unintentional falls in older people in the United Kingdom", Journal of Epidemiology and Community Health, vol. 57, no. 9, pp. 740-744.

242. Sharpe, J.A. & Sylvester, T.O. 1978, "Effect of aging on horizontal smooth pursuit", *Investigative Ophthalmology & Visual Science,* vol. 17, no. 5, pp. 465-468.

243. Shih, C., Shih, C. & Chiang, M. 2010, "A new standing posture detector to enable people with multiple disabilities to control environmental stimulation by changing their standing posture through a commercial Wii Balance Board", *Research in Developmental Disabilities,* vol. 31, no. 1, pp. 281-286.

244. Shorr, R.I., Mion, L.C., Chandler, A.M., Rosenblatt, L.C., Lynch, D. & Kessler, L.A. 2008, "Improving the capture of fall events in hospitals: combining a service for evaluating inpatient falls with an incident report system", *Journal of the American Geriatrics Society,* vol. 56, no. 4, pp. 701-704.

245. Simoneau, G.G., Leibowitz, H.W., Ulbrecht, J.S., Tyrrell, R.A. & Cavanagh, P.R. 1992, "The effects of visual factors and head orientation on postural steadiness in women 55 to 70 years of age", *Journal of Gerontology,* vol. 47, no. 5, pp. M151-M158.

246. Solaz, J., Porcar-Seder, R., Mateo, B., Such, M., Dürsteler, J., Giménez, A. & Prieto, C. 2008, "Influence of vision distance and lens design in presbyopic user preferences", *International Journal of Industrial Ergonomics,* vol. 38, no. 1, pp. 1-8.

247. Sommer, M.A. & Wurtz, R.H. 2002, "A pathway in primate brain for internal monitoring of movements", *Science (New York, N.Y.),* vol. 296, no. 5572, pp. 1480-1482.

248. Sony Computer Entertainment Asia, 2014-last update, PlayStation [Homepage PlayStation, Sony Computer Entertainment Asia], [Online]. Available: http://asia.playstation.com/hk/en/regional [2014, 01/01].

249. Spirduso, W.W., Francis, K.L. & MacRae, P.G., 2005, *Physical dimensions of aging,* 2nd edn, Human Kinetics, Champaign, IL.

250. Staggs, V.S., Mion, L.C. & Shorr, R.I. 2014, "Assisted and Unassisted Falls: Different Events, Different Outcomes, Different Implications for Quality of Hospital Care", *Joint Commission Journal on Quality and Patient Safety,* vol. 40, no. 8, pp. 358-364.

251. Stalenhoef, P., Diederiks, J., Knottnerus, J., Kester, A. & Crebolder, H. 2002, "A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study", *Journal of Clinical Epidemiology,* vol. 55, no. 11, pp. 1088-1094.

252. Steinman, R.M. 1965, "Effect of target size, luminance, and color on monocular fixation", *Journal of the Optical Society of America,* vol. 55, no. 9, pp. 1158-1164.

253. Stoffregen, T.A., Hove, P., Bardy, B.G., Riley, M. & Bonnet, C.T. 2007, "Postural stabilization of perceptual but not cognitive performance", *Journal of Motor Behavior,* vol. 39, no. 2, pp. 126-138.

254. Strasburger, H., Harvey, L.O. & Rentschler, I. 1991, "Contrast thresholds for identification of numeric characters in direct and eccentric view", *Perception & Psychophysics,* vol. 49, no. 6, pp. 495-508.

255. Stubbs, B., Binnekade, T., Eggermont, L., Sepehry, A.A., Patchay, S. & Schofield, P. 2014, "Pain and the risk for falls in community-dwelling older adults: systematic review and meta-analysis", *Archives of Physical Medicine and Rehabilitation,* vol. 95, no. 1, pp. 175-187.

256. Sugarman, H., Weisel-Eichler, A., Burstin, A. & Brown, R. 2, "Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study", *Virtual Rehabilitation International Conference 2*, pp. 111-116.

257. Sullivan, C.M. & Fowler, C.W. 1988, "Progressive addition and veriables focus lenses: A review", *Ophthalmic and Physiological Optics,* vol. 8, no. 4, pp. 402-414.

258. Teasdale, N., Stelmach, G.E. & Breunig, A. 1991, "Postural sway characteristics of the elderly under normal and altered visual and support surface conditions", *Journal of Gerontology,* vol. 46, no. 6, pp. B238-44.

259. The Hospital Authority (Hong Kong) 2011, 2012-last update, Hospital Authority Statistical Report 2010-2011, *[Homepage of The Hospital Authority (Hong Kong)]*, [Online]. Available: http://www.ha.org.hk/gallery/ha_publications.asp?Library_ID=15&lang=tc# [2014, 01/01].

260. Tian, J., Shubayev, I. & Demer, J.L. 2001, "Dynamic visual acuity during transient and sinusoidal yaw rotation in normal and unilaterally vestibulopathic humans", *Experimental Brain Research,* vol. 137, no. 1, pp. 12-25.

261. Timmis, M.A., Johnson, L., Elliott, D.B. & Buckley, J.G. 2010, "Use of single-vision distance spectacles improves landing control during step descent in well-adapted multifocal lens-wearers", *Investigative Ophthalmology & Visual Science,* vol. 51, no. 8, pp. 3903-3908.

262. Tinetti, M.E., De Leon, Carlos F Mendes, Doucette, J.T. & Baker, D.I. 1994, "Fear of falling and fall-related efficacy in relationship to functioning among community-living elders", *Journal of Gerontology,* vol. 49, no. 3, pp. M140-M147.

263. Tinetti, M.E. & Powell, L. 1993, "Fear of falling and low self-efficacy: A cause of dependence in elderly persons.", *Journal of Gerontology*, vol. 48, pp. 35-38.

264. Tinetti, M.E., Speechley, M. & Ginter, S.F. 1988, "Risk factors for falls among elderly persons living in the community", *New England Journal of Medicine,* vol. 319, no. 26, pp. 1701-1707.

265. Tousignant, M., Corriveau, H., Roy, P., Desrosiers, J., Dubuc, N. & Hébert, R. 2013, "Efficacy of supervised Tai Chi exercises versus conventional physical therapy exercises in fall prevention for frail older adults: a randomized controlled trial", *Disability and Rehabilitation,* vol. 35, no. 17, pp. 1429-1435.

266. Trachtman, J.N. 1973, "The relationship between ocular motilities and batting average in little leaguers", *American Journal of Optometry & Archives of American Academy of Optometry,* vol. 50, no.11, pp. 914-919.

267. Tsang, W.W. & Hui-Chan, C.W. 2003, "Effects of tai chi on joint proprioception and stability limits in elderly subjects", *Medicine & Science in Sports & Exercise,* vol. 35, no.12, pp. 1962-1971.

268. Tsang, W.W. & Hui-Chan, C.W. 2004a, "Effect of 4-and 8-wk intensive Tai Chi training on balance control in the elderly", *Medicine and Science in Sports and Exercise,* vol. 36, no. 4, pp. 648-657.

269. Tsang, W.W. & Hui-Chan, C.W. 2004b, "Effects of exercise on joint sense and balance in elderly men: Tai Chi versus golf", *Medicine and Science in Sports and Exercise,* vol. 36, no. 4, pp. 658-667.

270. Tsang, W.W., Wong, V.S., Fu, S.N. & Hui-Chan, C.W. 2004, "Tai Chi improves standing balance control under reduced or conflicting sensory conditions", *Archives of Physical Medicine and Rehabilitation,* vol. 85, no. 1, pp. 129-137.

271. Turano, K., Rubin, G.S., Herdman, S.J., Chee, E. & Fried, L.P. 1994, "Visual stabilization of posture in the elderly: fallers vs. nonfallers", *Optometry & Vision Science,* vol. 71, no. 12, pp. 761-769.

272. Turano, K.A., Broman, A.T., Bandeen-Roche, K., Munoz, B., Rubin, G.S. & West, S.K. 2004, "Association of visual field loss and mobility performance in older adults: Salisbury Eye Evaluation Study", *Optometry & Vision Science,* vol. 81, no. 5, pp. 298-307.

273. Turano, K.A., Rubin, G.S. & Quigley, H.A. 1999, "Mobility performance in glaucoma", *Investigative Ophthalmology & Visual Science,* vol. 40, no. 12, pp. 2803-2809.

274. Uchida, T., Hashimoto, M., Suzuki, N., Takegami, T. & Iwase, Y. 1979, "Effects of periodic saccades on the body sway in human subjects", *Neuroscience Letters,* vol. 13, no. 3, pp. 253-258.

275. Uchiyama, M. & Demura, S. 2008, "Low visual acuity is associated with the decrease in postural sway", *The Tohoku Journal of Experimental Medicine,* vol. 216, no. 3, pp. 277-285.

276. Ueda, T., NAWA, Y., Okamoto, M. & Hara, Y. 2007, "Effect of pupil size on dynamic visual acuity", *Perceptual and Motor Skills,* vol. 104, no. 1, pp. 267-272.

277. Ueda, T., Nawa, Y., Yukawa, E., Taketani, F. & Hara, Y. 2006, "Change in dynamic visual acuity (DVA) by pupil dilation", *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 48, no. 4, pp. 651-655.

278. Vaina, L.M., Belliveau, J.W., Des Roziers, E.B. & Zeffiro, T.A. 1998, "Neural systems underlying learning and representation of global motion", *Proceedings of the National Academy of Sciences,* vol. 95, no. 21, pp. 12657-12662.

279. Van Newkirk, M.R. 1997, "The Hong Kong vision study: a pilot assessment of visual impairment in adults", *Transactions of the American Ophthalmological Society,* vol.

95, pp. 715.

280. Verbaken, J. & Jacobs, R. 1985, "The technical problems of producing photographic prints for the measurement of human contrast thresholds", *Ophthalmic and Physiological Optics,* vol. 5, no. 4, pp. 459-465.

281. Verbaken, J. & Johnston, A. 1986a, "Clinical contrast sensitivity testing; the current status", *Clinical and Experimental Optometry,* vol. 69, no. 6, pp. 204-212.

282. Verbaken, J.H. & Johnston, A.W. 1986b, "Population norms for edge contrast sensitivity", *American Journal of Optometry and Physiological Optics,* vol. 63, no. 9, pp. 724-732.

283. Verghese, J., Holtzer, R., Lipton, R.B. & Wang, C. 2, "Quantitative gait markers and incident fall risk in older adults", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 64, no. 8, pp. 896-901.

284. Vicon Motion System Ltd., 2013-last update, Vicon Motion System [Homepage of Vicon Motion System], [Online]. Available: http://www.vicon.com [2014, 01/01].

285. Vital, D., Hegemann, S.C., Straumann, D., Bergamin, O., Bockisch, C.J., Angehrn, D., Schmitt, K. & Probst, R. 2010, "A new dynamic visual acuity test to assess peripheral vestibular function", *Archives of Otolaryngology—Head & Neck Surgery,* vol. 136, no. 7, pp. 686-691.

286. Voukelatos, A., Cumming, R.G., Lord, S.R. & Rissel, C. 2007, "A randomized, controlled trial of tai chi for the prevention of falls: the Central Sydney tai chi trial", *Journal of the American Geriatrics Society,* vol. 55, no. 8, pp. 1185-1191.

287. Wagner, L.M., Capezuti, E., Clark, P., Parmelee, P. & Ouslander, J. 2008, "Use of a falls incident reporting system to improve care process documentation in nursing homes", *Quality and Safety in Health Care,* vol. 17, no. 2, pp. 104-108.

288. Wallmann, H.W. 2001, "Comparison of elderly nonfallers and fallers on performance measures of functional reach, sensory organization, and limits of stability", *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 56, no. 9, pp. M580-M583.

289. Weissman, S. & Freeburne, C. 1965, "Relationship between static and dynamic visual acuity.", *Journal of Experimental Psychology*, vol. 70, no. 2, pp. 141-146.

290. Wichmann, F.A. & Hill, N.J. 2001, "The psychometric function: I. Fitting, sampling, and goodness of fit", *Perception & psychophysics*, vol. 63, no. 8, pp. 1293-1313.

291. Wichmann, F.A. & Hill, N.J. 2001, "The psychometric function: II. Bootstrap-based confidence intervals and sampling", *Perception & psychophysics*, vol. 63, no. 8, pp. 1314-1329.

292. Wick, B., Wingard, M., Cotter, S. & SCHEIMAN, M. 1992, "Anisometropic amblyopia: is the patient ever too old to treat?", *Optometry & Vision Science,* vol. 69, no. 11, pp. 866-878.

293. Wikstrom, E.A., Powers, M.E. & Tillman, M.D. 2004, "Dynamic stabilization time after isokinetic and functional fatigue", *Journal of Athletic Training,* vol. 39, no. 3, pp. 247-253.

294. Wist, E.R., Ehrenstein, W.H. & Schraus, M. 1998, "A computer-assisted test for the electrophysiological and psychophysical measurement of dynamic visual function based on motion contrast", *Journal of Neuroscience Methods,* vol. 80, no. 1, pp. 41-47.

295. Wist, E.R., Schrauf, M. & Ehrenstein, W.H. 2000, "Dynamic vision based on motion-contrast: changes with age in adults", *Experimental Brain Research,* vol. 134, no. 3, pp. 295-300.

296. Woo, J., Leung, J. & Lau, E. 2009, "Prevalence and correlates of musculoskeletal pain in Chinese elderly and the impact on 4-year physical function and quality of life", *Public Health,* vol. 123, no. 8, pp. 549-556.

297. Woodhull-McNeal, A.P. 1992, "Changes in posture and balance with age", *Aging (Milan, Italy),* vol. 4, no. 3, pp. 219-225.

298. World Health Organization 2010, 2010-last update, W00-W19, International Classification of Disease-10 (ICD-10), *[Homepage of International Classification of Disease-10 (ICD-10)]*,[Online].Available: http://apps.who.int/classifications/apps/icd/icd10online/index.

htm?gw00.htm [2014, 01/01].

299. Wrisley, D.M., Marchetti, G.F., Kuharsky, D.K. & Whitney, S.L. 2004, "Reliability, internal consistency, and validity of data obtained with the functional gait assessment", *Physical Therapy,* vol. 84, no. 10, pp. 906-918.

300. Wrisley, D.M., Walker, M.L., Echternach, J.L. & Strasnick, B. 2003, "Reliability of the dynamic gait index in people with vestibular disorders", *Archives of Physical Medicine and Rehabilitation,* vol. 84, no. 10, pp. 1528-1533.

301. Wu, C. & Hunter, D.G. 2006, "Amblyopia: diagnostic and therapeutic options", *American Journal of Ophthalmology,* vol. 141, no. 1, pp. 175-184.

302. Wun, Y., Lam, C. & Shum, W. 1997, "Impaired vision in the elderly: a preventable condition", *Family Practice,* vol. 14, no. 4, pp. 289-292.

303. Yavuzer, G., Senel, A., Atay, M.B. & Stam, H.J. 2008a, "Playstation eyetoy games" improve upper extremity-related motor functioning in subacute stroke: a randomized controlled clinical trial", *European journal of physical and rehabilitation medicine,* vol. 44, no. 3, pp. 237-244.

304. Yelnik, A. & Bonan, I. 2008, "Clinical tools for assessing balance disorders", *Clinical Neurophysiology,* vol. 38, no. 6, pp. 439-445.

305. Young, W., Ferguson, S., Brault, S. & Craig, C. 2011, "Assessing and training standing balance in older adults: A novel approach using the 'Nintendo Wii'Balance Board", *Gait & Posture,* vol. 33, no. 2, pp. 303-305.

306. Yu, P., Qin, Z., Shi, J., Zhang, J., Xin, M., Wu, Z. & Sun, Z. 2, "Prevalence and related factors of falls among the elderly in an urban community of Beijing", *Biomedical and Environmental Sciences,* vol. 22, no. 3, pp. 179-187.

307. Zijlstra, G., Van Haastregt, J., Van Eijk, J Th M, van Rossum, E., Stalenhoef, P.A. & Kempen, G.I. 2007, "Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people", *Age and Aging,* vol. 36, no. 3, pp. 304-309.