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Effect of Age on Visual Dependence for Spatial Orientation and Postural Control

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Effect of Age on Visual Dependence for Spatial Orientation and Postural Control

By

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2014

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Abstract

Effective spatial orientation and postural control requires the integration of proprioceptive, vestibular and visual inputs. Increased visual dependence has been reported in older adults but the underlying mechanisms remain unknown. The aims of this research were to investigate the methodological issues relevant to assessment of visual dependence in healthy younger (18-40 yrs) and older (>60 yrs) subjects and also the effect of sensory manipulation (vibratory and auditory) on visual dependence and postural control. Visual dependence is commonly assessed by the Rod and Disc Test (RDT) and used throughout the thesis. Postural control was assessed by postural sway when standing on a force plate during static (one and two legged stance) and dynamic (stepping) tasks with eyes open (viewing static and rotating images) and closed.

It was found in Chapter 2 that presentation shape (rectangular or round) had no effect on visual dependence. However pixellation on a TV screen could provide orientation cues to judge visual vertical i.e. decreased visual dependence as judged by the RDT and thus underestimates the amount of visual dependence. This was similar in both age groups.

Visual stimulation can impair balance and there are reports of habituation in response to repetitive stimulation and also that the habituation is less in healthy older people. Little is known about the effects of repeated visual stimulation on visual dependence. There was no effect on visual dependence of repeated visual stimulation by the RDT with two recovery intervals (~7 and 10

min) in either age group (Chapter 3). These findings suggest that visual dependence is less sensitive to visual stimulation than balance control.

Whole body vibration (WBV) is a sensory stimulus that can improve muscle power and balance after a single session but its effects on sensory systems is less understood. Five minutes of WBV improved visual dependence in the younger group for 20 minutes (p=0.03 – 0.05) but had no effect in the older one (Chapter 4). No such compensation occurred in older people who may have a less flexible and slower sensory reweighting ability.

In Chapter 5 balance control was assessed during standing on one and two legs when looking at both a static and rotating image also with eyes closed. There was a non-significant trend for balance improvement in both age groups. The sensory stimulation provided by WBV through proprioceptive and vestibular inputs may reduce reliance on vision.

Divided attention may increase visual dependence and disturb balance, particularly dynamic balance. . Auditory distraction, in the form of recordings of real street sounds, did not change the level of visual dependence or balance control during static bipedal stance or dynamic (stepping) in either age group. However, it did increase postural sway during the more challenging task of standing on one leg in younger subjects (p=0.048) and showed a non-significant trend (p=0.07) to do so in the older subjects (Chapter 6). This was the only study to find higher levels of visual dependence in the older age group (p=0.02 – 0.0001).

A key finding of majority of studies was the relatively similar level of visual dependence and response to sensory manipulation in the two age groups compared with the published literature, although the subjects studied were often older. They subjects were healthy and very active both physically and mentally and so may not be representative of their age group. This suggests that ageing *per se* may not necessarily lead to increased visual dependence in healthy people but relates to the development of specific pathologies.

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Abbreviations

1LS = one-leg stance

2LS = two-leg stance

CCW = counter-clockwise

CNS = central nervous system; a processing centre for the nervous system that receives information fro, and sends information to the peripheral nervous system

COG = centre of gravity; a point at the centre of the total body mass in space

COP = centre of pressure; a point that the COM perpendicularly projects to the ground

CW = clockwise

EC = eyes closed

EO = eyes open

FES-I = Falls Efficacy Scale – International; assessment of subject's concerns about falling

GVS = Galvanic vestibular stimulation; elicits the vestibular reflex by sending specific electronic message to a nerve in the inner ear

KQ = Kinetic Quotient; a ratio of postural sway velocity with looking at rotating and static images that reflects the influence of dynamic visual stimulation

MEG = magnetoencephalography; a functional neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents in the brain

ML = medial-lateral

PET = positron emission tomography; a nuclear medical imaging technique that produces a 3-dimentaionl image of functional processes in the brain and body

PROJ = projected image

rCBF = regional cerebral blood flow

RDT = Rod ad disc test; a dynamic visual dependence measurement by assessing the change of subjective visual vertical with a tilted frame of reference

RFT = Rod and frame test; a static visual dependence measurement by assessing the change of subjective visual vertical with a donut shape of rotating florescent discs

ROT = rotation

RQ = Romberg Quotient; a ratio of postural sway velocity in eyes closed and open which reflects influence of vision

SEM = standard error of mean

SVQ = situational vertigo questionnaire; assesses how frequently symptoms (disorientation, dizziness or unsteadiness) are provoked or exacerbated in environments with visual-vestibular conflict or intense visual motion

SVV = subjective visual vertical; the visual perception of verticality

T_{fixed} = repeated tests with fixed intervals between tests

$T_{variabel}$ = repeated tests with variable intervals between tests

TVR = tonic vibration reflex; a sustained contraction of a muscle subjected to vibration

TV_{rec} = TV screen with rectangular shape

TV_{round} = TV screen with circular shape

VOR = vestibule-ocular reflex; maintains visual acuity during head movement by moving the eyes in the direction opposite to the head’s movement in order to preserve a stable image on the retina

WBV = whole body vibration; a form of vibration that is applied to the entire body by standing on a vibrating platform

CHAPTER ONE INTRODUCTION

Effective spatial orientation and postural control require a complex interaction of neural and musculoskeletal systems. The central nervous system (CNS) merges and integrates inputs from vestibular, proprioceptive and visual systems, to form a single perceptual and internal representation of body position and motion in space. The CNS then transmits afferent signals to target muscles for stabilisation and movement of the body. However, sensory and motor systems and also sensory integration are reported to decline with increasing age as does balance and postural control.

Visual dependence is a term used to describe people who over-rely on visual input for orientation and balance, and has been reported in older adults. However, the underlying mechanisms of increased visual dependence with age remain unknown. Therefore, the purpose of this thesis is to investigate the effect of sensory modulation on the use of vision for orientation and balance and whether such responses differ with age.

This chapter focuses on the neural components of postural control and spatial orientation providing an overview of the literature relevant to the function of sensory systems, sensory integration, visual dependence and their relationship to ageing.

1.1 Spatial orientation and postural control

Spatial orientation is the perception of body orientation in relation to its environment. Effective orientation is based on the integration of visual, vestibular and proprioceptive sensory inputs; however, discrepancies between inputs can result in a sensory mismatch producing spatial disorientation (Lord et al., 1991b). Such discrepancies are seen in pilots (Wynbrandt, 2004), or with pathology of a sensory system i.e. vestibular neuritis, or during misinterpretation of, or mal-adaptation to, a novel situation (Redfern et al., 2001).

Postural control is the ability to maintain the centre of gravity (COG) within the area of the base of support (Nashner, 1981). It requires a complex interaction of musculoskeletal and sensory systems (Shumway-Cook, 2012, Fig.1.1). Normally, the central nervous system (CNS) integrates information from various sensory receptors and activates the appropriate motor responses to maintain postural control i.e. balance (Peterka, 2002). The relative weighting between the three sensory systems can also be modulated to facilitate movement and orientation within a particular environment (Horak, 2006).

Posture can be influenced by inaccurate spatial orientation (Isableu et al., 1997). A tilted or inappropriate internal representation of verticality results in a postural alignment incongruent with respect to gravity, which can lead to imbalance (Horak, 2006). Impairment of any of the receptors, effectors or higher integrative centres because of trauma, degeneration or disease, can have a negative effect on postural control if not compensated for (Sturnieks et al., 2008).

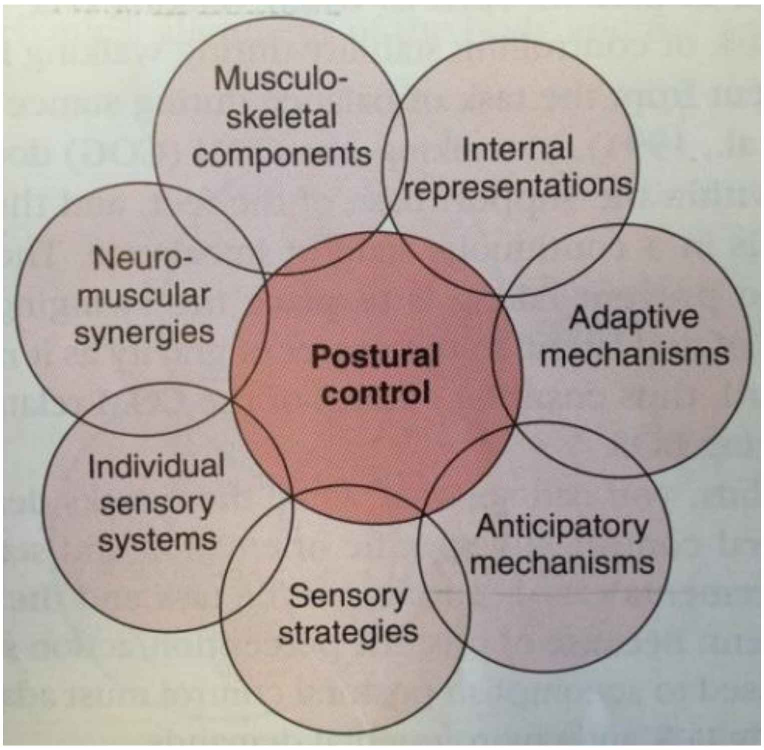


Fig. 1.1 Conceptual model representing the many inter-related components of postural control (Shumway-Cook, 2012)

1.2 Sensory systems

The CNS organises information from sensory receptors throughout the body in order to determine the body's position in space. Normally, peripheral inputs from vestibular, proprioceptive, and visual systems are available to detect the orientation and position of the body with respect to the environment.

1.2.1 Vestibular system

The vestibular system in each inner ear contains the semicircular canals and the otolith organs. The semicircular canals are sensitive to angular acceleration in the sagittal, frontal and horizontal planes, whereas the utricule is sensitive to changes in linear acceleration in the horizontal plane and the saccule in the vertical plane i.e. gravity (Baloh and Halmagyi, 1996). Vestibular apparatus, in particular the otolith, provides information regarding head position with respect to the vertical axis.

The primary function of the vestibulo-ocular (VOR) reflex is to stabilise vision and along with the vestibulo-cervical and vestibulospinal reflexes can contribute to postural control under some circumstances. Abnormal VOR function leads to instability and dizziness (Sloane et al., 1989). The vestibule-cervical and vestibulospinal reflexes allow vestibular inputs to be used for postural adjustments of the head and body respectively to maintain stability with respect to a gravity environment (Shupert and Horak, 1996, Buchanan and Horak, 2001).

When both proprioceptive and visual inputs are available and accurate, vestibular inputs play a minor role in controlling balance (Nashner et al., 1982, Maurer et al., 2000). However, the vestibular system becomes increasingly important in situations where proprioceptive and visual inputs are either unavailable or inaccurate i.e. conflicted (Nashner, 1993). It is considered as an absolute reference system against which visual and proprioceptive systems may be compared and calibrated (Black and Nashner, 1985) resolving situations involving visual-proprioceptive conflict.

Spatial orientation may be compromised when vestibular function is impaired or lost (Lackner and DiZio, 2005). Large deviations of subjective visual vertical from true vertical (Anastasopoulos et al., 1997) have been found in patients with uni- (~12^0, Lopez et al., 2006) and bi-lateral (10 - 40^0, Bronstein et al., 1996, Guerraz et al., 2001, Lopez et al., 2007) vestibular deficits which increased after vestibular neurotomy surgery suggesting distorted internal representation of verticality (Lopez et al., 2007). However, this was compensated for as early as the first postoperative month and was not different to normal subjects 1 year after surgery (Lopez et al., 2007). Visual vertigo with symptoms of spatial disorientation, is often reported by patients with a peripheral or central vestibular disorder (Redfern et al., 2001a). They complain of dizziness, disorientation and imbalance, which is triggered or made worse in visual environments including moving visual scenes or repetitive visual patterns e.g. walking in the aisle of a supermarket or along busy pavements (Bronstein, 1995).

Patients with unilateral vestibular deficit suffer from disequilibrium, tilt their head (Bronstein, 1988), shift body weight toward to the side of the lesion (Takemori et al., 19 85) and have other postural disturbances (Fukuda, 1984) and tend to fall toward the lesioned side (Nelson, 1968). Posturograpic recordings indicate larger oscillations of their centre of pressure (COP) (Gagey and Toupet, 1991) and increased postural sway when visual and/or proprioceptive inputs are altered (Fetter et al., 1990). However, those symptoms gradually disappeared in the long term (by 2 years) if other sensory systems i.e. visual and proprioceptive, are intact and able to compensate for maintenance of balance (Horak et al., 1990).

An age-related reduction in vestibular apparatus activity has been identified in both end organs and central pathways (Walther and Westhofen, 2007, Baloh et al., 2001a). Unsurprisingly, these abnormalities relate to an increased risk of falls. 73 % of older adults referred for multi-dimensional falls risk assessment displayed abnormal vestibular system function (Jacobson et al., 2008) and 80 % of fallers attending Accident and Emergency had symptoms of vestibular impairments (Pothula et al., 2004).

A decline in vestibular function with age would cause this absolute reference system to become less reliable. Older adults exhibit significantly greater postural sway in conditions where both visual and proprioceptive information are disturbed, indicative of reduced vestibular function leading to an inability to resolve sensory conflicts (Buatois et al., 2006). Abnormal VOR can also be found with increased age. Thirty percent of older fallers showed abnormal VOR gain in rotational testing (Jacobson et al., 2008), and older adults at high risk of falling were unable to control head accelerations when mobilising due to impaired VOR activity (Baloh et al., 2001a).

Vestibular signals in isolation alone cannot provide the CNS with a true picture of how the body is moving in space i.e. it cannot distinguish between a head nod and a forward bend using vestibular inputs alone (Horak and Shupert, 1994). Proprioception is a key element of postural control considered dominant when balance is relatively unchallenged (Allum et al., 1998).

1.2.2 Proprioceptive system

Proprioceptors, including muscle spindles, Golgi tendon organs, joint receptors and cutaneous mechanoreceptors, provide the relative location of body segments to one another and position and movement of the body with respect to the surrounding environment (Lackner and DiZio, 2005). Proprioceptive inputs from numerous parts of the body are able to contribute to postural control and body orientation (Roll and Roll, 1988). Although information from all three sensory systems influences balance, proprioceptive input is considered to be dominant when the support surface is stable (Diener et al., 1986) and during horizontal surface displacement (Dietz et al., 1991).

Reduction of afferent input from the lower extremities due to vascular ischemia (Asai et al., 1994) or anesthesia (Diener et al., 1984) result in greater postural sway (Nakagawa et al., 1993). Patients with proprioceptive impairments e.g.

peripheral neuropathy, had greater than normal instability when standing with no vision or on a moving platform (Ledin et al., 1990). They also showed prolonged muscle EMG latencies (Nardone et al., 2000) and reduced amplitude (Nardone and Schieppati, 2004) in response to postural perturbation.

Proprioceptive loss is common with increasing age. Diminished vibration sense and proprioception are both associated with decreased stability and increased sway and risks of fall (Abrahamova et al., 2009). In the healthy "young old" (aged 65 – 74 yrs), the incidence of vibration insensitivity and proprioceptive loss are 12 % and 21 % respectively. Whilst in the healthy "oldest old" (aged > 84 yrs), 68 % had vibration in sensitivity and 44 % had proprioceptive loss (Kaye et al., 1994). Proprioceptive loss is more extensive in older fallers (Lord and Ward, 1994). Age-related changes in tactile sensitivity (Kenshalo, 1986), vibration threshold (Bergin et al., 1995), and static and dynamic joint position (Kaplan et al., 1985, Thelen et al., 1998) have all been documented. Tactile sensitivity depends on impulses from Meissner and Pacinian corpuscles, which have been reported to reduce in number and show poorer innervation with increased age (Bruce, 1980). Loss of function is greater in the lower limbs, resulting in high frequency postural sway (Kristinsdottir et al., 2001, Pyykko et al., 1990). Motion detection and position replication at the knee are also impaired to a greater extent at slower speeds (Duncan et al., 1993).

Despite the importance of proprioceptive information for balance, the loss of proprioception/and or vestibular input can be compensated for by an increased sensitivity/reliance upon visual information.

1.2.3 Visual system

Visual signals are processed through different parts of the brain, from the retina to the primary and secondary visual cortices (Waxman, 1999). Processing involves a number of aspects, including visual acuity, depth perception, colour contrast, light sensitivity, the identification and categorisation of visual objects, assessment of relative distances/perspective, and guides bodily movements with respect to objects within the external world (Bruce, 2003).

Vision plays a significant role in spatial orientation and maintenance of posture by providing information regarding the position and movement of the head in relation to the environment, acting as a reference of visual verticality (Lopez et al., 2006). However, visual input can be misleading. Motion across the visual field can result from movement of either the viewer, or a viewed object. For example, the movement of a parallel slow-moving train may lead to a transient misperception of self-motion (Bronstein and Hood, 1986), which can be resolved by the presence/absence of congruent proprioceptive and/or vestibular feedback (Redfern et al., 2001a). However, individuals who over-rely on visual input i.e. are visually dependent, for spatial orientation and postural responses may experience difficulty in resolving situations where visual information is complex or inaccurate (Guerraz et al., 2001).

Vision plays a significant role in balance, particularly when proprioceptive input is disrupted e.g. standing on unstable surface and in patients with peripheral neuropathology (Wang et al., 2008). Blind people have increased sway and poorer balance control in a range of situations, utilising to a greater extent a hip strategy to maintain postural stability (Ray et al., 2008, Schmid et al., 2007). Decreased visual acuity (Paulus et al., 1984), discrimination (Owen, 1985), depth and contour (Nevitt et al., 1989), contrast sensitivity (Lord et al., 1991) and visual field size (Ivers et al., 1998), have also been reported to be associated with increased postural instability and fall risk.

Visual changes with increasing age are well documented in both fallers and non-fallers. Loss of visual acuity appears not to be strongly related to imbalance and falls. Rather visual field loss, diminished contour and depth perception, or reduced contrast sensitivity, visual field motion and ability to perceive extrinsic horizontal and vertical cues all have been related, to varying degrees, with falls risk and imbalance (Tang and Woollacott, 2004, Pitts, 1982, Overstall, 2004).

Although vision is a critical part of postural orientation and balance control, no single sensory system is able to provide the CNS with accurate information regarding the orientation and movement of the body in space in every situation and therefore the CNS must be able to integrate information from each sensory system and resolve sensory conflicts by changing the relative weighting of a sensory input in an appropriate manner – based on experience and thus expectation.

1.3 Sensory integration

The CNS integrates sensory inputs from vestibular, proprioceptive and visual systems to form a single perception and internal representation of body position in space by multi-sensory integration. Accurate perception of body position and motion is a prerequisite for postural control because motor commands to the musculoskeletal system require accurate assessment of current body state. Greater processing is required if the sensory inputs are in conflict (Mahoney et al., 2011, Peterka and Loughlin, 2004).

In a situation of sensory conflict, the CNS must first recognise the discrepancy and reduce the weighting (suppress) of the inaccurate input, while increasing the weighting of input from the sensory systems deemed to provide more reliable information (Horak et al., 1990, Nashner, 1997, Wolfson, 1997, Tang and Woollacott, 2004). This complex process is termed multiple-sensory re-weighting (Jeka and Lackner, 1994, Jeka and Lackner, 1995, Kuo et al., 1998, Nashner, 1982, Nashner, 1976, Peterka and Black, 1990, Oie et al., 2002) and is vital to maintain balance and orientation in an ever changing, and increasingly mechanised environment.

How the CNS integrates multiple sensory inputs for postural control can be tested via the dynamic posturography sensory organisation protocol (Fig. 1.2) (Nashner, 1976, Nashner, 1982). The subject stands quietly under 6 different conditions that alter the availability and accuracy of visual and proprioceptive inputs for postural control. Normal subjects sway the least in the conditions where only one sense was disrupted (conditions 1 - 4) and have the greatest sway (on average > 50 % than condition 1) when two senses are simultaneously altered and only one accurate set of inputs, vestibular, is available to support postural control (conditions 5 and 6). Healthy adults maintain adequate balance under all conditions, demonstrating that the CNS has the ability to effectively weight sensory inputs even when conditions change very rapidly (Nashner, 1982, Peterka and Black, 1990).

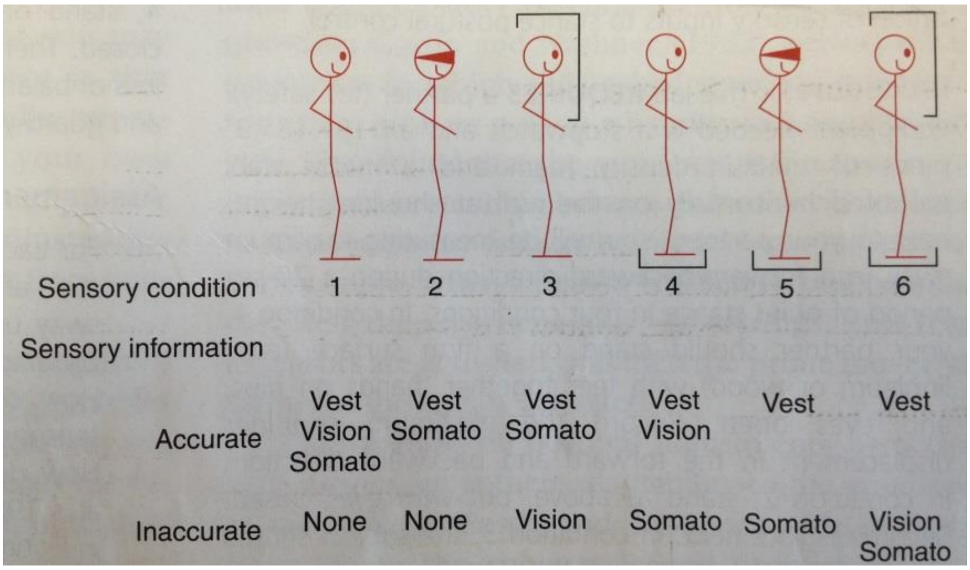


Fig. 1.2 The 6 sensory conditions used to test the ability to adapt sensory information for postural control (Shumway-Cook, 2012). Vest = vestibular, Somato = somatosensory.

Central sensory integration declines with age. Studies which manipulate visual and proprioceptive inputs suggest that an inability to compensate for sensory deficits and/or sensory conflicts increases with age and is related to imbalance and is likely to contribute significantly to falls in older people (Whipple et al., 1993, Wolfson et al., 1992, Woollacott, 1993). When presented with conflicting sensory inputs, young subjects swayed more but did not fall, whereas healthy older subjects often lost their balance, especially on the first trial of a novel condition (Judge et al., 1995, Wolfson et al., 1992, Woollacott et al., 1986). Healthy older adults showed instability when two senses were manipulated simultaneously, while older fallers become unstable when any single sense was altered (Judge et al., 1995, Manchester et al., 1989). Thus, the ability to integrate effectively challenging sensory inputs appears to be slowed with age and severely reduced in older fallers (Camicioli et al., 1997, Mahoney et al., 2011). An expression of ineffective sensory function, and/or its integration may be an inappropriately exaggerated reliance upon visual input.

1.4 Visual dependence

The extent by which an individual utilises visual input for balance and spatial orientation is termed visual dependence. However, visual cues may by inaccurate or unreliable, and thus in the absence of reliable proprioceptive and/or vestibular cues can evoke disorientation/imbalance (Bonan et al., 2004). In fact exaggerated visual dependence can reflect a multi-sensory re-weighting deficit (Bronstein et al., 1990, Talbott and Brookhart, 1980).

1.4.1 Visual dependence measurement

Subjective visual vertical (SVV), the perception of verticality measured by the angle between perceived visual vertical and gravitational vertical (0^0); normal subjects typically have a SVV of ± 2^0 from true vertical in the absence of external visual information (Howard, 1982). Visual dependence is commonly distinguished via assessment of change in SVV by the rod and frame test (RFT, Fig. 1.3 a) (Oltman, 1968) or the rod and disc test (RDT, Fig.1.3 b) (Dichgans et al., 1972). Subjects are asked to set a small tilted rod to their perceived vertical while a frame of reference is tilted (RFT) or the entire central visual field comprised of florescent discs rotating around the centre of the field (RDT). Both the RFT and the RDT evoke deviation of the SVV in the direction of tilt, or rotation respectively. It is suggested that people with a higher level of visual dependence show greater errors in both the RFT and the RDT and tend to use visual cues for SVV, while individuals who are relatively visually independent rely more upon gravitational or egocentric cues (Luyat et al., 1997).

Increased visual dependence is typically thought to be a response to pathology of the vestibular or proprioceptive systems. For instance, patients with vestibular disorders e.g. vestibular schwannoma (Hafstrom *et al*, 2004), Meniere's disease (Lopez et al., 2006) proprioceptive impairments e.g. Parkinson's disease (Bronstein et al., 1990) and following stroke (Slaboda et al., 2009), have all been reported to have an exaggerated degree of visual dependence for both spatial orientation and postural control compared with healthy controls.

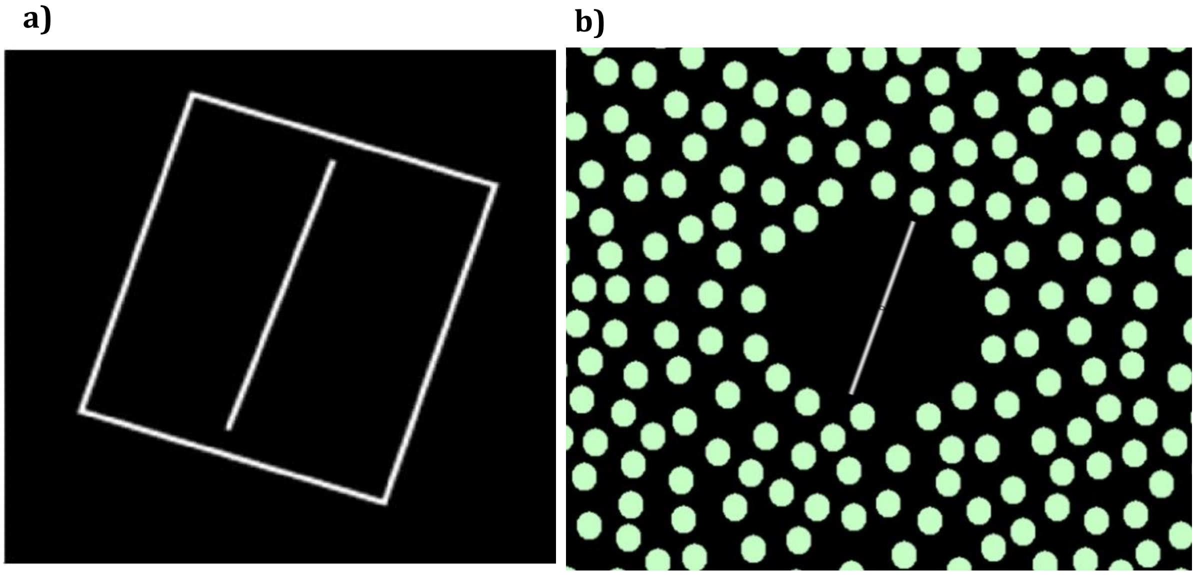


Fig. 1.3 Visual dependence measurements with a displaced (tilted) rod . a) Rod and Frame Test (RFT) with rotated frame and b) Rod and Disc Test (RDT) where dots rotate around the centre.

1.4.2 Visual dependence for patients with vestibular disorders

Exaggerated visual dependence in vestibular deficient patients can be measured by a greater than normal deviation of SVV induced by static (RFT) or dynamic (RDT) visual stimulation. Patients with vestibular schwannoma (Hafstrom et al., 2004) and Meniere's disease (Lopez et al., 2006) showed significant SVV deviations towards the lesion side before and after unilateral vestibular neurotomy. They also had increased visual dependence for postural control. Furthermore, in a moving room, patients with visual vertigo (most of whom are considered to have peripheral vestibular disorder) showed abnormally large postural responses, but not when standing with eyes closed or in an immobile room (Bronstein, 1995). Increased lateral sway and COP and head displacement when facing a titled frame or a rotated disc are also observed in patients with visual vertigo and labyrinthine deficits (Guerraz et al., 2001).

1.4.3 Visual dependence and proprioceptive impairments

Patients with a reduction in proprioception are thought to place a greater reliance on visual cues to maintain balance (Overstall, 2004, Redfern et al., 2001a). Those with Parkinson's diseases had normal SVV tilt with a rotating background (Bronstein et al., 1996, Barnett-Cowan et al., 2010) but showed greater sway responses to visual motion with postural deviation toward the direction of visual stimuli (Bronstein et al., 1990, Barnett-Cowan et al., 2010, Vaugoyeau et al., 2011), suggesting that visual perturbation may affect postural control to a greater extent than measures of spatial orientation. Some studies report that stroke patients with hemibody proprioceptive impairment had significant dynamic SVV deviation in the direction of visual stimuli in respect to the RFT (Slaboda et al., 2009), and RDT (Anastasopoulos and Bronstein, 1999) indicative of exaggerated visual dependence. However, others have argued that this effect was only evident in stroke patients with an infarction of the thalamus (some nuclei in this area are sensitive to vestibular stimulation) and with lesions of the central vestibular system in the brainstem and cortex (Karnath et al., 2000). Increased visual dependence on posture was also observed by a more rapid and larger COP displacement when exposed to a rotating visual scene (Yelnik et al., 2006, Slaboda et al., 2009). However, normal RDT dynamic SVV deviation was recorded in a case of proprioceptive loss below the neck (Yardley, 1990). Thus, over-reliance on vision in the maintenance of balance is presented in individuals with either proprioceptive or vestibular impairment, but subjective (orientation) perception of the visual world (SVV) appears preferentially affected by vestibular rather than proprioceptive input.

1.4.4 Visual dependence in older people

Older people often find difficulties in maintaining balance when their eyes are closed, emphasising the importance of vision (Wolfson et al., 1992). A greater influence of vision on spatial orientation and postural control has been also observed by manipulating static and dynamic visual cues. Older people, fallers particularly, had significantly greater errors in dynamic SVV (Lord and Webster, 1990, Kobayashi et al., 2002). Younger people have little sway in response to optic flow whilst older adults, especially fallers, had significantly more and showed continued COP oscillation even following visual disturbance (Wade et al., 1995, Sundermier et al., 1996, Borger et al., 1999). They also adopted hip strategies to restore balance in response to visual perturbation indicating they were extremely unstable (Horak and Nashner, 1986). These results indicate that older people may have higher levels of visual dependence. However, several studies reporting increased visual dependence in older people did not employ careful screening tests for vestibular and proprioceptive sensory impairments (Lord and Webster, 1990, Kobayashi et al., 2002, Wade et al., 1995, Sundermier et al., 1996, Borger et al., 1999). It is possible that the elevated visual dependence may be due to pathological peripheral sensory loss and not related to ageing *per se*. Thus, this thesis shall focus upon the effect of age in 'healthy' older people.

1.5 Sensory disturbance

Successful interaction with the real world demands a continuously updated awareness of the surrounding environment. The role of the vestibular, proprioceptive, and visual systems in spatial orientation and postural control is to detect information from the environment and transmit it to the CNS for subsequent processing. Therefore, if any one of the sensory system is disturbed, the CNS receives inaccurate sensory inputs which affect orientation and balance.

1.5.1 Vestibular disturbance

Galvanic vestibular stimulation (GVS) is a simple, safe and specific way to elicit the vestibular reflex, and has been used to assess the contribution of vestibular input to balance control (Fitzpatrick and Day, 2004). GVS causes a person to sway if they are standing or perceive illusory movements if they are not (Fitzpatrick et al., 1994). The virtual signal of head movement produced by GVS has a potent effect on whole body motor control, evoking reflex electromyographic responses (Britton et al., 1993) and a highly organised balance response involving the entire body in healthy people (Day et al., 2002).

1.5.2 Proprioceptive disturbance

Internal representation of verticality can be changed by vibrating the Achilles tendon when standing (Ceyte et al., 2007, Barbieri et al., 2008), thereby activating muscle spindles, which informs the CNS that the muscle is being stretched. This inaccurate interpretation causes an illusionary forward tilt and a compensatory postural response (Roll et al., 1989) e.g. significantly greater body sway than when quietly standing (Nakagawa et al., 1993), and whole body backward shift (Thompson et al., 2007).

Whole body vibration (WBV) is another form of vibration that is applied to the entire body. The subject stands on a vibrating platform with either rotational (plate rotating around the anterior-posterior axis, Fig 1.4a) or vertical oscillation (Fig 1.4b).

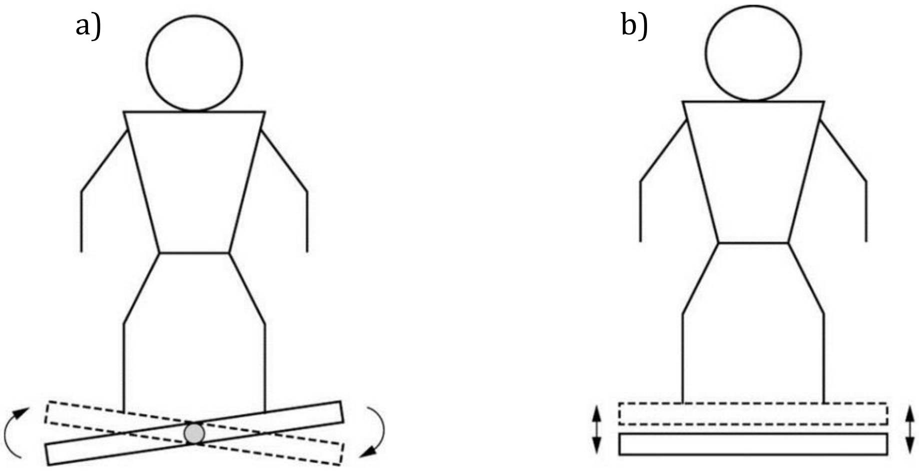


Fig. 1.4 Types of vibrating platforms. a) Rotational vibrating platform and b) vertical vibrating platform (Cardinale and Wakeling, 2005)

WBV has been reported to lead to long term improvements in strength, flexibility, muscle power, movement speed and balance (Merriman and Jackson, 2009), especially in older people (Rittweger, 2010). However, reduced cutaneous sensation (touch and pressure) at the foot and ankle (Pollock et al., 2011, Schlee et al., 2012, Sonza et al., 2013) occurred after an acute bout of WBV, and low-frequency occupational WBV in the work place i.e. <1 Hz, may cause vestibular disturbances accompanied by symptoms of dizziness, motion sickness and nausea (Seidel et al., 1990). Although there are limited studies on the immediate effect of WBV, it is possible that any negative effects of WBV in this respect might counter and even outweigh the beneficial effects on strength and power output.

1.5.3 Visual disturbance

A static tilted visual frame can affect orientation and the estimation of the visual verticality (Howard and Childerson, 1994). A slight body lean towards a tilted frame was also observed (postural frame effect) (Isableu et al., 1997b). Disorientation can be also induced by means of a large circular visual display of rotating dots i.e. motion-induced self-tilt effect (Dichgans et al., 1972). A moving room (Lee & Aronson, 1974), rotating discs (Wade, 1990) or horizontally moving dots (Kitamura and Matsunaga, 1990) are popular methods to evoke visually-induced postural sway and to investigate the effect of vision on postural control.

After linear or rotational displacements of the visual scene, SVV can be changed in 1 – 2 s (Dichgans et al., 1972) and electromyographic activity of leg muscles in 0.5 – 2 s (Lestienne et al., 1977). Compared with a static visual input, dynamic input has a greater influence on balance and governs the stabilisation of the whole body (Amblard et al., 1985). Visually dependent individuals were reported to show greater postural effects when watching a titled frame or a moving scene (Isableu et al., 2010, Isableu et al., 1998, Isableu et al., 1997a, Kitamura and Matsunaga, 1990). Such people also exhibited different body segmental stabilisation strategies (*en bloc* strategy) (Isableu et al., 2003). More difficult balancing tasks may require higher reliance on visual cues (Lee and Lishman, 1975, Isableu et al., 2010).

Different presentations of visual stimulation may affect balance. Postural sway is increased by viewing visual scenes that rotate or create a tunnel effect (Lestienne et al., 1976, van Asten et al., 1988), with the amplitude of sway dependent upon velocity and frequency of visual stimulus (Borger et al., 1999, Wang et al., 2008). Exposure to a linear or rotational movement of the visual field can induce postural sway in the direction of visual motion (Dichgans et al., 1972, Lestienne et al., 1976). Although very small room oscillations are used, subjects begin to sway with the oscillations (Lee and Lishman, 1975).

1.5.4 Divided attention

Normally, balance is automatic without requirement for conscious attention unless the situation is especially challenging. These requirements depend on the postural task, the age of the individual, and on their balance ability (Woollacott and Shumway-Cook, 2002). The influence of cognition on postural control has been investigated using dual-task paradigms which require performance of a secondary task (e.g. visual, memory, verbal or fine motor) whilst engaged in a ‘primary’ postural task (Teasdale et al., 1993, Yardley et al., 1999, Maylor et al., 2001, Ebersbach et al., 1995).

Kerr et al.’s study (1985) was the first to investigate the attentional demands on standing balance by measuring the number of errors in a visual-spatial memory task during standing and suggested postural control in younger adults may require more cognitive (attentional) resources than previously thought. Lajoie et al. (1993) reported that the amount of attention was increased (slower auditory reaction-time) when the challenge of maintaining balance was increased i.e. progressing from sitting, to standing with wide base of support, standing with feet together and then to walking in younger people. Furthermore, the attentional demand was greater in the single *vs*. double support phase of the gait cycle. Greater attentional demand (slower auditory reaction time) was also found in environments with reduced sensory inputs i.e. no vision or impaired proprioception or combination of both (Lajoie et al., 1996). The greater the attentional load i.e. the more complex secondary tasks, had the greater influence on postural control e.g. listening to a conversation had greater postural sway than listening to the white noise (Maki and McIlroy, 1996).

It appears that older people require more attention than younger people even in common daily activities, such as sitting and standing (Lajoie et al., 1996). “Stops walking while talking” is a clinical sign in older people, especially older fallers (Lundin-Olsson et al., 1997), which demonstrates that additional attention is needed. In more complicated sensory situations (visual and/or proprioceptive disturbances) the postural task becomes more difficult for older people and thus needs more attentional capacity (Shumway-Cook and Woollacott, 2000). Older adults with balance problems require more attention to balance than healthy older people without a history of falling, even under relatively simple conditions such as two legged stance with eyes open on stable surface (Shumway-Cook and Woollacott, 2000). It was suggested that balance-impaired older adults are unable to effectively allocate attention to balance when performing two tasks simultaneously, and therefore have a higher risk of falling than healthy older people under dual task conditions.

1.6 Summary

Effective spatial orientation and postural control requires the integration of proprioceptive, vestibular and visual inputs. People who have exaggerated reliance upon visual input for orientation and balance i.e. are visually dependent, may experience difficulty in resolving situations where visual information is complex or inaccurate, including crowded, noisy or busy environments. Increased visual dependence has been widely reported in older adults, and might be due to proprioceptive or/and vestibular impairments or sensory integration deficits but the underlying mechanisms of increased visual dependence with age remain unknown. Impairments in any one of the systems could affect orientation and postural control and thus sensory disturbances e.g. visual stimulation, proprioceptive perturbation and cognitive distraction can be expected to impact upon the degree of visual dependence.

Therefore, this thesis describes a number of studies on visual dependence in two age groups of healthy adults. These initially address methodological issues relevant to assessment of visual dependence in older and younger subjects (Chapters 2 and three). Subsequent chapters investigate the effects of sensory manipulation (vibratory and auditory) on visual dependence and also postural control. Healthy adults were studied in order to investigate the effects of ageing *per* se, rather than the effects of pathology.

The first study (Chapter 2) investigated the effect of pixellation and/or visual field shape upon static and dynamic SVV values in young and older healthy subjects as visual dependence is commonly assessed by the RDT but in varying configurations. However it is not known whether pixellation and/or visual field shape influences SVV values

The second study (Chapter 3) assessed visual dependence with different rest intervals between tests in younger and older subjects as there is evidence of adaptation to repetitive visual stimulation on balance, but whether this is the case with subjective visual vertical is unknown.

The third and fourth studies investigated visual dependence (Chapter 4) and postural control (Chapter 5) before and for 30' after postural disturbance provided by WBV in younger and older healthy subjects. It has been observed that older people find balance control more difficult after being in a moving environment such as in a bus. Whole body vibration (WBV) provides a potential model of low amplitude motion (albeit repetitive). Furthermore, it is commonly used in falls risk rehabilitation in order to improve muscle power and thereby balance, but little is known regarding its effect upon sensory integration.

The final experimental study (Chapter 6) provided auditory distraction by playing a background of traffic noise with intermittent sudden sounds i.e. car horns, sirens and shouting, to examine the effect of divided attention on visual dependence and balance including static and dynamic balance in healthy younger and older subjects. Divided attention may also possibly disturb balance control and make visual input more important (increased visual dependence) which might present problems in complex visual (and sound) environments such as metropolitan areas and transport hubs, both of which high falls risk areas.

CHAPTER TWO EFFECT OF PIXELLATION AND SHAPE OF VISUAL FIELD ON VISUAL DEPENDENCE IN HEALTHY YOUNGER AND OLDER SUBJECTS

2.1 Introduction

Testing for visual dependence is commonly performed via a perceptual test conducted in darkness whereby subjects align a tilted rod to their perceived vertical (subjective visual vertical; SVV). In the Rod and Frame Test (RFT) (Oltman, 1968, Witkin et al., 1972) a rod is presented in a static tilted frame and in the Rod and Disc Test (RDT) (Dichgans et al., 1972, Isableu et al., 1997) the rod is centred on a background covered with irregular dots which may remain static or rotate. In healthy subjects, the difference between SVV (rod) and gravitational vertical (0^0) without any visual disturbance is ~1^o (Guerraz et al., 2001, Pavlou et al., 2011) and the errors become larger with a moving visual background (Lord and Webster, 1990, Guerraz et al., 2001). The RDT is considered more challenging to spatial orientation and postural balance (Amblard et al., 1985) and has been suggested to be more sensitive in identifying visual dependence (Lord and Webster, 1990).

Different screen shapes have been used to display the RDT image i.e. rectangular (Bagust, 2005), circular (Kobayashi et al., 2002, Goto et al., 2003, Lopez et al., 2007) and hemispherical (Kobayashi et al., 2002, Goto et al., 2003), although the effect of display shape on visual dependence is unknown. The presence of vertical or horizontal features within the visual field provide spatial information that may be used to judge orientation (Isableu et al., 2011, Takasaki et al., 2012) and affect the accuracy of tests of visual dependence. Therefore some RDTs were performed with subjects wearing a pair of video glasses or looking at the screen through an optic tunnel to remove peripheral cues of verticality from their visual field (Isableu et al., 2008, Isableu et al., 2011, Takasaki et al., 2012). Testing can be conducted in a totally darkened room in order to exclude all the vertical and horizontal cues for the participants (Bagust, 2005, Bonan et al., 2006, Lopez et al., 2008). Many factors i.e. the frame of TV monitor to the buildings in the street, could become a visual reference of verticality for the orientation and maintenance of upright body relative to its surroundings (Lord, 2006). A tilted or moving visual frame can induce an illusion of self-tilt and affect the estimation of the subjective visual vertical (Howard and Childerson, 1994).

Originally a motorised circular board was used to generate the RDT, however more recently computerised simulation of the task is commonly used, necessitating the shielding of light emitted by the monitors used to generate the image (Bonan et al., 2006, Lopez et al., 2008, Pavlou et al., 2011). Digitisation brings the potential for providing orientation cues, particularly with lower resolution images (Takasaki et al., 2012). Indeed some subjects in a recent computerised RDT study in our laboratory spontaneously reported using pixellation to aid task performance. However, only one study from Docherty and Bagust (2010) raised the issue of pixellation and revealed that presentation of dots (two dots as two ends of a rod), rather than an entire rod for RFT, exposed greater errors in judging visual horizontal. It is a possibility that the pixellation would provide similar orientation cues for SVV in the RDT.

Therefore, either pixellation or vertical and horizontal features could become a visual frame of reference for spatial orientation and affect the estimation of visual dependence. The aims of this study were twofold. Study 1 compared dynamic SVV measured by a computerised RDT using pixellated (round and rectangular) and non-pixellated (round) images in young healthy adults. The results informed the protocol of Study 2, which examined the effect of pixellation and visual field on dynamic SVV in healthy young and older adults.

2.2 Methods

2.2.1 Subjects

Study 1

Eleven young subjects (aged 30 ± 5 (mean ± sem), range 23 – 39 yrs, 2 male) participated in this study.

Study 2

Ten younger (30 ± 5 (22 - 39) yrs, 2 male) and 10 older subjects (75 ± 7 (63-78) yrs, 3 male) were included. Four of younger subjects had participated in Study 1.

Healthy younger and older subjects were recruited from students and staff of the university. Exclusion criteria were a history of neurological disease including epilepsy, migraine or fainting, falls history, vertigo, head injury, known peripheral sensory loss or uncorrected visual. All subjects provided informed consent and local ethics committee approval was obtained (Appendix 1).

2.2.2 Protocol

Subjects sat upright on a padded armless chair with their eyes 80 cm from the screen whilst their chin was supported to minimise head movement (Fig. 2.1). Knees were partially flexed and the feet dorsiflexed so that only the heels were in contact with the floor in order to diminish possible proprioceptive cues from the plantar surface (Isableu et al., 2008). A custom built computerised RDT test provided the dynamic visual disturbance and SVV assessment in the three setups which were presented in a randomised order. The image and subject were surrounded by blackout material ensuring complete darkness to minimise any external vertical and horizontal visual reference cues (Bonan et al., 2006, Lopez et al., 2008, Pavlou et al., 2011).

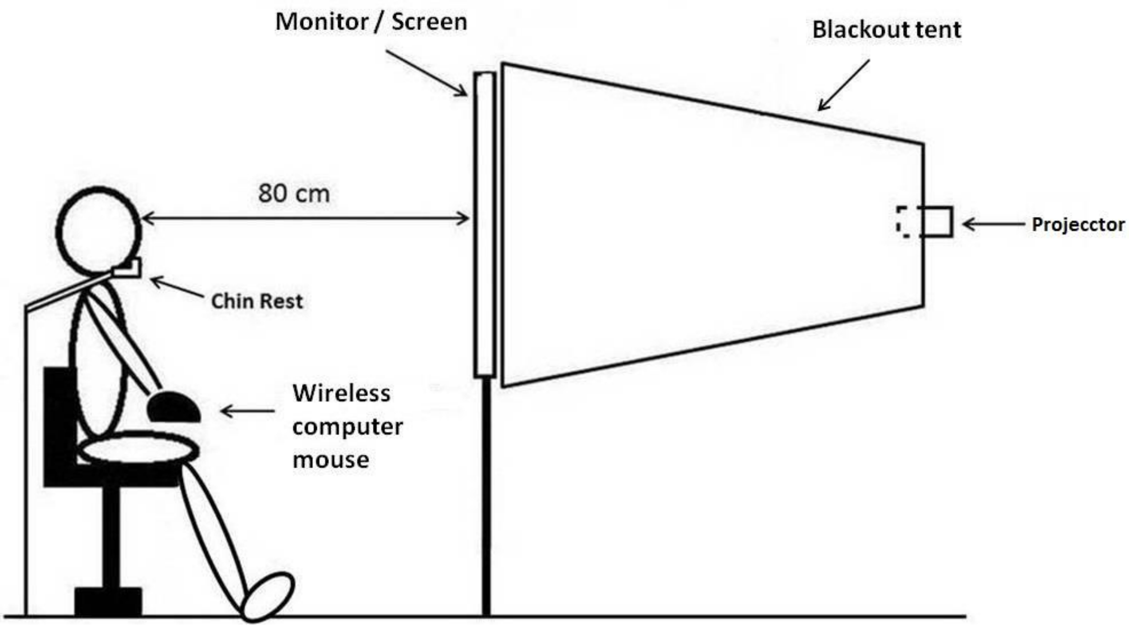


Fig. 2.1 Schematic experimental setup of the RDT with back projected image

For rectangular (TV_{rec}) and round (TV_{round}) setups the RDT was displayed on a LCD TV monitor (Model RZ-42PX11, LG, Korea; 92 by 53 cm; resolution 852 x 480 pixels with a refresh rate of 60 Hz; viewing angle of 40^0 in the vertical plane and 60^0 in the horizontal). In the TV_{rec} setup the entire screen was visible (Fig. 2.2a), whereas in TV_{round} the peripheral visual field was partially obscured by blackout material with a central round cut out (53 cm diameter) through which the RDT was viewed (Fig. 2.2b). Participants viewed the screen having placed their face (without contact) into the narrow end (8.5 cm diameter) of a conical viewing tunnel (larger end 11cm; length 45cm) composed of non-reflective black card. In PROJ the image was back projected (Model PJL7211, ViewSonic, USA) onto a 117x 84 cm screen (roller blind) enclosed within a black-out tent preventing light emission. The RDT image was made circular in the same manner as for TV_{round} (53 cm diameter, viewing angle of 40^0).

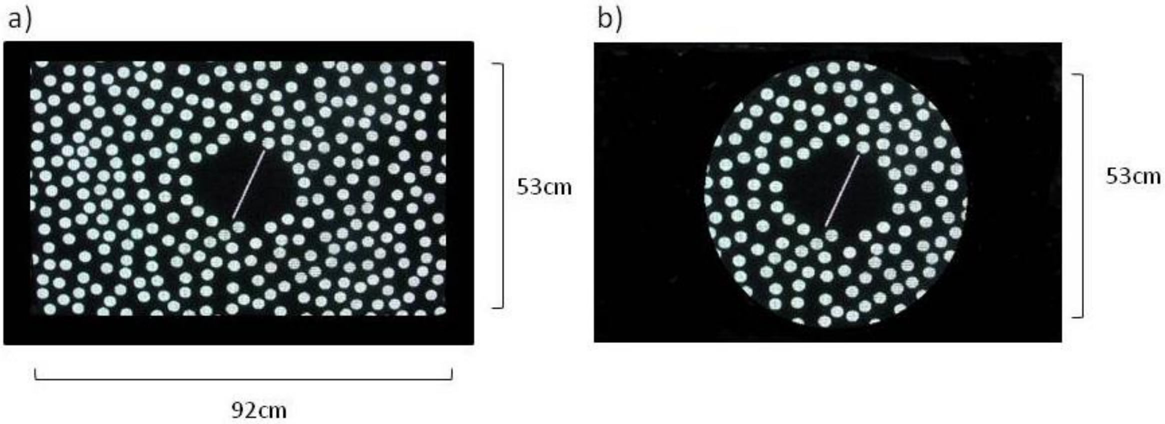


Fig. 2.2 The image seen by the subjects for a) TV_{rec} and b) TV_{round} and PROJ setups. In the darkened room, everything seen by the subjects was black except for the rod and discs

The centre of the rod (18 x 0.5 cm) was aligned to each subjects' eye level via adjustment of the projector and/or chair height. Subjects closed their eyes whilst the rod was deviated either 20^o clockwise (CW) or counter-clockwise (CCW) from the earth vertical in randomised order. They were then instructed to open their eyes and align the rod to their perceived vertical in their own time (static test), using the wheel of a wireless computer mouse and confirm completion verbally before re-closing their eyes. Thus, subjects over a period of less than 1 minute were exposed and responded to four randomised presentations of the deviated rod ($+20^o$ or -20^o to the earth vertical). Each subject re-aligned rod to their perceived vertical and the angle between that and true earth vertical was recorded.

This process was then repeated (8 trials) with the computerised disc rotating at 30°.s^{-1} in the CW (4 trials) and CCW (4 trials) directions (dynamic test) in a randomised order. All subjects had one practice trial with both static and rotating disc in CW direction with the room illuminated before recording. At the end of testing, subjects were asked whether they were aware of/used pixellation for orientation to vertical.

2.2.3 Statistical Analysis

SPSS (v17.0) was used for all statistical analysis. All data are presented as mean ± standard deviation (SD). Significance was assumed at $p<0.05$.

The RDT software automatically recorded angular deviations from true gravitational vertical (0°) measured in degrees during both the static and dynamic testing. Deviations of the top of the rod to the subject's right or left were indicated by positive or negative values respectively e.g. values of +10 and -10 would have a mean of 10.

The mean of the 4 signed angles were then computed as the SVV for each subject. Dynamic SVV values were calculated as the absolute deviations of the top of the rod (i.e. unsigned) minus the value calculated for SVV as no significant SVV differences were found between CW and CCW disk rotation

Study 1

Static SVV values were normally distributed and a one-way ANOVA was used to analyse the effect of setup with post-hoc Bonferroni corrected paired T-tests performed when significance was indicated. As dynamic SVV values were not normally distributed, Friedman's ANOVA with post-hoc Wilcoxon signed-rank test was used for between setup analysis.

Study 2

Static SVV data was normally distributed but dynamic SVV was not and so was ordered according to rank to permit use of a two-way ANOVA to determine the effect of setup (TV_{rec} & PROJ) and age. Post-hoc independent and paired T-tests used to examine between groups and setup as appropriate. The Wilcoxon rank test was used to compare subjects' static and dynamic SVV ranking between TV_{rec} and PROJ.

To examine whether there was similar variance between the two age groups in a particular condition, the F-Test Two-Sample for Variance was performed.

Spearman's rank correlation test examined the relationship between age and static or dynamic SVV values in both TV_{rec} and PROJ for all subjects and each age group independently.

2.3 Results

Study 1

Static SVV values were similar [F(2,27) = 0.51; p = 0.60] for all setups (TV_{rec} 0.13° ± 0.43, TV_{round} -0.16° ± 0.72 and PROJ -0.35° ± 0.95), and deviated little from true gravitational vertical. Dynamic SVV values differed between setups [$X^2(2) = 16.91$; $p = 0.001$], being significantly greater in PROJ vs. TV_{rec} ($p = 0.003$) and TV_{round} ($p = 0.003$) (Fig. 2.3). No significant differences between TV_{rec} and TV_{round} were observed.

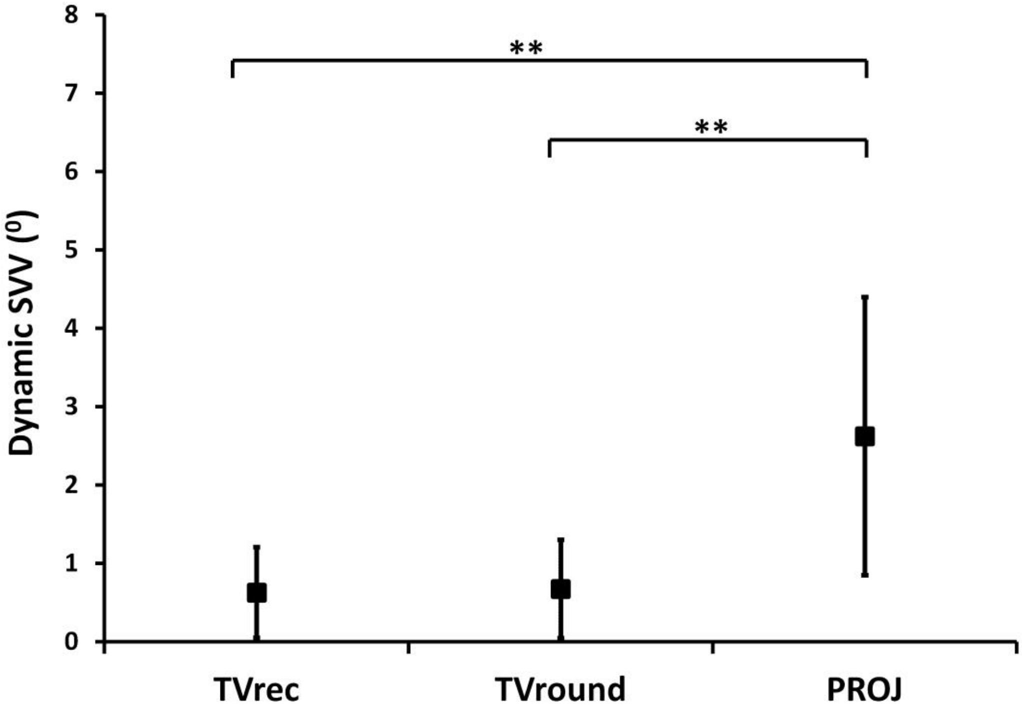


Fig. 2.3 (Mean ± SD) Dynamic SVV values assessed with TV_{rec}, TV_{round} and PROJ in healthy young subjects. The PROJ setup gave significantly higher values than both TV_{rec} and TV_{round}. ** denotes a statistically significant difference between setups at $p<0.05$

Study 2

Static SVV values were close to gravitational vertical for both TV_{rec} and PROJ in both younger (TV_{rec}: 0.28^{o} ± 0.42; PROJ: -0.16^{o} ± 1.81) and older subjects (TV_{rec}: -0.22^{o} ± 1.19; PROJ: 0.38^{o} ± 2.93) with no significant effect of age or setup. Variance was also similar in both age groups in TV ($p=0.06$) and PROJ ($p=0.25$).

Dynamic SVV was affected by setup [$F(1,9) = 19.37$; $p = 0.002$] with significantly greater error noted for PROJ vs. TV_{rec} in both younger ($p = 0.01$) and older ($p = 0.015$) subjects (Fig. 2.4). No significant age effect was noted although older people had a greater variance for TV ($p<0.001$) but not PROJ ($p=0.07$).

There was no significant difference in the ranking of individual subject's static or dynamic SVV values between TV_{rec} and PROJ.

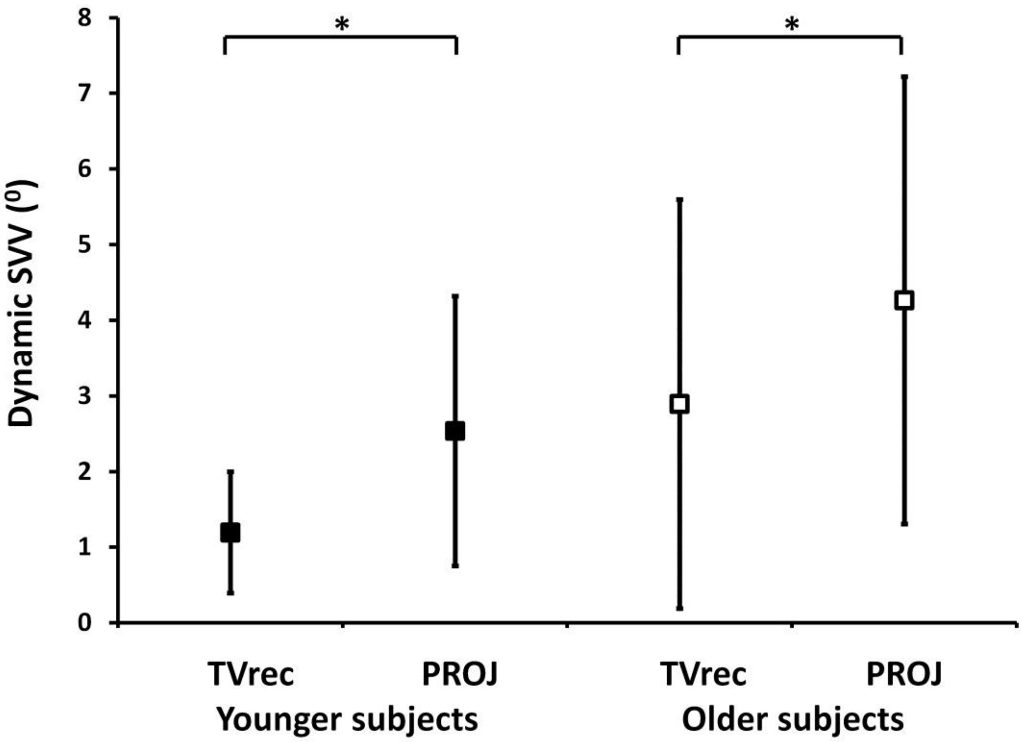
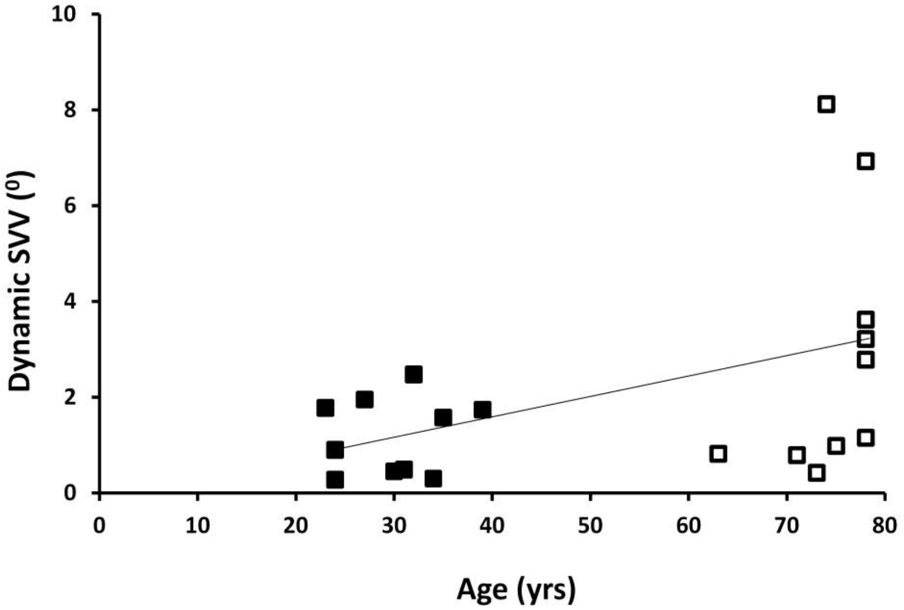


Fig. 2.4 (Mean ± SD) Dynamic SVV values assessed with TV$_{rec}$, and PROJ in healthy younger and older subjects. These were significant greater for the PROJ setup compared with TV$_{rec}$ in both young and older subjects. * denotes a statistically significant difference between setups at $p<0.05$.

A moderate positive correlation was identified only between age and dynamic values in both TV$_{rec}$ (Rho=0.484, p=0.030, Fig. 2.5a) and PROJ (Rho=0.524, p=0.018, Fig. 2.5b) across both groups but not within either of the two age groups. Static SVV did not correlate with age.

In both studies ~50% of subjects in each of the two age groups reported a conscious awareness and use of pixellation cues to judge verticality. However this was not formally documented and so the effect of this on SVV values remains unclear.

a)



b)

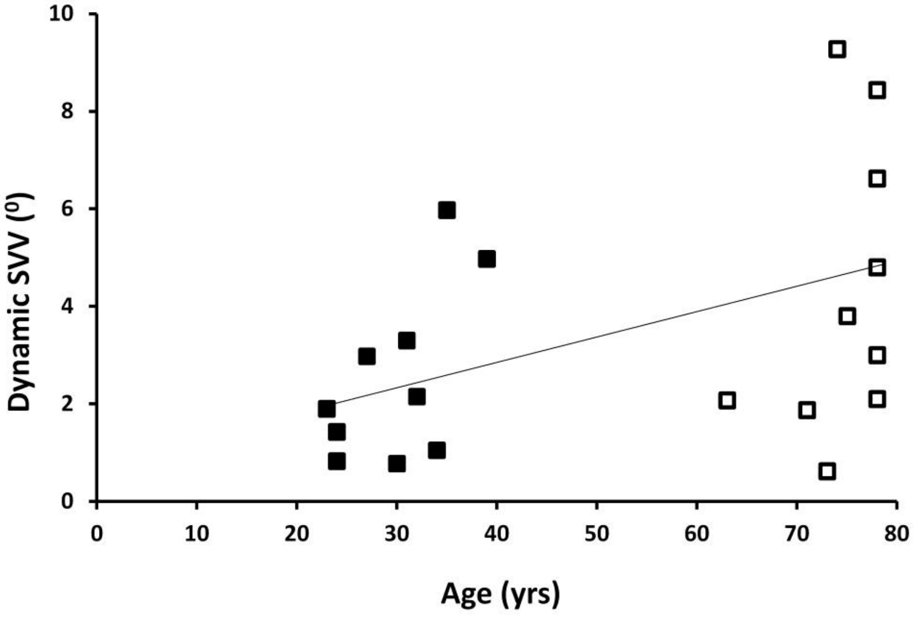


Fig. 2.5 Correlation between age (closed symbol: younger subjects; open symbol: older subjects) and dynamic SVV in a) TV_{rec} (Rho=0.484, p=0.030) and b) PROJ (Rho=0.524, p=0.018). There was a significant correlation between the two with a) TV_{rec} and b) PROJ.

2.4 Discussion

Study 1 compared dynamic SVV tilt measured by a computerised RDT using pixellated (round and rectangular) and non-pixellated (round) images in young healthy adults. The main finding was that when the RDT was presented with the non-pixellated projected image, dynamic SVV values were significantly greater than with the TV – irrespective of visual field shape, which had no independent effect.

Those results informed the protocol of Study 2 which examined the effect of pixellation and visual field on dynamic SVV tilt in healthy young and older adults. We found that healthy younger and older people both had higher dynamic SVV values when the round RDT was projected compared to when presented on a TV, and there was no difference in the rank order of subjects with respect to SVV values suggesting that all the subjects consistently increased errors in estimation of SVV from testing on TV to on PROJ. A trend towards increased SVV values was noted with increasing age but this was non-significant. Static SVV remained close to true gravitational vertical (0°) with no differences between setup or age group.

In both studies static SVV was close to gravitational vertical ($<1^\circ$) and similar for TV_{rec} and PROJ and similar in both age groups consistent with previous work in normal subjects aged 21 - 63 (Kobayashi et al., 2002) and 26 - 76 yrs (Bronstein et al., 1996).

Static SVV values were similar to those noted in previous studies (Dichgans et al., 1972, Guerraz et al., 2001, Pavlou et al., 2011) and were unaffected by setup. In contrast, dynamic SVV values were significantly greater when the RDT was back-projected (PROJ) as a non-pixellated image, compared to when presented on either a circular or rectangular TV monitor. The failure to observe an effect of shape suggests that dynamic SVV data with rectangular (Bagust, 2005) and circular (Lopez et al., 2007) screen presentations may be comparable across studies. This is despite the fact the circular screen was smaller (4876 vs. 2206 cm^2), as it has been suggested that a smaller image could decrease SVV values (Held et al., 1975) and also postural sway (Streepey et al., 2007, Dichgans et al., 1972).

Visual vertigo symptoms, which have been associated with increased visual dependency (Guerraz et al., 2001), also show a similar pattern whereby symptom improvement is similar regardless of the field size of the visual motion stimuli used for treatment (Pavlou et al., 2012). Presumably the screen size could be reduced to the point where the visual stimuli become ineffective e.g. a mobile phone, but that above that critical value the screen size is not important.

Increasing use of computerised RDT stimulation introduces the issue that light emission from the monitor and its reflection onto the non-screen structure of the monitor could act as a frame of reference, thereby providing spatial orientation cues (Bonan et al., 2006, Lopez et al., 2008, Pavlou et al., 2011). In the PROJ setup great care was taken to prevent light emission and black, non-reflective curtains surrounded the subject, therefore presumably the greater dynamic SVV in PROJ relates to the absence of perceptible pixellation. However, rod pixellation even with high-fidelity screens could give cues of verticality and error (Takasaki et al., 2012) used subconsciously or consciously. Spontaneous reporting of pixellation use for judging verticality in our previous studies was supported in this study by asking the subjects about pixel use at the end of the tests and half reported that they had done so.

Since RDT projection caused a significant increase in dynamic SVV values in Study 1, the aim of Study 2 was to investigate the visual effect of display on SVV values for young and older subjects by comparing the TV_{round} and PROJ (round) setup. As in Study 1, SVV values were small ($<1^{o}$) and similar for both setups and age groups, consistent with previous work in healthy normal subjects aged ~20-75 (Kobayashi et al., 2002, Bronstein et al., 1996). When subjects were ranked by SVV values the order with TV_{rec} and PROJ was similar. Dynamic SVV values tended to be higher i.e. worse, for older subjects with both setups, but this was not significant, in contrast to previous work (Bronstein et al., 1996, Kobayashi et al., 2002), despite the fact our subjects tended to be older (mean 75 years compared with 50 for Bronstein et al., 1996 and up to 60 for Kobayashi et al., 2002). When the two age groups were combined there was a correlation between SVV and age, but not within each group, although the range was small for both.

Several studies have reported higher visual dependence in older adults for both perceived orientation and postural control (Wade et al., 1995, Bronstein et al., 1996, Sundermier et al., 1996, Borger et al., 1999, Kobayashi et al., 2002). The favoured explanation is age- or disease- related peripheral sensory impairments in the proprioceptive and/or vestibular systems (Guerraz et al., 2001, Slaboda et al., 2009). If these inputs are inaccurate or unreliable, there may be an over dependence on vision and patients with vestibular dysfunction (Hafstrom et al., 2004) and stroke (Slaboda et al., 2009) have been reported to have increased visual dependence. However, the older subjects in this study did not show significantly increased visual dependence. This is perhaps because subjects with known peripheral sensory loss were excluded from this study and also the sample size was small. Another possibility could be that of individual variation since the older subjects had significantly greater variance with the TV screen for untransformed data only. However this was not the case for transformed data from the TV screen or PROJ and the latter was used in all subsequent studies. If proprioception and vestibular systems and processing are normal, no compensatory increase in the reliance on visual input is necessary.

An age-related decline in the function of sensory (vision, vestibular, proprioception) (Skinner et al., 1984, Baloh et al., 2001, Lord, 2006), motor (muscle strength, range of motion) (Skelton et al., 1994) and neuromuscular (balance strategy, coordination) (Lord and Ward, 1994) systems is widely accepted. It is associated with a decrement in balance. However, a number of studies report that balance degeneration with age is not necessarily linear, suggesting impairments are more important than chronological age (Kinsella-Shaw et al., 2006, Jeka et al., 2006, Lazarus and Harridge, 2010). This could explain no ageing effect on visual dependence in this study. In fact some older subjects had similar or even lower dynamic SVV values than younger ones and similar results have also been observed in other studies (Borger et al., 1999, Sundermier et al., 1996, Teasdale et al., 1991).

Additionally, our older subjects were all healthy with high function in physical and cognitive terms; most were currently in professional occupations or had recently retired from such and had relatively high socio-economic status. They were not selected on the basis of physical activity levels, but all were physically active although not engaged in competitive sport. As a result they may not have been representative of their age group in which an increased visual dependence with age has been reported (Bronstein et al., 1996, Kobayashi et al., 2002) but instead represent a group with particularly successful functional ageing (Rowe and Kahn, 1987). As such the small elevation in their dynamic SVV values might reflect 'true' age-related changes but could also result from central sensory integration (Allison et al., 2006) or sub-clinical (or undiagnosed) peripheral sensory organ impairment (Bronstein et al., 1996, Peterka, 2002, Kobayashi et al., 2002) or it could simply be that some individuals rely more on vision and others on vestibulo-proprioceptive cues (Isableu et al., 1997). Comprehensive testing of individuals is required to exclude such asymptomatic factors. Whether successfully aged people also have lower optic flow induced sway is unknown (Wade et al., 1995, Sundermier et al., 1996, Borger et al., 1999). However, a couple of studies have found larger postural responses to dynamic visual stimulation in older people despite the employment of thorough screening tests for proprioception and vestibular functions and the exclusion of subjects with such sensory impairments (Borger et al., 1999, Simoneau et al., 1999). Their findings argue against proprioception or vestibular loss as the sole or primary causative factor of visual dependence in healthy older adults.

Dynamic SVV values showed a moderate positive correlation with age for both TV_{rec} and PROJ across both groups, but the relationships had shallow slopes. Interestingly, visual dependence (as indicated by optic flow induced sway) might not increase linearly with age beyond 65-69 yrs (Lord and Ward, 1994, Kobayashi et al., 2002), and most of our older subjects were in this age range. Furthermore, the two groups were discontinuous in age with a gap of over 20 years rendering much of the relationship between the groups difficult to interpret. Future studies should recruit subjects over wider age ranges to investigate the effect of age on visual dependence throughout the life course, particularly the oldest old.

Factors that might affect the utilisation of pixellation may include knowledge of the TV grid structure and thereby the resultant spatial cues or visual acuity limiting the resolving power. All these may differ with age. For instance, a lack of pixel structure knowledge and straight line pixel alignment might be expected in individuals who have low technical literacy which is more likely in older people but can be excluded from our study as all were habitual computer users. Presentation of dots, rather than an entire rod for RFT, exposed greater errors in judging visual horizontal (Docherty and Bagust, 2010) and thus if applied to the RDT it may become more sensitive to change, including that related to ageing (Bronstein et al., 1996, Kobayashi et al., 2002). It would also help to understand whether pixellation or other factors explain the increased error in our study. Visual tests are influenced by visual acuity and contrast sensitivity, both of which tend to fall with age (Lord, 2006) and are associated with elevated falls risk (Lord and Webster, 1990). All our participants wore glasses or contact lenses if they wished. Some used bi- or vari- focal glasses and were asked if the projected images were clear and in focus or not. All stated that this was the case.

In conclusion, the effect of pixellation appears stronger than peripheral field characteristics in younger and older healthy individuals. As such non-pixellated (projected) presentation of the RDT appears to be advantageous when investigating visual dependence and may offer a more robust reproduction of the traditional mechanically produced RDT. However, the sensitivity of such testing highlights the value of each laboratory obtaining their own dynamic SVV normative values for validity and reliability. Such RDT testing in high functioning, normal vision individuals shows little effect of age, which suggests that specific sensory decrements or changes in central integration are likely drivers for the increments in visual dependence seen with age, rather than ageing *per se*. It is possible that previous studies have overestimated the effect of ageing in visual dependence as our healthy and highly functioning older people had relatively low visual dependence.

CHAPTER THREE EFFECT OF REPETITIVE VISUAL STIMULATION ON VISUAL DEPENDENCE IN HEALTHY YOUNGER AND OLDER SUBJECTS

3.1 Introduction

Vision plays an important role in spatial orientation in terms of the position and movements of body segments in relation to each other and to the environment (Lopez et al., 2006). Accurate perception of visual inputs can provide a reference frame in the maintenance of the upright position (Lord, 2006). However, moving visual fields can induce a powerful sense of self- motion, tilt observers' visual verticality toward the direction of a rotating display and provoke imbalance, spatial disorientation, vertigo and dizziness (Dichgans et al., 1972, Lee and Lishman, 1975).

Visually-induced disorientation and associated postural sway can be resolved by the presence of accurate proprioceptive and/or vestibular feedback (Redfern et al., 2001). People with elevated visual dependence are more likely to be disorientated or destabilised by rich or repetitive visual surroundings (Agarwal et al., 2012). Normally there are two adaptive processes in response to the same repetitive stimulation (Gilden et al., 1995). Habituation refers to a decrease in responses by repeated presentation of a stimulus (Dobie et al., 1990). The opposite is sensitisation, which refers to an increase in the elicited behaviour from repeated presentation of a stimulus (Gilden et al., 1995). The rate of habituation can be increased by greater repetition of the same visual stimuli or by providing shorter inter-stimulus intervals with a weaker stimulus (Codispoti et al., 2007). Sensitisation could result from a strengthening of synaptic transmission decreasing of the activation threshold (Collingridge et al., 2004) or may occur if insufficient recovery of the response to the eliciting stimulus is allowed before another stimulus is presented (Dobie et al., 1990).

Optokinetic stimulation training has been used in in both normal (Pavlou et al., 2011) and vestibular subjects (Vitte et al., 1994, Pavlou et al., 2012, 2013) to decrease dizziness, increase visual motion tolerance, and improve postural stability and gait. The training programmes are based on the principle of habituation to repeated exposure inducing adaptive changes, thereby decreasing the degree of visual dependence. The training duration has varied from 1 hour a day for 5 days (Pavlou et al., 2011) to 45 min weekly for 4 or 8 weeks (Pavlou et al., 2012, 2013). Generally the sessions lasted 2 min with 1 min break, with the stimulation stopped if a patient felt unable to continue due to dizziness or nausea and restarted if symptoms allowed (Vitte et al., 1994, Pavlou et al., 2012, 2013).

A few studies have investigated the effect of repeated exposure to visual stimuli within or between trials in a single session. After an initial exposure to visual stimulation older people had a greater increase in postural sway compared with younger people (Borger et al., 1999). A gradual reduction in postural sway was observed during continuous 30 - 60 s visual perturbation in healthy adults, irrespective of age (Loughlin et al., 1996, Loughlin and Redfern, 2001). However, within-trial habituation was slow and continuous in older group whilst it was more rapid in younger individuals and plateaued in <45 s (O'Connor et al., 2008).

A progressive attenuation of postural sway in response to visual stimulation over 5 trials was noted in both healthy younger and older adults, as well as older fallers, whether exposure was short (3.5 s with 20 – 45 s rest intervals, Sundermier et al., 1996) between trials or more prolonged (3 min with 2 min rest intervals, Jeka et al., 2006). Visual motion mediated postural effects significantly decreased and in some cases disappeared completely after 9 x 12 s exposures with 8 – 16 s rest intervals (Bronstein, 1986). Older adults and fallers in particular, showed slower habituation (Jeka et al., 2006).

Older adults, especially those with a history of falls, have greater difficulty adapting to different sensory environments including repeated stance perturbations or when potentially conflicting information is arriving from different sensory systems (Camicioli et al., 1997; Lin et al., 2005; Wrisley et al., 2007). This might be due to slower central processing of sensory information (Teasdale et al., 1991) and slower adaptive multi-sensory reweighting (Peterka and Loughlin, 2004). Older adults may be able to reweight sensory information but require more repetitions to achieve maximal habituation than younger adults (Woollacott et al., 1986, Woollacott et al., 1988). However, fall-prone older adults often lose their balance on the first exposure to conditions where both visual and proprioceptive inputs are altered, and may fail to adapt on subsequent exposures (Horak et al., 1989, Masdeu et al., 1989). Fall-prone older adults who are more visually dependent fail to use alternative proprioceptive cues in environments where visual inputs are unstable and may have less adaptive capability to sensory-changing situations (Brady et al., 2013).

The mechanisms underlying habituation to repetitive visual stimulation have been investigated (Fischer et al., 2000, Noguchi et al., 2004) with neural adaption in the visual ventral stream identified by magnetoencephalograph (MEG). A significantly reduced amplitude and shorter peak latency, but not duration of electrical currents in the brain, occurred after repetitive stimulation (Noguchi et al., 2004). Regional cerebral blood flow (rCBF) measured by Positron Emission Tomography revealed a decrease in the medial temporal cortex and the secondary occipital cortex indicating reduced neural input from visual areas with repeated exposures to visual stimulus (Fischer et al., 2000). Habituation can be observed in human behaviour (postural control), subjective feeling (symptoms), and cellular mechanisms (cerebral cortex).

Rather than habituation (attenuated response), visually induced sensitisation (amplified response) to motion on repeated stimulation has been noted (Dobie et al., 1990). Increased ratings of dizziness and velocity of self-motion (vection) across 10 x 30 s trials with undefined rest intervals (apparently ~10 s) were observed in healthy young subjects with normal sensitivity to visual stimulation when sitting inside a visually simulated rotating drum lined with alternating black and white vertical stripes (Dobie et al., 1990). Increased dizziness and disorientation after repetitive visual stimulation may affect visual orientation and tilt the subjective visual vertical (Dichgans et al., 1972, Lee and Lishman,

1975) however, the visual dependence was not measured and needs to be investigated.

Whilst there is clear evidence of habituation to visual stimulation in terms of postural control in both younger and older healthy adults (Borger et al., 1999; Loughlin et al., 1996; Sundermier et al., 1996; Loughlin and Redfern, 2001; Jeka et al., 2006; O'Connor et al., 2008), is unclear whether the same applies to perceived orientation i.e. subjective visual vertical. Postural habituation might result in motor learning from more efficient postural strategies to maintain balance or through reweighting of sensory information (Fransson et al., 2004). The Rod and Disk Test (RDT) (Dichgans et al., 1972), which estimates visual dependence at the perceptual level, may help to determine whether any changes in response to dynamic rotation visual stimulation are due to perceptual or postural mechanism, or a combination of both.

When examining the effect and duration of an intervention it is common practice to test at fixed time points following exposure but the time taken to complete the RDT varies considerably e.g. 1.5 – 5 min in our studies. Therefore, testing at fixed time points after an intervention means that the recovery period between repetitions varies, with those performing the test slowly having shorter recovery periods. The RDT represents a visual disturbance which in itself may affect visual dependence and the results may be due to summation of stimulation without sufficient recovery periods (Dobie et al., 1990). A 15 min rest interval between tests was suggested by Pavlou et al., (2011), however 2 –

3 min rests period have been used in previous studies (Sundermier et al., 1996, Jeka et al., 2006) and may be insufficient for complete recovery .

For an outcome measure to be useful in determining clinical progression or therapeutic effectiveness good repeatability on a particular day and also test-retest reliability is essential (Rankin and Stokes, 1998). Previous studies have used the RDT to measure the level of visual dependence before and after vestibular surgery (Lopez et al., 2007) as well as before and after treatment with optokinetic stimulation (Pavlou et al., 2011). However, its test-retest reliability appears not to have been assessed.

Therefore the purposes of this study were to investigate the effect of repeated exposures to optokinetic stimulation with the RDT on visual dependence in healthy younger and older adults. The test was performed at fixed 10 min intervals after the RDT, irrespective of the time taken for completion, and also with a 10 min rest interval between repeated tests, irrespective of the time taken for testing, on two days (Study 1). The first result of each day was used to determine the test-retest reliability of the RDT (Study 2).

3.2 Methods

3.2.1 Subjects

Study 1

Ten healthy young (aged 29 ±2 (mean ± sem), range 23 – 39 yrs, 1 male) and 10 healthy older (65 ± 2 (60 - 76) yrs, 5 male) subjects who were students or staff at King's College London gave written informed consent to participate in the study, which was approved by the local ethics committee (Appendix 1). Inclusion criteria were aged between 18 and 40 yrs for younger subjects and greater than 60 yrs for older subjects. Exclusion criteria were known neurological disorders, a history of peripheral or central vestibular disorders, clinically detectable peripheral proprioception loss, uncorrected visual impairments and a history of epilepsy, migraine, fainting or falling. One younger and two older subjects had participated in the previous RDT studies using the projected image.

Study 2

Twenty-three healthy subjects (45 ± 17 (23-76) yrs, 7 male) were recruited with the same exclusion criteria as in Study 1, in which 20 of them had also participated. An additional 3 subjects were also recruited (aged 27, 31 and 34 years).

3.2.2 Protocol

Study 1

Visual dependence was assessed by the RDT with back projection (Chapter 2.2.2, page 44). Subjects were invited to the laboratory on two occasions at least one day apart (79 ± 18 days, range 2 - 170 days). On each occasion the subjects performed 5 RDTs with different recovery periods between them. They were tested once with the 4 repeat tests with a 10 min rest intervals between tests after the initial RDT (T_{fixed}), and also at 10 min intervals irrespective of the time taken for completion ($T_{variable}$). Testing order was counter-balanced between subjects. The time taken to complete the RDT was measured by a stop watch.

Study 2

All subjects came to the laboratory on two occasions at least one day apart (79 ± 18 days, range 2 - 170 days).

3.2.3 Statistical analysis

Study 1

Group data are presented as mean ± sem. The Kolmogorov-Smirnov test was used to determine distribution. As no significant differences were noted in subjective visual vertical (SVV) between CW and CCW directions (Wilcoxon signed-rank test), they were averaged to obtain a mean dynamic SVV as in Chapter 2. Static SVV was normally distributed and dynamic SVV was ordered according to rank (as not normally distributed) to permit use of a two-way ANOVA to determine the effect of groups, repetitions, and their interaction in the two protocols respectively.

To examine whether there was similar variance between the two age groups in a particular condition, the F-Test Two-Sample for Variance was performed.

Since no effect of group was found in either protocol, all data was pooled. A subsequent two-way ANOVA was used to examine the effect of protocol, repetition, and their interaction on static and dynamic SVV. Statistical significance was assumed at $p \leq 0.05$ (IBM SPSS v19.0).

Study 2

Static and dynamic SVV were assessed by intraclass correlation coefficients (ICCs) (Shrout and Fleiss, 1979) and Bland and Altman analyses (Bland and Altman, 1986). ICCs were determined using SPSS (IBM v19.0) with one-way random model average measurements (Rankin and Stokes, 1998). An ICC value of 1 indicates perfect reliability with no measurement error while 0 indicates no reliability (Streiner and Norman, 2008). It was assumed that ICCs <0.4 are poor; 0.4 - 0.75 moderate; 0.75 - 0.9 good and >0.9 excellent (Shrout and Fleiss, 1979). Pearson's r correlation test examined the relationship between the first and second tests on static and dynamic SVV values in younger, older groups and pooled data of younger and older subjects respectively. Bland and Altman plots were constructed to examine the difference (bias) between tests against the average of the two tests. The mean difference between the first and second tests with 95 % limits of agreement was calculated. Younger and older groups were initially assessed separately to see the age difference and then all data were pooled and re-treated as a single group.

3.3 Results

Study 1

The mean time taken to complete an RDT trial did not differ between age groups (3.0 ± 0.2 min and 3.1 ± 0.2 min in the younger and older groups respectively). Subjects were exposed to an average 3.0 ± 0.1 min of visual stimulation in both protocols. Rest intervals between repeated tests were 7.0 ± 0.1 and 10.0 ± 0.0 min in $T_{variable}$ and T_{fixed} respectively. All static SVV values were close to gravitational vertical in younger (0.0^{0} ± 0.3 — -0.5^{0} ± 0.3) and older subjects (0.0^{0} ± 0.3 — 0.5^{0} ± 0.6) in 5 RDT tests irrespective of protocols or repetitions. There was no effect of age and repetition for static and dynamic SVV in either protocol (Table 3.1, Figs. 3.1 and 3.2). Variance was similar in both age groups at each of the time points on static (p=0.06 – 0.46) and dynamic SVV (p=0.06 – 0.49).

		$T_{variable}$				
		0’	10’	20’	30’	40’
Younger	Static SVV (^{0})	-0.3±0.3	-0.2±0.3	-0.1±0.3	-0.5±0.3	-0.2±0.3
	Dynamic SVV (^{0})	2.3±0.5	1.8±0.4	1.7±0.5	1.7±0.3	1.6±0.3
Older	Static SVV (^{0})	0.5±0.4	0.2±0.5	0.2±0.5	0.5±0.6	0.5±0.5
	Dynamic SVV (^{0})	1.5±0.3	1.8±0.3	1.5±0.3	1.6±0.3	1.5±0.4
		T_{fixed}				
		1st	2nd	3rd	4th	5th
Younger	Static SVV (^{0})	0.1±0.3	0.0±0.3	-0.1±0.3	0.2±0.2	0.4±0.3
	Dynamic SVV (^{0})	2.1±0.5	2.0±0.5	2.3±0.5	1.7±0.4	1.8±0.4
Older	Static SVV (^{0})	0.0±0.3	0.0±0.3	0.1±0.3	0.2±0.4	0.4±0.3
	Dynamic SVV (^{0})	1.6±0.3	1.3±0.3	1.5±0.2	1.3±0.2	1.4±0.3

Table 3.1 (Mean ± sem) Static and dynamic SVV values with repetitive testing in $T_{variable}$ and T_{fixed} in younger and older groups. There were no significant differences between repetitions or age groups in either protocol.

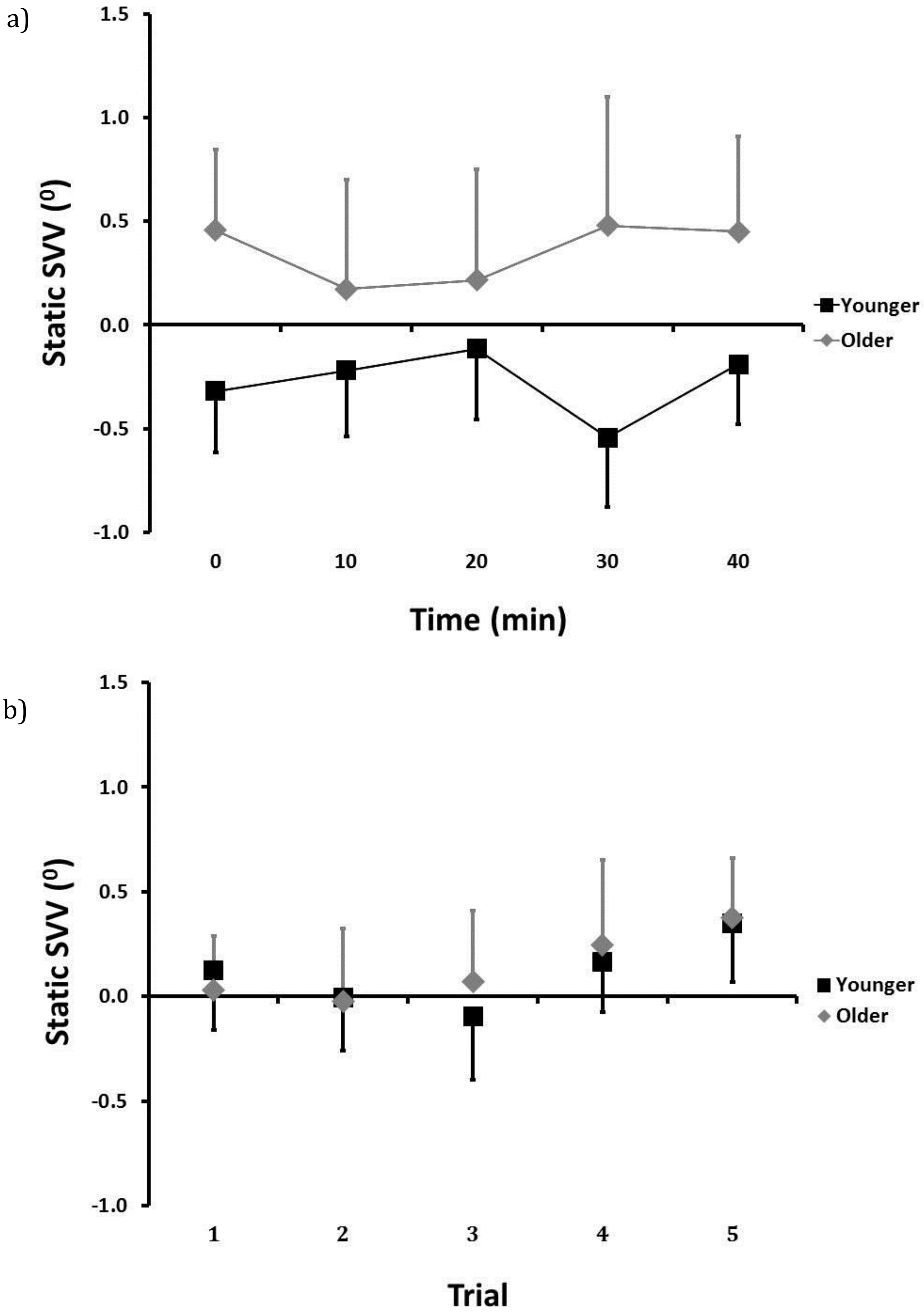
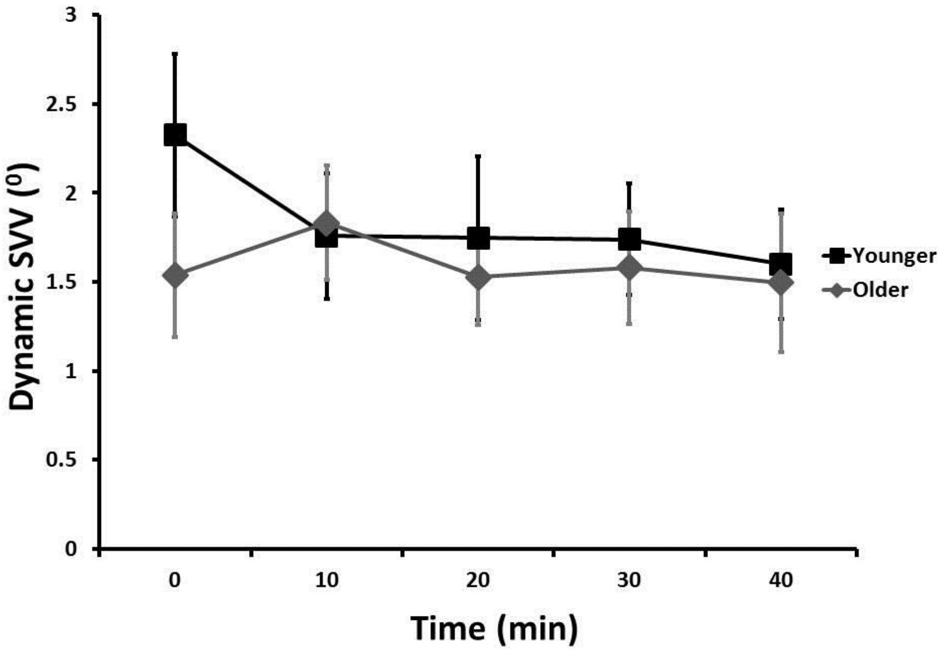


Fig. 3.1 (Mean ± sem) Static SVV with repetitive testing in a) $T_{variable}$ and b) T_{fixed} in younger and older groups. There was no significant effect of repetitions or age.

a)



b)

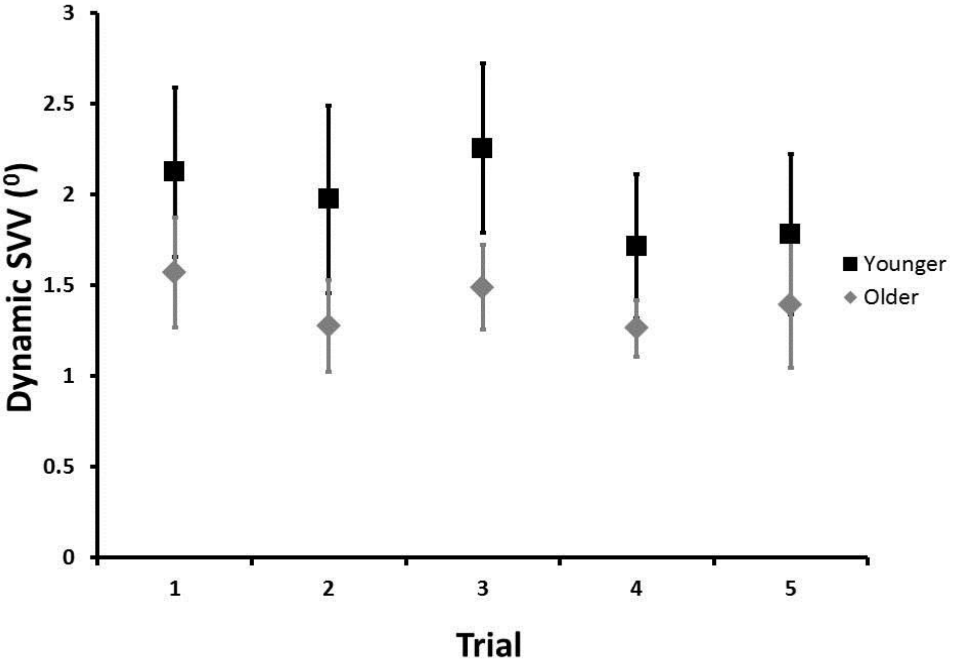


Fig. 3.2 (Mean ± sem) Dynamic SVV with repetitive testing in a) $T_{variable}$ and b) T_{fixed} in younger and older groups. There were no significant effect of repetitions or age.

Since data from the two age groups were not significantly different they were pooled. No significant differences between protocols for static and dynamic SVV emerged (Table. 3.2 and Fig. 3.3 and 3.4).

	$\mathbf{T_{variable}}$				
	0’	10’	20’	30’	40’
Static SVV (^{0})	0.1±0.3	0.0±0.3	0.1±0.3	0.0±0.4	0.1±0.3
Dynamic SVV (log ^{0})	1.9±0.3	1.8±0.2	1.6±0.3	1.7±0.2	1.5±0.2
	$\mathbf{T_{fixed}}$				
	1st	2nd	3rd	4th	5th
Static SVV (^{0})	0.0±0.2	0.0±0.2	-0.1±0.2	0.2±0.2	0.3±0.2
Dynamic SVV (log ^{0})	1.9±0.3	1.9±0.4	2.1±0.3	1.8±0.3	1.9±0.4

Table 3.2 (Mean ± sem) Static and dynamic SVV values with repetitive testing in both protocols in all subjects.

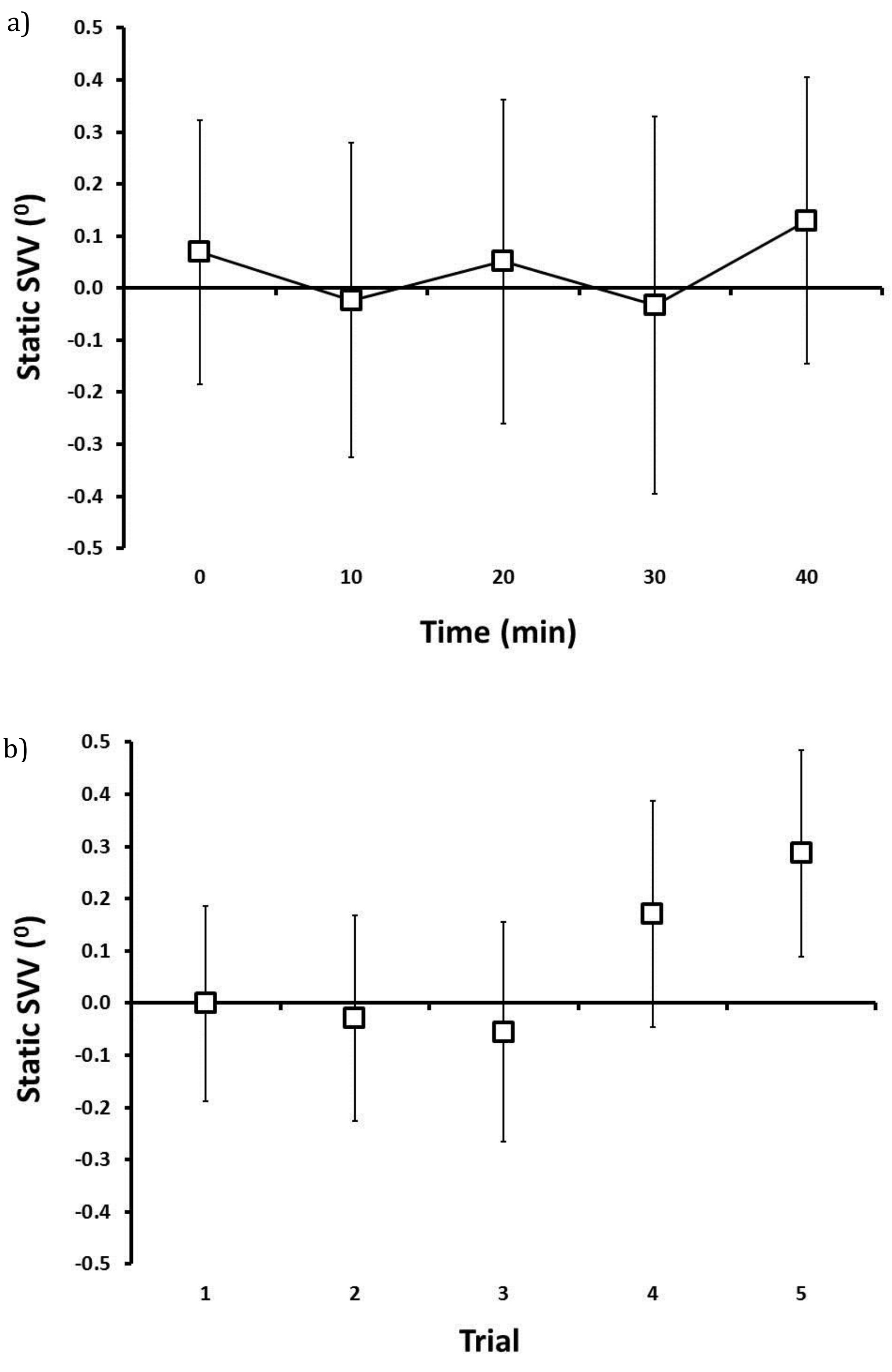


Fig. 3.3 (Mean ± sem) Static SVV with repetitive testing in a) $T_{variable}$ and B) T_{fixed} in all subjects. There were no significant differences between protocols and between repetitions.

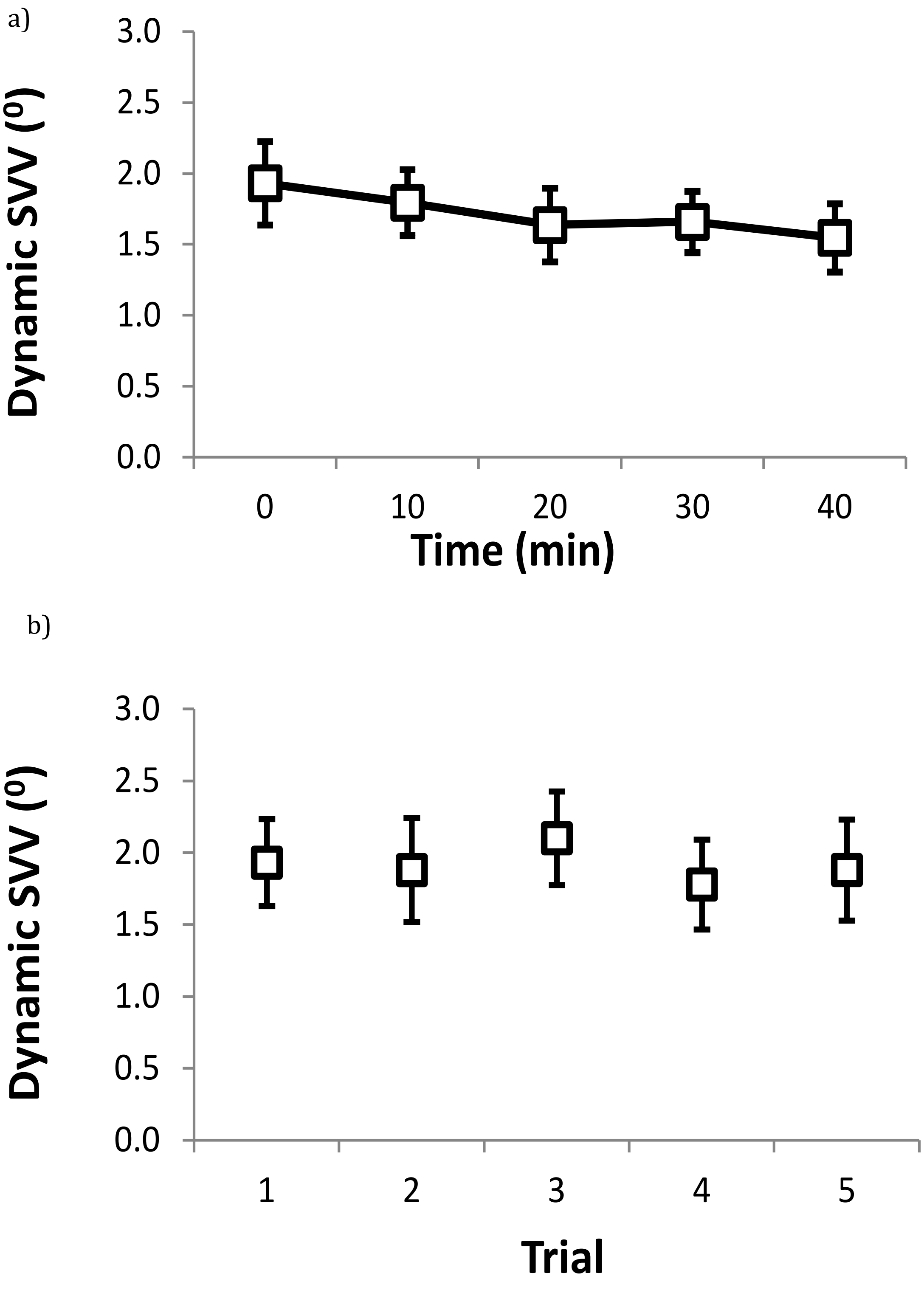


Fig. 3.4 (Mean ± sem) Dynamic SVV with repetitive testing in a) $T_{variable}$ and b) T_{fixed} in all subjects. There were no significant differences between protocols for dynamic SVV.

Study 2

Static SVV

ICC was 0.64 (moderate reliability) in older and 0.17 (poor reliability) in younger groups. The mean bias between the two tests was -0.49^{0} (SD 1.10^{0}) with -2.68^{0} – 1.70^{0} limits of agreement in younger subjects and 0.58^{0} (SD 1.02^{0}) with -1.45^{0} – 2.62^{0} limits of agreement in the older group (Fig. 3.5). However, there was no significant correlation between the first and second tests in either younger (r=0.11, p=0.73) or older (r=0.57, p=0.09) groups.

Dynamic SVV

ICC was 0.90 and 0.75 in younger and older groups respectively with both showing good reliability. The mean bias between tests was 0.27^{0} (SD 0.83^{0}) with -1.38^{0} – 1.92^{0} limits of agreement in younger subjects compared with bias of -0.21^{0} (SD 1.08^{0}) with -2.37^{0} – 1.96^{0} limits of agreement in the older group (Fig. 3.6). A good correlation was identified between the two tests in the younger group (r=0.80, p=0.001) but not in the older one (r=0.59, p=0.07).

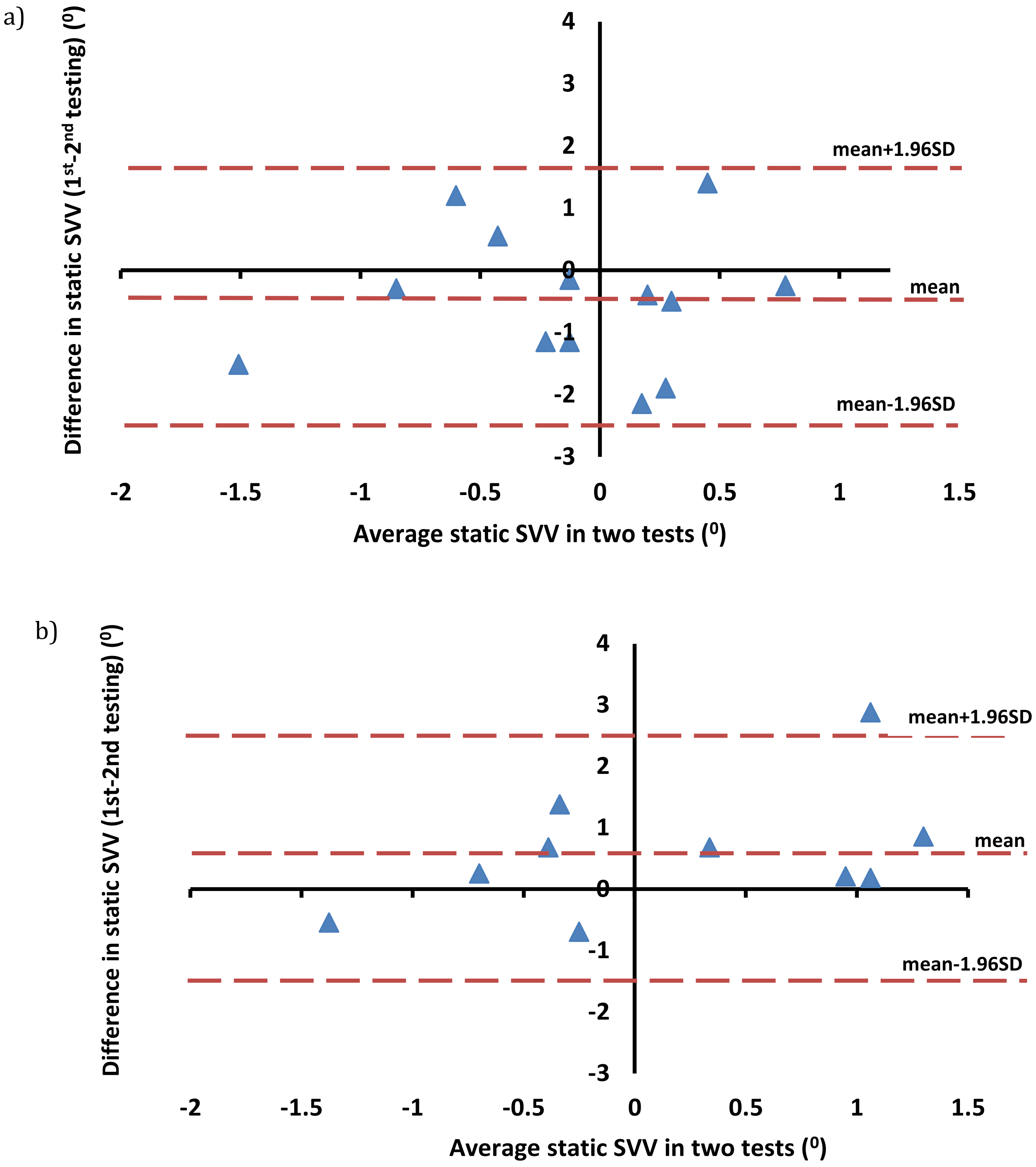


Fig. 3.5 Bland-Altman plot of average and difference of static SVV with mean and 95% Confidence Intervals indicating the limits of agreement in younger a) and older b) groups. Bias was -0.49 in younger and 0.58 in older subjects.

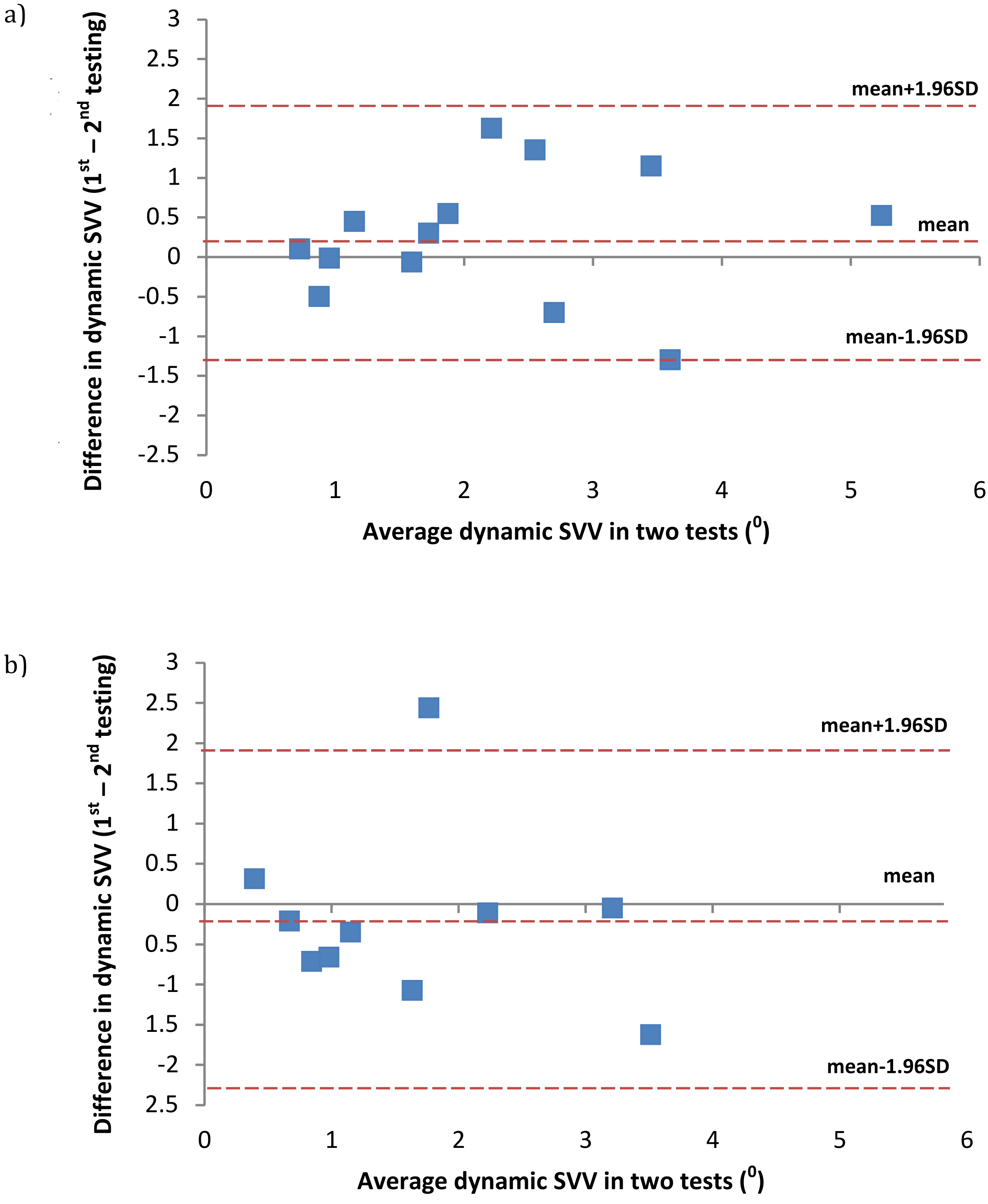


Fig. 3.6 Bland-Altman plot of average and difference of dynamic SVV with mean and 95% Confidence Intervals indicating the limits of agreement in younger a) and older b) groups. Bias was 0.27 in younger and -0.21 in older subjects.

SVV for pooled data

Static SVV ICC was 0.42 (moderate reliability) and the mean difference (bias) between tests was -0.02^0 (SD 1.17^0). Limits of agreement -2.32^0 – 2.27^0 (Fig. 3.7a) were acceptable. Dynamic SVV ICC was 0.85 (good reliability) and the mean bias between tests was 0.06^0 (SD 0.95^0) with -1.81^0 – 1.93^0 limits of agreement (Fig. 3.7 b). Bland and Altman plots showed that lower values ($<2^0$) were tightly grouped around the difference line, but there was a trend toward increased scatter around the bias line as mean value increased. There was a good correlation between the two tests for dynamic SVV ($r=0.73$, $p<0.001$) but not for static SVV ($r=0.25$, $p=0.24$).

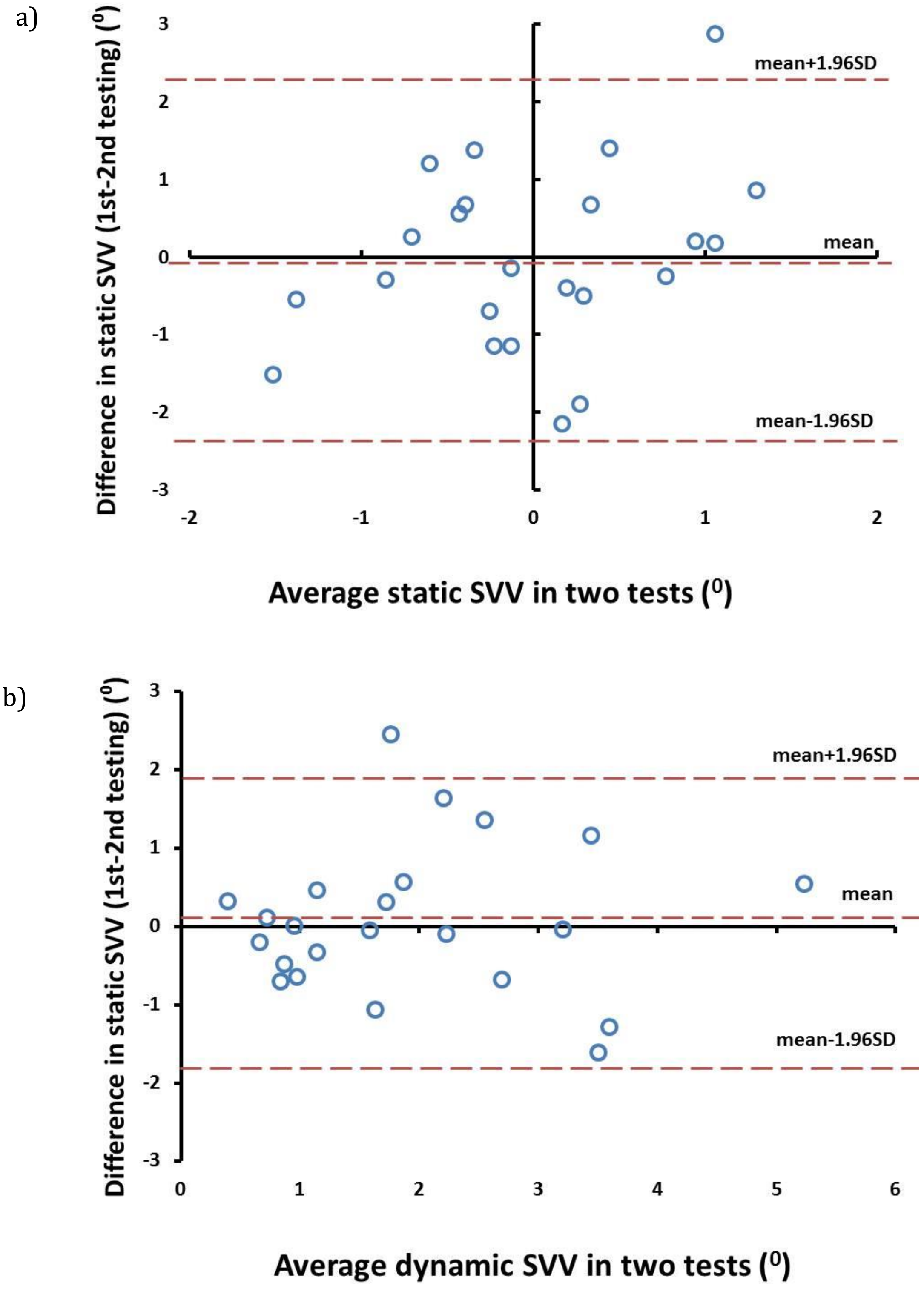


Fig. 3.7 Bland-Altman plot of average and difference of static SVV a) and b) dynamic SVV with mean and 95% Confidence Intervals indicating the limits of agreement in all subjects. Bias was -0.02 in static SVV and 0.06 in dynamic SVV.

3.4 Discussion

The aims of these studies were to investigate the effect of repetitive RDT visual stimulation performed with different rest periods between tests on subjective visual verticality in healthy younger and older adults as well as the test-retest reliability of the RDT. The main finding was that there was no effect of repeated testing on either static or dynamic SVV, irrespective of the duration of the rest period and also age. The RDT seems a reliable assessment of visual dependence in healthy subjects as good test-retest reliability of the dynamic SVV and moderate test-retest reliability of static SVV.

We found a lack of habituation to repeated visual stimulation with 7-10 minutes between exposure and previously Pavlou et al., (2011) have recommended >15 minutes. Previous stduies c reported a progressively reduced response i.e. habituation, with shorter recovery intervals in healthy younger and older adults (Jeka et al., 2006) as well as in older fallers (Sundermier et al., 1996). However, those studies used postural sway, and not perception of verticality, as the outcome measure and anticipation of a visual perturbation may lead to postural adjustments (Horak et al., 1989, Woollacott, 1993). Numerous studies have reported that repeated exposure to a postural perturbation allows learning more efficient strategies to maintain balance, both within a session and over time (Fransson et al., 2002, 2003a, b). Even in simple quiet stance with eyes closed, a progressive reduction in sway area and path occurred with repetition (Tarantola et al., 1997) but greater learning effects occurred during more complex tasks (Wrisley et al., 2007). The current study suggests that repetitive visual stimulation may have less influence on the perception of vertical than postural orientation.

Jeka and colleagues (2008) reported that the response to visual stimulation is proportional to its intensity because visual flow is greater and can destabilise upright stance. Therefore, the response i.e. adaptive change to repeated visual stimulation, possibly does not to occur when performing seated tests of visual dependence. Future studies need to compare both SVV and postural sway in the same subjects.

Both age groups in this study had levels of visual dependence that were similar and lower than those reported previously (Lord and Webster, 1990, Borger et al., 1999). Therefore they may rely on vestibulo-proprioceptive cues rather than visual ones i.e. visually independent, and thus would not be significantly influenced by this level of visual stimulation (Isableu et al., 1997). Some subjects in both age groups had mild dizziness or disorientation but these were experienced only during the first trial. This is in contrast to some healthy community-dwelling older subjects in some of other studies in our laboratory who reported substantial disorientation during the RDT and refused to continue, suggesting that our protocol and laboratory set up does not explain the lack of symptoms in the older people studied in this chapter.

The rest periods between exposures to bouts of visual stimulation used here (7 and 10 min for $T_{variable}$ and T_{fixed} respectively) were longer than in some previous studies (Sundermier et al., 1996, Jeka et al., 2006). The absence of any adaptation of the subjective visual vertical and lack of persistent symptoms suggested in both protocols that the rest interval between repeated tests was sufficient for any effect of previous exposure to have fully dissipated. However, a longer interval might be required for those have higher level of visual dependence (Pavlou et al., 2011) and a 2 – 3 min rest period used in previous studies (Sundermier et al., 1996, Jeka et al., 2006) may be too short, but 7 – 10 minutes of recovery is sufficient in adults who do not have higher than normal levels of visual dependence.

No effect of age was observed in the response to repetitive visual stimuli in this study although older people have been reported previously to have higher levels of perceptual visual dependence (Bronstein et al., 1996; Kobayashi et al., 2002). The reasons for elevated visual dependence in older people are unclear but might be due to an age-related declines in vestibular (Sloane et al., 1989) and/or proprioception (Kaplan et al., 1985) systems. The older subjects in this study were university staff, mentally and physically active, and had no relevant medical history. Variable levels of visual dependence have been found in groups of healthy adults of all ages and also in older fallers and some young adults have similar or even higher visual dependence than older ones (Sundermier et al., 1996). Therefore ageing *per se* may not affect visual dependence and these results are consistent with our findings in Chapter 2. Future studies could consider analysing subjects by the level of visual dependence, rather than just by chronological age.

This study provided consistent results over 5 RDT trials with both fixed and variable intervals between consecutive trials in both age groups. Therefore 7 min of recovery between tests can be used in future studies visual dependence in healthy people who are not visually dependent. However these results may not be extrapolated to people with pathological conditions that affect visual dependence. Previous studies reported that vestibular patients became less visually dependent between trials of visual stimulation (Agarwal et al., 2012) but retained similar degrees within a single trial (60 s) compared to healthy people (Loughlin et al., 1996), however the latter was measured based on changes in postural control and any change in judging the SVV is unknown.

Good levels of reliability are essential for a measurement to be useful to determine values at a given time and also over time (Rankin and Stokes, 1998). To the author's knowledge this is the first study to examine the test-retest reliability of static and dynamic SVV as assessed by the RDT. Lord and Webster (1990) investigated the reliability of visual dependence in healthy adults aged 59 – 97 years using the roll vection test, in which subjects align a central tilted rod in a motorised circular board with alternating black and white stripes over a 6 month period. Very good reliability of dynamic SVV (ICC 0.93) was obtained, but static SVV was not reported. In the current study test-retest reliability of static SVV was only moderate but the Bland and Altman analysis did not show any specific pattern, such as wide dispersion of data in a horizontal or vertical direction. Surprisingly, younger people had lower static SVV reliability than older ones based on the ICC values. These are commonly used to represent reliability, as it is a ratio of variability between and within subjects (Rankin and

Stokes, 1998). However, these subjects had very small static SVV values and greater variability might be found amongst these with higher values.

Bland-Altman analysis showed a trend for better reliability with the low dynamic SVV values ($<2^0$), which was consistent with Lord and Webster's study (1990), than with higher ones in both younger and older subjects. This may suggest the possibility that people with greater visual dependence show poorer test-retest reliability. Future studies could consider examining the test-retest reliability in healthy subjects of all ages and also people with higher degrees of visual dependence e.g. older fallers or patients with vestibular dysfunctions. If the reliability of the RDT is less in those who are visually dependent then results obtained before and after optokinetic treatment (Pavlou et al., 2011) or surgery (Lopez et al., 2007) need to be cautiously interpreted.

In conclusion, this study found no effect of repetitive visual stimulation by the RDT on SVV whether exposures were repeated at fixed times after the last test or with fixed rest intervals (~7 and 10 min rest periods respectively). It seems that repetitive visual stimulation may have less influence on perceived orientation than postural control. There were no significant differences between the two age groups of healthy adults. Good test-retest reliability of the dynamic SVV and moderate test-retest reliability of static SVV was found. A rest period of ≥7 min appears sufficient to avoid any effects of adaptation. The work presented in this Chapter informed the protocol of subsequent studies in this thesis.

CHAPTER FOUR EFFECT OF WHOLE BODY VIBRATION ON VISUAL DEPENDENCE FOR SPATIAL ORIENTATION IN HEALTHY YOUNGER AND OLDER SUBJECTS

4.1 Introduction

Many older people report that they find balance control more difficult during or after being in a moving environment such as a car or bus (Broome et al., 2009), indicating that balance can be perturbed by externally generated movement (vibration). Maintenance of balance is based on the integration of the visual, vestibular and proprioceptive systems (Maurer et al., 2000) and a disturbance in any one of them could result in postural instability (Isableu et al., 1997, Nakagawa et al., 1993, Britton et al., 1993) and perhaps higher visual dependence (Slaboda et al., 2009, Bronstein, 1995). Both postural instability and visual dependence have an increased incidence in older people (Kobayashi et al., 2002). Whole body vibration (WBV) is a form of vibration that is applied to the entire body through the feet by standing on a vibrating platform with either rotational or vertical oscillation (Cardinale and Wakeling, 2005). It has been reported to have long term improvements in strength and balance (Merriman and Jackson, 2009); however, the acute effect remains unclear. WBV intervention may have a similar effect to a moving vehicle that might disturb postural control and impair sensory systems. There is a large literature on local vibration to individual muscles and tendons, but the effects of whole body vibration have been little studied, although the technique is becoming popular.

Tendon vibration

This technique has been widely used (Ceyte et al., 2007). It activates the Ia, Ib and II afferent fibres from muscle spindles which inform the central nervous system that the muscle is being stretched and then elicits an illusion of movement (Courtine et al., 2007). Increased joint position error during repositioning may result from illusory movements during vibration, leading to the suggestion that tendon vibration has a detrimental effect on proprioception (Ishihara et al., 2004, Wierzbicka et al., 1998). Cutaneous mechanoreceptors including Merkel's cells (pressure), Ruffini endings (skin stretch), Meissner (vibration, touch) and Pacinian corpuscles (vibration) (Schmidt and Altner, 1986) were also reported to be influenced by vibration through the sole of the feet (Ribot-Ciscar et al., 1989, Vedel and Roll, 1982). Tendon vibration applied to the mastoid bone or the sternocleidomastoid muscles can excite not only cervical proprioceptors but also vestibular receptor cells (Magnusson et al., 2006, Karlberg et al., 2002). Effects include nystagmus (Hamann and Schuster, 1999) and tilted visual orientation (Karlberg et al., 2002) in patients with unilateral vestibular deficits. Therefore, tendon vibration has deleterious effects on proprioceptive and vestibular systems (Ishihara et al., 2004, Wierzbicka et al., 1998, Magnusson et al., 2006, Karlberg et al., 2002) that could be associated with increased visual dependence in accordance with the sensory reweighting hypothesis (Oie et al., 2002).

When tendon vibration was applied to the biceps brachii of subjects with closed eyes, greater errors were observed in the acuity of joint position sense in the upper limb (Cordo et al., 1995). Postural sway during tendon vibration became larger when subjects' eyes were closed (Patel et al., 2009, Gomez et al., 2009, Bove et al., 2009, Nakagawa et al., 1993, Hazime et al., 2012) or when they were looking at a moving image (Adamcova and Hlavacka, 2007). The responses to tendon vibration have been reported to be greater in older people (Abrahamova et al., 2009) and especially in those with impaired vibration sensation (Kristinsdottir et al., 2001). Proprioceptive impairments caused by tendon vibration may lead to elevated visual dependence with greater effects in older people and similar or greater effects may result from WBV.

Whole body vibration (WBV)

WBV is performed with a subject standing on a vibrating platform with either rotational (where the plate rotates around the anterior-posterior axis) or vertical oscillation (Cardinale and Wakeling, 2005). It has been reported to lead to long term improvements in strength, flexibility, muscle power, movement speed and balance (Merriman and Jackson, 2009), especially in older people (Rittweger, 2010), and is becoming increasingly popular as a form of exercise training (Cochrane and Stannard, 2005) and rehabilitation (van Nes et al., 2004, Lau et al., 2011). The long term (4 wks to 1yr) effects of WBV have been investigated with the majority of studies focusing on muscle performance, balance and functional mobility (Jordan et al., 2005). However, the immediate effects of WBV, especially on sensory systems e.g. visual dependence, are limited although they are an essential part of postural control.

Joint position sense at the ankle and knee joints did not change after WBV in young people (Pollock et al., 2011) but trunk repositioning has been found to improve after single and repeated bouts of WBV in people with low back pain (Fontana et al., 2005). Reduced cutaneous sensation at the foot and ankle (touch and pressure) occurred immediately after WBV (Pollock et al., 2011, Schlee et al., 2012) and can last for 2 hours (Sonza et al., 2013). The effect of WBV on vestibular function has not been investigated but there is a study reporting that low-frequency WBV (<1 Hz) may cause vestibular disturbances resulting in symptoms of dizziness, motion sickness and nausea (Seidel et al., 1990). These frequencies are similar to those in occupational WBV, although they conducted laboratory and not occupational studies. WBV was also reported to result in blurred vision by making images oscillate on the retina (Griffin, 1976). Visual blurring can impair visual acuity that worsens with higher frequencies of vibration (>7 Hz) and shorter distance (<1 meter) between subjects and objects (Griffin, 1975). However, to our knowledge there have been no studies investigating the effect of WBV on visual dependence although WBV is commonly used in older people (Rittweger, 2010) who have been reported to have higher levels of visual dependence (Kobayashi et al., 2002).

Visual dependence can result from impairments in the proprioceptive or vestibular systems (Slaboda et al., 2009, Bronstein, 1995). Both of these would be expected to be affected by WBV (Fontana et al., 2005; Sonza et al., 2013). It is possible that any negative effects of WBV in this respect might counter and even outweigh the beneficial effects on strength and power output.

The aim of the study presented in this chapter was to investigate the effect of WBV on perceived visual dependence as measured by the RDT in healthy younger and older subjects.

4.2 Methods

4.2.1 Subjects

Ten healthy young (aged 29 ± 1 (mean ± sem), range 22 – 34 yrs, height 162 ± 2 (148 – 173) cm, mass 61 ± 4 (47 – 82) kg, 2 male) and 10 healthy older (aged 65 ± 1 (61-73) yrs, height 172 ± 4 (155 – 188) cm, mass 71 ± 4 (53 – 89) kg, 5 male) subjects participated in the study. They were university students or staff or residents from neighbouring community centres. Inclusion criteria were aged 18 - 40 yrs for younger subjects and >60 yrs for older subjects. They did not have any known neurological disorders, history of peripheral or central vestibular disorders, clinically detectable peripheral somatosensory loss, uncorrected visual impairments or a medical history of epilepsy or migraine or fainting. As WBV was used subjects were excluded if they had any joint replacements, recent injuries to bones, joints or muscles. All subjects gave their informed consent to agree to participate in the study, which was approved by the local ethics committee (Appendix 1).

4.2.2 Protocol

WBV intervention (Fig. 4.1)

Five one min bouts of WBV (5 mm peak-to-peak amplitude and frequency of 20 Hz) with 30 s rest between bouts were performed on a rotating vibrating platform (Galileo 2000, Novotec Medical GmBH, Germany). Subjects were asked to stand barefoot on the platform with arms at their sides but were allowed to use the hand rail if they felt this was necessary. They were asked to stand straight legged without locking their knees in order to transmit less vibration to the head which may cause discomfort, visual problems or motion sickness (Rubin et al., 2003) whilst maintaining an even weight distribution bilaterally and between the forefoot and hindfoot while looking forwards and were 2 meters away from a blank wall.

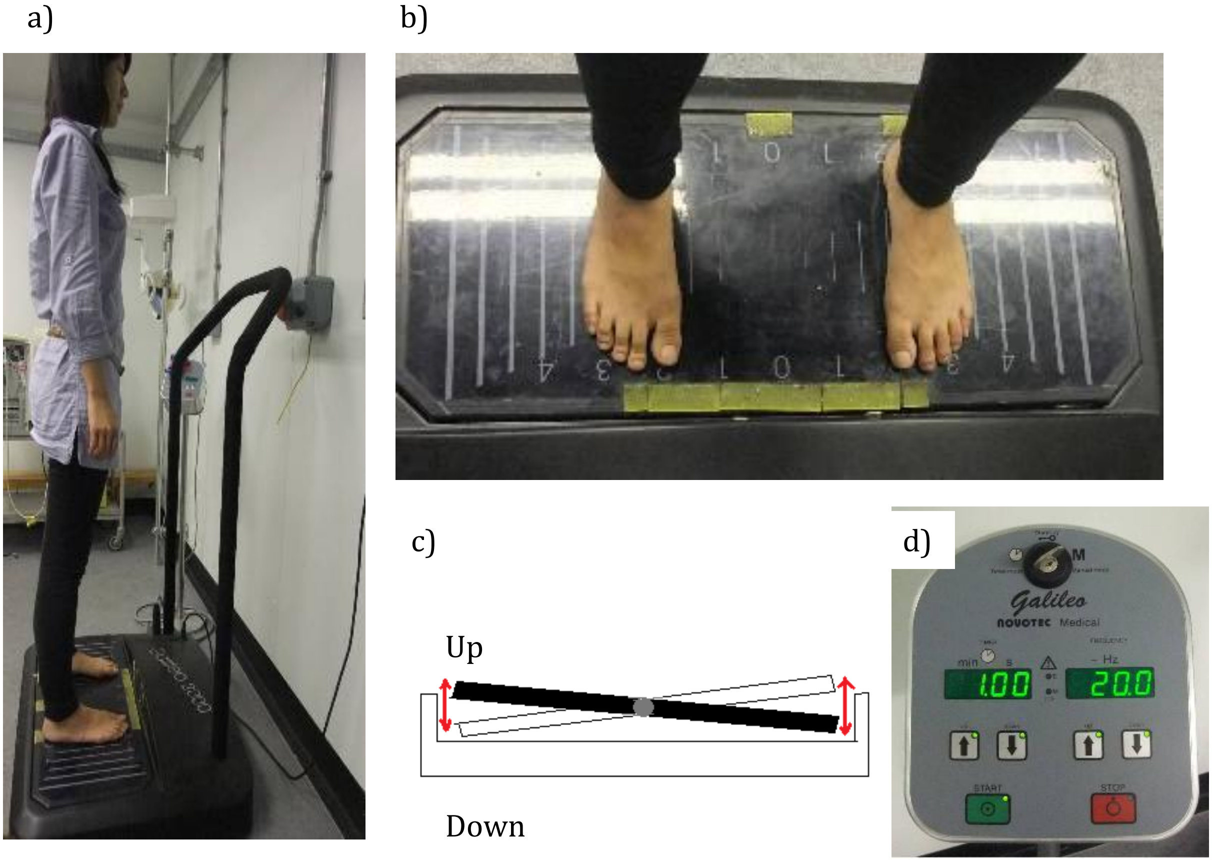


Fig. 4.1 The WBV machine. a) Quiet standing on the platform with straight knees, flat feet, arms at the sides while looking directly ahead. b) The subjects stood barefoot over marked foot positions (midline of foot is aligned to line 2.5) corresponding to 5mm peak-to-peak amplitude. c) Rotating vibrating platform. d) A frequency of 20 Hz was set using the control unit by a researcher.

The protocol of 5 repeated RDT tests at 10 min intervals has been described in Chapter 3. Reliability of visual dependence assessed by the RDT was found to be good and moderate for dynamic and static SVV respectively in healthy population of older and younger adults. Ten min test intervals between subsequent RDTs can prevent any habituation in that same population.

Therefore, these data informed the protocol used in this study in which visual dependence was assessed by the RDT (Chapter 2.2.2, page 44) before (BASELINE) and after WBV. To assess the time course of any changes, repeat RDTs were performed within 1 min after the end of WBV (T0) and then at 10 (T10), 20 (T20), and 30 minutes afterwards (T30). All the subjects had one practice attempt with both stationary and rotating discs in an illuminated condition for familiarisation. One more practice was allowed if they were still not clear or wrongly performed the first practice. Once they clearly understood the procedure testing began approximately one min afterwards. Subjects were asked whether any symptoms of nystagmus, dizziness and disorientation occurred during or after WBV,

4.2.3 Data analysis

SPSS v19.0 was used for all statistical analysis. All data are presented as mean ± standard error of mean (SEM). The Kolmogorov-Smirnov test was used to determine whether data were normally distributed. Significance was assumed at $p<0.05$.

As no significant differences were noted in subjective visual vertical (SVV) between CW and CCW directions (Wilcoxon signed-rank test), they were averaged to obtain a mean dynamic SVV as in Chapter 2. Static and dynamic SVV values were compared between and within the two age groups before and after vibration.

Static SVV values were normally distributed but dynamic SVV values were not and were ordered according to rank before parametric testing was applied.

Static and dynamic SVV were examined by a two-way ANOVA (2 age groups (younger vs. older) X 5 time points (BASELINE, T0, T10, T20, and T30)) test to determine the effect of groups, time, and interaction between groups and time. Post-hoc one way ANOVA with least significant difference (LSD) was used to investigate the time effect within group.

To examine whether there was similar variance between the two age groups in a particular condition, the F-Test Two-Sample for Variance was performed.

4.3 Results

4.3.1 Static SVV

There was no effect of time or group on static SVV (Table 4.1and Fig. 4.2). All static SVV values were close to gravitational vertical in younger (-0.9^0±0.3 — -0.5^0±0.4) and older subjects (-0.4^0±0.5 — -0.1^0±0.4). Variance was similar in both age groups at T0 (p=0.15) and T10 (p=0.14) except a greater variance in the older people at baseline (p=0.004), T20 (p=0.002) and T30 (p=0.03).

		Time (min) after vibration				
		BASELINE	T0	T10	T20	T30
Static SVV (^{0})	Younger	-0.7±0.2	-0.9±0.3	-0.9±0.3	-0.6±0.2	-0.5±0.4
	Older	0.2±0.6	-0.1±0.4	-0.4±0.5	-0.1±0.7	-0.3±0.7

Table 4.1 (Mean ± sem) Static SVV values in both age groups before and after WBV. No significant differences were found between groups or time points on static SVV.

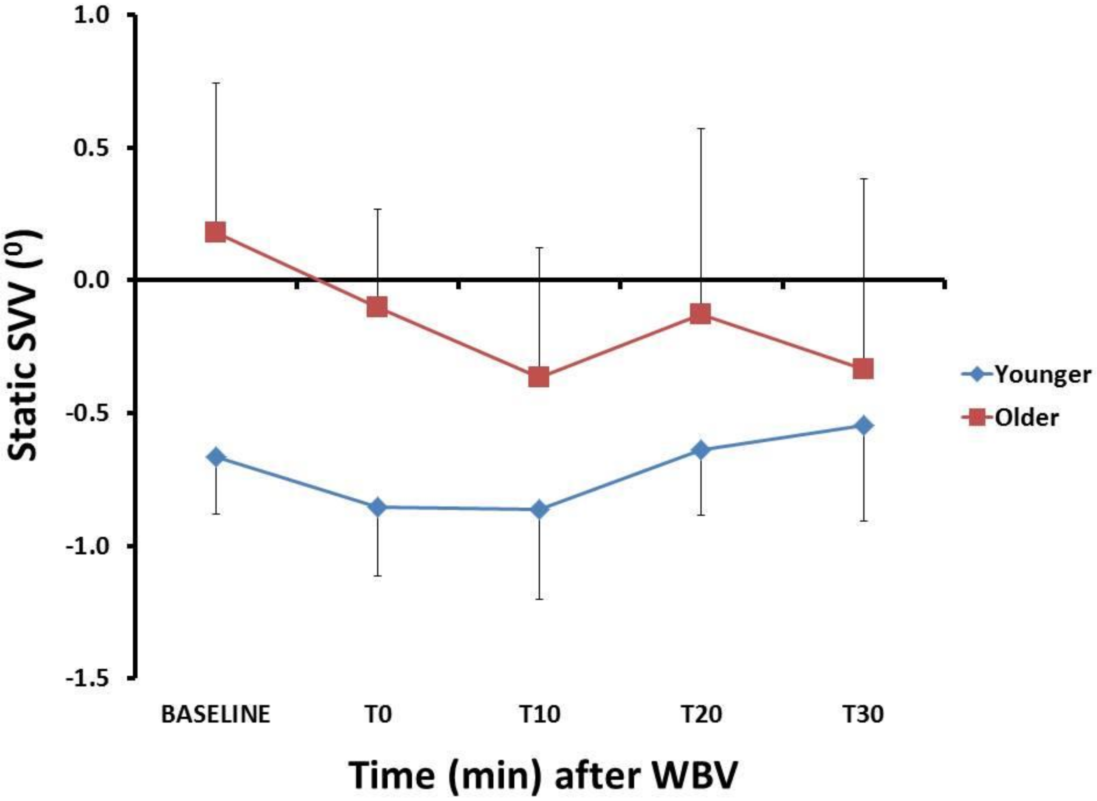


Fig. 4.2 (Mean ± sem) Static SVV before and after WBV in both age groups. There were no significant differences between groups or time points on static SVV.

4.3.2 Dynamic SVV

There was a significant time effect on dynamic SVV [F(4,36)=3.46, p=0.02] but no effect of groups or interaction between time and groups. One way ANOVA showed that dynamic SVV was improved after WBV in the younger group [F(4,36)=3.31, p=0.04] but was unchanged in the older subjects. Dynamic SVV immediately after WBV showed a nonsignificant trend for improvement (p=0.057) and this became significant after 10 (p=0.05) and 20 (p=0.03) min (Table 4.2 and Fig. 4.3). Variance was similar between age groups at each of time points (p=0.06 – 0.38).

		Time (min) after vibration				
		BASELINE	T0	T10	T20	T30
Dynamic SVV (^{0})	Younger	2.9±0.5	2.4±0.5¥	2.1±0.3*	2.1±0.4*	2.2±0.3
	Older	3.9±1.0	3.5±1.1	3.1±0.6	3.1±0.6	3.3±0.8

Table 4.2 (Mean ± sem) Dynamic SVV values in both age groups before and after WBV. Dynamic SVV was decreased (improved) at T10 and T20 compared to BASELINE in younger group only. * Statistically significant greater sway than BASELINE at p<0.05 (¥ nearly significant difference p=0.057).

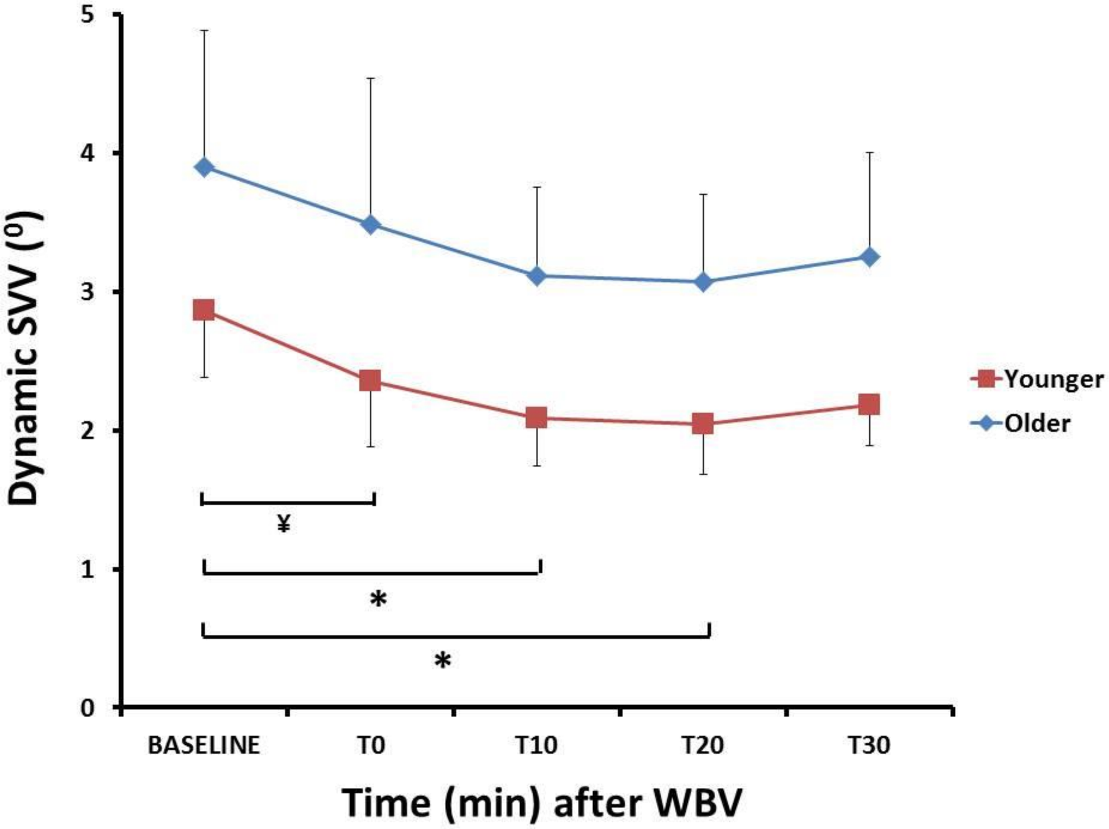


Fig. 4.3 (Mean ± sem) Dynamic SVV before and after WBV in both age groups. There was no effect of group on dynamic SVV. Values at T10, and T20 were significantly lower than BASELINE in younger group but unchanged in older group. * Statistically significant difference between time points at p<0.05 (¥trend toward significant difference p=0.057).

4.4 Discussion

The aim of this study was to investigate perceived visual dependence before and for 30 min after WBV in younger and older healthy subjects. Static and dynamic SVV were similar between age groups. Static SVV was unaffected by WBV but dynamic SVV decreased (improved) for 20 min after vibration in the younger group but was unchanged in the older one. Dynamic SVV values 30 min after WBV in both groups were lower than at baseline, although not significantly so.

This is the first study to investigate the effect of WBV on visual dependence which is often thought a compensatory response to inaccurate proprioceptive and/or vestibular inputs (Slaboda et al., 2009, Bronstein, 1995). It showed decreased visual dependence after vibration in the younger group only, suggesting that WBV may provide more afferent sensory stimulation, presumably proprioceptive and/or vestibular inputs, than visual and therefore reduce the reliance on vision. However, neither proprioceptive nor vestibular function was measured in the present study.

The acute effect of WBV on proprioception is still unclear. Previous studies reported that joint position sense at the ankle and knee joints did not show any difference after WBV in young people (Pollock et al., 2011). However trunk repositioning showed improvement after single and repeated bouts of WBV in people with low back pain (Fontana et al., 2005), suggesting that proprioception could be improved by WBV in subjects with musculoskeletal pathology, but not in healthy adults. Improved proprioception after long term WBV training has been also reported (Trans et al., 2009, Moezy et al., 2008) with knee movement proprioception improving after 8 weeks of WBV in women with knee osteoarthritis (Trans et al., 2009). Twelve weeks of WBV training improved knee joint position sense in patients who have had anterior cruciate ligament surgery (Moezy et al., 2008). It is possible that both an acute bout and also long term WBV training could improve proprioception, but this warrants further investigation.

Proprioception is affected by tendon vibration (Ishihara et al., 2004, Wierzbicka et al., 1998) but the effect is dependent of the frequency of vibration, as 100 Hz had a greater effect than 30 and 40 Hz (Kasai et al., 1992); the frequency of 20 Hz used in the study reported in this chapter were below this. Therefore, low WBV frequencies may be insufficient to impair sensory systems. In contrast, there is the possibility that WBV may improve proprioception due to a more efficient use of the proprioceptive feedback loop (Delecluse et al., 2005, Trans et al., 2009). It is known that the production of isometric force is controlled by many factors including the proprioceptive pathway i.e. Ia, Ib, and II afferents (Delecluse et al., 2005, Gandevia, 2001). Immediate improvements in muscle strength reported after WBV (Bedient et al., 2009, Da Silva-Grigoletto et al., 2009) are partly attributed to enhancements of the proprioceptive feedback loop resulting from excitatory stimulation of the afferent pathways. If this is so, then there may be an effect on proprioception. Thus, decreased levels of visual dependence in the younger group in the current study could be explained by possible increased inputs from proprioceptive systems.

Compared with the effects of WBV on proprioception, there is little known about its effect on the vestibular system. Previous studies found that local vibration on the mastoid bone or neck muscles may cause vestibular disturbances characterised by visual and postural illusion, symptoms of nystagmus, dizziness, and tilted visual orientation in healthy people and also patients with vestibular deficits (Hamann and Schuster, 1999, Magnusson et al., 2006, Karlberg et al., 2002). However, the vibration in those studies was directly applied near the vestibular organ and the frequencies used (55−85 Hz) were much higher (Hamann and Schuster, 1999, Magnusson et al., 2006, Karlberg et al., 2002) than the 20 Hz of WBV used here. The effects on vestibular function were also observed with very low frequency (<1 Hz) vibration, but the exposure was in an occupational setting and the duration substantially longer (Seidel et al., 1990).

Rotational WBV has less transmission to the head than vertical (Abercromby et al., 2007) and standing with flexed knees can decrease vibration magnitude in the upper body (Rubin et al., 2003) with very rare reports of discomfort (Cardinale and Rittweger, 2006). Both of these were used in the current study and also none of the subjects reported any of these symptoms of nystagmus, dizziness and disorientation during or after WBV, suggesting that the vestibular system was not disturbed by the acute bout of WBV at the frequency used here. Therefore, unlike local vibration, WBV may provide more afferent sensory stimulation *via* the proprioceptive and/or vestibular systems and thereby decrease reliance on vision.

Another possibility for the decreased visual dependence after WBV could be associated with blurred vision during vibration (Griffin, 1976). There is clear evidence of habituation to repetitive visual stimulation in neural (Fischer et al., 2000, Noguchi et al., 2004) and postural levels (Loughlin and Redfern, 2001, O'Connor et al., 2008). Visual judder for 5 min during WBV may cause the central nervous system to down-weight inaccurate visual inputs based on the sensory reweighting hypothesis (Oie et al., 2002) and this might explain the decreased dynamic SVV values after vibration. However, amount of change in younger people was small and unlikely to have a clinical or functional effect.

No such change in visual dependence during dynamic RDT testing occurred in the older people. They may have less flexibility in reweighting the sensory systems and thus lack effective adjustment to respond to an external influence (Horak et al., 1989). Indeed, older adults can have greater difficulty adapting to different sensory environments than young ones (Camicioli et al., 1997; Lin et al., 2005; Wrisley et al., 2007). This may be due to slower central processing of sensory information (Teasdale et al., 1991) and adaptive multi-sensory reweighting in older population (Peterka and Loughlin, 2004). Furthermore, previous studies reported that the magnitude of the vibration-induced reflex contraction e.g. inhibition of stretch reflexes (Burke et al., 1996) and of the H-reflex (Butchart et al., 1993), seems to be much less pronounced in the older adults and may be also associated with their lower response to acute of WBV. This could be hazardous for older people and potentially could lead to an increased incidence of falling in rapidly and continuously sensory changing environments. However, there was a trend for decreased dynamic visual dependence in older group although it did not reach statistical significance. This supports the suggestion that older adults may be able to reweight sensory information but require more time than younger adults (Woollacott et al., 1986, Woollacott et al., 1988). Nevertheless, no effect was seen in the 30 min following WBV and this period would be expected to include the time needed even with slow central processing

The effect of WBV on visual dependence in young people lasted for 20 min. Decreased postural sway induced by local vibration at the ankle and neck also lasted for 20 min (Wierzbicka et al., 1998) and the reduced cutaneous sensation caused by WBV lasted even longer (2 hours) (Sonza et al., 2013). It is suggested that the residual effect of vibration can be caused by either sensory (cutaneous sensation, visual dependence) or motor (balance) mechanisms, irrespective of which mode of vibration (local vibration at high frequencies and WBV at low frequencies) is used (Wierzbicka et al., 1998, Sonza et al., 2013).

Older people have been widely reported to have greater visual dependence for spatial orientation (Kobayashi et al., 2002, Bronstein et al., 1996). Previous work found that the dynamic, but not static, SVV increased with age in healthy adults aged 20-75 yrs (Kobayashi et al., 2002, Bronstein et al., 1996). However, the current study found that neither static nor dynamic SVV was affected by age, in line with the findings in Chapters 2 and 3, although the dynamic SVV in older group was still slightly higher than in the younger group, but not significantly so. Furthermore, some studies have reported greater variability in older people when performing the RDT and also in postural responses to visual motion stimulation (Borger et al., 1999, Sundermier et al., 1996, Teasdale et al., 1991). This was also indicated in this study by the larger SEM values in the older group. 'Older people' are a heterogeneous group since individuals of the same chronological age clearly have different levels of deterioration in various systems, leading to greater individual variability. There is progressively more interest in the suggestion that the age related functional decline may be more related to specific impairments rather than age *per se* (Kinsella-Shaw et al., 2006, Jeka et al., 2006, Lazarus and Harridge, 2010).

In most studies the sensory motor systems were tested after, but not during, WBV as in the present study. WBV was reported to result in blurred vision by making images oscillate on the retina and causing severe problems with reading (Griffin, 1976). Normal vision is required to execute the RDT and blurred vision during WBV may affect the accuracy of judging visual verticality. Recent work from our laboratory showed that static SVV values in the 5th bout of WBV were significantly higher (p=0.02) than the baseline (without vibration) in younger subjects who stood on a vibrating platform with concurrent RDT assessment (static background only). This supports the suggestion that the RDT should not be measured during WBV because of vision being blurred.

In conclusion, the only effect of WBV in these two age groups was a decrease in visual dependence for 20 min which occurred only during dynamic RDT testing in the younger age group. This may be due to the increased afferent sensory stimulation, presumably proprioceptive and/or vestibular inputs which are provided by WBV, or the adaptation to blurred vision and might result in sensory reweighting and reducing reliance on the visual system. However, the significant change was small and may be insufficient for a clinical or functional effect, but greater exposure could have a larger effect. No such compensation occurred in older people. They may have less reweighting ability between the sensory systems and this lack a comparable adjustment to reliance on different sensory systems than younger people in response to an external influence.

There is a relationship between visual dependence and the visual contribution to postural control (Luyat et al., 1997) and it is known that WBV can affect balance. Therefore, the aim of Chapter 5 was to investigate the immediate effect of WBV on postural control in healthy younger and older subjects.

CHAPTER FIVE EFFECT OF WHOLE BODY VIBRATION ON POSTURAL CONTROL IN HEALTHY YOUNGER AND OLDER SUBJECTS

5.1 Introduction

WBV training has been reported to have improved strength, flexibility, muscle power, movement speed and balance (Merriman and Jackson, 2009), especially in older people (Rittweger, 2010). However, there are relatively few studies investigating the acute effects of WBV on balance although it is an essential part of every day activities. The majority of acute studies (repeated bouts in a single session) focus on muscle strength and power (Cochrane and Stannard, 2005, Bosco et al., 1999, Bedient et al., 2009) but the sensory stimulation may also have a profound influence upon spatial orientation and postural control. As previously described in Chapter 4, local vibration can impair proprioceptive (Ishihara et al., 2004, Wierzbicka et al., 1998) and vestibular systems (Hamann and Schuster, 1999, Magnusson et al., 2006, Karlberg et al., 2002), which both provide important information for the maintenance of balance (Roll and Roll, 1988, Maurer et al., 2000). It is possible that WBV may have negative side effects such as a temporary reduction in postural control and thereby represent a risk of falling during or shortly after WBV.

The effects of vibration of a single muscle or tendon have been widely studied. Provocation of illusionary movement results in a compensatory postural response with a body tilt in the direction of the vibrated muscles (Roll et al., 1989) i.e. vibration of the Achilles tendon induces body backward tilt whereas forward tilt is provoked by vibrating the tendon of the tibias anterior muscle (Gomez et al., 2009).

This response is not a local one limited to a single joint, but a complex whole body postural synergy (Talis and Solopova, 2000). Kinematic and electromyographic data showed that bilateral Achilles tendon vibration induced increased postural sway, a backward displacement of the centre of gravity, trunk extension, flexion of the hips and knees, as well as changes in the muscle activity at the ankle and knee joints and in back muscles when subjects stood with eyes open (Patel et al., 2009, Thompson et al., 2011, Thompson et al., 2007, Gomez et al., 2009). Postural sway in response to vibration became larger when the eyes were closed (Patel et al., 2009, Gomez et al., 2009, Bove et al., 2009, Nakagawa et al., 1993) or when subjects viewed a moving image (Adamcova and Hlavacka, 2007). Balance was more affected by vibration when standing on one leg than two, especially when the eyes were closed (Hazime et al., 2012).

Older people demonstrated more rapid responses which have a higher frequency and more complex motion pattern of postural sway to Achilles tendon vibration (Fransson et al., 2004), and this was even more profound in older people with impaired vibration sensation (Kristinsdottir et al., 2001). The effects on balance persist for some time after the vibration is discontinued. For instance, 30s of bilateral Achilles tendon vibration increased body sway for >20 s (Thompson et al., 2007) whereas postural sway evoked by 30 s bilateral vibration of the ankle or cervical area did not return to baseline values until 19 min after cessation of vibration (Wierzbicka et al., 1998).

Local vibration affects balance (Nakagawa et al., 1993) and so may WBV, however, the immediate effects of WBV on balance are inconsistent in the literature. Some studies found no significant changes in postural sway in two legged standing after a single WBV session in either older women (Carlucci et al., 2010) or younger adults (Torvinen et al., 2002b) while other studies reported less postural sway in both one (Schlee et al., 2012) and two legged (Torvinen et al., 2002a) stance in young adults. WBV may cause an improvement in balance when it is moderately challenged such as in one legged stance (Schlee et al., 2012), but excessively difficult balance tasks i.e. standing on a movable surface with eyes closed, resulted in worsened balance immediately after vibration (Dickin et al., 2012).

Dynamic balance assessed by a tandem walk test and a shuttle run test did not change after vibration (Torvinen et al., 2002b, Torvinen et al., 2002a). An advantage of functional performance tests is their practicality for assessment in a variety of settings because of their low cost, lack of complex equipment and time efficiency. However, the tasks include many components i.e. running, turning, and squatting in a shuttle run test, so a slight change among the individual components may be masked by an overall performance scoring system. Laboratory measures, such as force plate data, can provide more detailed kinematic information and accurate measurements of postural sway.

It is difficult to draw a conclusion about the effect of WBV on balance from previous studies because of a limited number of studies which had different protocols i.e. frequencies of 10 – 60 Hz and peak to peak amplitude <1 – 10 mm, type of platform (rotational or vertical), balance tasks, outcome measures and populations (with respect to age and clinical history).

The majority of studies using local vibration indicate a negative effect on balance, especially in older people and during more challenging sensory situations. However, the effect of WBV on static and dynamic balance is unclear, particularly in more challenging sensory situations i.e. one leg standing and when vision is removed or distorted.

The study reported in Chapter 4 found that a single bout of WBV can affect visual dependence and therefore it may also affect postural control. Thus the aim of this study was to investigate the acute effect of WBV on postural control (sway) in healthy younger and older subjects. This was assessed during balance tasks with varying levels of visual complexity.

5.2 Methods

5.2.1 Subjects

Twelve healthy young (mean age 26 ± 1 (23 – 35) yrs; 6 male; height 170 ± 2 (161 – 178) cm; body mass 66 ± 3 (54 – 84) kg) and 12 healthy older (aged 68 ± 2 (60-79) yrs; 5 male; height 169 ± 3 (152 – 182) cm; mass 73 ± 5 (43 – 98) kg) subjects were recruited from the university and neighbouring community centres. They did not have any known neurological disorders, uncorrected visual impairments or a history of epilepsy, migraine or fainting. As WBV was used, subjects were excluded if they had any joint replacements, recent injuries to bones, joints or muscles. All subjects gave their informed consent to agree to participate in the study, which was approved by the local ethics committee (Appendix 1).

5.2.2 Protocol

Five one *min* bouts of WBV (5 mm peak-to-peak amplitude and frequency of 20 Hz) with 30 s rest between bouts were performed on a rotating vibrating platform (Galileo 2000, Novotec Medical GmBH, Germany). The WBV protocol is described in Chapter 4 (page 86).

It was not considered necessary to involve a control group in this study as force plate measurements have shown good reproducibility for measurements of postural sway by a number of groups in healthy adults aged 20-83 years. Thyssen et al., (1982) reported no significant differences in balance with eyes open and closed in one and two legged standing, measured both twice in one day and also over 5 consequtive days. Takala et al., (1997) also found no significant differences in two legged standing balance with eyes open and closed on two separate days. Du Pasquier et al., (2003) studied relaibility on three ocassions over a 6 month period and reported 79% reliability.

Static and dynamic balance was assessed by recording postural sway on a force plate and recorded by MatLab (R2010a, MathWorks Inc., USA) before (BASELINE), immediately (within 1 min) after WBV (T0) and 20 min later (T20).

Postural sway was assessed during static and dynamic balance conditions by calculating the trajectories of centre of pressure (COP), a representation of body motion in space detected at the interface of the feet ad the support surface, derived from a force plate (BP6001200, AMTI, Watertown, MA). Sampling frequency for static balance was 50 Hz and 200 Hz for dynamic balance.

Static balance

In two and one legged standing (2LS, 1LS) subjects were asked to stand barefoot on the force plate, 80 cm from the centre of the RDT screen (Chapter 2) at eye level, with their arms at their sides and to stand as still as possible. Subjects stood with their feet parallel, facing forward and shoulder width apart for 2LS while looking straight ahead (Fig. 5.1). The foot position was marked on the forceplate in order to ensure a constant foot placement throughout. Subjects chose their preferred leg for 1LS and used the same leg for all 1LS testings.

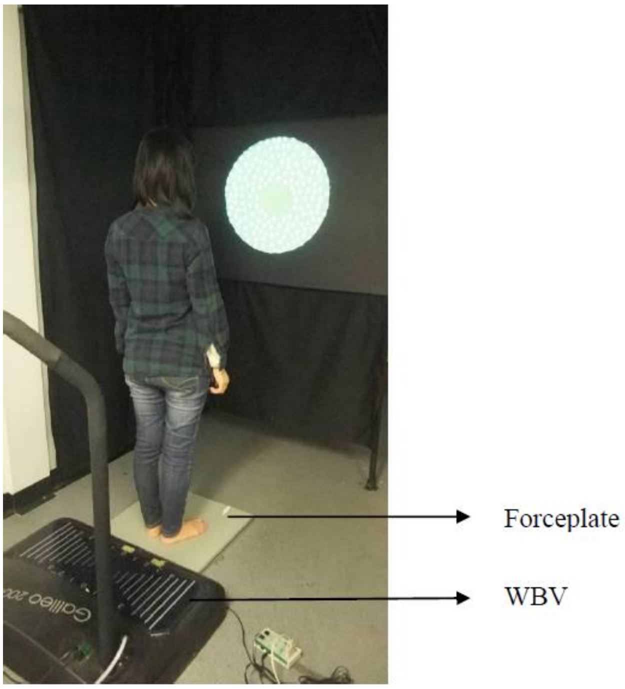


Fig. 5.1 Balance testing position. Standing barefoot on a forceplate 80 cm from the centre of the screen at eye level, with their arms at their sides.

Four visual conditions were used to test postural sway in both 1LS and 2LS. Each condition was repeated once: (1) Eyes open (EO): subjects stood looking at the static RDT screen; (2) Eyes closed (EC): subjects stood quietly with both eyes closed; (3) Visual disturbance – clockwise (CW): subjects stood while looking at the screen on which discs rotated at $30^{\circ}.s^{-1}$ in a CW direction; (4) Visual disturbance – counter-clockwise (CCW): the same as (3), but with discs rotating in a CCW direction. EO was carried out in a fully illuminated room while other conditions were in a darkened room. EO and EC were conducted in a counterbalanced order prior to CW and CCW, which were also conducted in a counterbalanced order. Subjects were required to close their eyes while standing on both legs for 5 s rest periods between visual conditions and trials.

Force plate data in 2LS in each condition was collected for 30 s and the middle 10 s was analysed in order to avoid postural adjustments at the beginning of the task. During 1LS the trial was stopped if the non-stance foot touched the ground and up to 3 further attempts were made as required until 5 s was achieved. Where possible postural sway in 1LS was recorded and analysed over 5 s but if subjects failed to stand on one leg for 5 s, then the first 2 s was analysed.

Measures of postural sway velocity ($m.s^{-1}$) under all conditions were calculated by dividing the total length of the trajectory of the COP (meters; m) by the recording period length (seconds; s). Sway velocity was defined as the average travel speed of the COP in the horizontal plane and reflects postural sway. Two quotients were computed from the sway velocity data: a) Romberg Quotient (RQ); the ratio of sway velocity in EC and EO which reflects influence of vision and b) Kinetic Quotient (KQ); the ratio of sway velocity with rotating (average of CW and CCW) and static disks, which reflects the influence of dynamic visual stimulation.

Dynamic balance

Subjects stepped onto the force plate leading with their preferred leg while looking at the RDT screen under three visual conditions: 1) stationary discs (EO); 2) discs rotating at $30°.s^{-1}$ in a CW direction and 3) discs rotating in a CCW direction. EO was presented first and the other two were in randomised order. Three trials for each visual condition were performed. COP was recorded from heel strike to toe off of the preferred leg i.e. a complete step. Medial-lateral (ML) deviation from 5 to 95 % of a step was analysed in all 3 conditions before, immediately after WBV and then at 20 min.

Mean ML deviation (m) was calculated as mean COP change in the lateral direction. From this KQ was calculated as described above. To examine any effect of direction of disk rotation the mean differences in ML deviation between both CW and CCW with EO was calculated at before, immediately and 20 min after WBV.

Static and dynamic testing was carried out in a randomised order. In rest periods the subjects were seated and the room lights were on. All the data were exported from Matlab to Excel for analysis.

5.2.3 Data analysis

SPSS v19.0 was used for all statistical analysis. All data are presented as mean ± standard error of mean (SEM). The Kolmogorov-Smirnov test was used to determine whether data were normally distributed. Significance was assumed at $p<0.05$.

<u>Static balance</u>

As no significant differences were noted in sway velocity between CW and CCW directions (Wilcoxon signed-rank test) in any of the standing positions, the pooled data were averaged to obtain mean rotation values (ROT). Postural sway velocity under all postural and visual conditions, as well as RQ and KQ in both age groups were ordered according to rank due to non-normal distribution and a two-way ANOVA with post hoc independent t-test was applied to determine the effect of groups (age), time, and interaction between groups and time on postural velocity in EO, EC, ROT as well as RQ and KQ.

Dynamic balance

There were no differences between CW and CCW disk rotation (Wilcoxon signed-rank test) in ML deviation and therefore the data was averaged to obtain a ROT value. ML deviation in EO was normally distributed but ROT and KQ were ordered according to rank due to non-normal distribution and then a two-way ANOVA with post hoc independent t-test determined the effect of groups (age), time and interaction between groups and time on ML deviation in EO, ROT, and KQ.

COP trajectory on ML direction during the dynamic balance task was illustrated by an XY plot in Excel. Time was represented as percentage of a complete step along the X axis. COP deviation towards right or left from central point was indicated as a positive or negative value in Y-axis. To measure whether the direction of rotating discs affect on direction of ML deviation in both age groups with and without WBV, a 3-way ANOVA (direction x group x WBV) with post hoc multiple comparisons test was used.

To examine whether there was similar variance between the two age groups in a particular condition, the F-Test Two-Sample for Variance was performed.

5.3 Results

5.3.1 Static balance

One subject in each age group chose their left leg for 1LS. All healthy younger (n=12) and 7 out of 12 older subjects were able to achieve 1LS for 5 s. However, 5 older subjects were unable to do so, but were able to achieve at least 2 s. Two of them could not stand for 5 s before vibration but could after; another 2 had an opposite response; another could not maintain 1LS for 5 s either before or after vibration. Therefore, 1LS with 5 s for all younger and 7 older subjects and 1LS with 2 s for all younger and older subjects were analysed.

There were no significant differences in sway velocity after vibration with 2LS, 1LS for 2 and 5 s under all visual conditions (Table 5.1). However, older subjects had a greater sway velocity with all conditions at all times ($p< 0.001$ – 0.04). Variance was similar between age groups in all conditions ($p=0.08$ – 0.51).

The RQ and KQ did not change after vibration and was similar in both age groups in 2LS (Fig. 5.2), 1LS (5s) (Fig. 5.3) and 1LS (2s) as shown in Table 5.2 and Fig. 5.4. Variance was similar between age groups in all conditions ($p=0.08$ – 0.51).

		EO			EC			ROT		
		BASELINE	T0	T20	BASELINE	T0	T20	BASELINE	T0	T20
2LS	YOUNGER	0.01 (0.00)	0.02 (0.00)	0.01 (0.00)	0.02 (0.00)	0.02 (0.00)	0.02 (0.00)	0.02 (0.00)	0.02 (0.00)	0.02 (0.00)
	OLDER	0.03* (0.01)	0.03* (0.01)	0.03* (0.01)	0.04* (0.01)	0.04* (0.01)	0.04* (0.01)	0.03* (0.01)	0.03* (0.01)	0.04* (0.01)
1LS (5s)	YOUNGER	0.07 (0.01)	0.07 (0.01)	0.07 (0.01)	0.12 (0.02)	0.13 (0.02)	0.11 (0.01)	0.09 (0.01)	0.10 (0.02)	0.10 (0.02)
	OLDER	0.17* (0.03)	0.19* (0.05)	0.20* (0.05)	0.28* (0.06)	0.33* (0.08)	0.31* (0.08)	0.31* (0.08)	0.28* (0.06)	0.26* (0.06)
1LS (2s)	YOUNGER	0.09 (0.01)	0.09 (0.02)	0.09 (0.01)	0.13 (0.02)	0.13 (0.02)	0.12 (0.02)	0.11 (0.01)	0.10 (0.01)	0.10 (0.02)
	OLDER	0.25* (0.05)	0.27* (0.05)	0.27* (0.05)	0.38* (0.08)	0.35* (0.07)	0.29* (0.05)	0.40* (0.09)	0.34* (0.07)	0.36* (0.08)

Table 5.1 Postural sway velocity ($m.s^{-1}$) in EO, EC and ROT (mean (sem)). There were no significant differences in sway velocity during one and two legged stance under all visual conditions after vibration in both age groups. Older people had greater postural sway velocity with 2LS, 1LS (5s) and 2LS (2s) than younger people at BASELINE, T0, and T20. * denotes a significantly greater sway in older than younger group at $p<0.05$.

		RQ			KQ		
		BASELINE	T0	T20	BASELINE	T0	T20
2LS	YOUNGER	1.09	1.05	1.06	1.09	1.04	1.06
		(0.04)	(0.06)	(0.06)	(0.10)	(0.05)	(0.06)
	OLDER	1.33	1.16	1.12	1.11	1.00	1.13
		(0.14)	(0.06)	(0.10)	(0.06)	(0.03)	(0.09)
1LS (5s)	YOUNGER	2.06	1.87	1.73	1.70	1.35	1.41
		(0.39)	(0.16)	(0.12)	(0.39)	(0.10)	(0.11)
	OLDER	1.57	1.77	1.55	1.69	1.51	1.40
		(0.22)	(0.17)	(0.18)	(0.25)	(0.14)	(0.11)
1LS (2s)	YOUNGER	1.82	1.54	1.43	1.55	1.15	1.20
		(0.48)	(0.12)	(0.11)	(0.41)	(0.08)	(0.07)
	OLDER	1.44	1.28	1.16	1.54	1.21	1.34
		(0.14)	(0.12)	(0.08)	(0.15)	(0.06)	(0.11)

Table 5.2 RQ and KQ with 2LS, 1LS (5s) and 1LS (2s) (mean (sem)). No significant differences in either value were found after vibration or between age groups in 2LS, 1LS (5s) and 1LS (2s). Romberg Quotient (RQ); the ratio of sway velocity in EC and EO. Kinetic Quotient (KQ); the ratio of sway velocity with rotating and static disks.

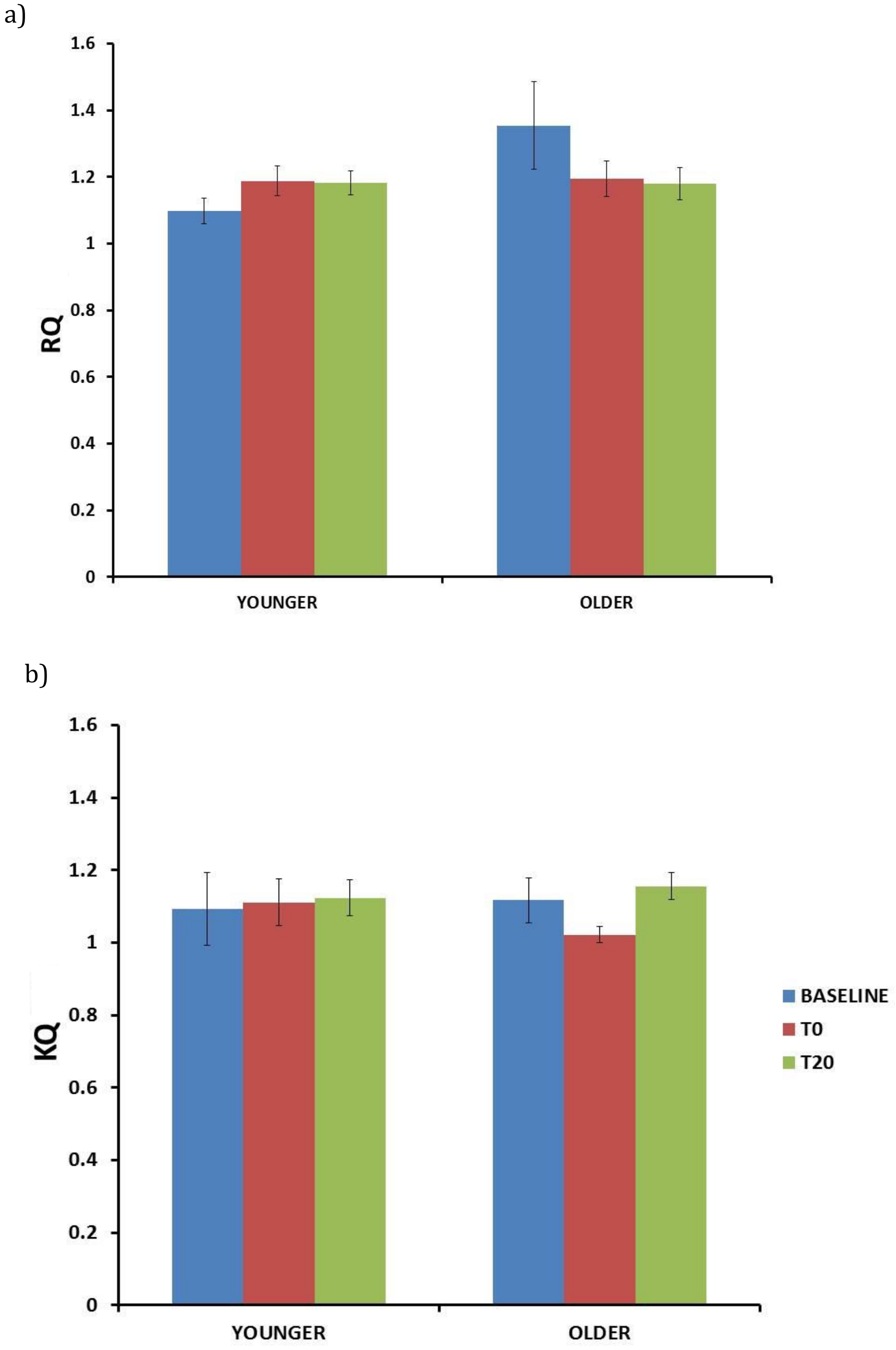


Fig. 5.2 (Mean ± sem) a) RQ and b) KQ with 2LS. Both values in 2LS did not change after vibration and between age groups. Romberg Quotient (RQ); the ratio of sway velocity in EC and EO. Kinetic Quotient (KQ); the ratio of sway velocity with rotating and static disks.

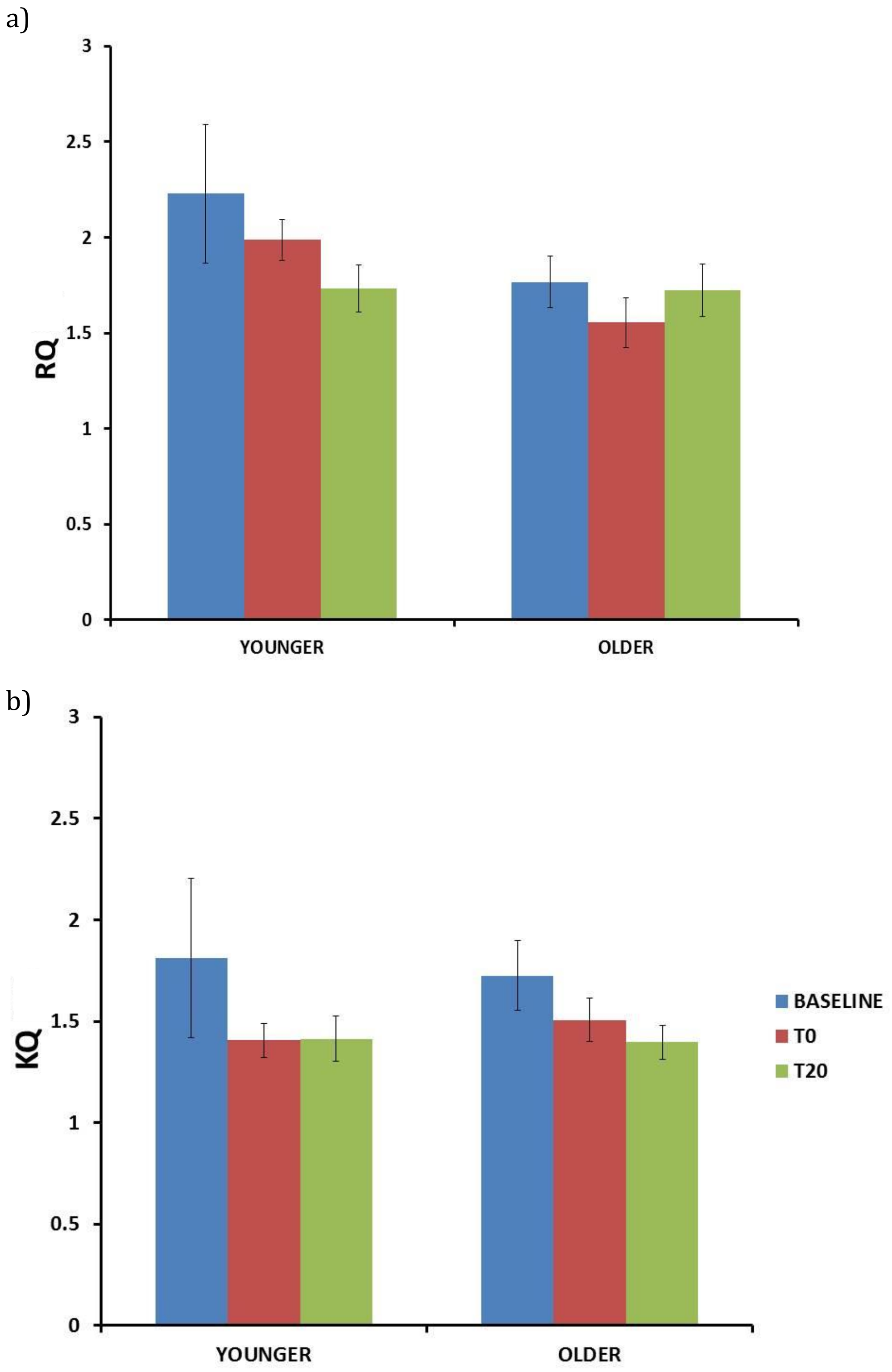


Fig. 5.3 (Mean ± sem) a) RQ and b) KQ with 1LS (5s). There were no significant differences in either value for 1LS (5s) after vibration or between age groups. Romberg Quotient (RQ); the ratio of sway velocity in EC and EO. Kinetic Quotient (KQ); the ratio of sway velocity with rotating and static disks.

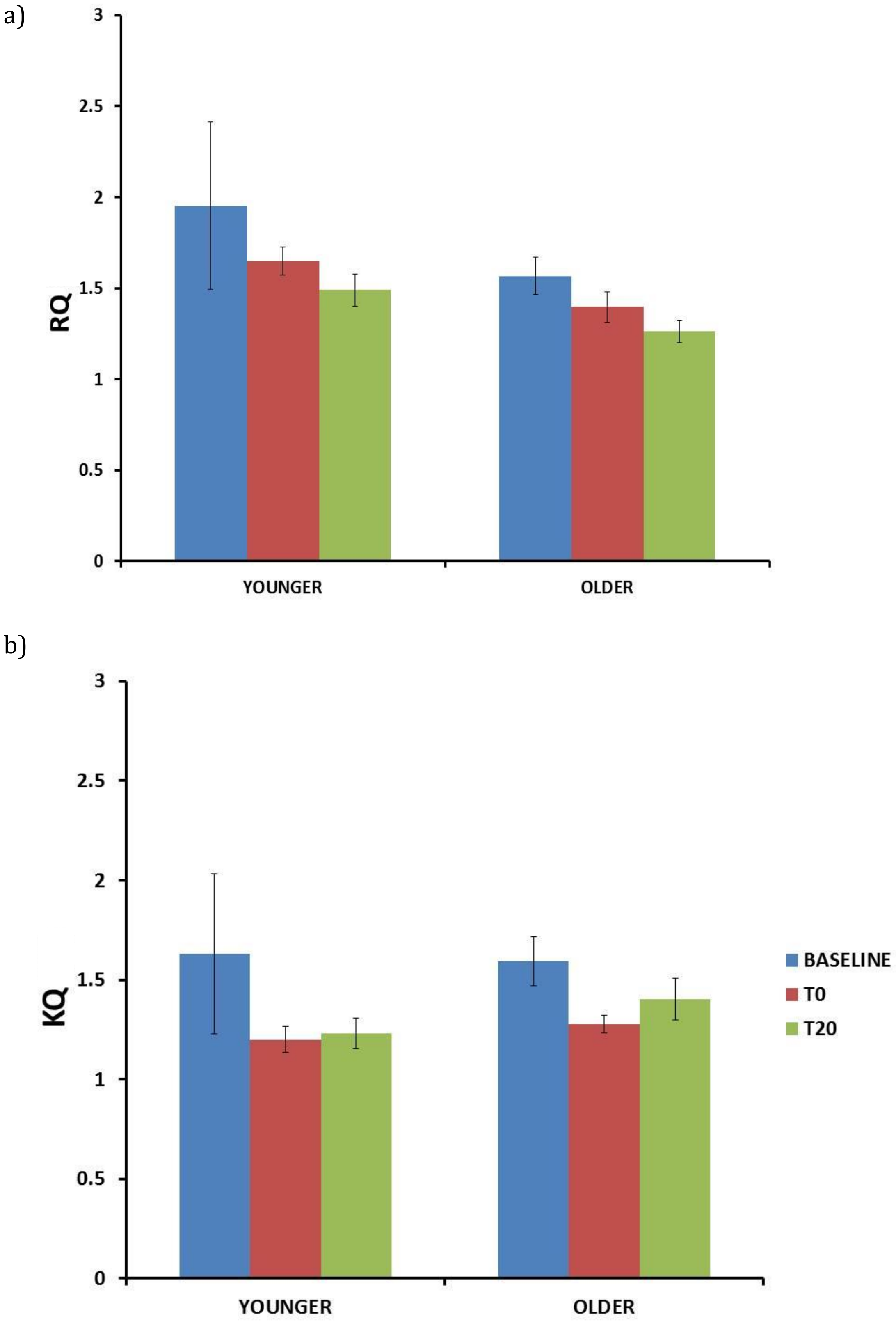


Fig. 5.4 (Mean ± sem) a) RQ and b) KQ with 1LS (2s). No significant differences in either value for 1LS (2s) were found after vibration or between age groups. Romberg Quotient (RQ); the ratio of sway

5.3.2 Dynamic balance

One subject in each age group used their left leg to step on to the force plate. There were no significant differences in ML deviation after vibration for EO and ROT in either group (Table 5.3). However, older subjects had greater sway in all conditions (p=0.02 - 0.04). Variance was similar between age groups at each of the conditions (p=0.07 – 0.50).

	EO			ROT		
	BASELINE	T0	T20	BASELINE	T0	T20
YOUNGER	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
OLDER	0.02* (0.01)	0.02* (0.00)	0.02* (0.00)	0.02* (0.01)	0.02* (0.01)	0.02* (0.01)

Table 5.3 ML postural deviation (m) in EO and ROT (mean (sem)). ML postural deviation was not different after vibration for EO and ROT but was significantly greater in older than younger subjects with EO and ROT. * denotes a significantly greater sway in older than younger group at p<0.05.

KQ did not change after vibration and was similar in both groups (Table 5.4 and Fig. 5.5). Variance was similar between age groups at each of time points (p=0.50).

The direction of postural sway followed that of the disk rotation (F(1,11)=26.12, p<0.001) in all subjects before and after vibration (p=0.003 - 0.02) (Fig. 5.6).

	BASELINE	T0	T20
YOUNGER	1.03	1.12	1.05
	(0.11)	(0.06)	(0.07)
OLDER	1.17	1.23	1.25
	(0.22)	(0.17)	(0.23)

Table 5.4 KQ (%) at BASELINE, T0, and T20 (mean (sem)). No significant differences in KQ between groups and after vibration. Kinetic Quotient (KQ); the ratio of sway velocity with rotating and static disks.

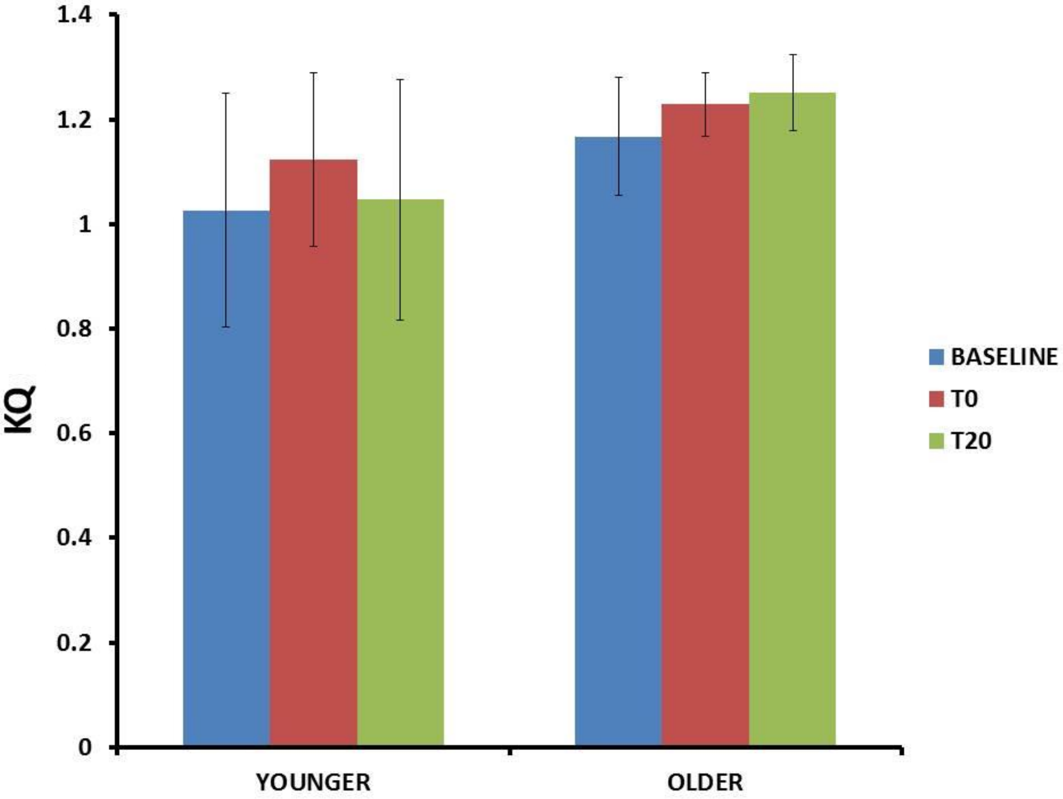


Fig. 5.5 (Mean ± sem) KQ at BASELINE, T0, and T20 in younger and older groups. There were no significant differences in KQ after vibration or between age groups.

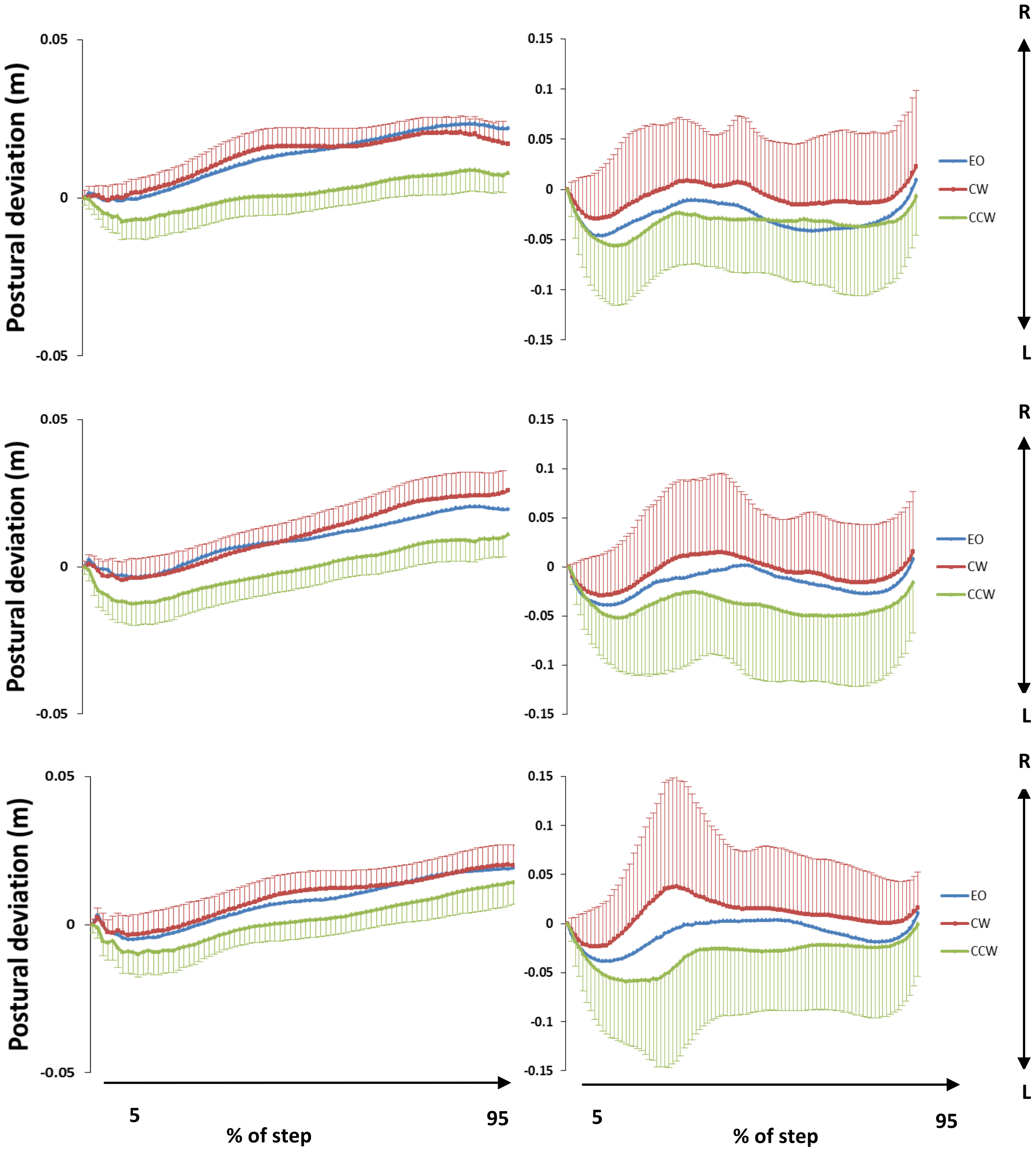


Fig. 5.6 (Mean ± sem) Medial-lateral deviation with EO (blue), CW (red) and CCW (green) in younger (left) and older (right) groups at BASELINE (upper), T0 (middle) and T20 (lower). A positive or negative value in Y-axis indicates postural deviation towards right or left respectively from centre (zero) of forceplate. There was an effect of direction of rotated image on direction of ML postural deviation at BASELINE, T0 and T20 in both age groups.

5.4 Discussion

The aim of this study was to investigate both static and dynamic balance before and for 20 min after WBV in younger and older healthy subjects. There were no significant differences in either static or dynamic balance after vibration in any visual conditions in either age group. Older subjects had greater sway velocity in both static and dynamic balance under all visual conditions throughout the study, but the RQ and KQ did not change after vibration and was similar in both age groups.

The present study covered different aspects of balance, involving dynamic components from two to one legged standing with intact, removed or distorted vision. However, none of sensory conditions significantly changed after WBV although there was a trend for postural sway to decrease after vibration in both age groups and this was more profound in 1LS. The current study partly supports the findings of previous studies in which unchallenging balance tasks, such as 2LS, WBV has little or no effect (Carlucci et al., 2010, Dickin et al., 2012), but it may have a greater effect when balance is more challenged, such as in 1LS (Schlee et al., 2012). This could also explain why acute WBV has been found to reduce postural sway in people with balance problems e.g. after stroke (van Nes et al., 2004), Parkinson's disease (Turbanski et al., 2005), and multiple sclerosis (Schuhfried et al., 2005).

Both RQ and KQ were >1 in both age groups, indicating that postural stability was affected by a lack of vision and also a rotating image. However, both values were unchanged after vibration although there was a trend of a decrease in both groups during 1LS, which suggested a decreased level of visual dependence on postural control. These results may support the findings that WBV may decrease visual dependence for orientation as reported previously (Chapter 4). There is a relationship between the level of perceptive visual dependence and the visual contribution to postural control (Luyat et al., 1997). The acute effect of WBV could possibly be to decrease the level of visual dependence on spatial orientation as well as postural control. If that is the case, WBV could be an intervention for the modulation of visual dependence.

Individual variation could possibly be the reason for the non-significant change in static balance after WBV. Each individual may be sensitive to a particular vibration frequency (Di Giminiani et al., 2009) and they may also have different balance abilities, both of which may cause varied responses of balance to WBV. This could be supported by the current study in that two older subjects were unable to stand for 5 s on one leg before WBV but were able to after i.e. improved balance after vibration, while another two had the opposite response (diminished balance after vibration).

Local vibration can impair balance but WBV may not. This may be related to the frequency of vibration. Local vibration is commonly applied at high frequencies (30 – 100 Hz) and 100 Hz had a greater effect than 30 and 40 Hz (Kasai et al., 1992). The lower frequencies of WBV ($\leq$30 Hz) may therefore not have the same effect on balance. It is also unlikely to be related to the mode of WBV application. There are a limited number of studies, although they have consistent findings, that neither amplitude (2 — 8 mm peak to peak) or frequency (10 – 30 Hz) have an effect on balance (Dickin et al., 2012, Pollock et al., 2011).

Although no effect of WBV was observed on static balance in either group, there was a trend for postural sway to decrease after vibration. The possibility of WBV improving balance stemmed from the idea that the majority of acute studies i.e. a single session, found that it increased muscle strength (Cochrane and Stannard, 2005, Bosco et al., 1999, Bedient et al., 2009) and this is highly related to balance performance (Wolfson et al., 1995). WBV in those studies was performed in different positions e.g. squatting, or with additional exercise in athletic populations, so the immediate effect on balance may not be seen in the current study in which subjects quietly stood on a platform. Another possibility is that increased balance ability was the result of the repeated exposure to WBV leading to an adaptive adjustment of postural control (Fransson et al., 2004, Gomez et al., 2009, Patel et al., 2009). An adaptive process that gradually decreases vibration induced postural sway occurred during the first 30 – 40 s of local vibration in a study by Fransson et al. (2004). This develops over time and by gained experience from repeated exposures to the balance disturbances. The current study provided 5 one min bouts of WBV which could possibly cause postural adaptation resulting in the improved balance. However, tendon vibration with higher frequencies was used in those studies and therefore the effect after WBV was not observed.

Improvement in balance after WBV may be related to the tonic vibration reflex (TVR) (Seidel, 1988; Pollock et al., 2012). The mechanical vibration that activates the sensory receptors of the skin, tendon and muscle spindles elicits an excitatory effect upon α-motoneurons causing a temporary increase in the recruitment of motor units. This could increase muscle strength and thereby may improve balance performance (Wolfson et al., 1995).

Improved balance may also be due to a learning effect induced by the requirement to maintain a stable position on the vibrating platform (Rees et al., 2009, Schuhfried et al., 2005). The practice of a movement can affect motor control and coordination (Connelly et al., 2000) and therefore the effort required to control movement on the platform may improve subsequent balance.

Tendon vibration is interpreted by the CNS as an elongation of that muscle and a illusionary movement is evoked (Roll et al., 1989), which impairs not only position sense at the sensory level but also alters the internal representation of verticality resulting in postural deviation from upright (Ceyte et al., 2007, Barbieri et al., 2008). However, WBV is transmitted throughout the body and affects both agonist and antagonist muscles and therefore the illusionary movement is unlikely (Merriman and Jackson, 2009).

This study indicated that the response to WBV may be not affected by age. However, previous studies reported that older people had greater postural responses to tendon vibration (Abrahamova et al., 2009, Fransson et al., 2004, Kristinsdottir et al., 2001), and a greater decrease in postural sway when vibration was applied to the feet (Priplata et al., 2003). Greater improvements in balance after chronic WBV have been reported in older people (Bautmans et al., 2005, Cheung et al., 2007, Rees et al., 2009). These findings have led to speculation that older people may be more sensitive to vibration in the longer term but there was no indication of this in the current study. Only older people with impaired vibration sensation were reported to have increased high-frequency sway while younger and older people with intact sensation had similar postural control during vibration (Kristinsdottir et al., 2001), suggesting that age *per se* may have little effect on vibration sensitivity. The older subjects in the present study were all healthy with high physical and cognitive functioning and had no relevant medical history. This may be the reason for lack of an age effect in responses to WBV on balance.

In dynamic balance testing postural deviation tended to follow the direction of the disc rotation in both age groups and was not affected by WBV. Step variability during walking has been found to be increased by visual disturbance (O'Connor and Kuo, 2009), in agreement with the present study. Visual information influences both stance and walking and possibly has an even stronger effect during walking (Logan et al., 2010). Vision plays a role in navigation (Warren et al., 2001) and thereby visual disturbance could affect walking patterns e.g. speed (Konczak, 1994) or stride length (Prokop et al., 1997). In the current study, KQ was >1 in both age groups, indicating that ML sway during walking was affected by a rotating image, and a deviation of walking path tended to follow the direction of the disc rotation revealed the role of vision on navigation. It has also been reported that the effect of visual disturbance on postural sway could be enhanced by tendon vibration

(Adamcova and Hlavacka, 2007) and the present study showed a non-significant trend for the deviation in both dynamic conditions to become larger after WBV in older people so WBV may have similar effect to tendon vibration in that respect.

There were no acute effects of WBV on dynamic balance in either age group, in line with previous studies. Torvinen et al. (2002a, b) reported no improvements in dynamic balance after WBV in healthy young people in functional performance tests e.g. tandem walk and shuttle run tests. Dynamic balance, controlling the position of the COP over the base of support, is critical to the successful performance of various functional tasks associated with activities of daily living (Topp et al., 1998). This study found that the ML direction of postural deviation under EO or ROT was not affected by WBV in either age group. Similarly KQ did not change after vibration in either group suggesting the level of visual contribution to dynamic balance was not affected by WBV. A review article reported that chronic WBV has a beneficial effect on dynamic balance (Rogan et al., 2011), so it is possible that a single acute bout would be insufficient.

Older people have been widely reported to have greater visual dependence for postural control (Sundermier et al., 1996, Borger et al., 1999). However, similar RQ and KQ values were found between age groups in the current study, suggesting the sway of the older people was not affected by visual disturbance to a greater degree than that of the younger people. However, all healthy younger subjects were able to maintain one legged standing balance over 5 s in all conditions whilst 5 of the 12 older subjects were not. The older people included for analysis had relatively better balance abilities. The findings of no effect of age on visual dependence for postural control may be overestimated.

It has been noted that the sensory motor systems have mainly been tested during local tendon vibration but not after WBV. Balance is commonly assessed by a forceplate and it would be very difficult to perform WBV on a force plate and also to analyse such data.

The use of WBV with older and clinical populations is growing and therefore safety is important. None of younger or older subjects lost their balance during or after 5 one min bouts of WBV in the current study, which is a well tolerated intervention by healthy people. The result is in line with a review by Rittweger (2010) that there have been no reports of falls in either healthy subjects of all ages or by patient groups.

In conclusion, neither static (one and two legged stance) or dynamic balance was significantly affected after WBV under all visual conditions in either age group, although there was a trend for improved static balance after vibration in both age groups and particularly in one legged stance. Postural sway of the older people was not changed by visual deprivation or disturbance more than that of the younger people. This study partly supports the findings reported in Chapter 4 and suggests that the immediate effect of WBV could possibly cause positive effects that decrease the level of visual dependence on both spatial orientation and postural control in both younger and older adults.

CHAPTER SIX EFFECT OF AUDITORY DISTRACTION ON VISUAL DEPENDENCE FOR SPATIAL ORIENTATION AND POSTURAL CONTROL IN HEALTHY YOUNGER AND OLDER SUBJECTS

6.1 Introduction

People use bilateral hearing for three dimensional spatial orientation, location and navigation (Nelson et al., 1998, Dozza et al., 2005). Sound can also be used as artificial auditory feedback to correct body sway (Easton et al., 1998), however auditory processing is slow compared with that in the visual, proprioceptive, and vestibular systems (Naatanen and Winkler, 1999). When visual and/or proprioceptive information is lost, the use of auditory information can assist in maintaining balance, as occurs in blind people (Ray et al., 2008). However, sound can be a noise which is loud, unpleasant, and an auditory disturbance. When exposed to a noisy background e.g. drilling sound from road construction, people have more body sway (Era and Heikkinen, 1985).

The direction of induced postural sway depends on the relative direction of the stationary and moving auditory stimulus. Lateral sway is significantly greater than anterior posterior when a pair of speakers are placed on the right and left sides of a subject when played simultaneously (stationary auditory stimulus) and when a sound is played from the right to left or *vice versa* (moving auditory stimulus) (Easton et al., 1998, Raper and Soames, 1991, Soames and Raper, 1992). A rotating sound can also induce an illusionary experience of self-rotation like a rotating visual field, but the effect is diminished if a stable visual environment is present (Lackner, 1977). Interestingly, the louder the sound the greater is the destabilising effect on posture (Pyykko et al., 1982). ‘Real’ background noise e.g. conversation or traffic, provokes postural instability more than white noise (Raper and Soames, 1991). Postural sway responses are greater when the eyes are closed (Soames and Raper, 1992, Tanaka et al., 2001) and in some older people (Pyykko et al., 1982, Tanaka et al., 2001, Raper and Soames, 1991, Soames and Raper, 1992, Easton et al., 1998).

Deleterious effects of noise on balance may be due to division of attention from a single pool of attentional resources (Kahneman, 1973). If two tasks are performed simultaneously and share the same attentional resources, then performance deteriorates (Wickens, 1989). Despite being in the main automatic, it has been suggested that there are significant attentional requirements for postural control (Teasdale et al., 1993, Lajoie et al., 1993, 1996, Shumway-Cook and Woollacott, 2000).

Kerr and colleagues’ study (1985) was the first to show the attentional demands of postural control during standing in younger adults. They reported increased error in a spatial memory task (consisting of placing numbers in imagined matrices and remembering their position of the numbers) when performing the concurrent tandem Romberg balance task (Kerr et al., 1985). Lajoie et al. (1993) observed that the amount of attention progressively increased (indicated by slower auditory reaction time) when being in sitting, two legged stance with the shoulder width apart, with feet together, to walking in young people. Furthermore, the attentional demand was greater in the single than the double support phase of the gait cycle (Lajoie et al., 1993). Attentional demand was also greater when sensory inputs were disturbed e.g. no vision, impaired proprioception or a combination of both (Lajoie et al., 1996).

Typically, older people require more attention to maintain balance during dual tasking (Teasdale et al., 1993, Lajoie et al., 1996, Shumway-Cook and Woollacott, 2000). Their auditory reaction time was delayed to a greater extent than in young adults by the deprivation of vision during quiet standing, suggesting that greater attentional resources are required (Teasdale et al., 1993). Where both visual and proprioceptive were disturbed by an optokinetic stimulator and a moving platform, an auditory reaction task had a greater negative effect on postural sway in older people (Shumway-Cook and Woollacott, 2000). This might be because disturbed sensory information makes postural task more difficult for older adults and therefore they need more attentional demand to maintain balance.

Interestingly, balance-impaired older people i.e. older fallers, required more attention on balance than healthy older people without a history of falling, even under relatively simple conditions such as two legged stance with eyes open on flat surface (Shumway-Cook and Woollacott, 2000). Therefore some falls may be not due to balance deficits, but related to difficulty in effectively allocating attention to balance in multi-task situations. Greater attentional demands for postural control have also been reported in individuals with Parkinson's disease (Brown and Marsden, 1991, Camicioli et al., 1998) and vestibular dysfunction (Andersson et al., 2003, Redfern et al., 2004, Yardley et al., 2001). It is interesting that both groups have been shown to have the higher levels of visual dependence for orientation and balance (Bronstein et al. 1996, Guerraz et al. 2001). However, it is unknown whether any relationship exists between attentional resources and visual dependence.

Divided attention may also influence perception of orientation. Yardley et al. (2002) found that both healthy adults and vestibular patients produced greater errors in detecting subjective visual vertical with concurrent arithmetic cognitive tasks, suggesting that monitoring spatial orientation requires a degree of mental effort or attention. Postural instability is increased more when performing concurrent cognitive tasks involving a spatial component than non-spatial component e.g. verbal memory task (Kerr et al., 1985; Lajoie et al., 1996). This suggests that those tasks require a stable spatial framework and thus have an effect on postural control and possibly spatial orientation (Hanes and McCollum, 2006).

The majority of studies have investigated the attentional requirements for postural control by examining the extent of changes in secondary tasks (Kerr et al., 1985, Lajoie et al., 1993, 1996). However, the effect of performing an attentionally demanding task on postural control has received relatively little attention. Decrements in postural stability are greater than those in cognitive measures when performed simultaneously and more prominent in older people (Shumway-Cook et al., 1997). The postural task is usually considered as the primary one and an additional activity is the secondary task to deflect attention from postural control (Kerr et al., 1985).

There are a number of ways of performing a secondary task e.g. pressing a button (motor task, O'Shea et al., 2002), visual memory tasks (visual task, Kerr et al., 1985) and answering questions (verbal task, Yardley et al., 2002). However, motor responses could slightly perturb postural stability or induce anticipatory postural adjustments (Teasdale et al., 1993, Marsh and Geel, 2000, Redfern et al., 2001). The ocular demands of visual fixation could also increase postural stability (Maylor et al., 2001, Stoffregen et al., 1999). Counting aloud significantly increases postural sway but silent counting does not, presumably due to the effects of articulation rather than mental activity *per se* (Yardley et al., 1999).

Some secondary tasks e.g. visual memory (Kerr et al., 1985) or arithmetic (Yardley et al., 2002), are not closely related to everyday tasks known to increase falls risk. Streets are a very common site of falls in older people (Ghodsi, 2003) and they can be caused by multiple factors e.g. pavement cracks, steps, construction work, uneven ground and slippery surfaces (Campbell et al., 1990). One of the factors may be exposure to a noisy background such as traffic or and intermittent sudden auditory distraction e.g. car horn, both of which can induce instability. In addition, being in busy visual environment (vehicles and pedestrians passing by) has also been reported to result in spatial disorientation and imbalance.

Therefore, divided attention may have a negative effect on orientation (Yardley et al., 1998, 1999, 2002) and balance, especially when vision is deprived or disturbed (Teasdale et al., 1993, Lajoie et al., 1996, Tanaka et al., 2001, Shumway-Cook and Woollacott, 2000). There seems to be a greater effect in the older population who also have been reported to have higher visual dependence (Kobayashi et al., 2002, Slaboda et al., 2009, Bronstein, 1995). Therefore, it is plausible that divided attention may increase visual dependence. The aim of this study was to investigate the effect of auditory distraction on visual dependence for spatial orientation and postural control in both younger and older people.

6.2 Methods

6.2.1 Subjects

Fifteen healthy young (aged 30 ± 1 (mean ± sem), range 22 – 39 yrs, 11 male; height 170 ± 2 (159 – 182) cm; body mass 64 ± 3 (49 – 82) kg)) and 15 healthy older (aged 70 ± 2 (61 – 83) yrs; 6 male; height 165 ± 2 (147 – 178) cm; mass 72 ± 5 (38 – 119) kg) drawn from university staff or residents from neighbouring community centres gave written informed consent (Appendix 1) to participate in the study, which was approved by the local ethics committee. Inclusion criteria were aged 18 - 40 yrs for younger subjects and >60 yrs for the older ones. The exclusion criteria were any known neurological disorders, a history of peripheral or central vestibular disorders, peripheral somatosensory loss, uncorrected visual impairments and a medical history of epilepsy or migraine or fainting. In addition, because of the balance test, subjects were excluded if they had a recent injury to bone, joint or muscle.

6.2.2 Protocol

Visual dependence was assessed by the RDT (Chapter 2.2.2, page 44) and postural control including static (single and double legged stance; 1LS and 2LS) and dynamic balance measured by a force plate (Chapter 5.2.2, page 108) were conducted with and without auditory distraction (SOUND and NO SOUND respectively). Distraction and condition order were counterbalanced (Fig. 6.1).

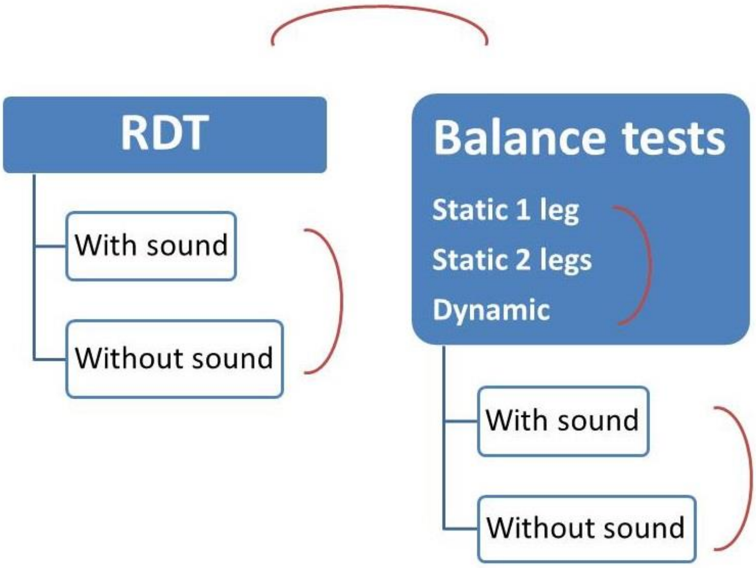


Fig. 6.1 The Rod and Disk (RDT) and balance test were conducted with and without sound in counterbalanced order. ⌒ denotes counterbalanced order.

During a 15 min rest period between visual dependence and balance testing, subjects sat quietly and relaxed with the projected image turned off and the room lights on.

Auditory distraction was provided via stereo speakers (MS16, Behringer, Germany) which played a background of constant traffic noise with intermittent sudden sounds such as car horns, sirens and shouting. The speakers were delivered at 70 - 80 dB, typical of daily traffic noise levels in a noisy urban area (Beranek, 1988). Two pairs of speakers carrying identical sounds were placed 50 cm from the centre of a force plate on which the subjects stood (Fig. 6.2).

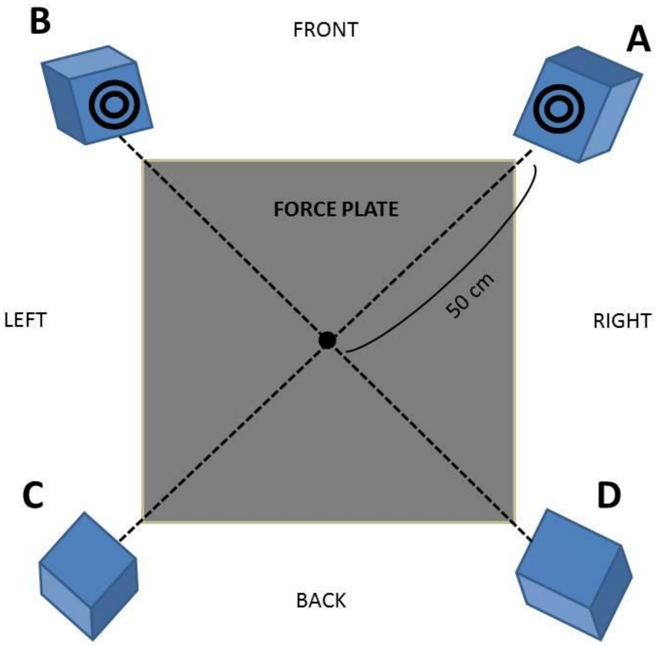


Fig. 6.2 The position of speakers. Two–pairs of speakers (A, C and B, D) were placed 50 cm from the middle of a forceplate. Speakers A and B were in front of the subject who stood in the centre of the forceplate while C and D were behind them.

In order to avoid habituation, each sound file was played once only with 6 files (90 s) randomly assigned to the 6 balance tasks (2LS, 1LS, and dynamic balance with and without auditory distraction) and two files to RDT testing (3 min) with and without auditory distraction. Approximately 30 s elapsed between files. Subjects were asked to silently count the number of sudden car horns, sirens and shouting in each trial in order to encourage attention to the sound. The number of intermittent sudden sounds was <6 in 90 s for balance tasks and <10 in 3 min for RDT testing to minimise counting errors.

Subjects completed the Situational Vertigo Questionnaire (SVQ) (Guerraz et al., 2001, Jacob et al., 1989) which consists of 19 questions, with a score from 0 (not at all), 1 (very slightly), 2 (somewhat), 3 (quite a lot) to 4 (very much). It measures how frequently symptoms (unusual disorientation, dizziness, giddiness, light-headedness or unsteadiness) are provoked or exacerbated in environments with visual-vestibular conflict or intense visual motion e.g. busy supermarket aisles. A score was obtained by dividing the total sum for activities experienced by the number of activities (Appendix 2).

Older subjects only were asked to complete the Falls Efficacy Scale-International (FES-I) (Yardley et al., 2005), which assesses subjects' concerns about falling. It consists of 16 questions related to everyday activities and subjects are asked to rate whether they were "not at all" (a score of 1), "somewhat" (2), "fairly" (3) or "very" (4) concerned about falling when doing that particular activity. The sum scores ranged 16 – 64 with higher scores indicating a greater fear of falling. FES-I scores of ≤ 22 are interpreted as a low to moderate level of concern, and scores of ≥23 as a high level of concern (Delbaere et al., 2010) (Appendix 3).

6.2.3 Data analysis

All data are presented as mean ± standard error of mean (SEM). SPSS (v19.0) was used for all statistical analysis with significance assumed at $p<0.05$. The Kolmogorov-Smirnov test was used to determine whether data were normally distributed.

Visual dependence

As no significant differences were found in dynamic SVV between clockwise (CW) and counter-clockwise (CCW) directions (Wilcoxon signed-rank test), they were averaged to obtain a mean dynamic SVV as in Chapter 2.

Static and dynamic SVV values were compared with and without sound between and within the two age groups. Static SVV data was normally distributed but dynamic SVV not and so was ranked before parametric testing was performed. Static and dynamic SVV were examined by a two-way ANOVA (group (younger vs. older) X sound (with vs. without)) to determine the effect of group, sound, and interaction between group and sound. A post hoc independent and a paired t-test were used to compare between age groups and between sound with and without respectively.

Static balance

Data from static and dynamic balance was analysed and evaluated in MatLab (R2010a, MathWorks Inc., USA). As no significant differences were noted in sway path length (m) between exposure to rotating discs in the CW and CCW directions (Wilcoxon signed-rank test) in 2LS, 1LS (5s) (sway in 1LS over 5 s) and 1LS (2s) (sway in 1LS for the first 2 s), they were averaged to obtain a mean rotation values (ROT). Sway path length with eyes open (EO), closed (EC) and ROT for 2LS, 1LS (5s) and 1LS (2s) in both age groups were ordered according to rank due to being non-normally distributed. A three-way ANOVA with post hoc multiple comparisons test was used to determine the effect of group (younger, older), sound (with, without), vision (EO, EC, ROT) and their interaction on path length in 2LS, 1LS (5s) and 1LS (2s) respectively.

The Romberg Quotient (RQ, a ratio of sway path length in EC and EO) and Kinetic Quotient (KQ, a ratio of sway path length in ROT and EO) were calculated to reflect postural stability as affected by lack of vision and a moving visual stimulus respectively. Both parameters were rank ordered due to not normal distribution. To determine the effect of group, sound, and interaction between groups and sound, a two-way ANOVA was applied on RQ and KQ with 2LS, 1LS (5s) and 1LS (2s). A post hoc independent and a paired t-test were used to compare between age groups and between sound with and without respectively.

Dynamic balance

No differences between CW and CCW directions (Wilcoxon signed-rank test) in ML postural deviation were noted, therefore they were averaged to obtain a mean ROT. ML deviation in EO and ROT was normally distributed and a three-way ANOVA with post hoc multiple comparisons test was used to determine the effect of group, sound and vision (EO, ROT), and their interaction on ML deviation.

KQ in dynamic balance (a ratio of ML deviation in EO and ROT) shows the effect of a moving visual stimulus. Because of non-normality it was rank ordered to permit use of a two-way ANOVA to determine the effect of group, sound, and interaction between group and sound. A post hoc independent and a paired t-test were applied to compare between and within age groups.

COP trajectory on ML direction during the dynamic balance task was illustrated by an XY plot in Excel. Time was represented as percentage of a complete step along the X axis. COP deviation towards right or left from central point was indicated as a positive or negative value in Y-axis. To measure whether the direction of rotating discs affected the direction of ML deviation in both age groups with and without sound, a 3-way ANOVA (direction x group x sound) with post hoc multiple comparisons test was used. To examine whether there was similar variance between the two age groups in a particular condition, the F-Test Two-Sample for Variance was performed.

Questionnaires

SVQ scores were normally distributed in the younger group only, therefore the Mann-Whitney test was used to compare between groups. FES-I data was presented with descriptive statistics only.

6.3 Results

6.3.1 Visual dependence

There was no significant effect of sound or group on static SVV (Fig. 6.3), however the variance was greater in the older group with (p=0.002) and without sound (p=0.02). All static SVV values deviated little from true gravitational vertical. However there was a trend for the deviation to be less with sound, although the individual variation was greater.

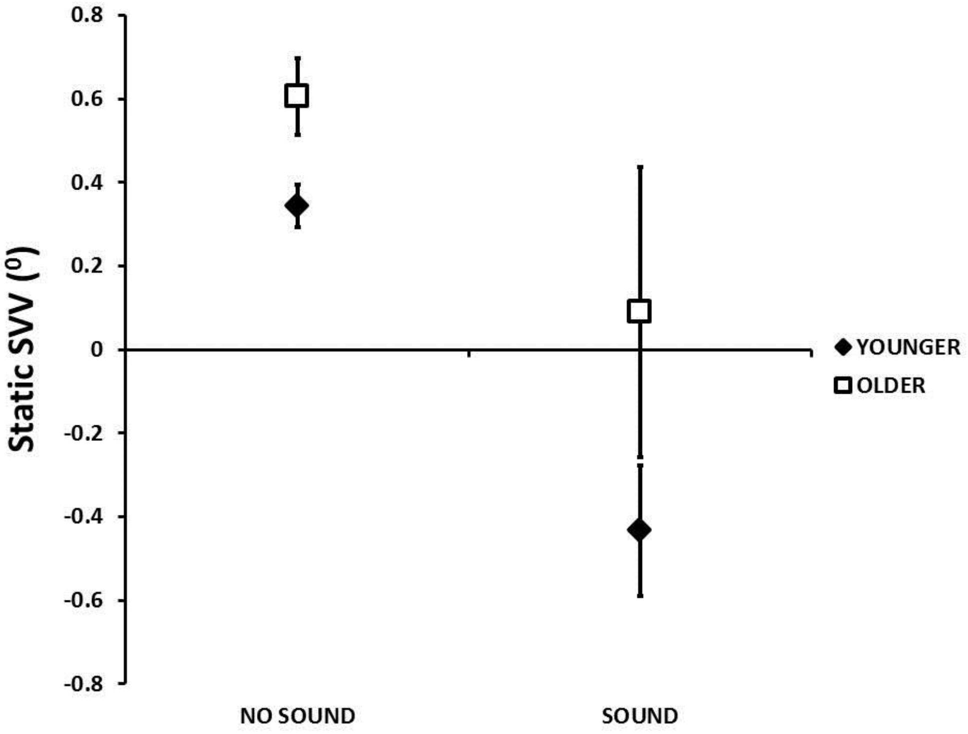


Fig. 6.3 (Mean ± sem) Static SVV with and without sound in younger and older groups. There were no significant differences between groups with or without sound.

However, there was a significant effect of group on dynamic SVV [F(1,14)=8.22, p=0.01] but no effect of sound or interaction (Fig. 6.4). Post-hoc analysis showed that dynamic SVV was significantly higher in the older group with (p=0.02) and without (p=0.001) sound. Variance was similar between age groups with (p=0.48) and without sound (P=0.42).

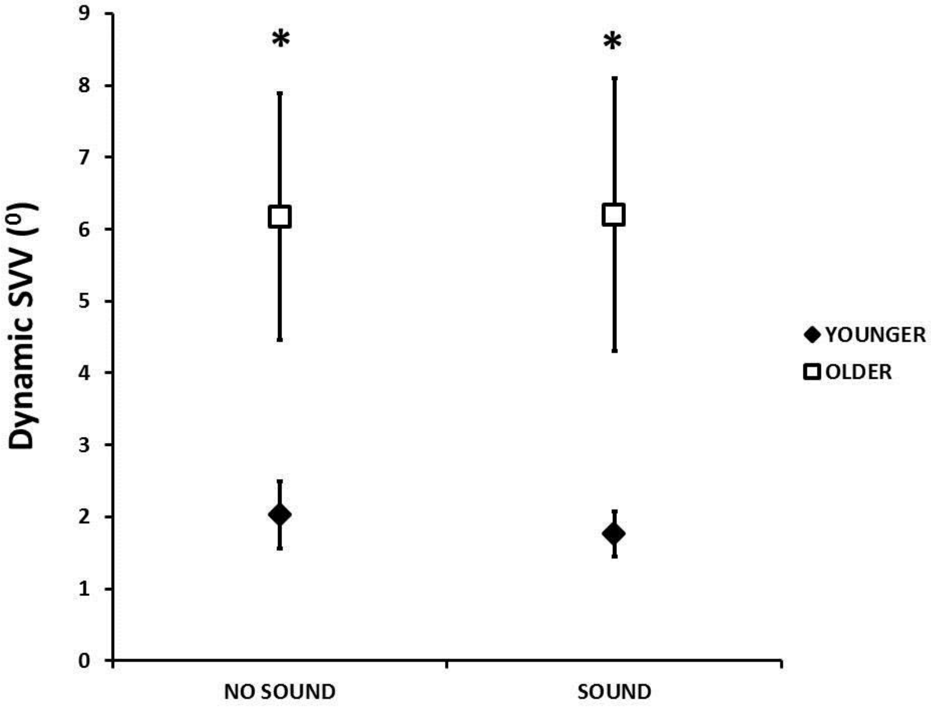


Fig. 6.4 (Mean ± sem) Dynamic SVV with and without sound in younger and older groups. Dynamic SVV was significantly higher in the older group with and without sound. No effect of sound was observed. * Statistically significant difference between groups at p<0.05.

6.3.2 Static balance

Fifteen younger and 15 older subjects were recruited but data from only 14 older subjects were analysed because of missing data. Nine younger (60 %) and 8 older (57 %) subjects chose the right leg for 1LS. All younger but only 7 older subjects were able to perform 1LS for 5 s. Five of the 7 were able to stand on one leg for 5 s without sound but not with. One had the opposite response whilst another could not maintain 1LS for >2 s either with or without sound. Therefore, 1LS for 5 s for all younger and 7 older subjects was analysed and 1LS for 2 s for all younger and 12 older subjects.

2LS

There was an effect of vision (F(2,54)=34.61, p<0.001) and age (F(1,27)=17.12, p<0.001) on sway path length with 2LS (Table 6.1). No significant effect of sound was found under any visual conditions in either group. Older people had greater sway path length than younger group in all conditions (p<0.001). Both age groups had a greater sway path length during EC and ROT than during EO with and without sound (p<0.05), but the postural sway with EC and ROT was not affected by sound in either age group. Variance was similar between age groups in all conditions (p=0.06 – 0.47).

	Younger			Older		
	EO	EC	ROT	EO	EC	ROT
NO SOUND	0.27±0.14	0.35±0.20¥	0.30±0.15¥	0.40±0.07*	0.46±0.08*¥	0.41±0.08*
SOUND	0.26±0.12	0.28±0.12¥	0.28±0.14	0.35±0.07*	0.41±0.08*¥	0.40±0.08*¥

Table 6.1 (Mean ± sem) Sway path length (m) with 2LS in EO, EC and ROT with and without sound in younger and older groups. Greater sway path length was found in the older than younger group under all conditions. Younger people had greater sway path length in EC and ROT than EO without sound and in EC than EO with sound whilst older people had greater sway path length in EC than EO without sound and in EC and ROT than EO with sound. * and ¥ denote statistically significant greater sway than younger group and greater sway than EO respectively at p<0.05.

There was no effect of sound or group on RQ with 2LS, however, an effect of group was found on KQ [F(1,27)=20.06, p=0.03] in that older people had a significantly greater KQ with sound (p=0.03) (Fig. 6.5). Also, there was an interaction between group and sound on KQ [F(1,27)=6.23, p=0.02] as in younger people decreased KQ while in older people it increased with sound. Variance was similar between age groups for RQ and KQ with and without sound (p=0.27 – 0.46).

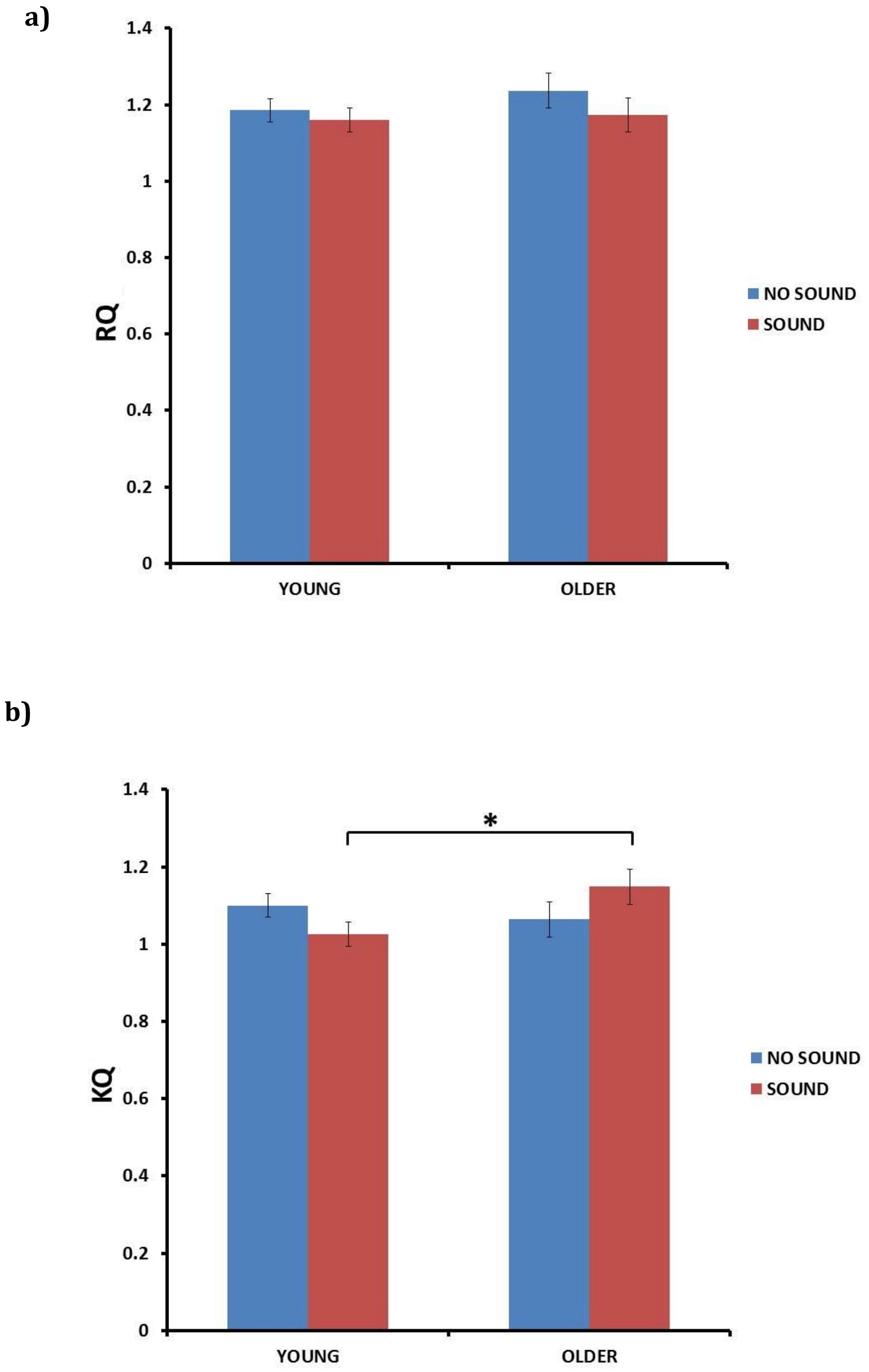


Fig. 6.5 (Mean ± sem) The a) RQ and b) KQ in 2LS with and without sound in younger and older groups. No effect of sound or group on RQ. There was no effect of sound on KQ but older people had greater KQ than younger people when added sound. * Statistically significant difference between groups at p<0.05.

1LS(5s)

There was a significant effect of vision (F(2,40)=29.66, p<0.001) and group (F(1,20)=13.07, p=0.002) on sway path length with 1LS (5s) (Table 6.2). No significant effect of sound was found under any visual conditions in either group. Older people had a greater sway path length in all conditions (<0.01) except EC with sound. Both age groups had a longer sway path length during EC and ROT than during EO under both sound conditions (p<0.01). Sway path length did not differ between EC and ROT with or without sound in either age group. Variance was similar between age groups in all conditions (p=0.13 – 0.33).

	Younger			Older		
	EO	EC	ROT	EO	EC	ROT
NO SOUND	0.65±0.31	0.96±0.46$^{¥}$	0.89±0.47$^{¥}$	1.38±0.32*	3.08±0.95$^{*¥}$	2.48±0.78$^{*¥}$
SOUND	0.57±0.24	1.29±0.70$^{¥}$	1.46±0.96$^{¥}$	1.24±0.44*	2.02±0.75$^{¥}$	2.39±0.89$^{*¥}$

Table 6.2 (Mean ± sem) Sway path length (m) with 1LS (5s) in EO, EC and ROT with and without sound in younger and older groups. Greater sway path length was found in older than younger group in all conditions except the condition of EC with sound. Both younger and older people had greater sway path length in EC and ROT than in EO with and without sound. * and ¥ denote statistically significant greater sway than younger group and greater sway than EO respectively at p<0.05.

For 1LS (5s), no effect of sound or group on RQ was found. There was no effect of group on KQ but there was for sound [F(1,20)=20, p=0.03] in the younger group who had a significantly higher KQ with sound (p=0.048). There was a trend for this in the older people but it did not reach significance (p=0.07) (Fig. 6.6). Variance was similar between age groups for RQ and KQ with and without sound (p=0.08 – 0.13).

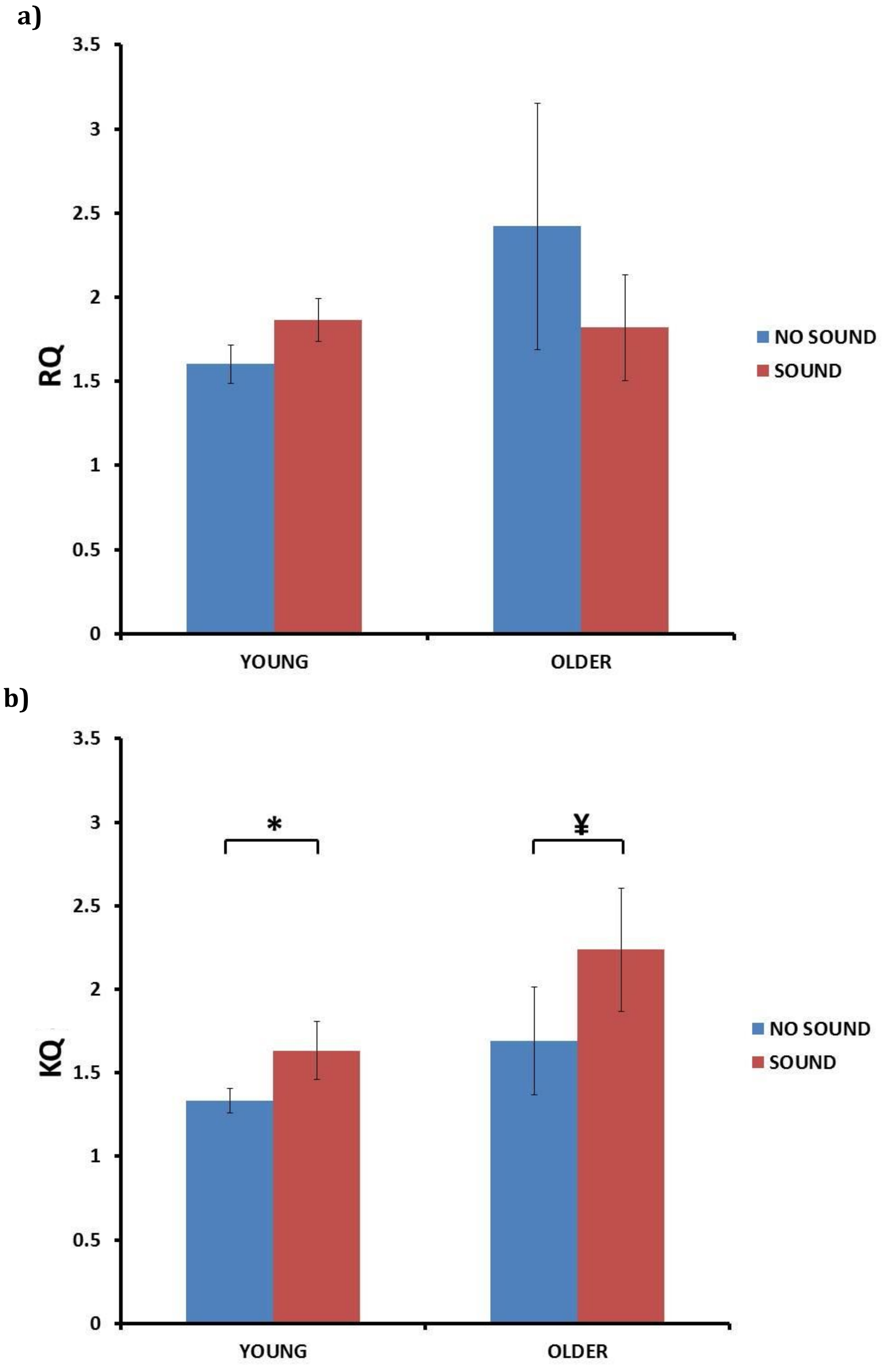


Fig. 6.6 (Mean ± sem) The a) RQ and b) KQ in 1LS (5s) with and without sound in younger and older groups. No effect of sound or group was observed on RQ. There was no effect of group but sound on KQ that both age groups had significantly higher KQ with sound than without. * Statistically significant difference between sound conditions at $p<0.05$. ¥ Nearly significant difference $p=0.07$

1LS(2s)

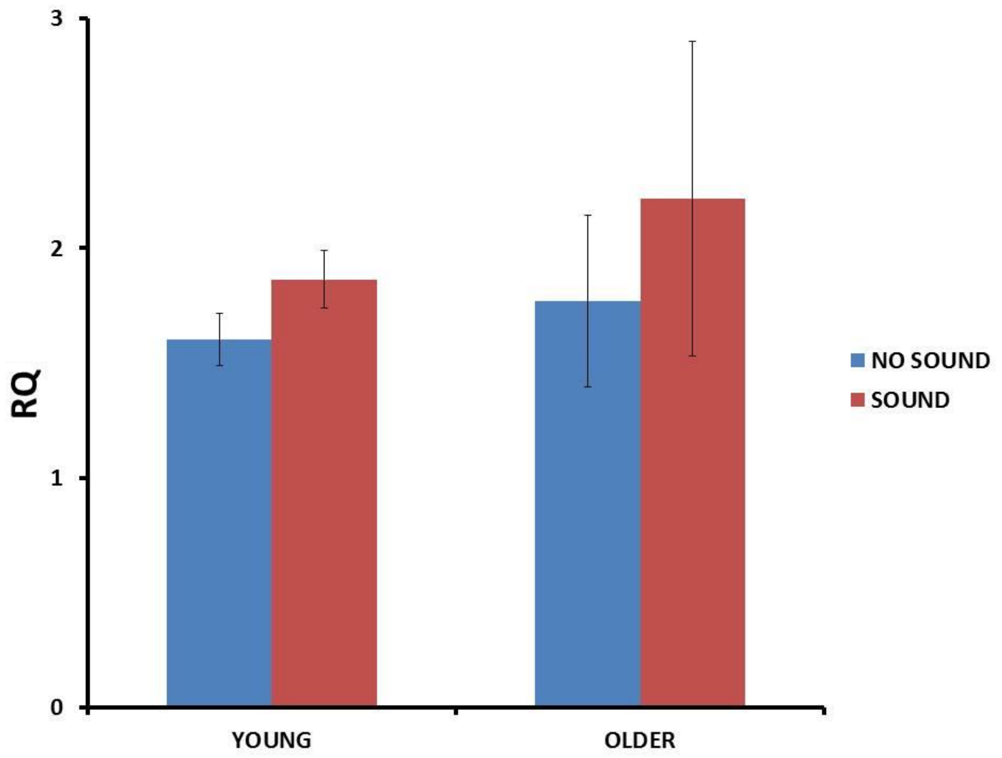
There was a significant effect of vision (F(2,50)=25.09, p<0.001) and group (F(1,25)=15.99, p<0.001) on sway path length with 1LS (2s) (Table 6.3). No significant effect of sound was found under any visual conditions in either group. Older people had significantly longer sway path length in each visual and sound condition (p<0.05). Both groups had greater sway path length during EC and ROT than during EO in both sound conditions (p<0.01) except that the sway path was similar between ROT and EO when there was no auditory disturbance in the older group. In contrast, the postural sway did not differ between EC and ROT with or without sound in either age group. Variance was similar between age groups in all conditions (p=0.09 – 0.42).

	Younger			Older		
	EO	EC	ROT	EO	EC	ROT
NO SOUND	0.31±0.15	0.40±0.19¥	0.37±0.19¥	0.50±0.08*	0.83±0.16*¥	0.82±0.16*
SOUND	0.32±0.15	0.45±0.20¥	0.64±0.44¥	0.42±0.09*	0.86±0.26*¥	0.70±0.18*¥

Table 6.3 (Mean ± sem) Sway path length (m) with 1LS (2s) in EO, EC and ROT with and without sound in younger and older groups. Greater sway path length was found in older than younger group in all conditions. Both younger and older people had greater sway path length in EC and ROT than in EO with sound and no sound but did not occur between ROT and EO without sound in older group. * and ¥ denote statistically significant greater sway than younger group and greater sway than EO respectively at p<0.05.

For 1LS(2s), there was no effect of sound or group on RQ. No effect of sound was observed for KQ but older people had a significantly higher value (F(1,25)=5.49, p=0.03) with sound (p=0.03) (Fig. 6.7). Variance was similar between age groups for KQ and RQ with and without sound (p=0.06 – 0.43).

a)



b)

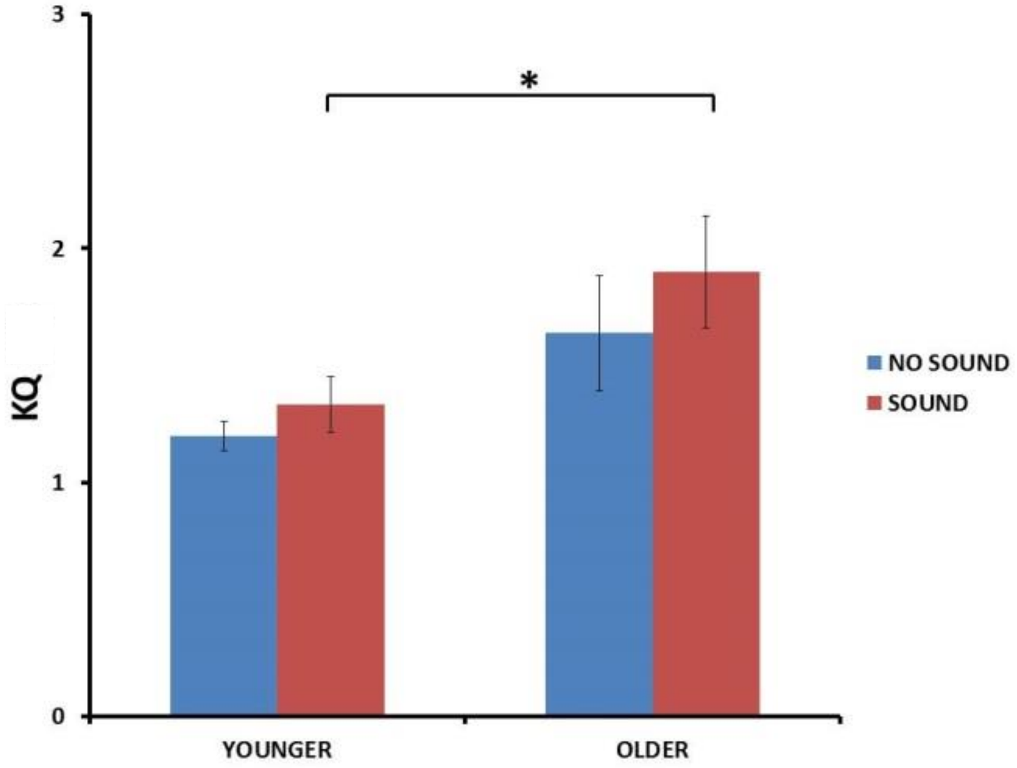


Fig. 6.7 (Mean ± sem) RQ and KQ in 1LS (2s) with and without sound in younger and older groups. No effect of sound or group on RQ was found. There was no effect of sound but older people had greater KQ than younger groups with sound but not without. * Statistically significant difference between groups at p<0.05.

6.3.3 Dynamic balance

One young and one older participant failed to complete the dynamic testing and therefore 14 subjects in each group were analysed.

There was no effect of sound but older people had greater ML deviation (F(1,26)=8.49, p=0.007) with (p=0.01) and without (p=0.002) sound (Table 6.4). ML deviation did not differ between EO and ROT in either age group or sound condition. Variance was similar in all conditions (p=0.12 – 0.26).

	Younger		Older	
	EO	ROT	EO	ROT
NO SOUND	0.008±0.001	0.009±0.001	0.021±0.005*	0.024±0.005*
SOUND	0.008±0.001	0.008±0.001	0.018±0.003*	0.021±0.006*

Table 6.4 (Mean ± sem) Dynamic balance ML deviation (m) during EO and ROT with and without in both younger and older groups. Older people had a significantly greater ML deviation than younger people in all visual and sound conditions but it did not differ between EO and ROT in either group with and without sound. * Statistically significant greater sway in older than younger group at p<0.05

There was no significant effect of sound or group on KQ (Fig. 6.8). Variance was similar between age groups for KQ without (p=0.34) and with sound (p=0.44).

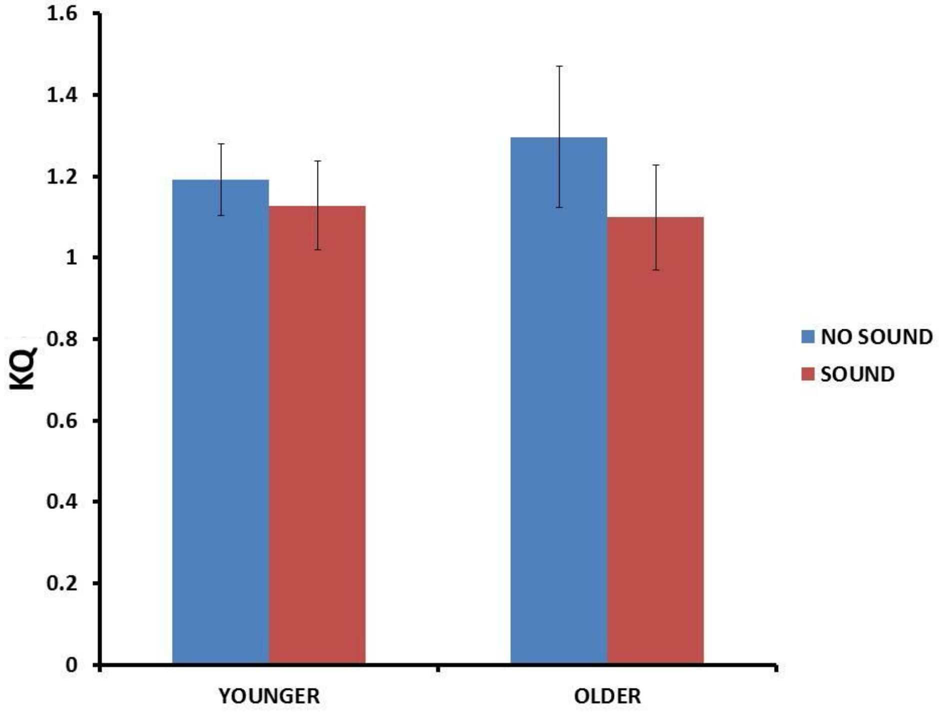


Fig. 6.8 (Mean ± sem) KQ dynamic ML balance with and without sound in younger and older groups. No effect of sound or group and interaction was observed.

The direction of postural sway followed that of the disk rotation (F(1,26)=41.12, p<0.001) in both groups and conditions (p<0.001 - 0.009) (Fig. 6.9).

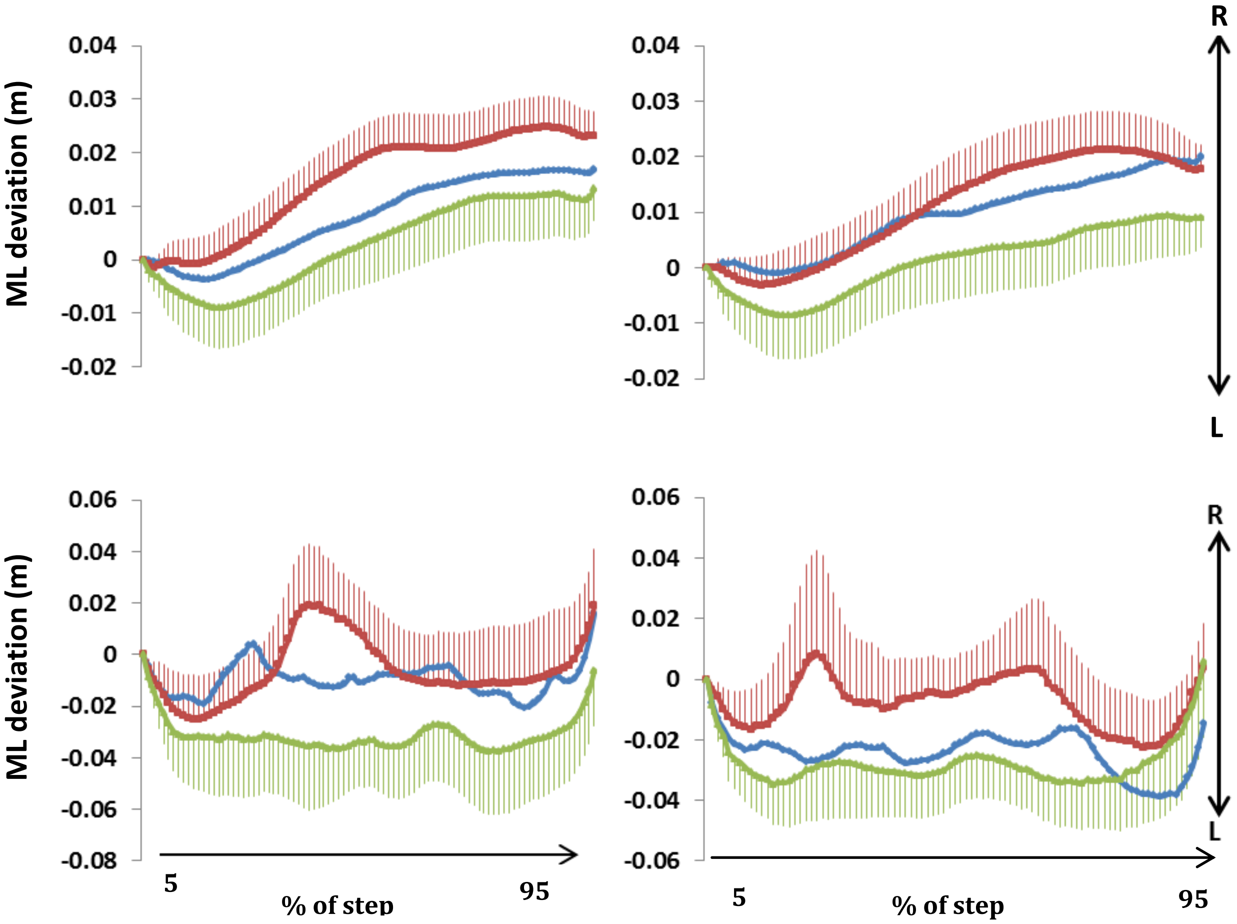


Fig. 6.9 (Mean ± sem) ML deviation with EO (blue), CW (red) and CCW (green) in younger (upper) and older (lower) groups with (right) and without sound (left). A positive and a negative value in the Y-axis indicate postural deviation towards right or left respectively from centre (zero) of forceplate. There was an effect of direction of rotated discs on direction of ML postural deviation with and without sound in both age groups.

6.3.4 Questionnaires

There was no difference in SVQ scores between groups (younger 0.21 ± 0.04, range 0 – 0.47 and older 0.43 ± 0.11, 0 – 1.26). Older people had a relatively lower FES-I score of 20.27 ± 0.66 (range 16 – 25) with only 2 of them having scores >23, indicating a low level of concern about falling.

6.4 Discussion

The aim of this study was to investigate the effect of auditory distraction on visual dependence for both spatial orientation and balance in healthy younger and older people. The findings showed 1) no effect of auditory distraction on either static or dynamic SVV in both age groups. However, dynamic SVV but not static SVV, was significantly higher in the older group; 2) RQ with 1LS and 2LS did not differ with age or distraction; (3) auditory distraction affected KQ with 1LS only in both age groups; older group had greater KQ with 2LS and 1LS than the younger group with added auditory distraction; 3) there was an interaction between group and distraction on KQ with 2LS indicating that younger people decreased KQ when added auditory distraction whilst older people increased it during 2LS; 4) KQ dynamic ML balance did not differ between age groups or with distraction.

Previous studies have found changes in visual dependency with distraction. Yardley et al. (2002) found that healthy younger adults produced greater errors in judging visual vertical when exposed to a visual field rotating with varying angular velocities and with the concurrent performance of a cognitive arithmetic task. However, the present study RDT had a very different protocol with respect to the nature of the distraction and the performance of the RDT. Distraction induced by traffic noise with intermittent sudden sounds which needed to be counted might be relatively easier for subjects and the RDT was certainly easier to perform than in the study of Yardley et al. and these discrepancies might explain the different findings between two studies. Even so, older people have been reported to have a higher dynamic, but not static, SVV than younger people irrespective of auditory distraction, indicating greater visual dependence on vision for spatial orientation (Kobayashi et al., 2002, Bronstein et al., 1996).

However, the results presented in Chapters 2, 3, and 4 found similar levels of visual dependence in the two age groups. The older subjects in this study were older (61 – 83 yrs) than other studies (60 –79 yrs) in this thesis and it could be possible that the often reported age related increase in visual dependence occurs more in the "older old".

No effect of auditory distraction on RQ during one and two legged standing, irrespective of age, was found in the current study. These findings differed from previous studies that have reported a greater effect of auditory disturbance on balance in absence of visual information (Soames and Raper, 1992, Tanaka et al., 2001). However, KQ was increased (i.e. worsened) during 1LS but not with 2LS with auditory distraction in both age groups. The one legged stance balance was not affected by auditory distraction when the eyes were closed but was when viewing rotating disks, suggesting that auditory distraction may increase postural visual dependence in a visually busy environment. A rotating visual field was reported to have a greater destabilising effect on balance than standing with eyes closed, particularly in older people (Sundermier et al., 1996). This could explain the higher incident of falls by older people when walking in streets (Ghodsi, 2003) that involves both auditory from traffic and visual distraction from vehicles and pedestrians passing by.

An effect of auditory distraction was only found in a more challenging situation i.e. standing on one leg exposed to a rotating visual field. Previous studies support the finding that attentional demands increase with the difficulty of the balance task (Lajoie et al., 1993, Shumway-Cook and Woollacott, 2000). The secondary task (auditory distraction) may have been insufficient to have an effect on the control of stance or gait during simple balance tasks, especially for people without balance problems (Lajoie et al., 1996).

There was no effect of age on RQ in contrast to previous studies that have found a greater effect of auditory disturbance on balance with visual deprivation (Soames and Raper, 1992, Tanaka et al., 2001), particularly in older people (Teasdale et al., 1993). However KQ with added auditory distraction was greater in the older group during both single and double legged standing.

Previous studies have reported that older people have greater attentional demands in both simple and challenging tasks (Teasdale et al., 1993, Lajoie et al., 1996, Shumway-Cook et al., 1997, Shumway-Cook and Woollacott, 2000). The older subjects in the present study also showed greater postural imbalance than younger subjects during auditory distraction when standing on one and two legs. An age-related increase in attentional demand may be due to an inability to divide attention between tasks, a reduction in attentional capacity, or associated with impairments in the postural control systems (Melzer et al., 2001, Huxhold et al., 2006, Jamet et al., 2007, Olivier et al., 2010). However, age-differences were only observed when looking at a rotating image but not when eyes were closed with added auditory distraction. This suggests increased attentional demands for re-weighting at a higher sensory integration level i.e. recognising the discrepancy, selecting and prioritising sensory inputs with conflicting sensory information (Shumway-Cook et al., 2000; Redfern et al., 2001, 2004; Teasdale et al., 2001).

Responses to auditory distraction on balance could be different in younger and older people. The results from the current study showed an interaction effect between group and distraction on KQ during two legged standing, such that balance improved in the younger group but decline in the older one when exposed to both visual and auditory distraction. The improvement in younger people may be associated with increasing cognitive load (Riley et al., 2005). The postural tasks could be easier for younger people and thus the secondary task might provide increased awareness of postural control rather being a distraction. In contrast, older people may find the same postural task more challenging and the secondary task was interpreted as a distraction and the need to share attention. Previous studies have reported the similar results that balance being affected in older people (Shumway-Cook and Woollacott, 2000) but not in younger ones (Palm et al., 2009) when preforming a concurrent cognitive task.

The older subjects in the current study did not have a history of falls and had low level of anxiety and fear of falling. Pervious studies reported that similar older people had slightly higher anxiety levels (Ersoy et al., 2009, Kempen et al., 2007) than those reported here. They did not report any balance problems and the auditory distraction had little effect on them.

All subjects were able to correctly count the number of sudden sounds, indicating the secondary task might be relatively easy and not involve substantially greater cognitive processing and therefore not affecting an easy postural task e.g. 2LS (Lemaire, 1996). Both age groups had only very slight symptoms of disorientation, or none at all, suggesting that both younger and older people did not experience difficulty in resolving situations where visual information is complex or inaccurate, and thus their level of visual dependence for orientation and balance were not easily affected by divided attention.

No differences were observed in dynamic ML deviation irrespective of distraction or age. This was assessed by stepping on to a forceplate i.e. a complete step in the walking cycle. Previous studies reported that subjects tended to decrease their walking speed (Ebersbach et al., 1995, Faulkner et al., 2006, Cho et al., 2008) or even stop when performing a secondary task (Lundin-Olsson et al., 1998), but this was not the case in this study. The postural demands of walking are different and more challenging than those for standing (Lajoie et al., 1993). However, digit recall was not affected by walking (Ebersbach et al., 1995) and ML deviation during walking has even decreased when answering math questions (Cho et al., 2008). This may suggest that subjects adopt a “motor degrees of freedom-freezing” strategy to maintain their balance so that the attentional demand associated with controlling multi-joint postural activity can be reduced and thus free up attentional resource to support the cognitive task (Riley et al., 2005). No significant change in dynamic balance ML deviation during auditory distraction was found in the current study but there was a trend of a decrease, suggesting that subjects could have adopted this conservative strategy although that is beyond the scope of this thesis.

Auditory distraction was provided through two pairs of spaced equal-distant from the subjects so that the sound had no obvious directional source (Easton et al., 1998). In order to mimic everyday life as far as possible speakers were used in this study instead of wearing a headphone and the intensity of the sound was 70 - 80 dB (Beranek, 1988).

In conclusion, auditory distraction did not affect visual dependence on spatial orientation in either group. There was also no effect on two legged balance with visual or auditory disturbance in either group. However, it did affect one legged stance balance when looking at a rotating image in both age groups. Dynamic balance was unaffected by auditory distraction or age in either group. These findings indicate that simultaneous auditory and visual disturbance are more likely to affect people with balance problems or less confidence in balance. Daily activities in real life are even more complicated and challenging. Multi-tasking could be engaged in addition to the primary motor task e.g. carry a heavy shopping bag or interacting with someone, that could consume more cognitive load and distract more attention from postural control and therefore increase imbalance and fall risks.

CHAPTER SEVEN SUMMARY AND CONCLUSIONS

7.1 Summary

This thesis presents a series of studies designed to investigate the effect of age on visual dependence for spatial orientation and postural control. Visual dependence is commonly assessed by the RDT (Isableu et al., 1997) presented on a TV monitor. This has pixellation and also vertical frames, both of which may provide orientation cues to influence the estimate of visual verticality (Isableu et al., 2011, Takasaki et al., 2012). Therefore, the work described in Chapter 2 examined the effect of pixellation and visual field shape on static and dynamic SVV values in younger and older healthy subjects. The findings showed visual field shape had no effect on SVV, but pixellation underestimated dynamic visual dependence in younger and older healthy individuals. No effect of age was observed in either static or dynamic SVV. Pixellation produced by digital devices with high fidelity screens could be used subconsciously or consciously to provide cues of verticality. Non-pixellated (projected) presentation of the RDT appears to be preferable for testing visual dependence. The sensitivity of such testing highlights the value of each laboratory obtaining their own dynamic SVV normative values.

There is clear evidence of an adaptation to repetitive visual stimulation on balance, but not on the perceived orientation. Chapter 3 investigated the effect of repetitive visual stimulation by measuring the SVV 5 times with different rest intervals between tests in younger and older subjects. The findings indicated neither an effect of age or repetitive visual RDT stimulation on both static and dynamic SVV, irrespective of whether exposures were at short variable rest intervals (~7 min) or at long fixed rest intervals (fixed 10 min). There are reports of a progressive reduction in postural sway in healthy younger and older adults (Pavlou et al., 2011), as well as older fallers (Sundermier et al., 1996, Jeka et al., 2006) after repeated visual stimulation, possibly due to activation of anticipatory postural adjustments (Horak et al., 1989). The results presented here indicate that repetitive visual stimulation has less influence on the perception of vertical than postural orientation. The data shows that a rest period of 7 min between bouts of visual stimulation was sufficient for any effect of previous exposure to have fully dissipated in people with normal levels of visual dependence, but this might not be the case for those who are visually dependent.

Older people often find balance control more difficult after being in a moving environment such as in a bus (Broome et al., 2009). WBV is commonly used in rehabilitation for its effect on muscle power and balance (Merriman and Jackson, 2009), but few studies have examined the immediate effect, especially on sensory systems. Chapters 4 and 5 investigated visual dependence and postural control respectively before and after postural disturbance provided by WBV in younger and older healthy subjects. The study presented in Chapter 4 was the first to investigate the effect of WBV on visual dependence. The findings showed decreased visual dependence after WBV in the younger group only, suggesting that the increased sensory stimulation generated, presumably proprioceptive and vestibular inputs, or adaptation to repetitive stimulation of visual judder can reduce the reliance on vision (Slaboda et al., 2009, Bronstein, 1995). This effect in young people lasted for 20 min, in agreement with previous studies (Wierzbicka et al., 1998, Sonza et al., 2013) on the duration of either sensory or motor changes resulting from vibration caused by any type of vibration lasted from 20 min (Wierzbicka et al., 1998) to 2 hours (Sonza et al., 2013). No such compensation occurred in older people. They may have less flexible and slower adaptive multi-sensory reweighting abilities and lack such an effective adjustment to response an external influence (Horak et al., 1989).

The study presented in Chapter 5 found no significant effect of WBV on static or dynamic balance under all visual conditions in both age groups. However there was a trend for postural sway to decrease after vibration in both age groups which was more obvious in one legged stance. This partly supports previous studies which reported that during relatively unchallenging balance tasks, such as two legged stance, WBV may have no effect (Carlucci et al., 2010, Dickin et al., 2012), although it may have a greater effect when balance is more challenged, such as with one legged stance (Schlee et al., 2012). This study partly supports the findings reported in Chapter 4 suggesting that an acute effect of WBV may be positive effects that decrease the level of visual dependence on both spatial orientation and postural control in both age groups. The use of WBV with older and clinical populations is growing and therefore safety is crucial. None of the younger or older subjects lost their balance during or after WBV which was well tolerated, in line with a review by Rittweger (2010) considering healthy subjects of all ages and various clinical groups. Therefore these results suggest that WBV could be a new exercise modality for the rehabilitation of visual dependence and postural control.

Divided attention could also possibly disturb balance control systems and make visual control more important. Chapter 6 provided auditory distractions by playing a background of traffic noise with intermittent sounds common in outside environments i.e. car horns, sirens and shouting. Auditory distraction did not affect the judgment of spatial orientation during static or dynamic RDT testing in either age group. There was also no effect on static two legged balance with visual deprivation or auditory disturbance in either group. However one legged stance balance was adversely affected, but only when looking at a rotating image, in both younger and older groups. Dynamic balance was unaffected by auditory distraction or age in either group. This leads to speculation that auditory and visual distraction is more likely to affect people with balance problems or less confidence in balance. Normal daily activities are even more complicated and challenging and could distract more attention from postural control and therefore increase instability and fall risks. Balancing tasks with added auditory distraction in visually busy environment could be used clinically as a form of exercise programme to improve postural control in challenging environments. It could help those who have a fear of falling, especially when walking outdoors, to regain a sense of confidence.

7.2 Healthy ageing and visual dependence

Several studies have reported higher visual dependence in older adults for both perceived orientation and postural control (Wade et al., 1995, Bronstein et al., 1996, Sundermier et al., 1996, Borger et al., 1999, Kobayashi et al., 2002). This is often thought to be due to either age- or disease- related peripheral sensory impairments in the proprioceptive and/or vestibular systems (Guerraz et al., 2001, Slaboda et al., 2009). However, the older subjects in Chapters 2, 3, and 4 did not show significantly increased visual dependence. Also, similar RQ and KQ values between age groups in Chapters 5 and 6 suggested that the sway of the older people was not affected by visual disturbance to a greater degree than that of the younger people. This could be because subjects with known peripheral sensory loss were excluded from these studies. Visual dependence may be more related to sensory impairments rather than chronological age. In fact some older subjects had similar or even lower dynamic visual dependence than younger ones and similar results have also been observed in other studies (Borger et al., 1999, Sundermier et al., 1996, Teasdale et al., 1991).

The older subjects studied in this thesis were all healthy with high function in physical and cognitive terms. As a result they may not have been representative of their age group in which an increased visual dependence with age has been reported (Bronstein et al., 1996, Kobayashi et al., 2002) but instead represent a group with particularly successful functional ageing (Rowe and Kahn, 1987). It is possible that previous studies may have overestimated the effect of age in visual dependence as our healthy and highly functioning older people had relatively low visual dependence. Visual dependence might be more related to age-declined sensory impairments rather than ageing *per se* and this would be another reason to encourage older people to stay physically and mentally active.

7.3 Future recommendations

The RDT is influenced by visual acuity and contrast sensitivity – which both decline with age. Therefore, it would be interesting to investigate their impact on visual dependence.

There was an absence of adaptation on the perception of visual vertical when the rest periods between bouts of visual stimulation were ~7 min. However the effect of shorter rest intervals between repeated RDT tests on both visual dependence and balance needs to be evaluated.

A rotating WBV platform was used in these studies, but many WBV machines vibrate vertically. The sensation is very different, even when the same amplitudes and frequencies are used, so these results cannot be extrapolated to vertically rotating machines. An acute effect of WBV could decrease the level of visual dependence and improve postural control. If that is the case, it is worth to investigate in future studies whether WBV could be a new intervention to decrease the level of visual dependence. However, whether the effects were a direct result of WBV itself or due to practice and learning are unclear.

7.4 Limitations

The older subjects studied in this thesis were all healthy as well as physically and mentally active and lived independently in the community. Thus they may not be representative of their age group and certainly were not representative of similarly aged people in sheltered or residential accommodation. Therefore, the results presented here may only apply to this particular older population.

No effects of age on visual dependence were observed except for those presented in Chapter 6. Those subjects were older than in other studies and it is possible that visual dependence is more affected by age in 'older old' (75 - 84 yrs) or 'oldest old' group (>85 yrs) rather than young old (65 - 74 yrs). Future research should investigate visual dependence in healthy older people in different age bands over the age spectrum.

The sample size of subjects in these studies was relatively small and this might result in a type II error due to the studies being underpowered. For instance, from the baseline data of the subjects studied in Chapter 2, power calculations estimate that 25 subjects in each age group are required to detect a change in the dynamic SVV between age groups with a power of 80% and *alpha* of 0.05. Future studies need to determine the appropriate numbers of participants beforehand in order to achieve the desired level of power and the results will be more robust.

7.5 Conclusion

The work presented in this thesis represents a series of novel studies of visual dependence and age. Although the subject number in these studies was relatively small, they have generated new and sometimes unexpected findings, often challenging conventional beliefs. They have also identified some directions for future research in this field. The key finding that was repeated in different studies was that ageing *per se* may not lead to increased visual dependence in healthy people. Thus study populations should be homogenous with respect to age, health and both physical and mental capacity.

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Appendix 1 Information sheet and consent form

INFORMATION SHEET FOR PARTICIPANTS

REC Reference Number: BDM/10/11-72

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of study: Effect of age on balance control

We would like to invite you to participate in this original research project. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Ageing is associated with many changes including more difficulty in balancing and an increased risk of falling, although it is not known why many falls happen. Older people often report that controlling balance is more difficult after being in a moving environment such as being in a car or bus and also when distracted by noise.

It is not known whether age affects how well we can balance when exposed to both movement and noise. We use many ways to help control balance and one of them is vision which is also affected by age. Movement could disturb our balance control systems and make visual control more important.

We want to know i) how much both movement and noise affect balance and also the role of vision in balance control and ii) if there is an effect of age.

We are looking for healthy volunteers in two age ranges – 18-30 years and also any age over 60. They should not have any known neurological diseases, joint replacements or a history of seizures or fainting. The study involves coming to a laboratory in Shepherd's House, next to Guy's Hospital at London Bridge for one and a half hours at the most. We are doing two tests.

In the first you stand on a large platform that measures how much you sway in any direction. We will ask to to stand still for 45 seconds with your eyes open ,then closed and finally when looking at a pattern of rotating dots.

The second test involves you looking at vertical rod on a screen. This will rotate either to the right or the left and we would like you to bring it back into the upright position using a small electronic wheel. Around the rod are a number of dots arranged in a circle. We will ask you to correct the position of the rod when the dots are not moving and again when they are rotating.

Both tests will be done in a quite environment and also when wearing headphones. Through the headphones you will hear the type of sounds usually heard in the street e.g. traffic noise, sirens, shouting etc.

These tests will be done before and after the movement which will be 5 bouts of 1 minute each standing on a vibrating platform. This is known as whole body vibration. It is a technique which is popular in gyms and fitness centres and is said to increase muscle strength and power and feels rather strange at first but people quickly get used to it.

Before and afterwards the vibration we will do both tests.

You will be asked to complete a questionnaire about any vertigo (dizziness, giddiness, light-headedness or unsteadiness) experienced in a number of everyday situations.

In any data that is analysed or presented you will be anonymous. We will be happy to give you a copy of the final report if you request this on the Consent Form. If you agree we will keep your contact details for possible involvement in future studies that you may be suitable for.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive. In addition to withdrawing yourself from the study, you may also withdraw any data/information you have already provided up until it analysed.

If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form.

If this study has harmed you in any way you can contact King's College London for further advice and information by emailing either di.newham@kcl.ac.uk or masimo.barcellona@kcl.ac.uk.

If you are interested in participating in the study please contact:
Shu-chun.lee@kcl.ac.uk (Phone number 0207 848 6679) or di.newham@kcl.ac.uk (Phone number 0207 848 6320).

CONSENT FORM FOR PARTICIPANTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.
Title of Study: Effect of age on balance control

King's College Research Ethics Committee Ref: BDM/10/11-72

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

- I understand that if I decide at any time during the research that I no longer wish to participate in this project, I can notify the researchers involved and withdraw from it immediately without giving any reason. Furthermore, I understand that I will be able to withdraw my data up to the point of analysis

- I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be handled in accordance with the terms of the Data Protection Act 1998.

- I agree to be contacted in the future by King's College London researchers who would like to invite me to participate in follow up studies to this project, or in future studies of a similar nature.

- I agree that the research team may use my data for future research and understand that any such use of identifiable data would be reviewed and approved by a research ethics committee. (In such cases, as with this project, data would not be identifiable in any report).

- The information you have submitted will be published as a report and you will be sent a copy. If you would like a copy please tick.

Please note that confidentiality and anonymity will be maintained and it will not be possible to identify you from any publications.

Participant's Statement:

I ____

agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Signed Date

Investigator’s Statement:

I ____ Confirm that I have carefully explained the nature, demands and any foreseeable risks (where applicable) of the proposed research to the participant.

Signed Date

Effect of age on balance control - circular

Circular email for use for recruitment of volunteers for study ref BDM/10/11-72, approved by BDM RESC (Health) Sub-committee. This project contributes to the College's role in conducting research, and teaching research methods. You are under no obligation to reply to this email, however if you choose to, participation in this research is voluntary and you may withdraw at anytime.

Title of study: Effect of age on balance control

Ageing is associated with many changes including more difficulty in balancing and an increased risk of falling, although it is not known why many falls happen. Older people often report that controlling balance is more difficult after being in a moving environment such as being in a car or bus and also when distracted by noise. This may be an important cause of falls by older people.

It is not known whether age affects how well we can balance when exposed to both movement and noise. We use many ways to help control balance and one of them is vision which is also affected by age. Movement could disturb our balance control systems and make visual control more important.

Participation involves you coming to Shepherd’s House on the Guy’s Campus for about an hour. We will measure your standing balance with eyes open and closed and also when looking at a rotating image. We will also measure how accurately you are able to detect the vertical position of a rod projected on a screen with a stationary and moving background. These tests will be performed before and after standing on a vibrating platform for a total of 5 minutes.

We are looking healthy people in two age groups; 18-40 and over 60 years. They should not knowingly have a neurological disease, uncorrected visual impairment, joint replacement or a history of seizures, migraine or fainting.

For further information, please contact me: Shu-Chun Lee (Phone 0207 848 6679 or email shu-chun.lee@kcl.ac.uk)

Appendix 2 Situational Vertigo Questionnaire

SITUATIONAL VERTIGO QUESTIONNAIRE

Vertigo is the medical term used for symptoms which patients often describe as feelings of unusual disorientation, dizziness, giddiness, light-headedness or unsteadiness. Please circle a number to indicate the degree to which each of the situations listed below causes feelings of vertigo, or makes your vertigo worse. If you have never been in one of the situations then for that item ring "N.T." for "Not Tried".

The categories are:

0	1	2	3	4	N.T.
Not at all	Very slightly	Somewhat	Quite a lot	Very much	Not tried

Riding as a passenger in a car on straight flat roads	0	1	2	3	4	N.T.
Riding as a passenger in a car on winding or bumpy roads	0	1	2	3	4	N.T.
Walking down a supermarket aisle	0	1	2	3	4	N.T.
Standing in a lift while it stops	0	1	2	3	4	N.T.
Standing in a lift while it moves at a steady speed	0	1	2	3	4	N.T.
Riding in a car at a steady speed	0	1	2	3	4	N.T.
Starting or stopping in a car	0	1	2	3	4	N.T.
Standing in the middle of a wide open space (e.g. large field or square)	0	1	2	3	4	N.T.
Sitting on a bus	0	1	2	3	4	N.T.

Standing on a bus	0	1	2	3	4	N.T.
Heights	0	1	2	3	4	N.T.
Watching moving scenes on the T.V. or at the cinema	0	1	2	3	4	N.T.
Travelling on escalators	0	1	2	3	4	N.T.
Looking at striped or moving surfaces (e.g. curtains, Venetian blinds, flowing water)	0	1	2	3	4	N.T.
Looking at a scrolling computer screen or microfiche	0	1	2	3	4	N.T.
Going through a tunnel looking at the lights on the side	0	1	2	3	4	N.T.
Going through a tunnel looking at the light at the end	0	1	2	3	4	N.T.
Driving over the brow of a hill, around bends, or in wide open spaces	0	1	2	3	4	N.T.
Watching moving traffic or trains	0	1	2	3	4	N.T.

Appendix 3 Falls Efficacy Scale- International

The Falls Efficacy Scale-International (FES-I)

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

		Not at all concerned 1	*Somewhat concerned 2*	*Fairly concerned 3*	*Very concerned 4*
1	Cleaning the house (e.g. sweep, vacuum or dust)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
2	Getting dressed or undressed	*1* ☐	*2* ☐	*3* ☐	*4* ☐
3	Preparing simple meals	*1* ☐	*2* ☐	*3* ☐	*4* ☐
4	Taking a bath or shower	*1* ☐	*2* ☐	*3* ☐	*4* ☐
5	Going to the shop	*1* ☐	*2* ☐	*3* ☐	*4* ☐
6	Getting in or out of a chair	*1* ☐	*2* ☐	*3* ☐	*4* ☐

7	Going up or down stairs	*1* ☐	*2* ☐	*3* ☐	*4* ☐
8	Walking around in the neighbourhood	*1* ☐	*2* ☐	*3* ☐	*4* ☐
9	Reaching for something above your head or on the ground	*1* ☐	*2* ☐	*3* ☐	*4* ☐
10	Going to answer the telephone before it stops ringing	*1* ☐	*2* ☐	*3* ☐	*4* ☐
11	Walking on a slippery surface (e.g. wet or icy)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
12	Visiting a friend or relative	*1* ☐	*2* ☐	*3* ☐	*4* ☐
13	Walking in a place with crowds	*1* ☐	*2* ☐	*3* ☐	*4* ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
15	Walking up or down a slope	*1* ☐	*2* ☐	*3* ☐	*4* ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* ☐	*2* ☐	*3* ☐	*4* ☐