VISUAL-VESTIBULAR INTERACTION FOR MAINTAINING STABILITY WHILE STANDING UP FROM A SITTING POSITION: EFFECTS OF AGING

by

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Abstract

Background: Sit-to-stand is a challenging task as it requires the transition from a large 3-point base of support to a small 2-point base of support while simultaneously controlling anteroposterior and vertical body acceleration. Age-related morphological changes in both the visual and vestibular system could impair the ability to extract and interpret sensory information necessary for motor control in older adults, which can increase instability and the risk of falls. The purpose of this study is to understand the effects of aging on visual-vestibular interaction for maintaining stability during sit-to-stand.

Methods: Fifteen younger (age=22.5±1.1) and fifteen older (age=73.9±5.3) healthy adults were asked to stand from a sitting position as quickly as possible. Vestibular input was manipulated using percutaneous bipolar galvanic vestibular stimulation where threshold intensity was individually calculated for each participant during quiet stance with eyes closed. Galvanic vestibular stimulation was applied at both threshold (1xGVS) and 2-times the participant's threshold intensity (2xGVS). Visual conditions included eyes opened, wearing custom-made vision blurring goggles, or eyes closed. Outcome measures included a global measure of performance (transition phase duration), mediolateral stability (peak-to-peak trunk roll angle, mediolateral center of mass displacement, mediolateral center of pressure displacement) and anteroposterior stability (peak braking force, peak-to-peak trunk pitch angle, and peak anteroposterior center of mass velocity).

Results: When vision was suboptimal (blurring goggles), older adults had significantly longer transition phase duration than younger adults ($p<0.05$). Older adults demonstrated greater mediolateral instability than younger adults. When vision was absent, trunk roll angle was significantly greater with 1xGVS than 2xGVS ($p<0.05$). Mediolateral center of mass displacement was greater when vision was absent than when vision was available, irrespective of age ($p<0.05$). No effects of age, vision or galvanic vestibular stimulation were seen in peak braking force, trunk pitch angle, and peak anteroposterior center of mass velocity ($p>0.05$).

Conclusion: Regardless of age, visual inputs were more critical to maintain stability during sit-to-stand than vestibular inputs. Differences between younger adults and older adults were only seen in the mediolateral direction. Despite having greater mediolateral instability, older adults utilized similar strategies as younger adults to overcome sensory perturbations during sit-to-stand.

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Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

The ability to rise from a seated position, otherwise known as sit-to-stand, is a mobility task that is frequently performed on a daily basis. Safe execution of sit-to-stand is critical for older adults to maintain independence as it is a prerequisite for many activities within the home or community environment (e.g., getting out of bed, rising from the seats in a movie theater or church). Evaluation of sit-to-stand performance has been integrated into clinical assessments such as the Timed Up and Go (Aslan, Cavlak, Yagci, & Akdag, 2008; Chen & Chou, 2013; Steffen, Hacker, & Mollinger, 2002) and Five Times Sit-to-stand Test (Meretta, Whitney, Marchetti, Sparto, & Muirhead, 2006; Whitney *et al.*, 2005) in order to assess safety and independence in daily life. However, clinical assessments such as the Five or Ten Times Sit-to-stand are considered a functional assessment of lower limb strength and the role of sensory information is not investigated thoroughly with these tests. Lord, Murray, Chapman, Munro, & Tiedemann (2002) found sensory functions such as visual contrast sensitivity, lower limb proprioception and tactile sensitivity can be used as predictors of sit-to-stand performance. Whitney *et al.* (2005) found people with balance or vestibular disorders have poorer sit-to-stand performance as they required more time to complete the Five Times Sit-to-stand Test than healthy controls. These two studies provide evidence that sensory inputs may be critical when performing sit-to-stand. However, the interaction between visual and vestibular functions during sit-to-stand has not been thoroughly investigated. Further research is needed to understand how age-related changes in sensory function can impact sit-to-stand performance.

Postural control requires the integration of the sensory inputs from the visual, somatosensory and vestibular systems (Redfern, Yardley, & Bronstein, 2001). The visual system provides instantaneous feedback for body orientation with respect to the environment, whereas the somatosensory system provides feedback about body position, location of body segments relative to each other and the support surface (Raju, 2012; Redfern *et al.*, 2001). The vestibular system provides a stable gravitational reference that can be used to resolve conflict between visual and somatosensory inputs in order to maintain postural control (Raju, 2012). Although the sensory systems are independent sensory channels, interaction between these systems occurs. For example, visual and vestibular inputs can interact (visual-vestibular interaction) to control eye movement and maintain postural control (Ventre, 1985; Wylie, 2009). During this interaction, sensory inputs from the vestibular system travel to the central nervous system via the vestibular nerve and project onto the vestibular nuclear complex and the cerebellum (Hain & Helminski, 2007; Rutka, 2004). The vestibular nuclear complex (consisting of 4 nuclei: medial, lateral, superior and descending) integrates vestibular inputs with visual and somatosensory inputs along with other inputs from the spinal cord and cerebellum (Goldberg, Walker, & Hudspeth, 2012; Hain & Helminski, 2007). This integration of inputs from the visual, vestibular and somatosensory systems allows for reflexes that contribute to postural control. The superior and medial nuclei provide inputs for the vestibulo-ocular reflex (Hain & Helminski, 2007); the lateral and medial vestibular nuclei provide inputs for the vestibulo-spinal reflex (Hain & Helminski, 2007); the vestibulo-ocular reflex and the vestibulo-spinal reflex contribute to the coordination of head, eye and body movements necessary to maintain stability during dynamic tasks such as sit-to-stand (Goldberg *et al.*, 2012; Hain & Helminski, 2007).

Generally, stability has been defined as the ability to maintain or control one's center of mass within the base of support (Shumway-Cook & Woollacott, 2012). In gait, standing and sit-to-stand studies, peak-to-peak (difference between maximum and minimum value) calculations of center of mass displacement (Schrager, Kelly, Price, Ferrucci, & Shumway-Cook, 2008), center of pressure displacement (Cheng *et al.*, 1998; Hay, Bard, Fleury, & Teasdale, 1996) and trunk angle (Allum *et al.*, 2001) have been used as outcome measures to reflect stability. Therefore, in our current study, instability has been defined as increase in peak-to-peak center of mass displacement, center of pressure displacement or trunk angle.

Sensory interaction has been investigated during dynamic tasks to understand the role of each sensory system in the maintenance of postural control. Deshpande & Patla (2007) investigated visual-vestibular interactions during gait and found that visual inputs are predominantly used to maintain postural control during optimal (normal) visual inputs. However, vestibular inputs are more prominent when visual input was either suboptimal or not available. Although the role of the visual system has been explored during sit-to-stand, the role of the vestibular system has only been contemplated in the literature. Linear accelerations experienced in both the anteroposterior and vertical direction during sit-to-stand may provide stimulation to the vestibular system. Brown, Whitney, Marchetti, Wrisley, & Furman (2006) found that 82% of their participants with vestibular dysfunction were unable to complete the Five Times Sit-to-stand Test. Therefore, it may be possible that the vestibular system provides information necessary to maintain balance and vertical orientation during sit-to-stand. Currently, visual-vestibular interaction during sit-to-stand has not been thoroughly investigated but it is important to understand how vision and vestibular system interact as both may be used to maintain postural control.

Successful and safe execution of sit-to-stand may be compromised in older adults as age-related declines in sensory function may lead to postural instability reducing the precision necessary during body transitions. In terms of vision, older adults experience reduced visual acuity, contrast sensitivity, dark adaptation, depth perception, color discrimination and peripheral vision (Poole, 1992; Sturnieks, St George, & Lord, 2008). Age-related declines in the vestibular system cause deficits in vestibular reflexes and increase the chances of pathologies which may cause symptoms such as dizziness and vertigo (Baloh, 2002; Matheson, Darlington, & Smith, 1999; Shumway-Cook & Woollacott, 2012). Aging impairs the ability of visual and vestibular system receptors to extract sensory information from the environment, whereas age-related decline of the central integrative mechanisms impairs the ability to process and interpret sensory information. Collectively, declines in any of the sensory functions or central integrative mechanisms can negatively affect postural stability in older adults.

How age-related decline in sensory functions affects sit-to-stand is currently unknown. Optimal vision is especially crucial in older adults as they require visual feedback to fine-tune body orientations for precise postural control during sit-to-stand (Mourey, Grishin, d’Athis, Pozzo, & Stapley, 2000). Thus, with the increased reliance on vision in older adults and the age-related declines in vision, sit-to-stand performance could be negatively affected. Age-related declines in vestibular function may impair the ability to generate a stable reference in relation to gravitational vertical needed for maintaining balance during sit-to-stand. In addition, age-related changes in visual-vestibular interactions have not been well explored. Horvat *et al.* (2003) demonstrated that people with visual impairments rely more heavily on the vestibular and somatosensory systems to maintain stability when standing. However, how the availability and quality of the visual inputs impact the role of the vestibular system during sit-to-stand is also unknown.

1.2 Rationale/Current Limitations

Although many studies have investigated sensory function in gait (Bent, McFadyen, Merkley, Kennedy, & Inglis, 2000; Deshpande & Patla, 2005, 2007; Lepecq *et al.,* 2006), visual-vestibular interactions during sit-to-stand have not yet been extensively researched. In particular, Deshpande & Patla (2005) found that during goal-directed locomotion, vision is dominantly used. Bent *et al.* (2000) on the other hand, suggested a greater vestibular contribution during the transition between tasks such as the initiation and termination phases of gait. Although gait and sit-to-stand are both dynamic tasks, Brown *et al.* (2006) reported that only 18% of their participants with vestibular dysfunction could complete the Five Times Sit-to-stand Test whereas 86% could complete the Dynamic Gait Index. This suggests that sit-to-stand may be more challenging in people with vestibular dysfunction than gait. However, it is unknown how declines in sensory function impact postural control when transitioning the body during sit-to-stand, especially in older adults. It is hypothesized that during sit-to-stand, vestibular inputs may play a critical role to maintain postural control and older adults will have greater instability compared to younger adults.

1.3 Purpose

The purpose of this study is to understand the effects of aging on visual-vestibular interaction for maintaining stability during sit-to-stand.

Chapter 2

Literature Review

Rising from a seated position, otherwise known as sit-to-stand, is a complex mobility task that is performed on average 60 times a day (Dall & Kerr, 2010). Given the frequency of sit-to-stand in daily activities, the inability to safely execute sit-to-stand may result in decreased independence in older adults (Dall & Kerr, 2010). Sit-to-stand has been incorporated into many clinical tests to evaluate physical function (Aslan *et al.*, 2008; Brown *et al.*, 2006; Lord *et al.*, 2002; Meretta *et al.*, 2006; Takai *et al.*, 2009; Whitney *et al.*, 2005; Yamada & Demura, 2009). Although clinical assessments often evaluate global performance and lower limb strength, it is important to also assess sensory function (often neglected) which plays a critical role in maintaining postural control during dynamic tasks such as sit-to-stand (Horak, 2006). Sit-to-stand involves multiple systems and requires the transition of the body from a larger to a smaller base of support. The aim of this literature review is to: (1) synthesize the current literature regarding sit-to-stand, (2) understand the effects of aging, (3) outline the role of sensory inputs, and (4) examine sit-to-stand stability in the mediolateral and anteroposterior directions.

2.1 Sit-to-stand

2.1.1 Phases of sit-to-stand

The three phases of sit-to-stand that have been used to analyze the task are acceleration, transition and deceleration (Figure 1) (Mourey *et al.*, 2000; Riley, Schenkman, Mann, & Hodge, 1991; Roebroeck, Doorenbosch, Harlaar, Jacobs, & Lankhorst, 1994). The acceleration phase is defined as the period between the initiation of movement to maximum center of mass velocity in the anteroposterior direction; the transition phase is from the maximum center of mass velocity in the anteroposterior direction to maximum center of mass velocity in the vertical direction; the deceleration phase is from maximum center of mass velocity in the vertical direction to the end of the task (Mourey *et al.*, 2000; Riley *et al.*, 1991; Roebroeck *et al.*, 1994).

At the beginning of sit-to-stand, the center of mass is located behind the feet and must then be brought within the base of support when standing (Mourey *et al.*, 2000). The ability to maintain anteroposterior and vertical body accelerations when performing sit-to-stand is crucial to avoid falls. The reduction of base of support occurs during the transition phase, making this phase the most unstable phase of sit-to-stand. In order to successfully complete sit-to-stand, one must safely and effectively transition from a large 3-point base of support to a smaller 2-point base of support while simultaneously controlling anteroposterior and vertical body accelerations (Pai & Lee, 1994; Roebroeck *et al.*, 1994).

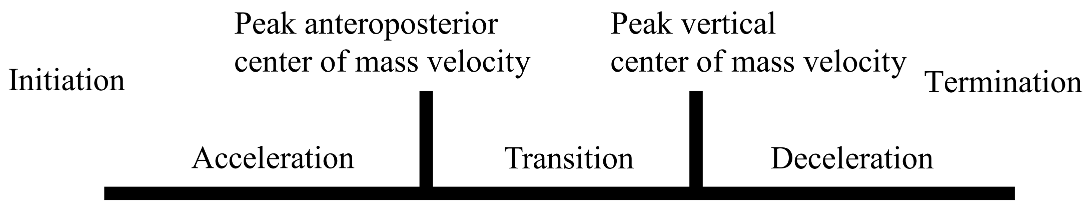

Figure 1 Three phases of sit-to-stand.

The task of sit-to-stand broken down into three phases: acceleration, transition and deceleration. The acceleration phase is defined as the period between the initiation of movement to maximum center of mass velocity in the anteroposterior direction; the transition phase is from the peak center of mass velocity in the anteroposterior direction to peak center of mass velocity in the vertical direction; lastly, the deceleration phase is from peak center of mass velocity in the vertical direction to the end of the task.

2.1.2 Sit-to-stand and aging

Age-related declines in lower limb strength, balance and sensory systems have independently been shown to impair safe and efficient execution of sit-to-stand in older adults (Lord *et al.*, 2002; Schenkman, Hughes, Samsa, & Studenski, 1996). Effects of healthy aging have been studied through comparison of sit-to-stand performance between younger, middle-aged and older adults (over 65 years of age) (Aslan *et al.*, 2008; Mourey *et al.*, 2000). Temporal outcome measures are often used as a global measure of sit-to-stand performance. When comparing sit-to-stand performance between age-groups, older adults require more time to complete sit-to-stand than both younger and middle aged adults (Aslan *et al.*, 2008; Lusardi, Pellecchia, & Schulman, 2003; Mourey *et al.*, 2000). This increased time to complete sit-to-stand in older adults may reflect age-related declines in lower limb strength, reaction time, and sensory systems.

Older adults require both a greater amount of time and additional support from the upper body (arms) or assistive devices to complete sit-to-stand (Lindemann *et al.*, 2007; Lusardi *et al.*, 2003). Specifically, of 270 participants over the age of 65 who were recruited to perform sit-to-stand, 39% were excluded due to their inability to perform sit-to-stand without either the arm support or assistive devices (Lindemann *et al.*, 2007); this provides evidence that sit-to-stand is a challenging task for older adults. Age-related decline increases the need for additional support possibly due to declines in lower limb strength or sensory function. Lusardi *et al.* (2003) compared the need for additional support in older adults by comparing four age ranges: 60-69, 70-79, 80-89 and 90-101 years. As age increased, the need for additional support when performing sit-to-stand also increased (Lusardi *et al.*, 2003). Collectively, these studies suggest that sit-to-stand is a challenging task for older adults as the ability to perform sit-to-stand without the use of additional support declines with age.

2.1.3 Requirements of sit-to-stand

Lower limb strength has been extensively studied during sit-to-stand (Roebroeck *et al.*, 1994; Schlicht, Camaione, & Owen, 2001; Takai *et al.*, 2009; Yamada & Demura, 2009) and is known to be a predictor of future falls. Therefore, sit-to-stand has been incorporated into clinical tests such as the Five and Ten Times Sit-to-stand Test or number of sit-to-stand in 10 or 30 seconds as an objective measure of lower limb strength in older adults (Lord *et al.*, 2002). Older adults demonstrated a decline in lower limb strength compared to their younger counterparts (Yamada & Demura, 2009) which may explain the greater difficulty in performing sit-to-stand. Although clinical assessments provide ways to compare muscular function, the role of sensory function has often been neglected despite the fact that Lord *et al.* (2002) found that sensory inputs (such as visual contrast sensitivity, lower limb proprioception and tactile sensitivity) along with lower limb strength (such as knee extension, flexion and ankle dorsiflexion strength) are all independent predictors of sit-to-stand performance. These findings by Lord *et al.* (2002) suggest that sit-to-stand performance in older adults is influenced by multiple factors rather than lower limb strength alone and the role of sensory systems should be investigated.

2.2 Sensory Systems

Postural control requires the integration of sensory inputs from visual, vestibular and somatosensory systems along with the ability to coordinate sensory inputs with motor outputs (Shumway-Cook & Woollacott, 2012). In older adults, when one or more sensory systems are suboptimal or impaired, balance and postural control may be affected (Grace Gaerlan, Alpert, Cross, Louis, & Kowalski, 2012). When one sensory system becomes less reliable, information from the unreliable sensory system is sent to the brain and conflicts with the input from the remaining two sensory systems (Shumway-Cook & Woollacott, 2012). The inputs from the unreliable sensory system are down-regulated and the inputs from remaining two sensory systems are up-regulated. When two or more sensory systems are unreliable, postural control can be further impaired as seen through increased sway and risk of falls (Shumway-Cook & Woollacott, 2012).

As central integration mechanisms decline with age, older adults may experience greater difficulty in reweighing sensory inputs which could lead to declines in postural control when compared to their younger counterparts (Hay *et al.*, 1996). When sensory inputs are absent and later reintroduced, older adults are not able to incorporate the reintroduced sensory inputs as quickly as younger adults (Hay *et al.* 1996). This suggests that the ability to maintain balance and reweigh sensory inputs appropriately is limited by the central integration mechanisms to process the inputs quickly (Hay *et al.*, 1996).

2.2.1 Visual system

The visual system is important as it allows for the ability to process visual information from the environment. To do this, light enters the eyes through a hole in the iris called the pupil. The iris contains both the pupillary sphincter muscles and pupillary dilator muscles, which changes the diameter of the iris to allow different amounts of light to enter the eye. Directly behind the iris is the lens, and it is responsible for focusing images on the retina by changing its shape. The lens is made of capsular fibers that have an elastic property. When the capsular fibers contract, the lens becomes spherical in shape and allows for the ability to focus on nearby objects. In order to focus on further objects, suspensory ligaments that are attached to the lens tighten and flatten the lens. In order to see, light that enters the eye through the pupil passes through the lens and interacts with photoreceptors on the retina. There are two types of photoreceptors: rods and cones. Rods are light sensitive and allow us to see in dimly lit environments while cones allow us to see color. Information from the cones and rods are sent to the optic disc, which is attached to the optic nerve. The two optic nerves (1 from each eye) diverge at the optic chiasm where half of the fibers from one eye cross over to join half of the fibers from the other eye and move down the optic tract to the lateral geniculate. The reason for half of the fibers to cross over is so that visual information from the left side of each retina goes to the left lateral geniculate nucleus and the right side of each retina goes to the right lateral geniculate nucleus. The visual information from the lateral geniculate nucleus then projects to the primary visual cortex in the brain (Martini, Timmons, & Tallitsch, 2009).

2.2.1.1 Visual system and postural control

The visual system provides visual cues and continuously updates the brain about the environment to allow the person to fine-tune their body position (Rossignol, 1996). The ability to maintain postural control requires the ability to accurately judge distance, speed, and direction; plan movement; or avoid obstacles (Rossignol, 1996). When visual inputs are absent, postural stability decreases (as seen through increased sway) which indicates the importance of visual inputs (Poole, 1992; Ricci, de Faria Figueiredo Gonçalves, Coimbra, & Coimbra, 2009; Tomomitsu, Alonso, Morimoto, Bobbio, & Greve, 2013). Visual input can also compensate for other sensory systems; when both vestibular and somatosensory inputs are suboptimal, reliance on visual inputs for postural control increases (Choy, Brauer, & Nitz, 2003). The reliance on visual input also increases as the difficulty of the task increases. Tomomitsu *et al.* (2013) reported when younger adults stand on one leg (a task that placed greater demands on their ability to maintain postural control compared to two legged stance), they are more unstable when visual inputs are absent (eyes closed). During dynamic tasks such as walking, vision also plays a dominant role (Deshpande & Patla, 2005; Tomomitsu *et al.*, 2013).

Vision is often the dominant sensory input used, especially by older adults (Choy *et al.*, 2003; Grace Gaerlan *et al.*, 2012; Hay *et al.*, 1996; Poole, 1992; Redfern *et al.*, 2001; Ricci *et al.*, 2009). Choy *et al.* (2003) found that by the age of 60, women dominantly rely on visual inputs for balance; thus, standing on a firm suface without vision becomes more challenging. Hay *et al.* (1996) compared postural control between younger adults and older adults during quiet stance and found that when visual input is not available, older adults show greater instability than younger adults. The authors suggested that greater instability in older adults may be caused by either greater dependence on visual inputs than their younger counterparts, or the lack of visual input may be more detrimental for older adults due to age-related decline in both the vestibular and somatosensory systems.

2.2.1.2 Age-related morphological and physiological changes in the visual system

Declines in vision start approximately at the age of 50 (Gittings & Fozard, 1986). Age-related morphological declines can be seen in the components of the eye, including loss of elasticity and reduced transparency of the lens (Poole, 1992; Vrensen, 1995). These age-related morphological changes can cause problems such as reduced visual acuity, contrast sensitivity, dark adaptation, depth perception, color discrimination and peripheral vision (Poole, 1992; Sturnieks *et al.*, 2008). Often times, the age-related morphological changes are caused by diseases such as macular degeneration, glaucoma, and cataracts which are common in older adults and reduce visual function (Raju, 2012; Vrensen, 1995).

Loss of visual function can be problematic as visual acuity is important for object detection. Loss of visual contrast sensitivity and depth perception impacts the ability to judge distance and perceive spatial relationships, which are necessary to avoid obstacles and navigate in the environment (Lord & Dayhew, 2001). Impaired vision has an effect on older adults as poor depth perception in this population is a significant risk factor for falls (Lord & Dayhew, 2001). Furthermore, loss of contrast sensitivity decreases the ability to discriminate between objects in the environment and may cause problems such as tripping in older adults (Owen, 1985).

2.2.2 Vestibular System

The vestibular system provides information about head position in space and changes in movement of head direction relative to gravity as it senses linear and angular accelerations (Martini *et al.*, 2009; Rutka, 2004). The vestibular system consists of semicircular canals (i.e., superior, posterior and horizontal), two otolith organs (saccule and utricle) and the vestibular nerve (Martini *et al.*, 2009; Rutka, 2004). These organs make up part of the membranous labyrinth of the inner ear and sit in the bony labyrinth (Martini *et al.*, 2009).

The semicircular canals are largely responsible for detecting angular accelerations (Rutka *et al.*, 2004). There are three semicircular canals on each side, superior, posterior and horizontal, that are positioned at 90 degree angles to each other. The semicircular canals on either side of the head work in conjunction with each other as they are paired to detect head movements/rotations in any direction (Purves *et al.*, 2001; Rutka, 2004). During head movement, the fluid in the membranous labyrinth, known as endolymph, pushes against the cupula, which is attached to the hair cells (Martini *et al.*, 2009). Depending on the movement of the endolymph, hair cells are either stimulated or inhibited, which sends information about head movement to the brain (Martini *et al.*, 2009).

Similar to the semicircular canals, hair cells in the otolith organs help to detect linear acceleration (Martini *et al.*, 2009; Rutka, 2004). The hair cells of the otolith organs are located in the maculae where it also projects into a gelatinous material, the otolithic membrane (Martini *et al.*, 2009). On top of the otolithic membrane is a layer of calcium carbonate crystals called otoliths or otoconia. When the head is in a neutral position, the otoliths rest directly on top of the maculae and push down vertically on the hair cells (Martini *et al.*, 2009). When the head tilts, gravity pushes the otoliths to one side, which causes a bend in the hair cells and signals travel to the brain to indicate that the head is no longer level (Martini *et al.*, 2009). There are two maculae, the utricle macula lies on the horizontal plane, whereas the saccule macula lies on the vertical plane (Shumway-Cook & Woollacott, 2012). Therefore, the utricle detects horizontal head movements and the saccule detects vertical head movements (Martini *et al.*, 2009; Rutka, 2004). Collectively, the otolith organs detect linear acceleration (Martini *et al.*, 2009; Rutka, 2004).

Information from the hair cells in the semicircular canals and otolith organs activate primary sensory neurons which have cell bodies located in the vestibular ganglia or Scarpa’s ganglia (Rutka, 2004). The sensory fibres from the vestibular ganglia form the vestibular branch of the vestibulocochlear nerve (8th cranial nerve) and connect the peripheral vestibular system to the brainstem (Martini *et al.*, 2009; Rutka, 2004).

2.2.2.1 Vestibular system and postural control

The vestibular system plays an important role in providing a reference that is used by both the vision and somatosensory systems to determine appropriate postural control strategies (Raju, 2012). However, when visual and somatosensory information conflict, the vestibular system is used to resolve the conflict and maintain postural control (Raju, 2012). The vestibular system is also responsible for a variety of reflexes that contribute to postural control, which includes the vestibulo-ocular, vestibulo-spinal, vestibulo-collic and vestibulo-sympathetic reflex (Hain & Helminski, 2007; Rutka, 2004). Vestibulo-ocular reflex receives sensory input from both the visual and vestibular system and uses the information to stabilize images on the retina by moving the eyes in opposite direction of the head (Raju, 2012; Rutka, 2004). The vestibulo-spinal reflex is responsible for stabilizing both the head and body through the activation of neck, trunk and limb muscles to maintain an upright posture and to avoid falls (Hain & Helminski, 2007; Sturnieks *et al.*, 2008). Unlike the vestibulo-ocular reflex, the vestibulo-spinal reflex relies heavily on the sensory input from the otolith organs which provides information about linear motion (Hain & Helminski, 2007; Sturnieks *et al.*, 2008). The vestibulo-collic reflex helps to stabilize the head position vertically and counteracts movement sensed by the vestibular organs through activation of neck responses (Sturnieks *et al.*, 2008). The vestibulo-sympathetic reflex plays a role in the activation of the sympathetic system to maintain blood pressure when transitioning to an upright position (Ray & Monahan, 2002; Sauder, Conboy, Chin-Sang, & Ray, 2008; Yates, 2004). All four reflexes, vestibulo-ocular, vestibulo-spinal, vestibulo-collic and vestibulo-sympathetic, collectively contribute to the maintenance of postural control.

2.2.2.2 Age-related morphological and physiological changes in the vestibular system

Age-related morphological declines of the vestibular system begin around the age of 40 and have been observed in the hair cells, neurons, and axons, resulting in decreased vestibular function (Richter, 1980; Rosenhall & Rubin, 1975; Rosenhall, 1973; Sloane, Baloh, & Honrubia, 1989). Significant age-related decline is seen in the number of hair cells and neurons, and axon thickness in older adults (Richter, 1980; Rosenhall & Rubin, 1975; Rosenhall, 1973; Sloane *et al.*, 1989). Compared to younger adults, the number of hair cells in older adults decline by 21% in the utricule macula, 24% in the saccule macula and 40% in the semicircular canal (Rosenhall, 1973). Decline in the number of neurons is most prominent between the ages of 30 to 60, where a peak decline of 5.05% per year is seen at approximately age 44 (Park, Tang, Lopez, & Ishiyama, 2001). Lastly, older adults show approximately 39% reduction in the number of neuron fibers compared to younger and middle aged adults (Bergström, 1973). In terms of axons, age-related changes start at the age of 40 (Engstrom, Bergstrom, & Rosenhall, 1974). Overall, normal aging causes a decrease in the number of hair cells, number of neurons, and axon thickness, which can cause decline of vestibular function (Agrawal *et al.*, 2012; Bergström, 1973; Igarashi, Saito, Mizukoshi, & Alford, 1993; Park *et al.*, 2001; Richter, 1980; Rosenhall, 1973; Sloane *et al.*, 1989)

With advanced age and deterioration of anatomical structures, the function of the vestibular system is impaired. Manchester, Woollacott, Zederbauer-Hylton, & Marin (1989) found that when both visual and somatosensory inputs are suboptimal (experimentally manipulated), older adults lose their balance more often than younger adults. It was suggested that as one ages, there is a loss in redundancy of sensory input and vestibular function which may affect older adults' ability to overcome external perturbations (Manchester *et al.*, 1989). Age-related morphological changes can also cause symptoms such as dizziness, reduced sense of equilibrium (disequilibrium) and vertigo, which interferes with daily activities (Matheson *et al.*, 1999). Vertigo, a type of dizziness, is defined as "the illusory sensation of motion of either oneself or one's surroundings" (Furman & Cass, 1999). There are many pathologies that lead to dizziness causing people to adopt different and sometimes maladaptive strategies (Horak, 2006). Many of these pathologies are more common with increased age such as benign paroxysmal positional vertigo, Menière's disease, and vestibular neuritis, and these can create a sense of imbalance or unsteadiness (Baloh, 2002; Shumway-Cook & Woollacott, 2012). Older adults who adopt different strategies may demonstrate signs of instability and balance problems that can ultimately lead to consequences such as falling (Furman &

Cass, 1999; Raju, 2012; Sturnieks *et al.*, 2008). Also, older adults who experience dizziness may have balance problems during dynamic activities (such as gait) and psychological distress (anxiety, depression, and fear of falling), which often affect older adults to a greater degree (Sloane *et al.*, 1989). The psychological distress that is the fear of falling often causes older adults to reduce the type of daily activities they perform. Over time, this inactivity causes decreased confidence and increased anxiety, which creates a cycle and increases the risk of falls (Matheson *et al.*, 1999).

2.2.3 Somatosensory system

Somatosensory inputs provide feedback about body position and the location of body segments relative to each other and to the support surface (Raju, 2012). Mechanoreceptors such as muscle spindles and Golgi tendon organs relay information regarding proprioception to the brain (Ribeiro & Oliveira, 2007). Muscle spindles provide information about muscle length and velocity of contraction (Shaffer & Harrison, 2007). Golgi tendon organs, located in the muscle tendon, detect tensile force (Shaffer & Harrison, 2007). As a whole, the somatosensory system allows for the detection of joint position and movement which is necessary for postural control (Shaffer & Harrison, 2007).

2.2.3.1 Age-related morphological and physiological changes in the somatosensory system

Age-related morphological declines in the somatosensory system include reduction in the diameter of muscle spindles, number of total intrafusal fibers and chain fibers of certain muscles (Shaffer & Harrison, 2007). Muscle spindles become less sensitive with age, which may cause physiological problems such as loss of sensation, which affects the ability to extract and interpret sensory information necessary to maintain postural control (Redfern *et al.*, 2001; Shaffer & Harrison, 2007). Ribeiro & Oliveira (2007) examined age-related declines in the somatosensory system, and concluded that compared to younger adults, older adults have reduced sensation in the knee, ankle, elbow and finger. Age-related declines of the somatosensory system can result in less accurate detection of joint movement and joint angles, which may increase the risk of falls (Ribeiro & Oliveira, 2007; Shaffer & Harrison, 2007).

2.3 Sensory Interaction

Postural control requires the integration of the sensory inputs from the visual, somatosensory and vestibular systems (Redfern *et al.*, 2001). Although the sensory systems are independent sensory channels, interaction between these systems occurs. During this interaction, sensory inputs from the vestibular system travel to the central nervous system via the vestibular nerve and project onto the vestibular nuclear complex and the cerebellum (Hain & Helminski, 2007; Rutka, 2004). The vestibular nuclear complex (consisting of 4 nuclei: medial, lateral, superior and descending) integrates vestibular inputs with visual and somatosensory inputs along with other inputs from the spinal cord and cerebellum (Goldberg *et al.*, 2012; Hain & Helminski, 2007). This integration of inputs from the visual, vestibular and somatosensory systems allows for reflexes that contribute to postural control. The superior and medial vestibular nuclei receive inputs from the semicircular canals and provide inputs for vestibulo-ocular reflex to control gaze (Goldberg *et al.*, 2012; Hain & Helminski, 2007). The neurons in the superior vestibular nucleus are inhibitory while the neurons in the medial vestibular nucleus are excitatory (Goldberg *et al.*, 2012). The lateral vestibular nucleus receives input from the semicircular canals and the otolith organs and is the dominate nucleus for the vestibulo-spinal reflex allowing for postural reflexes (Goldberg *et al.*, 2012; Hain & Helminski, 2007). The medial vestibular nucleus also provide inputs for the vestibulo-spinal reflex (Hain & Helminski, 2007). Together, the vestibulo-ocular and vestibulo-spinal reflexes allow for the coordination of head, eye and body movements necessary to maintain stability during dynamic tasks such as sit-to-stand (Goldberg *et al.*, 2012; Hain & Helminski, 2007). The descending vestibular nucleus, sometimes called the neural integrator, connects the vestibular nuclear complex with the cerebellum (Hain & Helminski, 2007; Rutka, 2004). The cerebellum receives and provides inputs to the vestibular nuclear complex, calibrates and monitors the vestibular reflexes and readjusts them as necessary. Collectively, the integration of sensory inputs allow for reflexes needed to maintain postural control.

2.3.1 Visual-vestibular interaction

Visual and vestibular inputs can interact (visual-vestibular interaction) to control eye movement and maintain postural control (Ventre, 1985; Wylie, 2009). Vestibular inputs are processed in the vestibular nuclear complex and the cerebellum together with visual inputs (Hain & Helminski, 2007). It is here that visual and vestibular inputs interact to provide a vestibulo-ocular reflex which is used to maintain a stable visual field while the head is in motion (Hain & Helminski, 2007). Head movement is detected by the vestibular system and is sent to the medial and superior vestibular nuclei (part of the vestibular nuclear complex) and the cerebellum (Hain & Helminski, 2007). Excitatory impulses from the brainstem are sent to the oculomotor nuclei which activates the right and medial rectus muscles (Hain & Helminski, 2007). If gaze is not moving at the appropriate speed to accommodate for the head movement, this will cause retinal slips as images cannot be properly focused (Hain & Helminski, 2007). In addition to maintaining a stable visual field during dynamic tasks, visual and vestibular inputs interact to maintain balance. Deshpande & Patla (2007) investigated visual-vestibular interactions during gait and found that visual inputs are predominantly used while vestibular inputs are more prominent only when visual input is either suboptimal or not available.

Age-related declines in both sensory function and central integrative mechanisms negatively affect postural control. Visual-vestibular interactions are crucial for postural control and vestibulo-ocular reflex during dynamic tasks (Ventre, 1985; Wylie, 2009). Optimal function of the vestibulo-ocular reflex is crucial as it allows for the ability to focus images during dynamic tasks such as walking or sit-to-stand. In healthy adults, the retinal slip can be corrected through modification of the firing rate of the neurons in the vestibular nuclei (Hain & Helminski, 2007). However, age-related declines result in decreased accuracy and speed of the vestibulo-ocular reflex (Ito, 1982) which causes older adults to experience difficulty in maintaining gaze during head movement. This difficulty arises from an inability to focus an image on the retina (Bruenech & Haugen, 2012; Rutka, 2004). Retinal slip can lead to balance problems as it affects the quality of visual inputs, which may lead to falls (Bruenech & Haugen, 2012; Crane & Demer, 1997; Honaker & Shepard, 2010; Rutka, 2004).

2.4 Sensory Manipulation

Sensory manipulation techniques have been used either in combination or alone to understand the function of one or more sensory systems (Deshpande & Patla, 2005; Fitzpatrick & Day, 2004; Hay *et al.*, 1996; Polastri, Barela, Kiemel, & Jeka, 2012). Sensory manipulation has been used in various populations including healthy younger adults (to examine the role of sensory inputs), older adults (to understand age-related declines), and populations with pathology (to understand the effect of the illness) (Deshpande & Patla, 2005; Murray, Hill, Phillips, & Waterston, 2005; Serrador, Lipsitz, Gopalakrishnan, Black, & Wood, 2009).

2.4.1 Visual manipulations

Several techniques have been used to alter visual input to better understand how humans use visual inputs for postural control. These methods include removal of visual input (eyes closed) or alteration in the quality of visual information (Hunter & Hoffman, 2001). Two commonly used visual manipulations that alter visual input include liquid-crystal goggles (Hay *et al.*, 1996; Mohagheghi, Moraes, & Patla, 2004; Oudejans &

Coolen, 2003), and blurring goggles (Bochsler, Legge, Kallie, & Gage, 2012; Deshpande & Patla, 2007; Novak & Deshpande, 2011).

Liquid-crystal goggles allow the experimenter to control the availability of visual input to the participant through the transparency of the lens (Mohagheghi *et al.*, 2004). When the lens are opaque, participants receive no visual input regarding their surroundings or body movement (Mohagheghi *et al.*, 2004). The advantages of liquid-crystal goggles include the ability to precisely determine when visual inputs are available or removed, and the ability to program or manually control the level of transparency of the goggles (Mohagheghi *et al.*, 2004; Oudejans & Coolen, 2003).

Unlike liquid-crystal goggles where visual inputs are either available or removed, blurring goggles interfere with the quality of visual information. For example, Bochsler *et al.* (2012) used vision blurring goggles and reported that both visual acuity and contrast sensitivity are reduced in participants. Another type of blurring goggles specifically simulate the effects of cataracts, a prevalent disease in older adults (Deshpande & Patla, 2007; Novak & Deshpande, 2011). People with cataracts have decreased visual acuity, depth perception, and contrast sensitivity, all of which can increase the risk of falls (Hodge *et al.*, 2007; Honaker & Shepard, 2010).

2.4.2 Vestibular Manipulation

Galvanic vestibular stimulation has been used to manipulate vestibular input and provide suboptimal vestibular information (Bent *et al.*, 2000; Chang, Cheng, & Young, 2010; Day, Séverac Cauquil, Bartolomei, Pastor, & Lyon, 1997; Deshpande & Patla, 2005, 2007; Lepecq *et al.*, 2006; Son, Blouin, & Inglis, 2008). Galvanic vestibular stimulation is a technique where an electrical current is sent through a set of electrodes that are placed on the mastoid processes of the participant (the site at which the vestibular nerve is most superficial) (Bent, McFadyen, & Inglis, 2004; Day *et al.*, 1997; Deshpande & Patla, 2007). The electrical current causes an increased firing rate of the afferent signals of the vestibular nerve in the cathode side and decreased firing rate on the anode side (Goldberg, Smith, & Fernandez, 1984). The imbalance created by the galvanic vestibular stimulation induces a body tilt towards the side of the anode electrode when standing (Day *et al.*, 1997; Fitzpatrick, Wardman, & Taylor, 1999) and a deviation in path trajectory towards the anode electrode when walking (Bent *et al.*, 2000; Deshpande & Patla, 2007).

2.5 Mediolateral and Anteroposterior Stability

The ability to maintain postural control in both the mediolateral and anteroposterior directions is crucial for successful completion of sit-to-stand. Therefore, the inability to control mediolateral stability causes problems in postural control which increases the risk of falls (Maki, Holliday, & Topper, 1994). Older adults who have a history of falls demonstrate an increased sway in the mediolateral direction (Lord, Rogers, Howland, & Fitzpatrick, 1999; Maki *et al.*, 1994). Additionally, Serrador *et al.* (2009) found that subjects who fell during a balance test had greater sway in both the mediolateral and anteroposterior directions. Mediolateral sway during standing with eyes closed has been shown to be a good predictor of future falls in older adults without a recent history of falling (Maki *et al.*, 1994). In addition, Hilliard *et al.* (2008) also demonstrated that mediolateral stepping performance is a significant predictor of future falls in community-dwelling older adults. The ability to control mediolateral stability may deteriorate faster than anteroposterior stability, as seen through functional and lateral reach tests (Hilliard *et al.*, 2008).

The vestibular system has been suggested to play a critical role in the maintenance of mediolateral stability. In particular, decreased utricular otolith-ocular function has been linked to increased mediolateral sway in older adults (Serrador *et al.*, 2009). In order to investigate vestibular function, the application of galvanic vestibular stimulation has been used to manipulate vestibular input. Postural sway elicited by galvanic vestibular stimulation can also be used to counteract mechanical perturbations and reduce mediolateral sway (Scinicariello, Eaton, Inglis, & Collins, 2001). Scinicariello *et al.* (2001) suggested that similar methods may also be used to reduce anteroposterior sway caused by mechanical perturbations.

Although most studies focused on the importance of mediolateral stability during standing (Choy *et al.*, 2003; Hilliard *et al.*, 2008; Lord *et al.*, 1999; Maki *et al.*, 1994; Melzer, Benjuya, & Kaplanski, 2004), it is important to also investigate anteroposterior stability with respect to sit-to-stand. During sit-to-stand, adequate anteroposterior stability is necessary as the task requires the person to safely and effectively control his/her body acceleration in the anteroposterior direction. Du Pasquier *et al.* (2003) found that the anteroposterior center of pressure velocity during a two-legged stance is also a reliable method to assess age-related decline in postural stability. Maki, Holliday, & Topper (1991) found that older adults with a fear of falling have greater anteroposterior center of pressure displacement during spontaneous sway without visual input than those with no fear of falling. Thus, it is important also to examine anteroposterior stability in addition to mediolateral stability in older adults with respect to the sit-to-stand task.

2.6 Hypothesis

Within in this study, three hypotheses were tested:

1. Older adults will have a decreased global performance of sit-to-stand, increased mediolateral instability and increased anteroposterior instability
2. Vestibular inputs plays a critical role in maintaining postural control during sit-to-stand as vestibular manipulations will have an effect on the outcome measures
3. A scaling effect of both visual and vestibular manipulations will be seen

2.7 Specific Objectives

The objectives of this study were to:

1. compare sit-to-stand performance between younger and older adults through a global performance measure (transition phase duration), mediolateral stability measures (trunk roll angle, center of mass displacement and center of pressure displacement) and anteroposterior stability measures (peak braking force, trunk pitch and peak anteroposterior center of mass velocity)

2. understand the effects of sensory manipulations when performing sit-to-stand with no visual input (eyes closed), suboptimal visual input (wearing vision blurring goggles) and suboptimal vestibular inputs (galvanic vestibular stimulation)
3. investigate visual-vestibular interactions while performing sit-to-stand with both visual (no vision and suboptimal vision) and vestibular (galvanic vestibular stimulation) manipulations
4. understand scaling effects of both visual and vestibular manipulations using 3 levels of visual (normal vision, suboptimal vision and no vision) and 3 levels of vestibular (no galvanic vestibular stimulation, galvanic vestibular stimulation at participant’s threshold and 2-times threshold intensity) conditions

Chapter 3

Methods

3.1 Participants

A total of 15 younger (20-30 years of age) and 15 older (>60 years of age) healthy adults participated in this quasi-experimental design study. Participants were recruited via word of mouth and using a pre-existing contact list within the Motor Performance Lab. Individuals were excluded if they had a history of vision disorders (such as uncorrected cataracts or glaucoma), neuromuscular diseases (such as stroke or Parkinson's), vestibular disorders or had more than one idiopathic fall in the last year. An idiopathic fall was classified as a fall that occurred due to an unknown cause and was not the result of any abnormalities (Dominguez & Bronstein, 2000).

Participants were also excluded if they had a Mini-Mental State Examination Score of less than 24/30, Center for Epidemiologic Studies Depression Scale score above 16/60 and Activities-specific Balance Confidence Scale score less than 67%. The Mini-Mental State Examination (Appendix D) was used to ensure that none of the participants had signs of cognitive impairment (Folstein, Folstein, & McHugh, 1975; Rovner & Folstein, 1987). The Center for Epidemiologic Studies Depression Scale (Appendix E) was used to screen for depression where a score above 16 suggests clinically relevant depressive symptoms (Radloff, 1977). It has been reported that people with depression are associated with reduced walking speed, delayed reaction times and longer time required to execute motor movements (Kvelde *et al.*, 2013; Lord, Clark, & Webster, 1991). Activities-specific Balance Confidence Scale (Appendix F) was used to determine balance confidence of participants when performing activities of daily living where a score of less than 67% indicates a risk of falls for older adults (Lajoie & Gallagher, 2004; Powell & Myers, 1995). The Mini-Mental State Examination, the Center for Epidemiologic Studies Depression Scale and the Activities-specific Balance Confidence Scale were all administered by the same person.

Participants signed an informed consent (Appendix A) and video consent form (Appendix B) approved by the Queen’s University Health Sciences Research Ethics Board (Appendix C).

3.2 Sensory Manipulations

Visual input was manipulated using custom-made vision blurring goggles that were sand-treated in the optometry laboratory at the University of Waterloo to simulate the effects of severe cataracts (Deshpande & Patla, 2007). Blurring goggles fit comfortably on top of corrective lens. On randomly selected trials, participants were instructed to perform trials with either normal vision (eyes open), suboptimal visual input (vision blurring goggles), or no visual input (eyes closed).

Vestibular input was manipulated by administering percutaneous bipolar galvanic vestibular stimulation to the participants using the Grass S48 Square Pulse Stimulator (Grass Medical Instruments, MA, USA). Self-adhesive electrodes (Bystat, St. Laurent, QC, Canada) were placed on both mastoid processes with the anode electrode placed on the right mastoid process. Galvanic vestibular stimulation causes an increased firing rate of the afferent signals of the vestibular nerve on the side with the cathode electrode (left) and decreased firing rate on the side with the anode electrode which causes an experimental imbalance in the vestibular input to the brain (Fitzpatrick & Day, 2004; Goldberg *et al.*, 1984). The imbalance created by the galvanic vestibular stimulation induces a body tilt towards the side of the anode electrode when standing (Day *et al.*, 1997; Fitzpatrick *et al.*, 1999) and a deviation in path trajectory towards the anode electrode when walking (Bent *et al.*, 2000; Deshpande & Patla, 2007). The onset of galvanic vestibular stimulation induces sudden initial postural instability; therefore, the verbal cue to commence the sit-to-stand task was given two seconds after the galvanic vestibular stimulation was initiated allowing for the effects of galvanic vestibular stimulation to stabilize prior to the start of the task (Deshpande & Patla, 2007). On randomly selected trials, participants had either non-perturbed vestibular information (no galvanic vestibular stimulation), or perturbed vestibular information at individualized threshold intensity (1xGVS) or two times individualized threshold intensity (2xGVS). Both levels of galvanic vestibular stimulation were square wave pulse stimulations and were given for 10 seconds (Bent *et al.*, 2000; Lepecq *et al.*, 2006). Two levels of galvanic vestibular stimulation were used to understand scaling effect of vestibular manipulation on sit-to-stand performance, aging and visual manipulation (Deshpande & Patla, 2007).

Prior to testing, the threshold intensity for each participant was determined by applying galvanic vestibular stimulation with the participant standing, feet shoulder width apart and eyes closed. The current level was slowly increased until the first visually observed sway of the participant towards the side of the anodal electrode (right side). Maximum galvanic vestibular stimulation current for 2xGVS was capped at 1.2 mAmp. Mean threshold intensity was 0.31 mAmp (0.14 – 0.62 mAmp) for younger adults and 0.29 mAmp (0.13 – 0.77 mAmp) for older adults. 2xGVS was capped for one younger and one older adult. There was no significant difference in the threshold intensity between younger adults and older adults. Galvanic vestibular stimulation intensity at two times the participant's threshold level has been used before in both younger adults and older adults to manipulate vestibular input and have been well tolerated with little to no side effects (Bent *et al.*, 2000; Deshpande & Patla, 2007; Lepecq *et al.*, 2006).

Participants performed sit-to-stand with visual (eyes open, wearing vision blurring goggles, or eyes closed) and vestibular (no galvanic vestibular stimulation, 1xGVS, 2xGVS) manipulations. Experimental conditions were performed in a randomized order (both visual and vestibular manipulations were randomized) and included the following 9 conditions: (1) eyes open no galvanic vestibular stimulation, (2) eyes open 1xGVS, (3) eyes open 2xGVS, (4) eyes blurred no galvanic vestibular stimulation, (5) eyes blurred 1xGVS, (6) eyes blurred 2xGVS, (7) eyes closed no galvanic vestibular stimulation, (8) eyes closed 1xGVS, and (9) eyes closed 2xGVS. Each condition was performed twice, consecutively, for a total of 18 trials. The Borg's Rating of Perceived Exertion was used to ensure participants did not experience fatigue after all 18 trials were completed (Borg, 1970).

3.3 Instrumentations

The OPTOTRAK 3020 system (Northern Digital, Waterloo, ON, Canada) with two arrays of optoelectronic motion tracking cameras was used to obtain kinematic data. Rigid marker clusters with infrared light emitting diodes (IREDs) were placed bilaterally on the top of the foot, mid-shank and mid-thigh as well as on the 4th lumbar vertebra and 7th cervical vertebra. Six single IREDs were also used and placed at the vertex of the head, 12th thoracic vertebra (rough estimate as a midpoint between the 12th ribs) and bilaterally on the top of the ears and acromion processes of the scapula. Placement of IREDs can be seen in the diagram in Figure 2. Data from cluster IREDs allow for the detection of the orientation and three dimensional marker location of each leg segment, pelvis and trunk. With the participant standing, a probe with four IREDs was used to landmark anatomical points (both right and left 1st and 5th metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanter, anterior superior iliac spine, and the tip of the acromion process of the scapula) to determine joint centers and planes and axes of motion. Previously developed pipelines within C-motion analysis software were used to obtain outcome measures. Anthropometric (height and weight) and kinematic data were used to calculate the position of the center of mass during sit-to-stand.

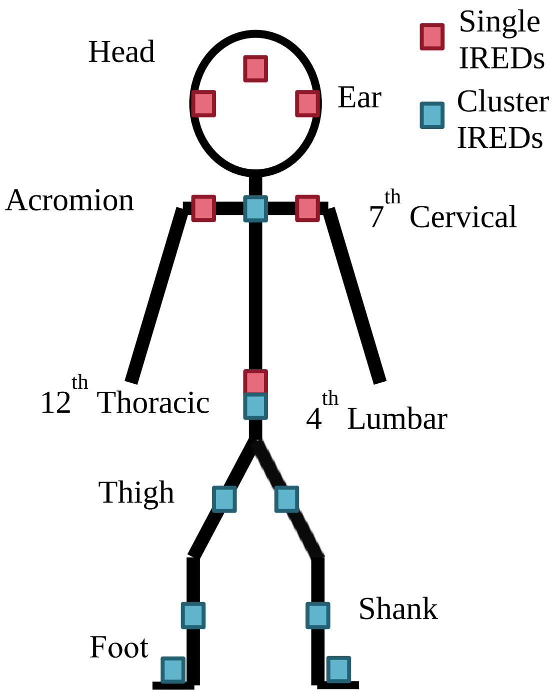

Figure 2 Single and cluster IRED placement.

Force plates (Advanced Medical Technology, Inc., Watertown, Massachusetts, USA) were used to collect the ground reaction force data. A total of three force plates were used, one was placed under the chair and one under each foot. Force data from the force plates under the two feet were combined. Force data in both the mediolateral and anteroposterior direction were used to calculate position and movement of center of pressure and peak braking force during sit-to-stand.

3.4 Data Processing

Force plate data, collected at 100 Hz, and OPTOTRAK data, collected at 50 Hz (Benvenuti *et al.*, 1999; Hoozemans, Slaghuis, Faber, & van Dieën, 2007), were synchronized in C-Motion. This method of collecting force plate and OPTOTRAK data has been previously used in the Motor Performance Lab, Queen’s University. All data were interpolated and filtered with a low-pass, dual-pass Butterworth filter with a cut-off frequency of 12 Hz to reduce noise from the signal. A cut-off frequency of 6 Hz was initially used; however, after visual comparison of both 6 and 12 Hz filtered data, a cut-off frequency of 12 Hz was selected.

3.5 Outcome Measures

3.5.1 Main outcome measures

3.5.1.1 Global Performance

The global performance of sit-to-stand was assessed using the transition phase duration. The total time needed to complete the transition phase was measured in seconds. Again, the transition phase of sit-to-stand occurred from maximum anteroposterior center of mass velocity to maximum vertical center of mass velocity. It is during the transition phase that one needs to transition from a 3-point base of support to a 2 point base of support. As a result of the reduced base of support, the transition phase is of interest as it is the most unstable phase of sit-to-stand. Representative profiles of younger adults and older adults for transition phase duration at baseline condition (eyes open, no galvanic vestibular stimulation) are displayed in Figure 3.

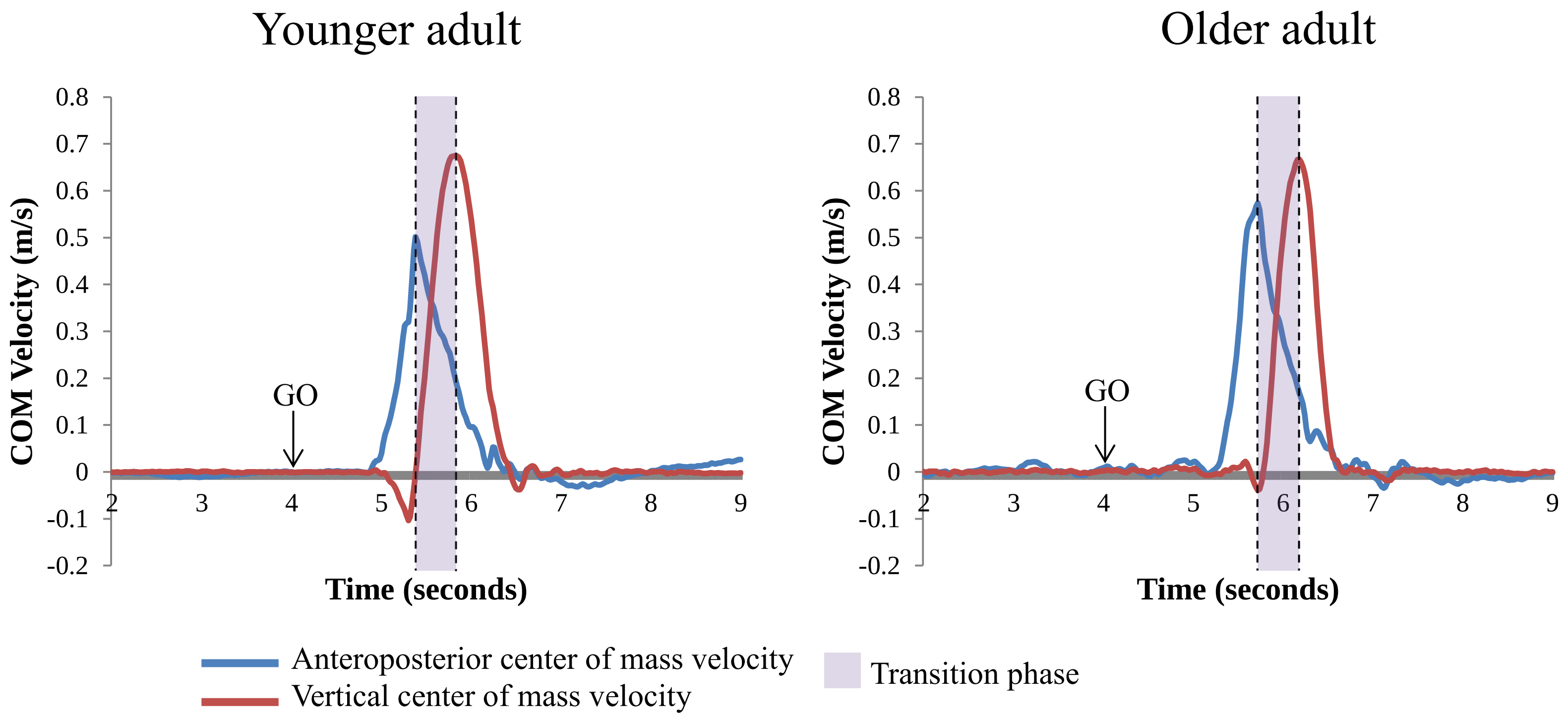

Figure 3 Representative profiles of younger adults and older adults for transition phase duration baseline condition (eyes open, no galvanic vestibular stimulation).

The transition phase (measured in seconds) was delineated using the peak center of mass velocity in the anteroposterior direction and the peak center of mass velocity in the vertical direction. The dotted lines on the graph delineate the start and end of the transition phase.

3.5.1.2 Postural Stability in the Mediolateral Direction

Three outcome measures, trunk roll angle, mediolateral center of mass displacement and mediolateral center of pressure displacement were used to depict postural stability in the mediolateral direction. Representative profiles of younger adults and older adults for trunk roll angle, center of mass displacement and center of pressure displacement at baseline condition (eyes open, no galvanic vestibular stimulation) are displayed in Figures 4, 5 and 6 respectively. Each outcome measure provided information regarding different aspects of postural stability in the mediolateral direction. Trunk roll angle allowed for the direct analysis of trunk control whereas mediolateral center of mass displacement allowed for analysis of total body control in the mediolateral direction. Mediolateral center of pressure displacement provided information regarding the participant’s ability to manipulate center of mass in the mediolateral direction with respect to the base of support limits (Winter, Prince, Frank, Powell, & Zabjek, 1996; Winter, 1995).

To analyze stability, peak-to-peak calculations were used as it provided information regarding displacement. Peak-to-peak was calculated as the difference between maximum and minimum value and was confirmed visually. Generally, the greater the displacement seen in each outcome measure, the greater instability of the participant when performing sit-to-stand. Although the peak-to-peak displacement provided information about the change in position of each outcome measure, the raw data provided directional information about motion of the participant throughout the entire task (i.e. if movement was towards the right or the left).

3.5.1.2.1 Trunk Roll Angle

Trunk roll angle is defined as the movement of the trunk segment along the frontal plane about the anteroposterior (sagittal) axis (Bent, Inglis, & McFadyen, 2002; Fitzpatrick & Day, 2004). The three single IRED markers placed on the right and left acromion processes and the 12th thoracic vertebra were used to calculate trunk roll angle using the following formula:

$$Absolute\ trunk\ roll\ angle$$
$$= arctan(\frac{\left(\frac{y\ Right\ Acromion - y\ Left\ Acromion}{2}\right) - y\ T12}{\left(\frac{z\ Right\ Acromion - z\ Left\ Acromion}{2}\right) - z\ T12})$$

y = is the location of the specific marker in the mediolateral direction

z = is the location of the specific marker in the vertical direction

T12 = 12th thoracic vertebra single IRED marker

Right acromion = Right acromion IRED marker

Left acromion = Left acromion IRED marker

Trunk roll angle was calculated as it indicates trunk tilt in the frontal plane. A reference angle was taken by averaging the trunk roll angle between 1 to 1.5 seconds as this was when the person was sitting. Relative trunk roll angle was then calculated by using the following formula:

$$Relative\ trunk\ roll\ angle = absolute\ trunk\ roll\ angle - reference\ trunk\ roll\ angle$$

Peak-to-peak trunk roll angle was reported in degrees. The trunk was of particular interest as it is the largest body segment and precise trunk control is essential to maintain an upright posture following perturbation to balance (Marigold & Misiaszek, 2009). As well, in the absence of visual information, the galvanic vestibular stimulation has been known to induce trunk roll towards the anodal direction as a compensatory response in absence of vision (Day *et al.*, 1997). Furthermore, the direction of sway for individuals with vestibular deficit is mainly in the roll plane (side to side) (Allum *et al.*, 2001). Trunk roll angle has been used previously as a measure to investigate the effects of aging on postural control (Deshpande & Patla, 2005, 2007; Goutier, Jansen, Horlings, Küng, & Allum, 2010).

3.5.1.2.2 Mediolateral Center of Mass Displacement

The cluster IREDs coordinates were used to calculate total body center of mass position during the task of sit-to-stand. The formula used to calculate total body center of mass was similar to that used by Winter (1990):

$$Total\ body\ COM = \frac{\sum_i (m_i y_i)}{\sum_i m}$$

y_i= coordinates in the mediolateral direction

m_i= is the mass of each segment

Center of mass displacement (in centimeters) in the mediolateral direction was calculated as the peak-to-peak center of mass deviation of the participant.

3.5.1.2.3 Mediolateral Center of Pressure Displacement

Using force plate data, center of pressure was measured in centimeters. Peak-to-peak center of pressure displacement was calculated in the mediolateral direction. The formula used to calculate center of pressure in the mediolateral direction was similar to that used Winter *et al.* (1996):

$$COP_{net}(t) = COP_l(t)\left[\frac{R_{vl}(t)}{R_{vl}(t) + R_{vr}(t)}\right] + COP_r(t)\left[\frac{R_{vr}(t)}{R_{vl}(t) + R_{vr}(t)}\right]$$

$COP_{net}(t)$ = net center of pressure measured in the mediolateral direction

$COP_l(t)$= center of pressure under the left foot

$COP_r(t)$= center of pressure under the right foot

$R_{vl}(t)$= vertical reaction forces under the left foot

$R_{vr}(t)$= vertical reaction forces under the right foot

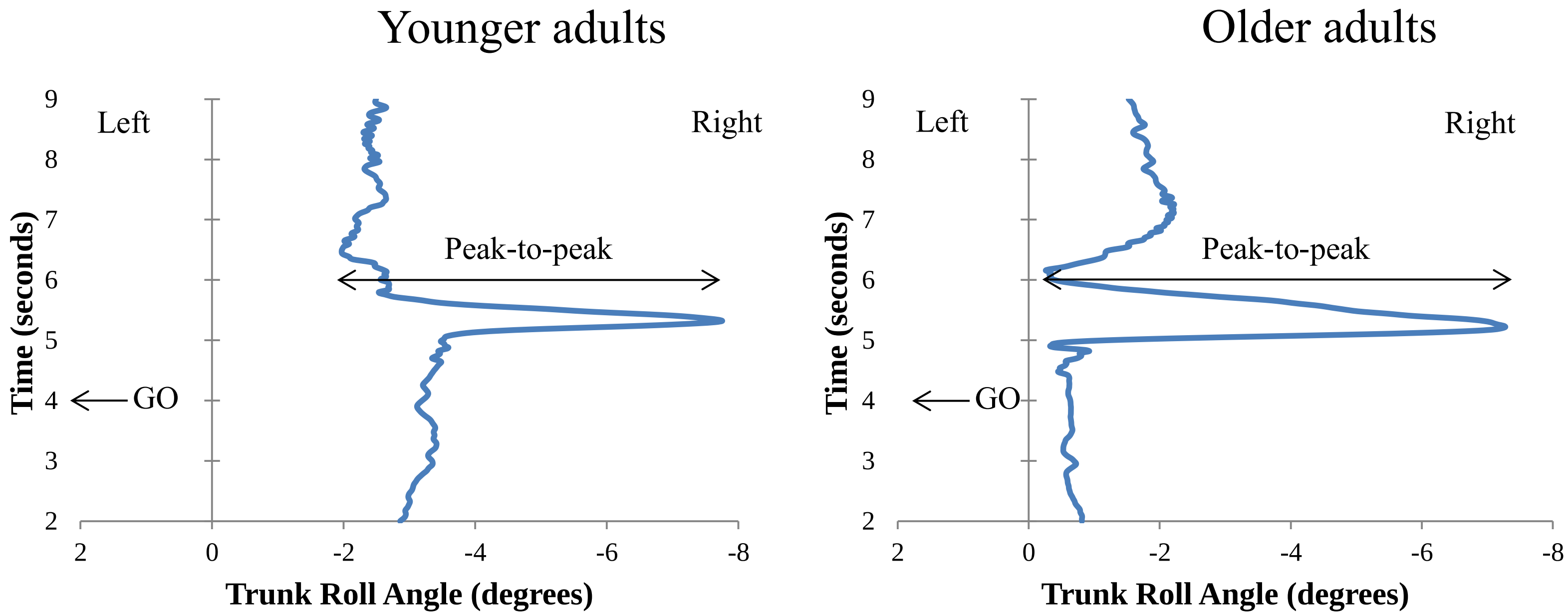

Figure 4 Representative profiles of younger adults and older adults for trunk roll angle at baseline condition (eyes open, no galvanic vestibular stimulation).

The positive values on the horizontal axis indicated movement towards the left while the negative values indicated movement towards the right. Trunk roll angle is defined as the movement of the trunk segment along the frontal plane about the anteroposterior (sagittal) axis. Peak-to-peak trunk roll angle was calculated and reported in degrees.

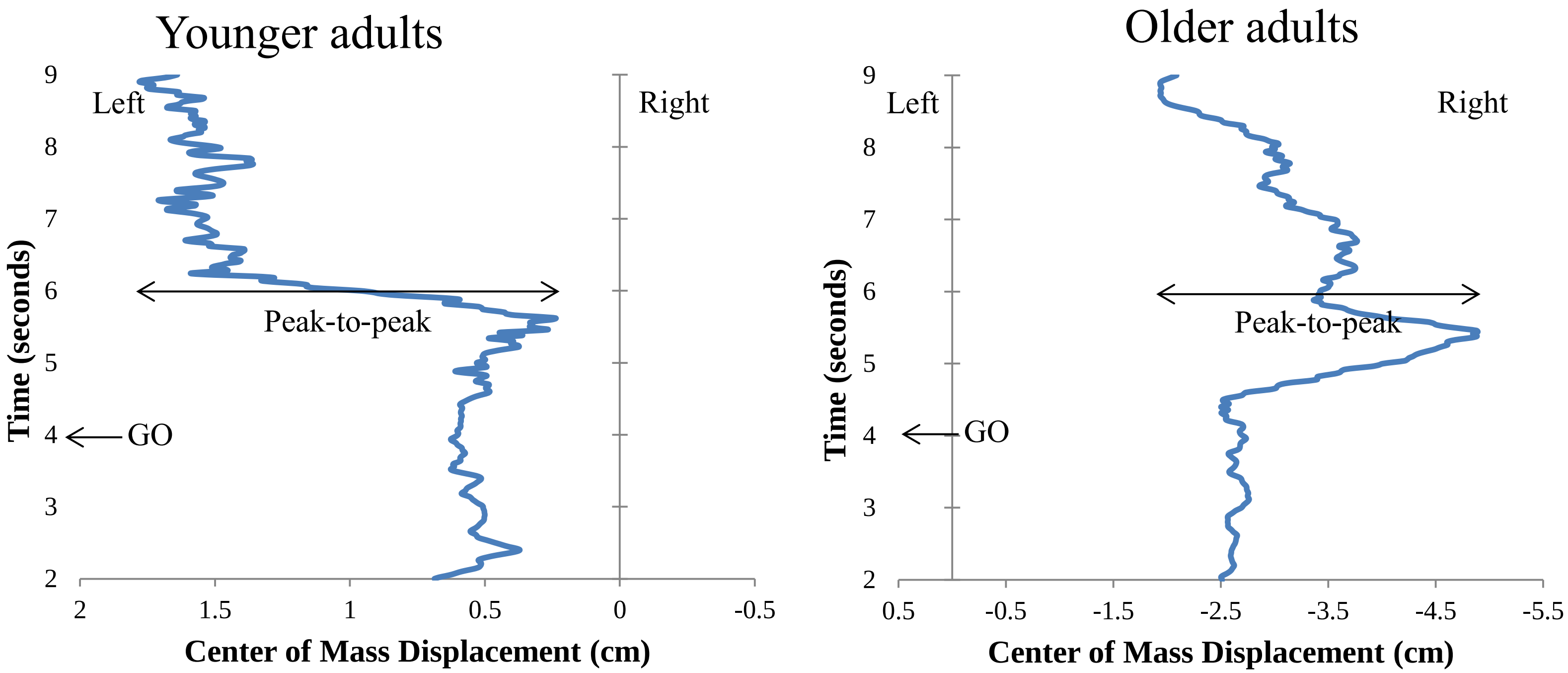

Figure 5 Representative profiles of younger adults and older adults for mediolateral center of mass displacement at baseline condition (eyes open, no galvanic vestibular stimulation).

The positive values on the horizontal axis indicated movement towards the left while the negative values indicated movement towards the right. Mediolateral center of mass displacement (in centimeters) was calculated as the peak-to-peak center of mass deviation of the participant.

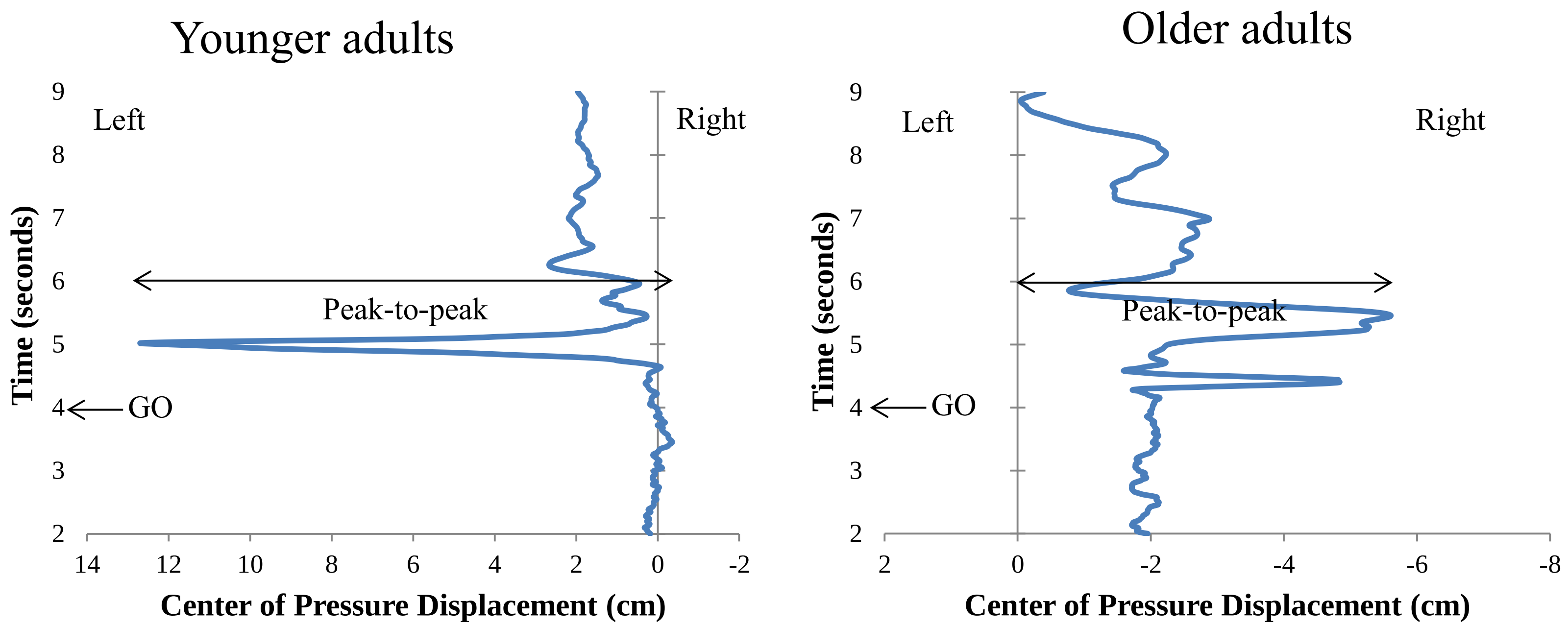

Figure 6 Representative profiles of younger adults and older adults for mediolateral center of pressure displacement at baseline condition (eyes open, no galvanic vestibular stimulation).

The positive values on the horizontal axis indicated movement towards the left while the negative values indicated movement towards the right. Mediolateral center of pressure displacement (in centimeters) was calculated as the peak-to-peak center of pressure deviation of the participant.

3.5.1.3 Postural stability in the Anteroposterior Direction

Three outcome measures, peak braking force, trunk pitch angle and anteroposterior center of mass velocity were used to determine postural stability in the anteroposterior direction. Representative profiles of younger adults and older adults for peak braking force, trunk pitch angle and anteroposterior center of mass velocity at baseline condition (eyes open, no galvanic vestibular stimulation) are shown in Figures 7, 8 and 9 respectively.

3.5.1.3.1 Peak Braking Force

Braking force is the force generated to counteract anteroposterior movement during sit-to-stand and prevent falling (Oates, Patla, Frank, & Greig, 2005). The forces calculated from the two force plates that were placed under each foot were summed and peak braking force was calculated as the maximum horizontal force in the negative direction (Oates *et al.*, 2005).

3.5.1.3.2 Trunk Pitch Angle

Trunk pitch angle is defined as the angle along the sagittal plane in the vertical axis (Marigold & Patla, 2008). The 3 single IRED markers placed on the right and left acromion processes and the 12th thoracic vertebra were used to calculate trunk pitch angle. The formula used to calculate trunk pitch angle was:

$$Absolute\ trunk\ pitch\ angle$$

$$= arctan(\frac{\left(\frac{X\ Right\ Acromion - X\ Left\ Acromion}{2}\right) - X\ T12}{\left(\frac{Z\ Right\ Acromion - Z\ Left\ Acromion}{2}\right) - Z\ T12})$$

x = is the location of the specific marker in the anteroposterior direction

z = is the location of the specific marker in the vertical direction

T12 = 12th thoracic vertebra single IRED marker

Right acromion = Right acromion IRED marker

Left acromion = Left acromion IRED marker

Trunk pitch angle was calculated as it is a crucial movement for performing the task of sit-to-stand. A reference angle was taken by averaging the trunk pitch angle between 1 to 1.5 seconds as this was when the person was sitting. Relative trunk pitch angle was then calculated by using the following formula:

$$Relative\ trunk\ pitch\ angle$$

$$= absolute\ trunk\ pitch\ angle - reference\ trunk\ pitch\ angle$$

Peak-to-peak trunk pitch angle was reported in degrees.

3.5.1.3.3 Peak Anteroposterior Center of Mass Velocity

Anteroposterior center of mass velocity was calculated by taking the first derivative of the total body center of mass displacement in the anteroposterior direction. Peak anteroposterior center of mass velocity was then identified as the maximum velocity in the anteroposterior direction. Peak anteroposterior center of mass velocity was of interest as it was used to delineate the start of the transition phase as well as the fact that higher speeds will generate greater momentum in the anteroposterior direction.

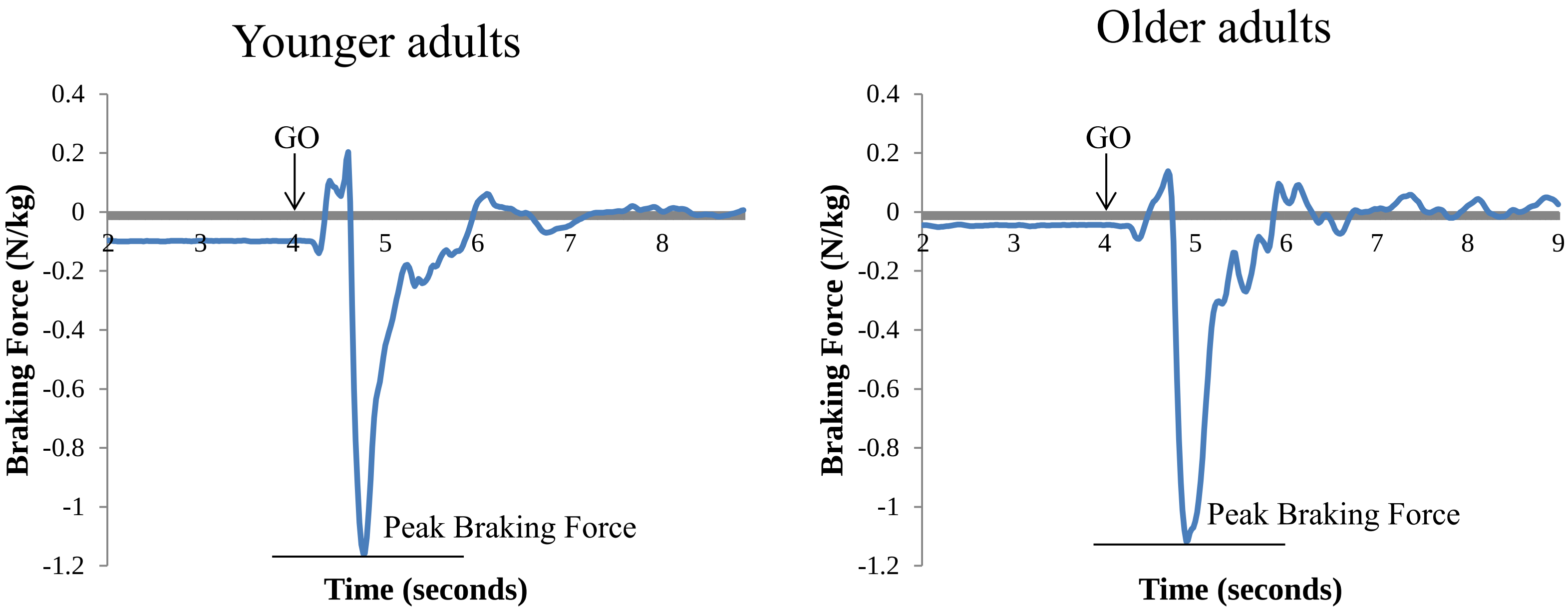

Figure 7 Representative profiles of younger adults and older adults for peak braking force at baseline condition (eyes open, no galvanic vestibular stimulation).

The forces calculated from the two force plates that were placed under each foot were summed and peak braking force was calculated as the maximum horizontal force in the negative direction reported in Newtons/kg.

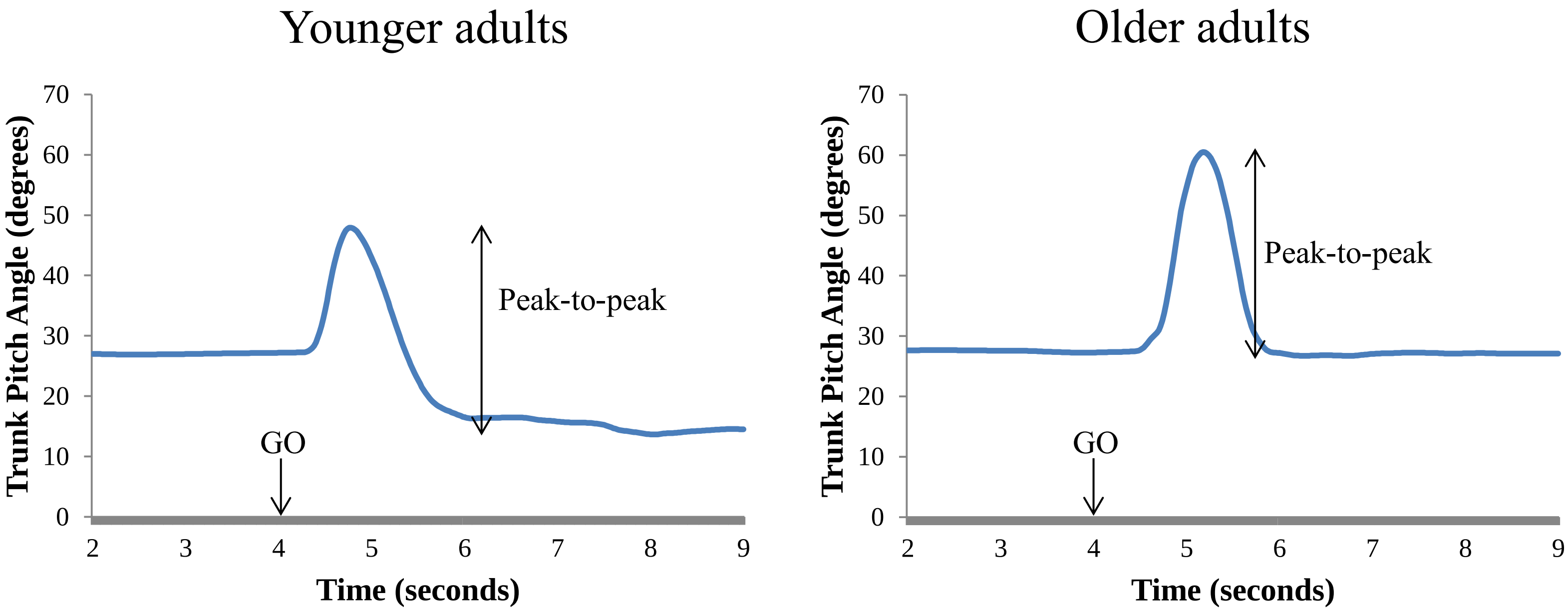

Figure 8 Representative profiles of younger adults and older adults for trunk pitch angle at baseline condition (eyes open, no galvanic vestibular stimulation).

Trunk pitch angle is defined as the movement along the sagittal plane in the vertical axis. Peak-to-peak trunk pitch angle was calculated and reported in degrees.

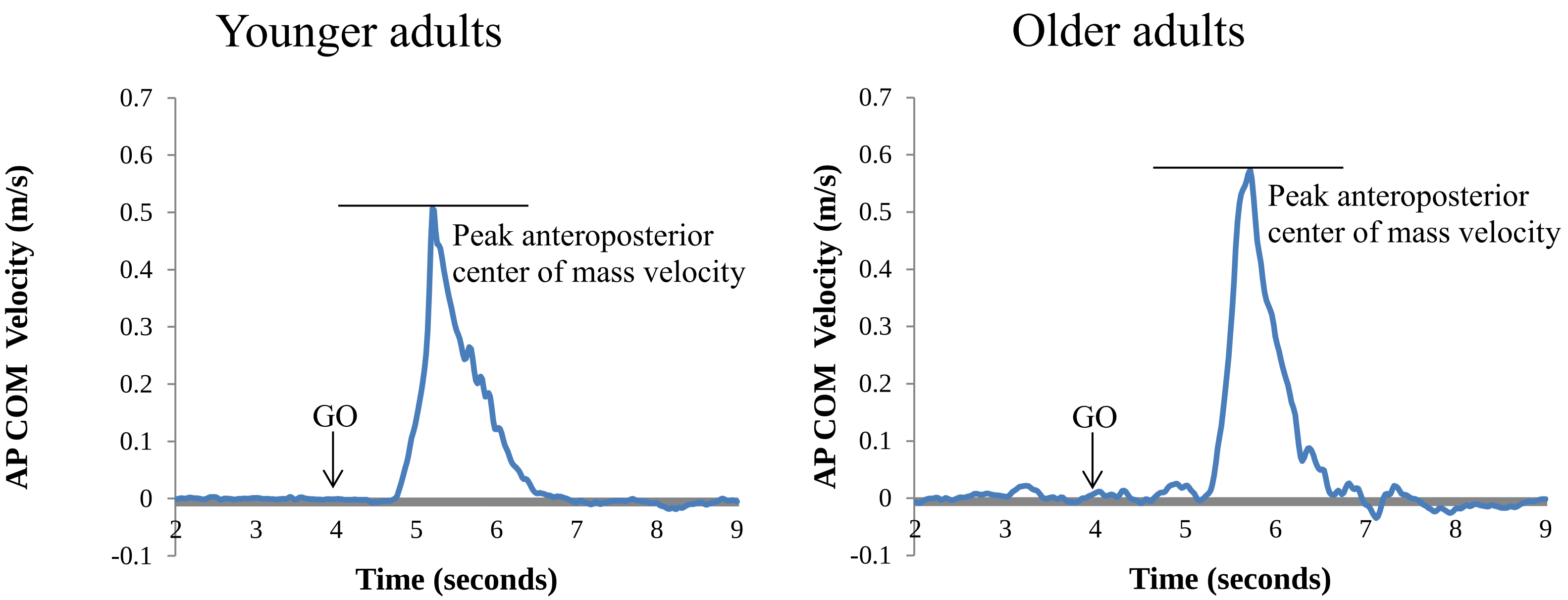

Figure 9 Representative profiles of younger adults and older adults for peak anteroposterior center of mass velocity at baseline condition (eyes open, no galvanic vestibular stimulation).

Anteroposterior center of mass velocity was calculated by taking the first derivative of the total body center of mass position in the anteroposterior direction. Peak anteroposterior center of mass velocity was then identified as the maximum velocity in the anteroposterior direction reported in meters/second.

3.5.2 Descriptive Measures

Descriptive measures included base of support measurement and the Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 Balance Test (Appendix G). Base of support was measured as the distance between the two medial malleoli. The Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 was used to quantify standing balance (Rossiter-Fornoff, Wolf, Wolfson, & Buchner, 1995). The participant was required to stand in 4 different positions where the feet were placed at parallel, semi-tandem, full tandem and single limb stance. A sub-score was given for each task using a scale of 0 to 4 (where 0 represents needs help to prevent loss of balance and 4 represents ability to remain in desired position for 10 seconds safely) (Rossiter-Fornoff *et al.*, 1995). A higher overall score indicated better static balance (Rossiter-Fomoff *et al.*, 1995). Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 challenges balance as base of support is reduced as one progress throughout the test. Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 incorporates a sensory component with having visual inputs either available or absent. Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 was always administered by the same person.

3.6 Protocol

The experiment was performed at the Motor Performance Laboratory at Queen’s University, Kingston, Canada. Upon arrival to the lab, participants signed the informed consent and video consent forms. Participant demographics (age, height, weight, and sex), descriptive measures (base of support, and Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 score) and medical history were recorded prior to data collection. All participants completed the Mini-Mental State Examination, the Center for Epidemiologic Studies Depression Scale and the Activities-specific Balance Confidence Scale which were used as screening tools. After screening, participants were instrumented with both the single and cluster the IREDs as outlined in Figure 2. Next, 2 electrodes (anode and cathode) were placed on both mastoid processes of the participant. The anode electrode was always placed on the right mastoid process of the participant. Threshold intensity was determined by gradually increasing the galvanic vestibular stimulation until first visually observed sway towards the anode electrode was seen in the participant.

A backless armless chair was used for the task of sit-to-stand and was set at a standard height of 46cm. Through a series of 2-3 practice trials, participant's self-selected foot position was recorded as the distance between the two medial malleoli. This base of support was outlined using tape and maintained throughout the entire testing session. As the testing commenced, participants were instructed to fold their arms across their chest and rise as quickly as possible when the examiner gave a verbal instruction of "go" for all trials. Four seconds of baseline data were obtained prior to the instruction of "go". For the entire testing sessions, there were a total of 18 sit-to-stand trials in a randomized order and rest periods between each trial was given as needed. The Borg's Rating of Perceived

Exertion Scale was administered at the end of all 18 trials. The entire testing session took approximately two hours.

3.7 Data Analysis

Statistical analyses were performed using the SPSS Statistic Version 20 (SPSS Inc., San Rafael, CA). Independent *t*-tests were performed to compare participant demographics and descriptive measures between younger adults and older adults. Paired *t*-tests were conducted to determine if the data from trial 1 and 2 in the same experimental condition were significantly different. If no significant difference was seen between the two trials, then the data from trial 1 and 2 in the same experimental condition was averaged. If there was a significant difference seen between the two trials, then trial 1 was used to perform statistical analysis. A three-way mixed factor analysis of variance (ANOVA) was used to determine differences between age-groups (younger adults and older adults), vision manipulations (eyes open, blurred, and closed vision), and vestibular manipulations (no galvanic vestibular stimulation, 1xGVS and 2xGVS). Bonferroni correction was used to correct for multiple comparisons. Statistical significance was set at 95% confidence interval where $\alpha=0.05$. Further analyses were performed if a significant interaction was found. Data for transition phase duration, trunk roll angle, center of mass and center of pressure displacement were not normally distributed and therefore logarithmically transformed. Data were back transformed for display purposes. Data in graphs are presented as means and standard deviations.

Chapter 4

Results

4.1 Participant Characteristics:

Fifteen younger adults and fifteen older adults participated in this study. The demographics (age, sex, height, weight) and descriptive measures (base of support, and Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 score) for both age-groups are presented in Table 1. Independent *t*-tests revealed no significant differences in height [$t(28)=0.021$, $p=0.983$] and self-selected base of support [$t(28)=0.390$, $p=0.699$] between older adults and younger adults. However, weight [$t(28) = -2.350$, $p=0.026$] was significantly different between the two age-groups as older adults were significantly heavier than younger adults. When assessing static balance, older adults had lower Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 balance assessment scores [$t(28)=3.265$, $p=0.005$] in comparison to younger adults indicating poorer static balance and possibly poorer lower limb strength.

Table 1 Mean and standard deviation of participant demographics and characteristics.

Demographics include age, sex, height and weight. Descriptive measurements include base of support, and Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 score.

	Younger Adult	Older Adults	*p*-Value
Age (years)	22.5 ± 1.1	73.9 ± 5.3	0.000*
Sex	11 females : 4 males	6 females : 9 males	0.065
Height (m)	1.70 ± 0.09	1.70 ± 0.09	0.983
Weight (kg)	64.0 ± 11.6	73.5 ± 10.5	0.026*
Base of support (cm)	19.57 ± 6.35 (10-30cm)	18.77 ± 4.77 (10.5-27cm)	0.699
Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 (score out of 28)	27.9 ± 0.52	25.8 ± 2.40	0.005*

*$p < 0.05$

4.2 Outcome Measures

4.2.1 Global Performance

The mean values of transition phase duration during sit-to-stand for younger adults and older adults across all nine sensory conditions are shown in Figure 10. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) of transition phase duration revealed an interaction of vision x age-group [$F_{(2,56)}$=3.818, p=0.028]. Further analysis of the data using independent *t*-tests revealed that when vision was suboptimal (blurring goggles), older adults had significantly longer transition phase duration than younger adults [$t_{(88)}$= -3.647, p=0.000]. Generally, older adults had a longer transition phase duration than younger adults across all nine conditions.

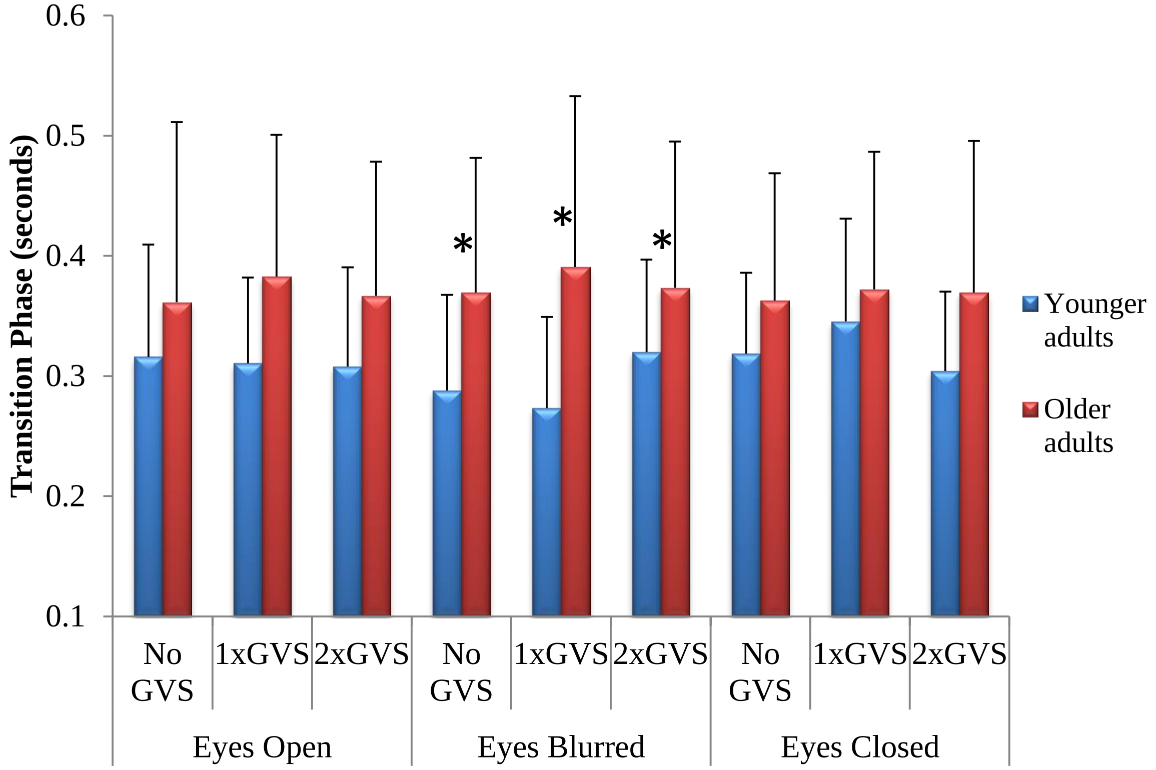

Figure 10 Comparison of transition phase duration between younger adults and older adults across all nine sensory conditions measured in seconds (mean and standard deviation).

Under suboptimal visual inputs (eyes blurred), older adults demonstrated a significantly longer transition phase duration than younger adults. Statistical significance (p<0.05) is indicated by the asterisk.

4.2.2 Postural Stability in the Mediolateral Direction

4.2.2.1 Trunk Roll Angle

The mean values of peak-to-peak trunk roll angle during sit-to-stand for younger adults and older adults across all nine sensory conditions are shown in Figure 11. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) revealed main effect of age-group where older adults had greater trunk roll angle compared to younger adults [$F_{(1,28)}$=5.611, p=0.025]. In addition, an interaction of vision x galvanic vestibular stimulation [$F_{(4,112)}$=3.010, p=0.021] revealed that when vision was absent, trunk roll angle was significantly greater with 1xGVS than 2xGVS ($p<0.05$).

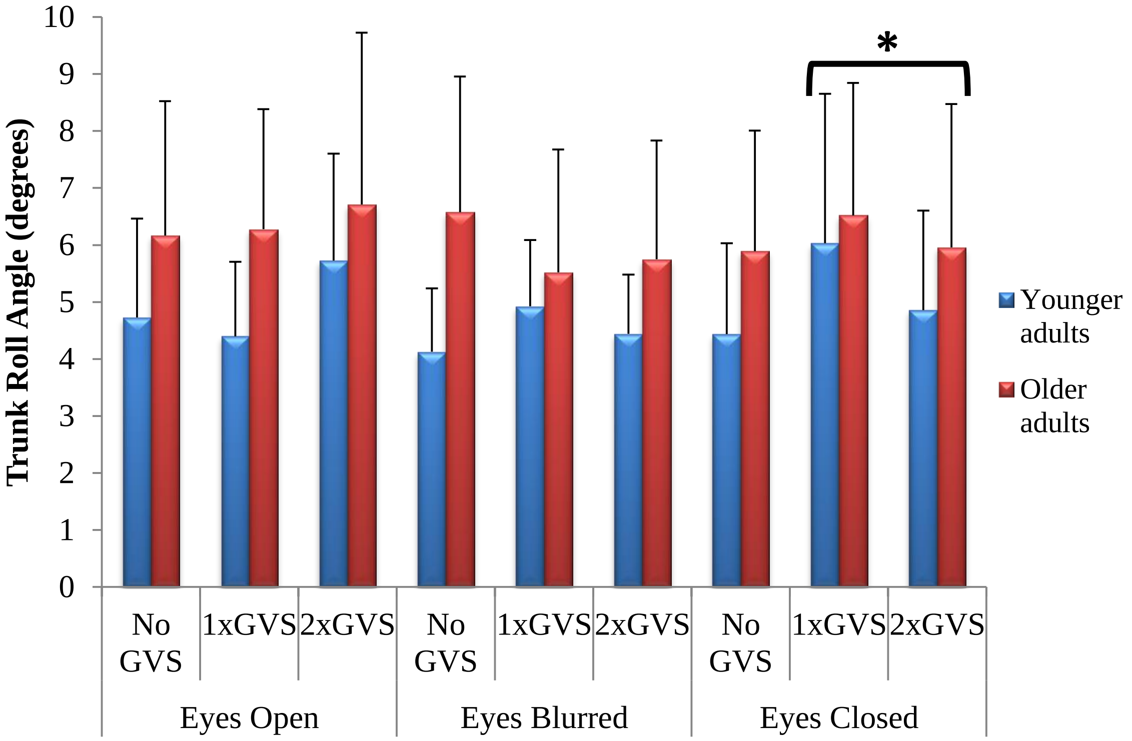

Figure 11 Comparison of peak-to-peak trunk roll angle between younger adults and older adults across all nine sensory conditions measured in degrees (mean and standard deviation).

Older adults demonstrated significantly greater trunk roll angle compared to younger adults. When visual inputs were absent, trunk roll angle was significantly greater at 1xGVS than 2xGVS irrespective of age. Statistical significance ($p<0.05$) is indicated by the asterisk.

4.2.2.2 Mediolateral Center of Mass Displacement

The mean values of peak-to-peak mediolateral center of mass displacement during sit-to-stand for younger adults and older adults across all nine sensory conditions are displayed in Figure 12. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) revealed older adults had a significantly greater mediolateral center of mass displacement than younger adults irrespective of vision or galvanic vestibular stimulation conditions [$F_{(1,28)}=16.397$, $p=0.000$]. Furthermore, there was a main effect of vision [$F_{(2,56)}=4.436$, $p=0.016$] which revealed when visual input was absent (eyes closed), mediolateral center of mass displacement was greater than when visual input was available (eyes open) ($p<0.01$).

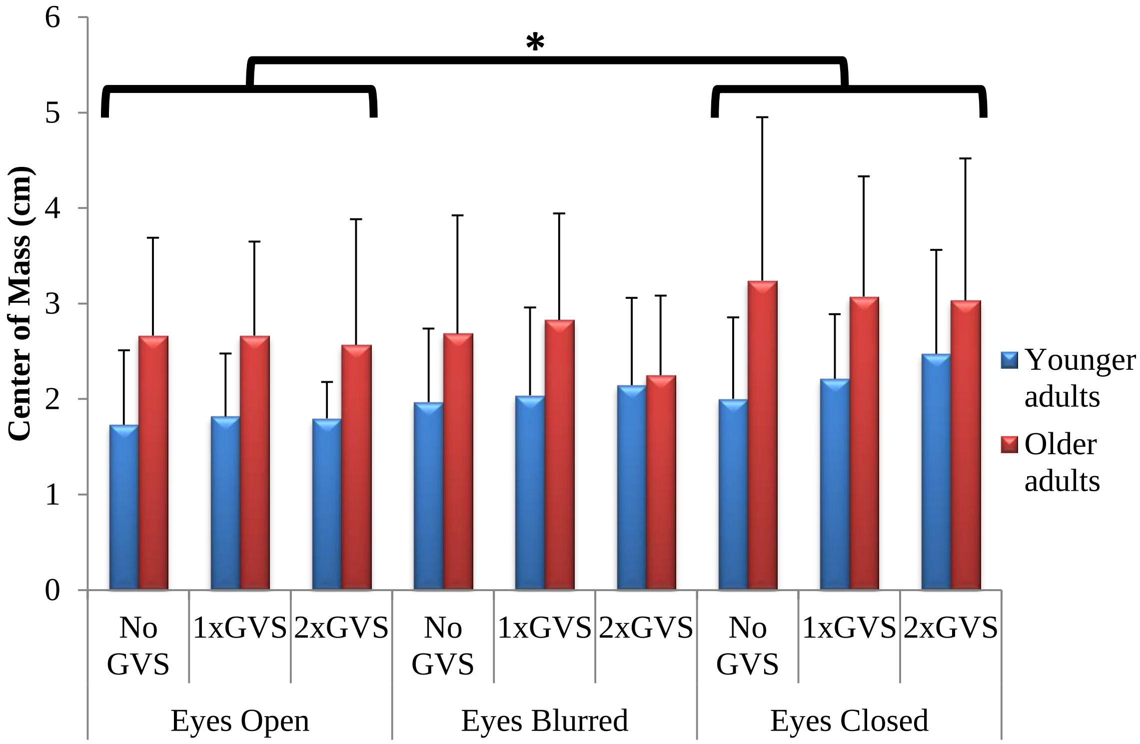

Figure 12 Comparison of peak-to-peak mediolateral center of mass displacement between younger adults and older adults across all nine sensory conditions measured in centimeters (mean and standard deviation).

Older adults demonstrated significantly greater peak-to-peak mediolateral center of mass displacement compared to younger adults. When visual inputs were absent, peak-to-peak mediolateral center of mass displacement was greater than when visual input was available. Statistical significance ($p<0.05$) is indicated by the asterisk.

4.2.2.3 Mediolateral Center of Pressure Displacement

The mean values of peak-to-peak mediolateral center of pressure displacement during sit-to-stand for younger adults and older adults across all nine sensory conditions are displayed in Figure 13. Sample size was reduced to 12 (n=12) when calculating mediolateral center of pressure displacement due to technical problems as there were missing data points in 6 participants (3 younger adults, 3 older adults). A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) revealed older adults had a greater mediolateral center of pressure displacement than younger adults irrespective of vision or galvanic vestibular stimulation conditions [$F_{(1,22)}=5.666$, $p=0.026$]. Center of pressure was not influenced by vision [$F_{(2,44)}=1.332$, $p=0.274$] or galvanic vestibular stimulation [$F_{(2,44)}=0.671$, $p=0.516$] factors.

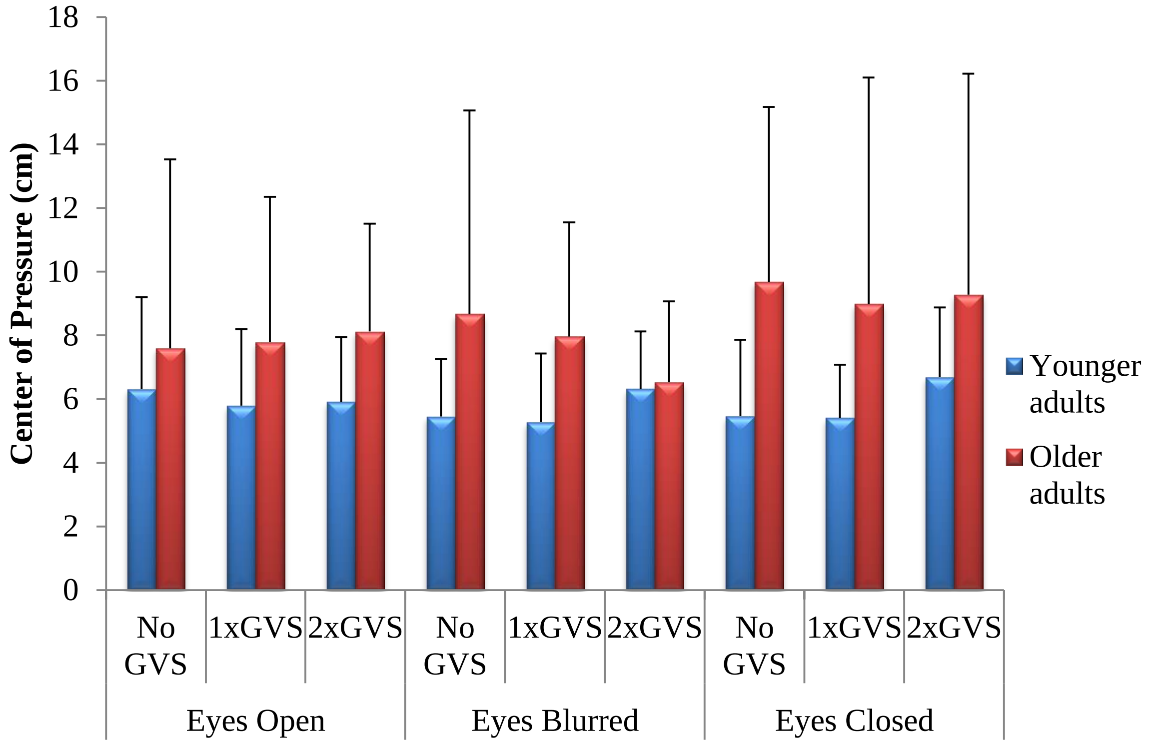

Figure 13 Comparison of peak-to-peak mediolateral center of pressure displacement between younger adults and older adults across all nine sensory conditions measured in centimeters (mean and standard deviation).

Older adults demonstrated greater peak-to-peak mediolateral center of pressure than younger adults.

4.2.3 Postural Stability in the Anteroposterior Direction

4.2.3.1 Peak Braking Force

The mean values of peak braking force during sit-to-stand for younger adults and older adults across all nine sensory conditions are displayed in Figure 14. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) of peak braking force revealed no significant difference between age-group [$F_{(1,28)}$= -0.00, *p*=0.988], vision [$F_{(2,56)}$=0.285, *p*=0.753] or galvanic vestibular stimulation [$F_{(2,56)}$=0.992, *p*=0.377] factors.

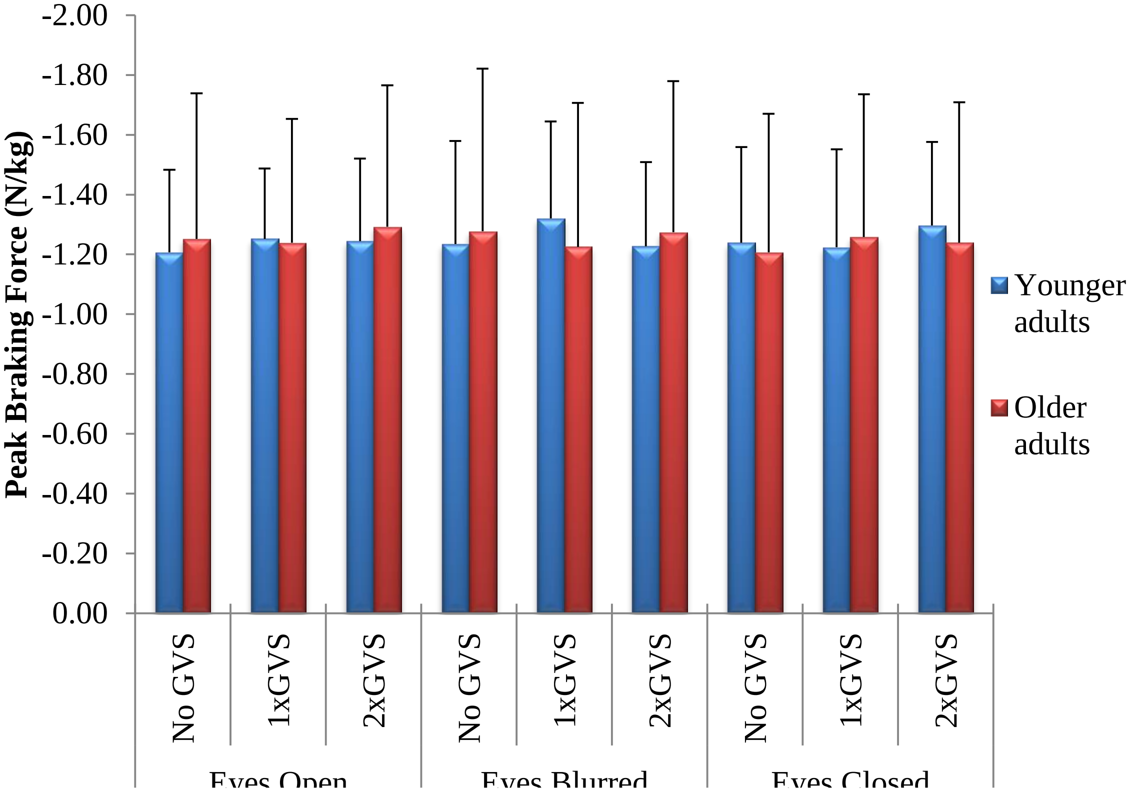

Figure 14 Comparison of peak braking force between younger adults and older adults across all nine sensory conditions measured in N/Kg (mean and standard deviation).

No significant difference was seen between age-groups and no significant differences were seen in either visual or vestibular manipulations.

4.2.3.2 Trunk Pitch Angle

The mean values of peak-to-peak trunk pitch angle during sit-to-stand for younger adults and older adults across all nine sensory conditions are displayed in Figure 15. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) of trunk pitch angle revealed no significant difference between age-group [$F_{(1,28)}$= -0.03, p=0.958], vision [$F_{(2,56)}$=0.123, p=0.885] or galvanic vestibular stimulation [$F_{(2,56)}$=0.587, p=0.560].

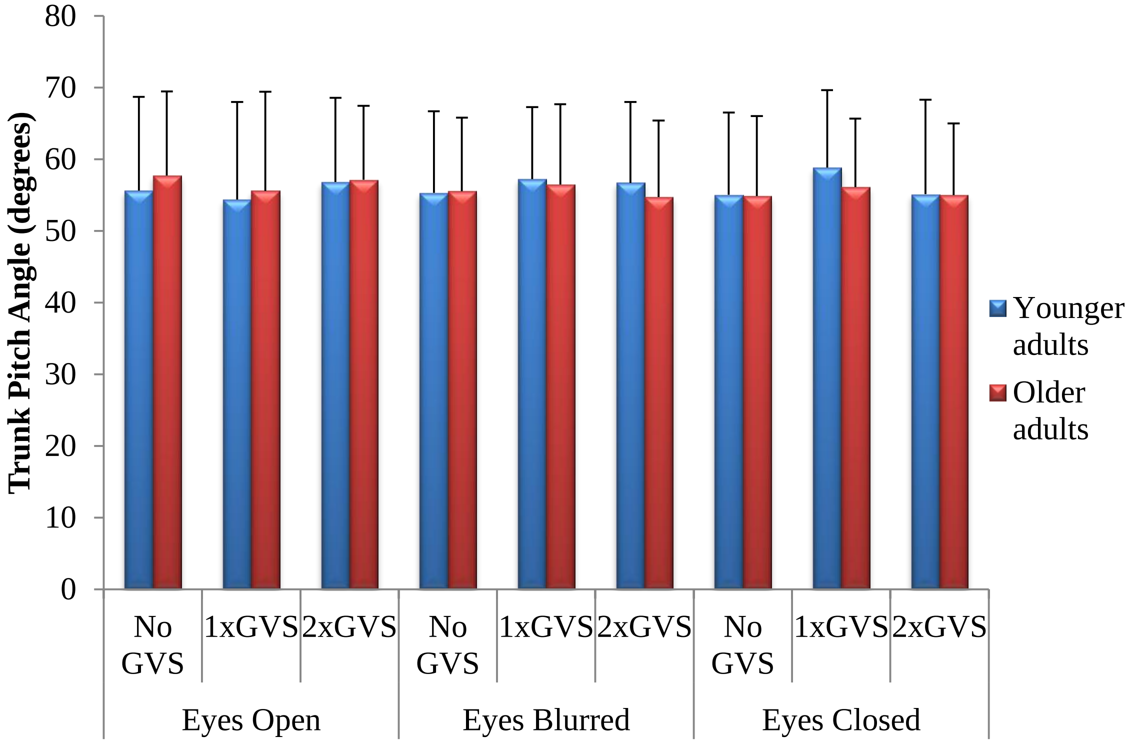

Figure 15 Comparison of peak-to-peak trunk pitch angle between younger adults and older adults across all nine sensory conditions measured in degrees (mean and standard deviation).

No significant difference was seen between age-groups and no significant differences were seen in either visual or vestibular manipulations.

4.2.3.3 Peak Anteroposterior Center of Mass Velocity

The mean values of peak anteroposterior center of mass velocity during sit-to-stand for younger adults and older adults across all nine sensory conditions are displayed in Figure 16. A three-way mixed factor ANOVA (age-group x vision x galvanic vestibular stimulation) of peak anteroposterior center of mass velocity revealed no significant difference between age-group [$F_{(1,28)}$=0.156, p=0.696], vision [$F_{(2,56)}$=0.449, p=0.641] or galvanic vestibular stimulation [$F_{(2,56)}$=0.455, p=0.637].

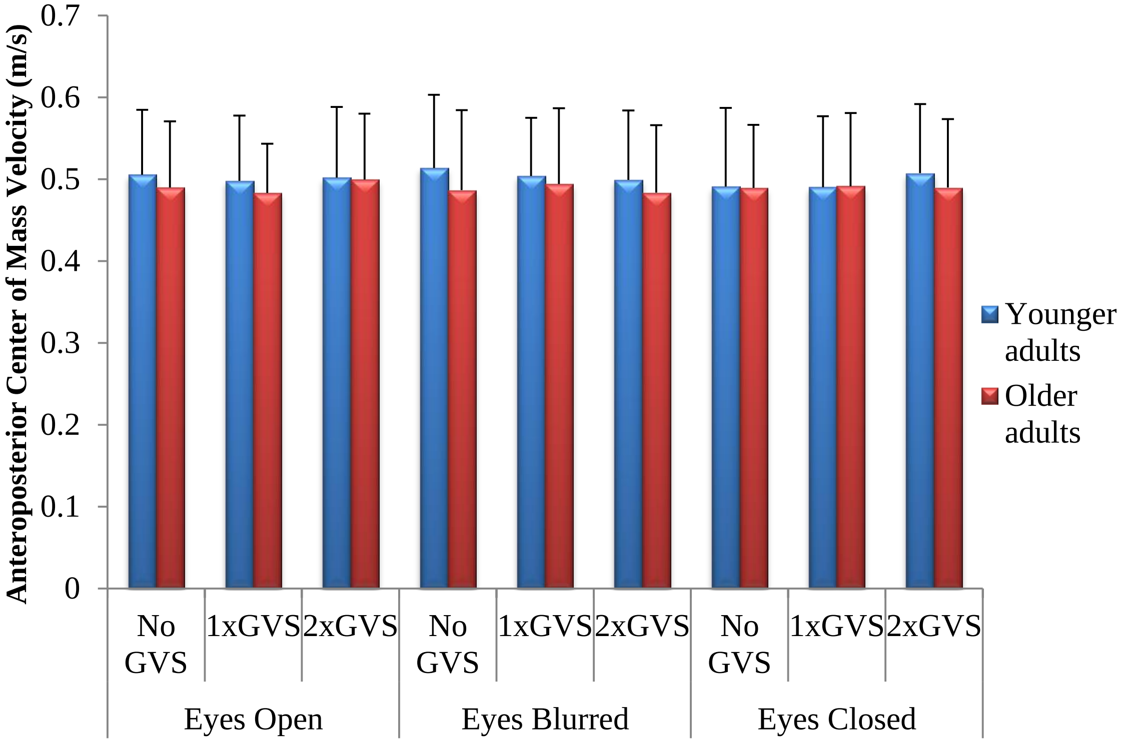

Figure 16 Comparison of peak anteroposterior center of mass velocity between younger adults and older adults across all nine sensory conditions measured in m/s (mean and standard deviation).

No significant difference was seen between age-groups and no significant differences were seen in either visual or vestibular manipulations.

Chapter 5

Discussion

The purpose of this study was to determine the effects of aging on visual-vestibular interactions for maintaining stability during sit-to-stand. Regardless of age, visual inputs were more dominantly used to maintain stability during sit-to-stand rather than vestibular inputs. Older adults demonstrated greater mediolateral instability despite both age-groups having opted for a stiffening strategy to overcome the galvanic vestibular stimulation-induced mediolateral sway when visual inputs were absent.

5.1 Global Performance

When visual inputs were either available or absent, the time needed to complete the transition phase did not differ between younger adults and older adults. However, when visual inputs were suboptimal, older adults required longer time to complete the transition phase compared to younger adults (Figure 10) which may reflect the dominant use of visual information in older adults when available, regardless of the quality, to complete sit-to-stand. This increase in transition phase duration was only seen in older adults as they may have greater dependency on vision than younger adults, and younger adults are able to utilize other systems (which are not subjected to age-related decline) to compensate for the suboptimal visual inputs (Choy *et al.*, 2003; Hay *et al.*, 1996; Poole, 1992; Redfern *et al.*, 2001; Ricci *et al.*, 2009). In a MRI study, Marx *et al.* (2004) reported that when eyes are open in the dark, there is an expectation of visual stimulation as the lateral geniculate nucleus is activated. This suggests that when the brain expects visual stimulation, the visual information is used regardless of the quality. It is speculated that by prolonging the transition phase duration, older adults may have implemented a cautious strategy. However, it could be maladaptive as it prolongs the time spent in the most unstable phase of sit-to-stand.

Our results are inconsistent with Novak & Deshpande (2011) who had found a longer transition phase duration in older adults compared to younger adults when visual inputs are absent. Within this study, older adults had a lower Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 score than younger adults. Further analysis with Frailty and Injuries: Cooperative Studies of Intervention Techniques 4 score as a covariate revealed a main effect of age-group possibly suggesting a decline in sit-to-stand performance in older adults. The inconsistency in results between this current study and Novak & Deshpande (2011) could also be due to differences in methodology. Collectively, the longer transition phase duration seen in older adults when visual inputs are absent (Novak & Deshpande, 2011) and when visual inputs are suboptimal (this current study) provide further evidence that visual inputs are critical for the sit-to-stand performance in older adults. As transition phase duration is the most unstable phase of sit-to-stand, it would be important to investigate further whether transition phase duration correlates with falls in older adults.

Contrary to our hypothesis, vestibular manipulations did not affect transition phase duration regardless of age. However, a trunk stiffening strategy may have been sufficient to overcome the galvanic vestibular stimulation-induced mediolateral sway (please refer to 5.2.1 Trunk Roll). This may explain why an increased transition phase duration was not seen as it may be a maladaptive strategy to employ in addition to stiffening of the trunk, the heaviest and largest segment of the body.

5.2 Postural Stability in the Mediolateral Direction

5.2.1 Trunk Roll

When vision was absent, trunk roll angle significantly increased with 1xGVS but no differences were seen at 2xGVS compared to the control condition irrespective of age (Figure 11). This contrasts with our hypothesis that greater trunk roll would occur with increasing galvanic vestibular stimulation intensity, and the study by Deshpande & Patla (2007) who reported a scaling effect of galvanic vestibular stimulation intensity on trunk roll during gait in older adults. Galvanic vestibular stimulation induces a body tilt when standing (Day *et al.*, 1997; Fitzpatrick *et al.*, 1999). The decline in trunk roll angle suggests the use of a stiffening strategy with higher intensity galvanic vestibular stimulation to overcome the galvanic vestibular stimulation-induced mediolateral sway; however, literature documenting trunk stiffening could not be cited to support this idea. At 1xGVS, the galvanic vestibular stimulation-induced sway may have been insufficient to generate a trunk stiffening response. However, when the galvanic vestibular stimulation intensity had increased to 2xGVS, it is possible that certain mechanisms were triggered causing the trunk to stiffen. In people who are visually dependent, trunk stiffening has been utilized to reduce the degrees of freedom and possibly enhance somatosensory cues during standing in heel-to-toe configuration (Isableu, Ohlmann, Crémieux, & Amblard, 2003). Stiffening of the trunk segment during sit-to-stand may also reduce the degrees of freedom (especially when visual and vestibular inputs are manipulated within this study) and may help to enhance sensory inputs from the remaining sensory systems. A similar stiffening strategy was not seen when visual inputs were available or suboptimal, suggesting that visual inputs are also crucial for maintaining trunk stability. Further research is needed to confirm these findings.

5.2.2 Mediolateral Center of Mass Displacement

As the trunk is the largest body segment, it was anticipated that the effects of galvanic vestibular stimulation on trunk roll angle would also be seen in mediolateral center of mass displacement. However, no effect of galvanic vestibular stimulation (both 1xGVS and 2xGVS) was seen in mediolateral center of mass displacement. Our results showed during 1xGVS, trunk roll angle increased without changes to mediolateral center of mass displacement. As peak-to-peak mediolateral center of mass displacement was measured, the direction of center of mass movement was not calculated. Currently literature comparing mediolateral center of mass displacement and trunk roll during sit-to-stand could not be cited. It is speculated that participants may have shifted their hips in the opposite direction to counteract sway of the trunk to maintain stability and as a result, no effect of galvanic vestibular stimulation was seen in mediolateral center of mass displacement at 1xGVS. During 2xGVS, no increase in trunk roll angle was seen as a result of a possible stiffening strategy which was reflected in the lack of change in mediolateral center of mass displacement.

Regardless of age, when visual inputs were absent, greater mediolateral center of mass displacement was observed than when visual inputs were available (Figure 12). This increase in mediolateral center of mass displacement suggest that, similar to trunk stability, visual inputs are critical to maintain balance of the entire body during sit-to-stand. In support of this, greater mediolateral instability has been observed while walking in the absence of visual inputs (Wuehr *et al.*, 2013). In addition, mediolateral stability during gait is sensitive to the absence of visual inputs as mediolateral stabilization requires sensory feedback control (Wuehr *et al.*, 2013). Bauby & Kuo (2000) suggested that visual-vestibular feedback is required to maintain mediolateral stability but not anteroposterior stability during gait. Therefore, the need for sensory inputs to maintain mediolateral stability in gait may also explain the increase in mediolateral center of mass displacement seen during sit-to-stand when visual inputs are absent.

5.2.3 Mediolateral Center of Pressure Displacement

Unlike trunk roll angle and mediolateral center of mass displacement, mediolateral center of pressure displacement was not affected when visual inputs were absent (Figure 13). The increase in mediolateral center of mass displacement and the lack of change in mediolateral center of pressure displacement suggests that center of mass is moving closer to the limits of center of pressure. As center of pressure is continuously moving anteriorly or posteriorly to center of mass, when distance between center of mass and center of pressure is reduced, the corrective movement of center of pressure becomes less efficient to maintain postural control (Winter *et al.*, 1996). However, the increase in mediolateral center of mass displacement when visual inputs were absent was still smaller than mediolateral center of pressure displacement suggesting center of mass was still within the range of center of pressure. As the range of center of pressure must be greater than that of center of mass in order to maintain stability (Winter *et al.*, 1996), this may explain why no changes were seen in mediolateral center of pressure displacement during visual manipulations.

5.2.4 Postural Stability in the Mediolateral Direction and Aging

Older adults demonstrated greater mediolateral center of mass displacement, mediolateral center of pressure displacement, and trunk roll angle than younger adults (Figure 11, 12 and 13), which indicates greater mediolateral instability when performing sit-to-stand. These findings are consistent with the literature as standing and walking studies have shown that older adults have larger mediolateral center of mass and center of pressure displacement than younger adults (Hay *et al.*, 1996; Schrager *et al.*, 2008).

Older adults have difficulty controlling mediolateral stability when walking (Maki, 1997; Tirosh & Sparrow, 2005) and as a result, many falls occur in the mediolateral direction causing serious consequences such as hip fractures (Hilliard *et al.*, 2008; Lord *et al.*, 1999; Maki *et al.*, 1994; Schrager *et al.*, 2008). The ability to control mediolateral stability may deteriorate faster with age than anteroposterior stability, as seen through functional and lateral reach tests (Hilliard *et al.*, 2008). Since mediolateral instability increases with age, measures of mediolateral stability such as mediolateral stepping performance, have been shown to be a good predictor of future falls in older adults without a recent history of falling (Maki *et al.*, 1994). When provoked by external perturbations, Mille *et al.*, (2013) reported that older adults take a greater number of steps to prevent falling than younger adults especially upon lateral perturbations. Since postural control in the mediolateral direction is challenging for older adults during gait and standing, it is not surprising that mediolateral instability was also seen in older adults during sit-to-stand.

5.3 Postural Stability in the Anteroposterior Direction

Although older adults had greater mediolateral instability, no difference between age-groups was observed in anteroposterior stability in peak braking force, peak anteroposterior center of mass velocity and trunk pitch angle (Figure 14, 15 and 16). These results suggest that older adults had anteroposterior stability which was not different from that in younger adults. Older adults generated comparable peak anteroposterior center of mass velocity and peak braking forces as younger adults and all participants were able to successfully complete sit-to-stand.

When visual inputs were suboptimal, older adults had a longer transition phase duration than younger adults. Since peak braking forces were not different between younger adults and older adults, the longer transition time seen in older adults when visual inputs were suboptimal may have been required to generate similar peak braking force to younger adults. Although time required to achieve peak braking force was not calculated and compared between younger adults and older adults, it is possible that older adults compensated for suboptimal visual inputs by slowing down the rate of braking force generation. As peak braking force was calculated rather than braking impulse, it is possible that older adults had a braking impulse that was in proportion to their body mass.

In both younger adults and older adults, visual and vestibular manipulations had no significant effect on peak braking force, trunk pitch angle and peak anteroposterior center of mass velocity. These findings suggest that our sensory manipulations may not affect anteroposterior stability during sit-to-stand and that decline in anteroposterior stability occurs more slowly than mediolateral stability. Further investigation regarding the role of sensory function is needed as sensory manipulations could only provide suboptimal input but not completely occlude it. Occlusion of sensory inputs could be achieved by studying populations with absent sensory function such as those with vestibular deficits. The lack of age or sensory effects on peak braking force and peak anteroposterior center of mass velocity were inconsistent with the literature. Mourey *et al.* (2000) found that older adults (n=7) have slower anteroposterior center of mass velocities than younger adults (n=7) especially when visual inputs are absent. Novak & Deshpande (2011) found older adults (n=6) has lower peak braking force than younger adults (n=6) while performing sit-to-stand as quickly as possible especially when visual inputs are absent. When visual inputs were absent, anteroposterior stability during sit-to-stand in older adults worsened (Mourey *et al.*, 2000; Novak & Deshpande, 2011).

During gait, the effects of sensory perturbations decrease as gait speed increases (Brandt, Strupp, & Benson, 1999; Wuehr *et al.*, 2013). The effect of visual inputs on anteroposterior gait variability is dependent upon gait speed as visual inputs are more critical to maintain balance at slower gait speed. At higher gait speeds, the effects of absent visual inputs are dampened as gait is controlled by automated central pattern generators rather than sensory control (Jahn, Strupp, Schneider, Dieterich, & Brandt, 2001; Wuehr *et al.*, 2013). Brandt *et al.* (1999) reported that when vestibular inputs were suboptimal (vestibular neuritis or experimentally manipulated by spinning healthy subjects) it was easier to maintain balance when gait speed increased. It may be possible that similar dampening effects of sensory manipulations in the anteroposterior direction may have occurred as a result of the participants performing sit-to-stand as quickly as possible. This may have allowed for the use of momentum or central pattern generators to maintain anteroposterior stability when performing sit-to-stand quickly.

5.4 Limitations

In the current study, the foot position of the participant throughout the entire testing session was self-selected by each participant. The self-selected foot positions allowed for the sit-to-stand performance in the lab setting to better resemble the participant’s daily performance. However, self-selected foot positions resulted in large variability in base of support measurement (measured between the two malleoli) within our group of participants. The base of support measurement ranged from 10 to 30 cm in younger adults and 10.5 to 27 cm in older adults. Within this study, base of support was not normalized to the participant's hip width. Although base of support measurement was not significantly different between younger adults and older adults, it may be possible those with a wider self-selected base of support demonstrated better mediolateral stability than those with a smaller self-selected base of support.

Although the older adults who participated in this study reported 9.5 hours of physical activity per week, majority of the hours included physical activities that required low levels of physical exertion such as walking. However, six participants engaged in some higher levels of physical exertion activities such as swimming, biking and cardio exercises. With that said, physical activity levels of older adults were often not reported in the studies that were cited therefore, it is unknown whether our sample is comparable to literature.

5.5 Future implications and directions

In our experiment, somatosensory inputs were unperturbed in comparison to visual and vestibular inputs. Therefore, somatosensory inputs could have possibly compensated for the suboptimal visual and vestibular inputs during sit-to-stand. It would be interesting to examine how visual-vestibular interaction changes when the somatosensory system is not functioning optimally (e.g. patients with peripheral neuropathy) during sit-to-stand. This can be experimentally achieved by standing on a compliant surface to produce a suboptimal somatosensory input. Compliant surfaces have been used in several studies (Benvenuti *et al.*, 1999; Lord, Caplan, Colagiuri, Colagiuri,

& Ward, 1993; Lord, Menz, & Tiedemann, 2003; Novak & Deshpande, 2011) to disrupt or reduce lower limb somatosensory inputs and provide an unstable support surface.

As visual and vestibular pathologies are more prevalent in older adults due to age-related morphological and physiological changes, visual-vestibular interaction may change as a result of these pathologies. Visual pathologies may reduce visual function such as visual acuity, contrast sensitivity and depth perception (Poole, 1992; Sturnieks *et al.*, 2008) while vestibular pathologies could cause dizziness, and create a sense of imbalance or unsteadiness (Baloh, 2002; Shumway-Cook & Woollacott, 2012). Vision is crucial for judgment of distances and to maintain stability, and Lord *et al.* (2002) suggested that adequate vision can provide additional cues for safe and quick execution of sit-to-stand. Brown *et al.* (2006) reported that only 18% of their participants (n=22) with vestibular dysfunction could perform the Five Times Sit-to-stand Test. Together, the reduced visual and vestibular function may impair visual-vestibular interactions necessary for postural control during dynamic tasks such as sit-to-stand.

5.6 Conclusion

Regardless of age, visual inputs were dominantly used compared to vestibular inputs to maintain mediolateral trunk stability and orientation during sit-to-stand. It is possible that sensory inputs are more important for stability in the mediolateral direction than in the anteroposterior direction during sit-to-stand. Differences between younger adults and older adults were only seen in the mediolateral direction and not in the anteroposterior direction. Despite having greater mediolateral instability, older adults utilized similar strategies as younger adults to overcome sensory perturbations during sit-to-stand. Therefore, this study provided additional support that older adults have greater mediolateral instability during dynamic tasks.

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Appendix A

Letter of Information and Consent

Letter of Information and Consent

Project Title: When is vestibular information critical for maintaining stability while rising up from a sitting position: Effects of aging

Investigator: Dr Nandini Deshpande, School of Rehabilitation Therapy, Faculty of Health Sciences, Queen’s University, Kingston, Ontario

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The inner ear balance detecting system is critical for maintaining balance. It is proposed that significant number of falls in older persons occur possibly because of improper functioning of this system. This system could be stimulated while standing up from a sitting position due to the accelerations experienced by the head during this movement. Considering that many falls occur in older persons while standing up from a sitting position, the first purpose of this study is to understand how our brain uses sensory information from inner ear balance detectors for maintaining balance while standing up from a sitting position. The second purpose is to understand whether normal/healthy aging has any effect on when/how this sensory information is used when information available from other sensory systems (vision and lower limb movement detection system) is unreliable.

You are invited to participate in this study if you are in the age group of 20 to 30 or ≥ 65 years and if you do not have medical problems of your vision, inner ears and neuromuscular system or pain in your legs while walking. You will be required to complete a medical screening form. There is one session of two hours to this study.

Procedure:

The testing will involve approximately two hours visit to the laboratory.

1. You will be asked to wear your pair of regular walking shoes. Your height and weight will be recorded. Vision will be tested using vision charts (similar to those at optometrist). The ability to detect touch on the skin of the foot-sole will be tested. The function of the inner ear balance detectors will be tested by, a. asking you to read the vision chart while walking on a treadmill and b. by asking you to align a line in a vertical direction on the wall in front of you. The strength of your knee muscles will be measured by asking you to push against resistance and balance will be assessed using Frailty and Injuries Cooperative Studies of Intervention Techniques (FICSIT) balance test by asking you to stand with your feet in different configurations, with eyes open and then with eyes closed.

2. Two electrodes will be placed behind your ears and the intensity of a mild current for feeling slight pin-prick sensation will be measured.

3. A total of 12 markers will be fitted on your body (the mid-foot, mid-leg, and mid-thigh bilaterally and over the lower and upper back, and 4 on the head). These markers will allow us to record your body movements.

4. You will be required to stand up from a sitting position without using hand support. On some trials we will control the sensory information from your inner ear system that your can brain receives. For this purpose a very mild current will be momentarily applied behind your ears (approx. 0.6 – 0.8 m Amp). On some trials you will be asked to wear goggles that will simulate cataract vision. And on some trials a piece of foam will be placed under your feet and on your chair to reduce information coming from support surfaces.

5. The head and torso movements and placement of the feet will be calculated. For your safety, one of the team members will stand close to you during all trials.

With your agreement, you will also be videotaped for the purpose of tracking the responses to these sensory manipulations as well as a means of verifying results from other data collected.

Risks: The use of mild galvanic current will cause slight pinprick sensation behind the ears and a mild instability while standing up; however, no health risks have been reported in the literature for the current settings being used in this study. One of the team members will stand closely besides you to prevent a fall. There are no anticipated health risks in these procedures.

However, the testing session will be terminated as soon as you indicate that you wish to discontinue, for whatever reason.

Benefits: There are no direct benefits to the participants. The indirect benefit to the young participants will include an opportunity to get familiarized with the research activities in the department. The results will provide useful information about how the brain uses this sensory information for standing up from a sitting position without losing balance. The older adults may not receive direct benefit from participating. However, the results will provide the information that can be used for improving balance and mobility of this population and the knowledge can be further extended to develop the strategies that can be taught to patients who suffer from deficits of this critical sensory system, thereby, improving balance and mobility of people in the future.

Confidentiality: Any information obtained in this study will be retained indefinitely and will be held in strict confidence. It will be available only to the investigators. The computers are password protected and computer data files will contain a code number rather than the name. The video tapes will be stored in locked cabinets accessible only to the investigators. When the information from this study will be published in scientific journal or in professional meetings, your identification will be kept strictly confidential.

Free parking will be available for you in a parking lot that is located very close to the laboratory. You will be given $25 cash on completion of the test session.

Your participation in this study is voluntary and you are not obliged to answer any questions that you find objectionable or complete any aspect of the study which make you feel uncomfortable.

If you have any questions now or later, please feel free to contact the investigator.

Dr Nandini Deshpande: 613 533 2916 / 613 449 6760

This project has been reviewed by, and received ethics clearance through, Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board. If you have any comments or concerns resulting from your participation in this study, you may contact the Chair, Dr Albert Clark, Research Ethics Board at 613-533-6081.

Your signature below indicates that you are aware that you may contact the principle investigator *or* the department head *or* the Research Ethics Board if you have any questions, concerns or complaints about the research procedures.

Principle investigator: Dr Nandini Deshpande

Tel: 613 533 2916 / 613 449 6760, email: nandini.deshpande@queensu.ca

Research Assistant: Grace Lui
Email: 7kyl1@queensu.ca
Department Head: Dr Elsie Culham
Tel: 613 533 6727, email: elsie.culham@queensu.ca
Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board Chair: Dr Albert Clark Tel: 613 533 6081, email: clarkaf@queensu.ca

Your signature below indicates that you have read this Letter of Information and have had any questions answered to your satisfaction. Please keep a copy of this letter for your records.

Name of the participant: ___________________________

Date: ____________________________

Signature: ________________________

Name of the RA who obtained the consent: ___________________________

Date: ____________________________

Signature: ________________________

Appendix B

Video Consent

Consent for Videotaping

As a participant in this study, I agree to being videotaped for the purpose of tracking the response while walking as well as a means of verifying results from other data collected.   I am aware that I may withdraw this consent at any time without penalty, at which point, the videotape will be erased.

I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board Chair: Dr. Albert Clark at Tel: 613-533-6081.

Print Name: ______________________   ________________________
Signature of Participant

Date: ______________________________

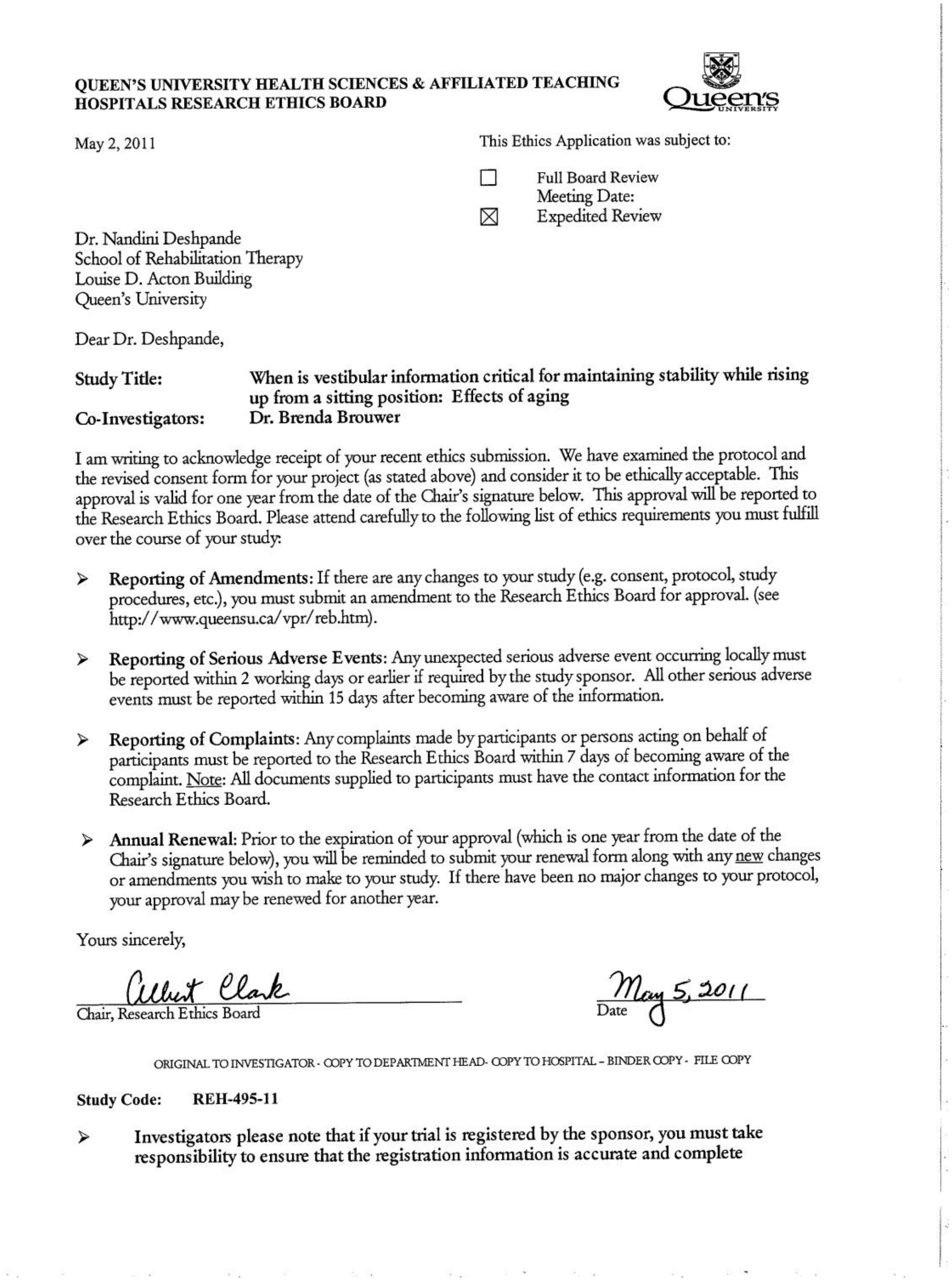
Name of the RA who obtained the consent: ___________________________

Date: ____________________________

Signature: ________________________

Appendix C

Ethics



QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD

May 2, 2011

This Ethics Application was subject to:

☐ Full Board Review
Meeting Date:
☒ Expedited Review

Dr. Nandini Deshpande
School of Rehabilitation Therapy
Louise D. Acton Building
Queen's University

Dear Dr. Deshpande,

Study Title: **When is vestibular information critical for maintaining stability while rising up from a sitting position: Effects of aging**

Co-Investigators: **Dr. Brenda Brouwer**

I am writing to acknowledge receipt of your recent ethics submission. We have examined the protocol and the revised consent form for your project (as stated above) and consider it to be ethically acceptable. This approval is valid for one year from the date of the Chair's signature below. This approval will be reported to the Research Ethics Board. Please attend carefully to the following list of ethics requirements you must fulfill over the course of your study:

- **Reporting of Amendments:** If there are any changes to your study (e.g. consent, protocol, study procedures, etc.), you must submit an amendment to the Research Ethics Board for approval. (see http://www.queensu.ca/vpr/reb.htm).
- **Reporting of Serious Adverse Events:** Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.
- **Reporting of Complaints:** Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board.
- **Annual Renewal:** Prior to the expiration of your approval (which is one year from the date of the Chair's signature below), you will be reminded to submit your renewal form along with any new changes or amendments you wish to make to your study. If there have been no major changes to your protocol, your approval may be renewed for another year.

Yours sincerely,

Albert Clark
Chair, Research Ethics Board

May 5, 2011
Date

ORIGINAL TO INVESTIGATOR - COPY TO DEPARTMENT HEAD- COPY TO HOSPITAL – BINDER COPY - FILE COPY

Study Code: **REH-495-11**

- **Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete**

QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS RESEARCH ETHICS BOARD

The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards as defined by the Tri-Council Policy Statement; Part C Division 5 of the Food and Drug Regulations, OHRP, and U.S DHHS Code of Federal Regulations Title 45, Part 46 and carries out its functions in a manner consistent with Good Clinical Practices.

Federalwide Assurance Number : #FWA00004184
#IRB00001173

Current 2011 membership of the Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board

Dr. A.F. Clark	**Emeritus Professor, Department of Biochemistry, Faculty of Health Sciences, Queen's University (Chair)**
Dr. H. Abdollah	**Professor, Department of Medicine, Queen's University**
Dr. R. Brison	**Professor, Department of Emergency Medicine, Queen's University**
Dr. M. Evans	**Community Member**
Dr. S. Horgan	**Manager, Program Evaluation & Health Services Development, Geriatric Psychiatry Service, Providence Care, Mental Health Services** **Assistant Professor, Department of Psychiatry**
Ms. D. Morales	**Community Member**
Dr. W. Racz	**Emeritus Professor, Department of Pharmacology & Toxicology, Queen's**
Dr. B. Simchison	**Assistant Professor, Department of Anesthesiology, Queen's University**
Dr. A.N. Singh	**WHO Professor in Psychosomatic Medicine and Psychopharmacology** **Professor of Psychiatry and Pharmacology** **Chair and Head, Division of Psychopharmacology, Queen's University** **Director & Chief of Psychiatry, Academic Unit, Quinte Health Care, Belleville General Hospital**
Dr. E. Tsai	**Associate Professor, Department of Paediatrics and Office of Bioethics, Queen's University**
Rev. J. Warren	**Community Member**
Ms. K. Weisbaum	**LL.B. and Adjunct Instructor, Department of Family Medicine (Bioethics)**

Appendix D

Mini-Mental State Examination (MMSE)

Mini-Mental State Examination (MMSE)

Patient's Name: ____________________________________ Date: _______________

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	**Patient's Score**	**Questions**
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: ____________
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, …) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.)
30		TOTAL

(Adapted from Rovner & Folstein, 1987)

Source: www.medicine.uiowa.edu/igec/tools/cognitive/MMSE.pdf

Provided by NHCQF, 0106-410

Appendix E

Center for Epidemiologic Studies Depression Scale (CES-D)

DEPRESSION- CESD

"I am going to read a list of ways you may have felt or behaved in the past week. For each, I will ask you if you felt or behaved this way 1) rarely or none of the time (less than 1 day in the past week), 2) some or a little of the time (1-2 days last week), 3) occasionally or a moderate amount of time (3-4 days last week), 4) most or all of the time (5-7 days a week)."

Read each question in its entirety, including each response category.

	During the past week…	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasion-ally or a moderate amount of the time (3-4 days)	Most or all of the time (5-7 days)
1	I was bothered by things that don't usually bother me.				
2	I did not feel like eating; my appetite was poor.				
3	I felt that I could not shake off the blues even with the help of my family and friends				
4	I felt that I was just as good as other people				
5	I had trouble keeping my mind on what I was doing.				
6	I felt depressed				
7	I felt that everything I did was an effort				
8	I felt hopeful about the future				
9	I thought my life				

	had been a failure				
10	I felt fearful				
11	My sleep was restless				
12	I was happy				
13	I talked less than usual				
14	I felt lonely				
15	People were unfriendly				
16	I enjoyed life				
17	I had crying spells				
18	I felt sad				
19	I felt that people disliked me				
20	I could not get going				

Appendix F

Activities-specific Balance Confidence (ABC) Scale

The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0%	10	20	30	40	50	60	70	80	90	100%
no confidence										**completely confident**

"How confident are you that you will not lose your balance or become unsteady when you…

1. …walk around the house? ____%

2. …walk up or down stairs? ____%

3. …bend over and pick up a slipper from the front of a closet floor ____%

4. …reach for a small can off a shelf at eye level? ____%

5. …stand on your tiptoes and reach for something above your head? ____%

6. …stand on a chair and reach for something? ____%

7. …sweep the floor? ____%

8. …walk outside the house to a car parked in the driveway? ____%

9. …get into or out of a car? ____%

10. …walk across a parking lot to the mall? ____%

11. …walk up or down a ramp? ____%

12. …walk in a crowded mall where people rapidly walk past you? ____%

13. …are bumped into by people as you walk through the mall?____%

14. … step onto or off an escalator while you are holding onto a railing? ____%

15. … step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%

16. …walk outside on icy sidewalks? ____%

Appendix G

Frailty and Injuries: Cooperative Studies of Intervention Techniques

(FICSIT-4)

FICSIT-4

(Frailty and Injuries: Cooperative Studies of Intervention Techniques)

Tests of Static Balance:
parallel, semi-tandem, tandem, and one-legged stance tests

Journals of Gerontology Series A: Biological Sciences and Medical Sciences, Vol 50, Issue 6 M291-M297, Copyright © 1995 by The Gerontological Society of America

MULTICENTER STUDY

A cross-sectional validation study of the FICSIT common data base static balance measures. Frailty and Injuries: Cooperative Studies of Intervention Techniques

JE Rossiter-Fornoff, SL Wolf, LI Wolfson and DM Buchner
Division of Biostatistics, Washington University School of Medicine, St. Louis, USA.

BACKGROUND. Two simple balance scales comprising three or four familiar tests of static balance were developed, and their validity and reliability are described. The scales were such that the relative difficulties of the basic tests were taken into consideration. METHODS. Using FICSIT data, Fisher's method was used to construct scales combining ability to maintain balance in **parallel, semi-tandem, tandem, and one-legged stances**. Reliability was inferred from the stability of the measure over 3-4 months. Construct validity was assessed by cross- sectional correlations. RESULTS. Test-retest reliability (over 3-4 months) was good (r = .66). Validity of the FICSIT-3 scale was suggested by its low correlation with age, its moderate to high correlations with physical function measures, and three balance assessment systems. The FICSIT-4 scale discriminated balance over a wide range of health status; the three-test scale had a substantial ceiling effect in community samples. CONCLUSION. A balance scale was developed that appears to have acceptable reliability, validity, and discriminant ability.

INSTRUCTIONS: Demonstrate each position to the subject, then ask them to perform and time.

F-1. **FEET CLOSELY TOGETHER**, UNSUPPORTED, **eyes open** (ROMBERG POSITION)
INSTRUCTIONS: Stand still with your feet together as demonstrated for 10 seconds. ***[Berg #7 = 60 seconds]***

☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling

If subject is able to do this, proceed to the next position, if not, stop.

F-2. **FEET CLOSELY TOGETHER**, UNSUPPORTED, **eyes closed** (ROMBERG POSITION)
INSTRUCTIONS: Please close your eyes and stand still with your feet together as demonstrated for 10 seconds.

☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling

If subject is able to do this, proceed to the next position, if not, stop.

F-3. **SEMI-TANDEM**: **eyes open** HEEL OF 1 FOOT PLACED TO THE SIDE OF THE 1ST TOE OF THE OPPOSITE FOOT (SUBJECT CHOOSES WHICH FOOT GOES FORWARD)
INSTRUCTIONS: Please stand still with your feet together as demonstrated for 10 seconds.

☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling

If subject is able to do this, proceed to the next position, if not, stop.

F-4. **SEMI-TANDEM**: **eyes closed** HEEL OF 1 FOOT PLACED TO THE SIDE OF THE 1ST TOE OF THE OPPOSITE FOOT (SUBJECT CHOOSES WHICH FOOT GOES FORWARD)
INSTRUCTIONS: Please close your eyes and stand still with your feet together as demonstrated for 10 seconds.

☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling

If subject is able to do this, proceed to the next position, if not, stop.

F-5. **FULL TANDEM**: **eyes open** HEEL OF 1 FOOT DIRECTLY IN FRONT OF THE OTHER FOOT (SUBJECT CHOOSES WHICH FOOT GOES FORWARD) ***[Berg #14 = 30 seconds]***
INSTRUCTIONS: Please stand still with your feet together as demonstrated for 10 seconds.

☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling

If subject is able to do this, proceed to the next position, if not, stop.

F-6. **FULL TANDEM**: **eyes closed** HEEL OF 1 FOOT DIRECTLY IN FRONT OF THE OTHER FOOT (SUBJECT CHOOSES WHICH FOOT GOES FORWARD)
INSTRUCTIONS: Please stand still with your feet together as demonstrated for 10 seconds.
☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling
If subject is able to do this, proceed to the next position, if not, stop

F-7. **STANDING ON ONE LEG**: **eyes open** ***[Same as Berg #13]***
INSTRUCTIONS: Stand on one leg as long as you can without holding.
☐ 4 able to stand 10 seconds safely
☐ 3 able to stand 10 seconds with supervision
☐ 2 able to stand 3 seconds
☐ 1 unable to stand 3 seconds but stays steady
☐ 0 needs help to keep from falling
Total FICSIT-4 Static Balance score = ____ / 28

Appendix H

Peak Braking Force Values using 2 Force Plates

Table 2 Peak braking forces (newtons/kg) and voltages in the anteroposterior direction of two force plates.

The subject stood at two different locations on the force plate (center and corner of the force plate) as the load was placed at the heel and gastrocnemius.

Position on the force plate	Trial	Load Placement	Force applied (pounds)	Duration of force applied (sec)	Peak force (newtons/kg)	Peak voltage
Center of force plate 1	1	Heel	28	6.4	-1.68842	-0.08184
	2	Heel	28	6.0	-1.69475	-0.154926
	3	Gastroc	25	4.8	-1.67645	-0.3765
	4	Gastroc	31	5.2	-1.87924	-0.45756
Corner of force plate 1	5	Heel	28	6.8	-1.57785	-0.11068
	6	Heel	28	7	-1.60909	-0.28117
	7	Gastroc	21	9.2	-1.26344	-0.07941
	8	Gastroc	27	8.4	-1.52073	-0.16679
Center of force plate 2	9	Heel	29	5.4	-1.64364	-0.10652
	10	Heel	30	5.2	-1.65913	-0.08254
	11	Gastroc	24	5.8	-1.00433	-0.16697
	12	Gastroc	34	4.8	-2.18409	-0.52338
Corner of force plate 2	13	Heel	30	4.6	-1.6118	-0.24056
	14	Heel	31	4.6	-1.77974	-0.34648
	15	Gastroc	32	5.0	-1.81016	-0.14982
	16	Gastroc	33	6.0	-1.88588	-0.23008

Table 3 Peak braking forces in the anteroposterior direction for two subjects during sit-to-stand during 3 different speeds (slow, normal and fast).

Subject	Speed	Peak braking force (newtons/kg)
1	Slow	-0.26231
	Slow	-0.1993
	Normal	-0.413169185
	Normal	-0.59039748
	Fast	-1.35973
	Fast	-1.31364
2	Slow	-0.85152
	Slow	-0.94439
	Normal	-1.07433
	Normal	-1.10115
	Fast	-1.52564
	Fast	-1.0402

Appendix I

Comparing Trunk Roll Between Younger and Older Adult

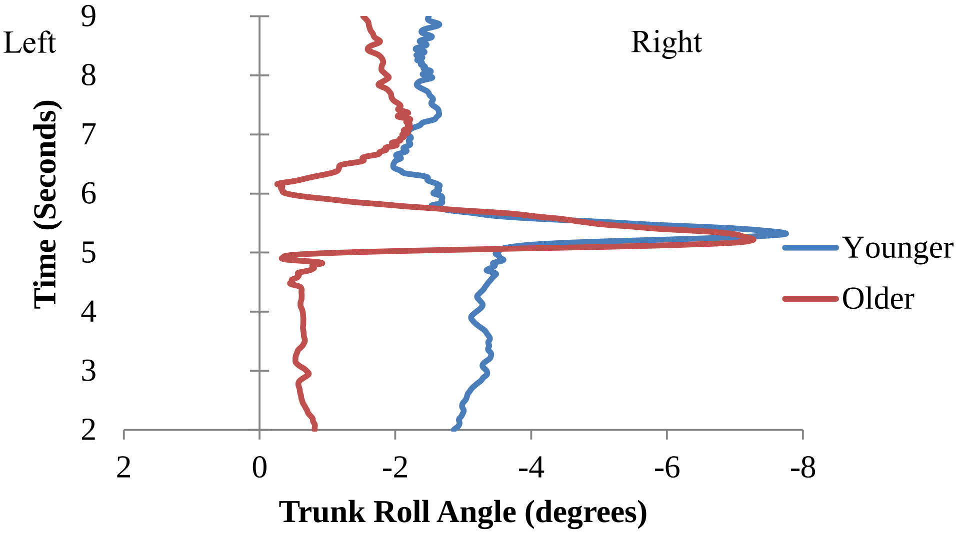


Figure 17 Representative profiles comparing younger and older adult for trunk roll angle at baseline condition (Eyes Open, No galvanic vestibular stimulation).

The positive values on the horizontal axis indicated movement towards the left while the negative values indicated movement towards the right.